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Synthetic Turf

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SYNTHETIC TURF
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CPSC Staff Finds Synthetic Turf Fields OK to Install

U.S. Consumer Product Safety Commission

NEWS from CPSC

U.S. Consumer Product Safety Commission

Office of Information and Public Affairs Washington, DC 20207

FOR IMMEDIATE RELEASE
July 30, 2008
Release #08-348

CPSC Hotline: (800) 638-2772
CPSC Media Contacts: (301) 504-7908

CPSC Staff Finds Synthetic Turf Fields OK to Install, OK to Play On

WASHINGTON, D.C. - The U.S. Consumer Product Safety Commission (CPSC) staff today released its evaluation (pdf) of various synthetic athletic fields. The evaluation concludes that young children are not at risk from exposure to lead in these fields.

CPSC staff evaluation showed that newer fields had no lead or generally had the lowest lead levels. Although small amounts of lead were detected on the surface of some older fields, none of these tested fields released amounts of lead that would be harmful to children.

Lead is present in the pigments of some synthetic turf products to give the turf its various colors. Staff recognizes that some conditions such as age, weathering, exposure to sunlight, and wear and tear might change the amount of lead that could be released from the turf. As turf is used during athletics or play and exposed over time to sunlight, heat and other weather conditions, the surface of the turf may start to become worn and small particles of the lead-containing synthetic grass fibers might be released. The staff considered in the evaluation that particles on a child's hand transferred to his/her mouth would be the most likely route of exposure and determined young children would not be at risk.

Although this evaluation found no harmful lead levels, CPSC staff is asking that voluntary standards be developed for synthetic turf to preclude the use of lead in future products. This action is being taken proactively to address any future production of synthetic turf and to set a standard for any new entrants to the market to follow.

As an overall guideline, CPSC staff recommends young children wash their hands after playing outside, especially before eating.

 Consumers can also view a video clip (transcript) about lead and synthetic turf. This is in "streaming video" format.

Send the link for this page to a friend! The U.S. Consumer Product Safety Commission is charged with protecting the public from unreasonable risks of serious injury or death from more than 15,000 types of consumer products under the agency's jurisdiction. Deaths, injuries and property damage from consumer product incidents cost the nation more than $800 billion annually. The CPSC is committed to protecting consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard. The CPSC's work to ensure the safety of consumer products - such as toys, cribs, power tools, cigarette lighters, and household chemicals - contributed significantly to the decline in the rate of deaths and injuries associated with consumer products over the past 30 years.

To report a dangerous product or a product-related injury, call CPSC's hotline at (800) 638-2772 or CPSC's teletypewriter at (800) 638-8270, or visit CPSC's web site at www.cpsc.gov/talk.html. To join a CPSC email subscription list, please go to https://www.cpsc.gov/cpsclist.aspx. Consumers can obtain this release and recall information at CPSC's Web site at www.cpsc.gov.

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Study Finds Crumb Rubber Turf Poses No Significant Threat To Air/Water Quality

Tests Show No Health Concerns at Synthetic Turf Fields

New York State Department of Environmental Conservation (DEC) and the Department of Health (DOH)

For Release:

Friday, May 29, 2009

Study Finds Crumb Rubber Turf Poses No Significant Threat To Air/Water Quality

Tests Show No Health Concerns at Synthetic Turf Fields

A new study released today by the New York State Department of Environmental Conservation (DEC) and the Department of Health (DOH) concludes that crumb rubber material used in synthetic turf fields poses no significant environmental threat to air or water quality and poses no significant health concerns.

The study, available on DEC's web site (details below), assessed the potential release of chemicals in crumb rubber to the environment. Crumb rubber, produced by grinding scrap tires, is a common "infill" material for synthetic turf fields. It provides cushioning and helps to hold the carpet down and keep synthetic grass fibers upright. The study only addressed the crumb rubber infill and did not address pigments used in synthetic turf fibers that in older applications are known to contain lead.

The study found:

-- No significant threat from chemicals leaching into surface water and groundwater. While some chemicals can be released from crumb rubber over time, they are in small concentrations and are reduced by absorption, degradation and dilution -- resulting in no significant impact on groundwater or surface water.

-- Lead concentrations in crumb rubber are well below federal hazard standards for lead in soil and do not represent a significant source of lead exposure.

-- Levels of chemicals in the air at synthetic turf fields do not raise a significant health concern.

-- Synthetic turf fields can have significantly higher surface temperatures compared to nearby grass and sand fields, although factors of heat stress did not differ noticeably among surfaces. Still, the study notes that prolonged contact with hotter surfaces has the potential to create discomfort, cause thermal injury and contribute to heat-related illness.

To carry out the study, state scientists conducted lab tests on crumb rubber samples obtained from manufacturers and conducted tests at synthetic fields. They tested for leaching, exposure to acid rain and acid digestion, exposed samples to a range of temperatures to observe impacts, assessed chemical particle sizes for their potential to move through soil and air, collected soil samples at wells down-gradient from existing synthetic turf fields and measured air samples upwind and downwind of such fields. DEC will continue groundwater and surface water testing related to this issue.

Led by DEC's Division of Solid and Hazardous Materials and the Division of Air Resources, the state pursued a comprehensive evaluation of potential chemical releases from crumb rubber. It involved an interdisciplinary approach, drawing upon expertise in DEC's and DOH's other programs including water resources, remediation, laboratory, chemistry and fish and wildlife.

The study is available on DEC's "Waste Tire" Web page (at the bottom of the page). For more information about crumb-rubber infilled fields, see the DOH fact sheet: http://www.health.state.ny.us/environmental/outdoors/synthetic_turf/crumb-rubber_infilled/fact_sheet.htm

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SYNTHETIC TURF
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Fact Sheet: Crumb-Rubber Infilled Synthetic Turf Athletic Fields

New York State Department of Health (DOH)

Fact Sheet: Crumb-Rubber Infilled Synthetic Turf Athletic Fields

- Fact Sheet: Crumb-Rubber Infilled Synthetic Turf Athletic Fields is available in Portable Document Format (PDF, 97KB, 9pg.)

Purpose

There are several kinds of synthetic turf surfaces (e.g., surfaces that use a fill material ("infill") between the blades of artificial grass and those that do not), and synthetic turf may be installed for different uses (e.g., single or multiple sport athletic fields, landscaping, golf applications). The focus of this fact sheet is athletic fields with crumb rubber infilled synthetic turf. This fact sheet was developed to assist people in making decisions about installing or using this kind of synthetic turf athletic field. Considerations related to other kinds of synthetic turf fields are not addressed in this fact sheet.

Background

The first well-publicized use of AstroTurf, a synthetic turf for athletic fields, was at the Houston Astrodome in 1966. This first generation of synthetic turf was essentially a short pile carpet with a foam backing. Since then, design changes have resulted in a greater variety of synthetic turf athletic fields. One type of synthetic turf is fabricated using synthetic fibers, manufactured to resemble natural grass, and a base material that stabilizes and cushions the playing surface. The fibers are typically made from nylon, polypropylene or polyethylene and are connected to a backing material. The base material, also called infill, consists of one or more granular materials that are worked in between the fibers during the installation process. Commonly used base materials are granulated crumb rubber (usually from used tires), flexible plastic pellets, sand, and rubber-coated sand. A combination of sand and crumb rubber is often used.

Crumb rubber is produced by grinding used tires. Steel and fiber tire components are removed during the process and the rubber pellets are sorted by size. Pellet sizes ranging from about one-sixteenth to one-quarter inch in diameter are used on synthetic turf. Crumb rubber is typically applied at a rate of two to three pounds per square foot of field surface.

Health And Safety Considerations

Some potential health and safety considerations related to synthetic turf have generated public concern. These include:

- Heat stress
- Injury
- Infection
- Latex allergy
- Chemical exposure

Heat Stress

Synthetic turf fields absorb heat, resulting in surface temperatures that are much higher than the temperatures of the surrounding air. In June 2002 at Brigham Young University (BYU) in Utah, the average surface temperature on a synthetic turf field was reported to be 117°F while the average surface temperatures on natural turf and asphalt were 78°F and 110°F, respectively. A maximum surface temperature of 200°F on the BYU synthetic turf field was reported. A turfgrass specialist at the University of Missouri reported measuring an air temperature of 138°F at "head-level" height on the university's synthetic turf field on a sunny 98°F day. The surface temperature of the field was reported to be 178°F. A study conducted at Penn State University measured surface temperatures on experimental plots of nine different types of infilled turf. Temperature measurements were made on three occasions. The average air temperatures reported were 79°, 78°, and 85°F. The corresponding average surface temperatures reported for the synthetic turf plots are 120°, 130° and 146°F.

Water can be applied to synthetic turf to reduce the surface temperatures on warm days. A study at BYU found that watering synthetic turf lowered the surface temperature from 174°F to 85°F, but the temperature rose to 120°F in five minutes and to 164°F in twenty minutes. A study conducted by Penn State University on

experimental synthetic turf plots examined the effect of watering synthetic turf on surface temperature. Measurements were made on three occasions. For one monitoring period, surface temperatures ranging from about 130° to 160°F were lowered initially to about 75°F, but increased within 30 minutes to temperatures ranging from about 90° to 120°F, where they remained fairly stable for the three-hour monitoring period.

The surface temperatures reported on synthetic turf fields can get high enough to reach levels of discomfort and may contribute to heat stress among users of the fields. While watering synthetic turf may reduce surface temperatures, other factors are likely to influence its effectiveness. At the present time, NYSDOH is unaware of any studies that have examined the role of synthetic turf in contributing to heat stress or that have compared the occurrence of heat stress among athletes playing on natural turf and synthetic turf.

Because of the potential for high temperatures on infilled synthetic turf fields, it is important that people who play or work on the fields be provided with adequate warnings regarding the potential for heat stress. People should also be advised to remain hydrated and to seek relief from the heat in shaded areas. The potential for and frequency of high surface temperatures warrant consideration when making decisions about installing and using a synthetic turf field.

Injury

There is a common perception that there are more sports injuries on synthetic than on natural turf athletic fields. Many factors influence the rate of sports injuries, including the type of playing surface. The many kinds of synthetic turf surfaces and changes in the turf products over the years complicate the assessment of how the playing surface affects injury rates. Other risk factors have been implicated in injury rates among athletes, in addition to the type of playing surface. These risk factors include level of competition, skill level, age, shoe type, previous injury and rehabilitation, and a number of individual physical characteristics. We identified five studies that compared injury (e.g., sprains, lacerations, fractures) rates among athletes when playing on infilled synthetic turf and natural turf fields. Although the ability of the studies to detect differences in the injury rates was limited by the small number of injuries reported, the studies concluded that there were no major differences in overall injury rates between natural and infilled synthetic turf. Although each study found some differences in specific injury types, there was no consistent pattern across the studies.

The potential for head injuries from contact with the surfaces has been assessed by determining the ability of the surfaces to absorb impacts. Tests have shown that the force of impact on asphalt surfaces is much higher than the level generally accepted to be associated with serious head injury. The force of impact on many types of natural turf and all types of synthetic turf tested are below this level. The force of impact on frozen natural turf is typically above the acceptable level. No data are available for the force of impact on frozen synthetic turf.

The abrasiveness of synthetic turf fibers may contribute to the injury risk among athletes, particularly for abrasions or "turf burns." The degree of abrasiveness appears to be dependent on the composition and shape of the turf fibers. A study conducted at Penn State University suggests that synthetic turf with nylon fibers is more abrasive than synthetic turf with other types of fibers.

Infection Risk

Some people have expressed concern that infections, including methicillin-resistant *Staphylococcus aureus* (MRSA), may be more common among users of synthetic turf fields than users of natural turf fields. This possibility has not been studied systematically, and no definitive statements can be made about differences in risk between the two surfaces.

At least two questions are important in evaluating the risk of infection. Does skin damage occur more frequently on synthetic turf than natural turf, thus providing a place where infections are more likely to occur? Are there more germs on synthetic turf than natural turf?

While injury studies have not consistently identified differences in abrasion and laceration risks between natural and infilled synthetic turf, some types of synthetic turf may result in more skin abrasions. Although very few tests have been performed, the available data do not suggest the widespread presence of infectious agents, such as MRSA, on synthetic turf fields. Also, the available information indicates that outdoor or indoor synthetic turf surfaces are no more likely to harbor infectious agents than other surfaces in those same environments. Disease outbreak investigations conducted in response to illnesses caused by a variety of germs (e.g., MRSA, *Campylobacter*, meningococcus, echovirus, herpes simplex virus, hepatitis virus, coxsackie virus) have not identified playing fields, either natural or synthetic, as likely to increase the risk of transmitting infections.

Skin cuts and abrasions that may result from contact with athletic fields, including both natural and synthetic fields, are susceptible to infection. Athletes and others developing skin abrasions should clean the wounds and seek prompt medical attention. Athletes should avoid sharing towels (on and off the field), equipment, razors, soap and other objects with others, because sharing these items can spread germs.

Latex Allergy

Latex, a substance found in natural rubber, contains substances called "latex allergens," which can cause an allergic response in some people. About 6 percent of the general population is allergic to the substances in latex. Tire rubber contains the latex allergen, although at much lower levels than in latex gloves and other consumer products. People playing on synthetic turf may be exposed to latex allergens through direct contact with the skin (dermal exposure) and inhalation of small rubber particles suspended in the air.

A study conducted for the California Environmental Protection Agency tested samples of tire rubber on the skin of guinea pigs. None of the animals developed any rashes or allergic reactions from contact with the rubber.

Whether crumb rubber can cause an allergic response in people is not known. NYSDOH is unaware of any occurrences of latex allergy associated with contact with crumb rubber or synthetic turf fields.

Chemical Exposure

Exposure to a chemical requires contact with it. Contact with a chemical occurs in three ways: swallowing it (ingestion exposure), breathing it (inhalation exposure), and having it come in contact with the skin (dermal exposure) or eyes (ocular exposure). The potential for harmful effects from exposure to a chemical depends on the amount of the chemical a person contacts, how the chemical enters the body (ingestion, inhalation, dermal, or ocular), how often contact occurs, and the toxic properties of the chemical. The ability of a chemical to be released from a substance (e.g., crumb rubber) is an important factor in determining how much exposure actually occurs. Other factors that can influence a person's risk for adverse health effects from environmental chemicals include age, gender, general health, genetic differences, exposure to other chemicals and lifestyle choices.

Tires are manufactured from natural and synthetic rubbers along with numerous chemical additives, including zinc, sulfur, carbon black, and oils that contain polyaromatic hydrocarbons (PAHs) and volatile organic chemicals. Because crumb rubber is manufactured from used tires, it probably contains the same chemicals as tire rubber.

Studies have been conducted by the California Environmental Protection Agency Office of Environmental Health Hazard Assessment and the Norwegian Institute of Public Health to assess the potential for ingestion exposure to the chemicals in crumb rubber by children playing on synthetic turf. Both studies concluded that health risks to children resulting from the ingestion of crumb rubber are low.

The Norwegian Institute of Public Health also collected data to assess potential health risks resulting from dermal and inhalation exposures to chemicals contained in synthetic turf fields. Health assessments were conducted for adults and children. The researchers concluded that adverse health effects resulting dermal exposures to crumb rubber or from inhalation exposures to organic chemicals released from the fields are unlikely. No health assessment of the concentrations of rubber particles in the air was made.

A French study measured the concentrations of organic chemicals emitted as gases (known as volatile organic compounds or VOCs) from crumb rubber under laboratory conditions. The data were used by the French National Institute for Industrial Environment and Risks to evaluate possible health effects from inhaling VOCs released from synthetic turf. The study authors concluded that the concentrations of organic compounds emitted did not pose a health concern for athletes, officials or spectators.

Some types of synthetic turf fibers contain elevated levels of lead (e.g., in the range of about 2,000 to 9,000 parts per million). Degradation of these fibers can form a dust that presents a potential source of lead exposure to users of the fields. The Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry addressed the potential for lead exposures from synthetic turf fibers in a June 2008 Health Advisory (http://www.cdc.gov/nceh/lead/artificialturf.htm). For new or replacement installations, select synthetic turf products that do not have elevated lead levels.

Our review of the available information on crumb rubber and crumb rubber infilled turf fields indicates that ingestion, dermal or inhalation exposures to chemicals in or released from crumb rubber do not pose a significant public health concern.

Other Considerations

A number of other factors may need to be considered when installing and using synthetic turf.

Use:

Synthetic turf is more durable than natural turf and can be used without the rest periods that natural turf requires to keep the turf healthy. The New York City Department of Parks and Recreation (NYCDPR) estimates that on an

annual basis, permitted use (hours per year) for synthetic turf athletic fields is 28 percent higher than for natural grass fields.

Installation:

Installation costs of synthetic turf vary depending on the amount of site preparation required and the specific field design. The installation costs of synthetic turf are generally much higher than the installation costs of natural turf.

Maintenance:

The maintenance costs of synthetic turf will vary depending on the field's use and design, but are typically estimated to be lower than the maintenance costs of natural turf. Natural turf requires regular mowing, fertilizer application, pest control and possibly watering. Synthetic turf requires replacing infill materials, repairing seams and removing weeds and moss. Specialized equipment, which may or may not be included in the field's purchase price, is required for these activities.

Lifetime:

NYCDPR estimates that the lifetime of a natural turf field is on the order of five years. The synthetic turf industry estimates that the lifetime of an infilled synthetic turf athletic field is eight to ten years, depending on care during installation and use. NYCDPR and other New York entities have seen similar lifetimes.

Summary of Information for Crumb-Rubber Infilled Synthetic Turf Athletic Fields

Health Concern	Finding
Heat stress	Surface temperatures on crumb-rubber infilled synthetic turf fields can reach levels of discomfort and may contribute to heat stress. This warrants consideration when making decisions about installing and using a synthetic turf field. While watering synthetic turf may briefly reduce surface temperatures, a number of factors may influence its effectiveness. People using these fields should be advised to remain hydrated and to seek relief from the heat in shaded areas.
Injury	Overall, studies have found no consistent differences in injury rates between natural and crumb-rubber infilled synthetic turf.
Infection	Skin cuts and abrasions that may result from contact with athletic fields (natural and synthetic turf) are susceptible to infection. Athletes and others developing skin abrasions should clean the wounds and seek prompt medical attention. Athletes should avoid sharing equipment, razors, towels, soap and other objects with others, because these items can spread germs.
Latex allergy	At the present time, NYSDOH is unaware of any occurrences of latex allergy resulting from contact with crumb rubber or synthetic turf fields.
Chemical exposures	Based on the available information, chemical exposures from crumb rubber in synthetic turf do not pose a public health hazard.

Where Can I Get More Information?

If you have any questions about the information in this fact sheet or would like to know more about in-filled synthetic turf athletic fields, please call the NYSDOH at 518-402-7530 or 1-800-458-1158 or write to the following address:

New York State Department of Health
Bureau of Toxic Substance Assessment
Flanigan Square, 547 River St.
Troy, NY 12180-2216

Some Relevant References

Temperature of In-filled Synthetic Turf Athletic Fields

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Revised: March 2011

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Synthetic Turf Beneficial Use Determination Letter

Massachusetts Executive Office of Energy and Environmental Affairs (EOEEA)

COMMONWEALTH OF MASSACHUSETTS
EXECUTIVE OFFICE OF ENERGY & ENVIRONMENTAL AFFAIRS
DEPARTMENT OF ENVIRONMENTAL PROTECTION
ONE WINTER STREET, BOSTON, MA 02108 617-292-5500

DEVAL L. PATRICK
Governor

TIMOTHY P. MURRAY
Lieutenant Governor

IAN A. BOWLES
Secretary

ARLEEN O'DONNELL
Commissioner

July 12, 207

Matthew P. Garvey
Ropes & Gray
One International Place
Boston, MA. 02110-2624

Re: Synthetic Turf Beneficial Use Determination

Dear Matthew,

I am writing in response to your letter dated July 9, 2007, written on behalf of the Town of Wayland, in which you request confirmation from MassDEP that MassDEP does not intend to issue a Beneficial Use Determination (BUD) regarding the use of crushed tires used in synthetic athletic fields.

MassDEP does not intend to issue a site-specific BUD for the use of tire crumb rubber in the synthetic athletic field in Wayland. The use of tire crumb as infill in synthetic turf fields is a well-established practice where the tire crumb substitutes for virgin rubber materials or rubber and soil mixtures. Synthetic turf fields have been constructed at numerous locations within Massachusetts. This use of tire crumb is in a restricted setting where the material will be disposed at the end of life of the field. MassDEP believes this use of tire crumb in synthetic athletic fields to be an acceptable recycling/reuse of tire rubber that does not warrant further review by MassDEP. Therefore, the Town of Wayland and the Wayland Booster's Association are not required by MassDEP to obtain a BUD for this use.

Sincerely,

James A. Doucett

James A. Doucett
Deputy Director
Business Compliance Division
Bureau of Waste Prevention

This information is available in alternate format. Call Donald M. Gomes, ADA Coordinator at 617-556-1057. TDD Service - 1-800-298-2207.

MassDEP on the World Wide Web: http://www.mass.gov/dep
Printed on Recycled Paper

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Environmental Compatibility Concept According to DIN 18035

Test Procedures and Background

SGS Institut Fresenius - Dresden1 Zabel Presentation

SGS

INSTITUT FRESENIUS



Environmental combatibility concept according DIN 18035

Test procedures and background

I1

Structure

- Environmental basic statements of the DIN 18035
- Background of Quality Assurance
- Generalisation Findings
- Points of Criticism
- Future Outlook

Slide 2

I1 lutz_zabel; 01.10.2006

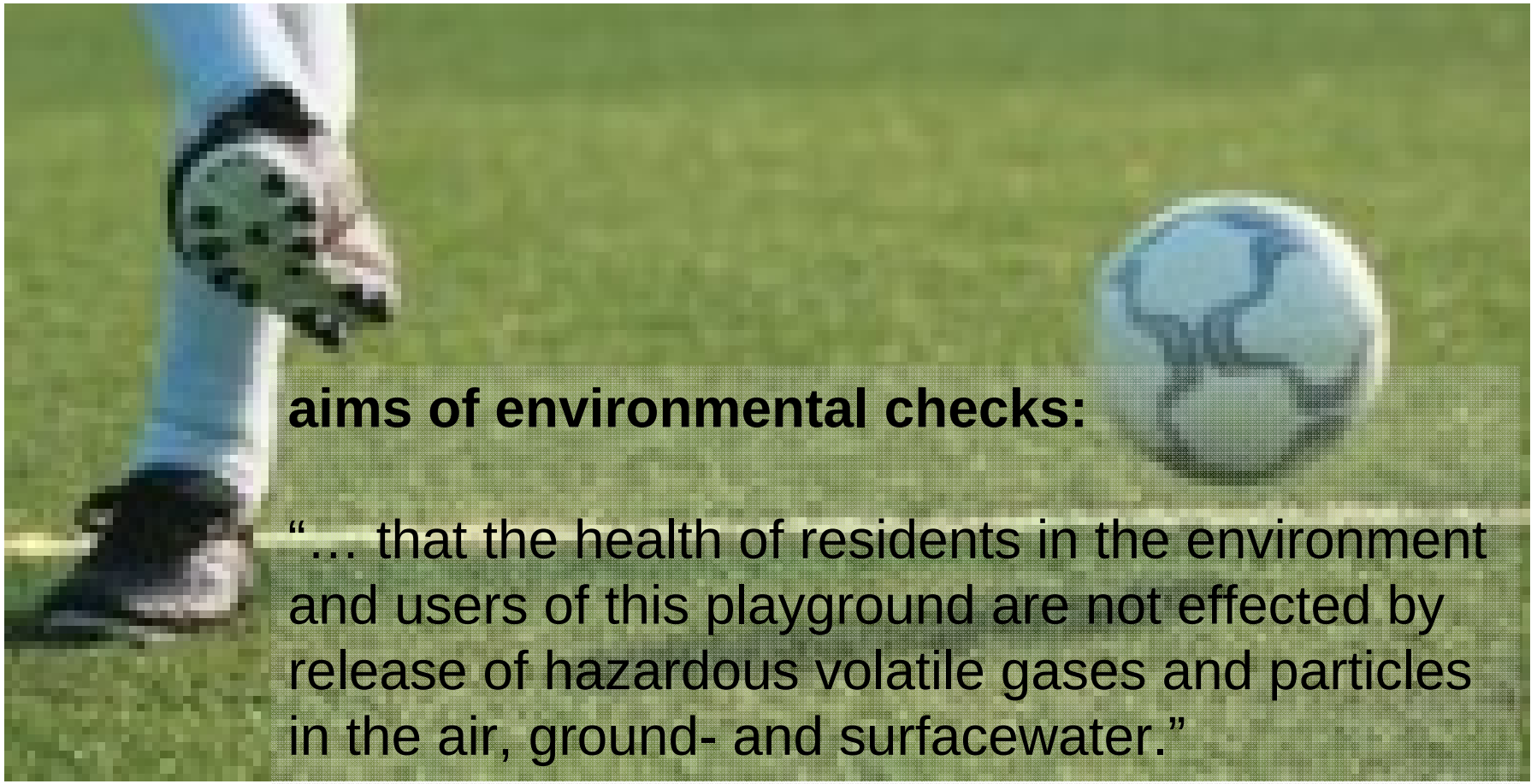
DIN 18035 - History

- First Investigations by German authorities in the 1990's
- Result: no relevant dangers by use of artificial playgrounds
- Draft of a standard

  DIN E 18035-6 synthetic surfaces for outdoor sports areas (2004)

  DIN E 18035-7 synthetic turf surfaces for outdoor sports surfaces (2002)

DIN 18035 - aims



aims of environmental checks:

“… that the health of residents in the environment and users of this playground are not effected by release of hazardous volatile gases and particles in the air, ground- and surfacewater.”

Environmental requierements

parameter	synthetic turf surfaces			synthetic surfaces		
	origin [mg/kg]	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]	origin [mg/kg]	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]
DOC		< 20 / < 40			< 20 / < 40	
EOX	<100			<100		
Pb			<0,04			<0,04
Cd			<0,005			<0,005
Cr			<0,05			<0,05
Cr-VI			<0,008			<0,008
Hg			<0,001			<0,001
Zn		< 0,5*	< 3			< 3
Sn			<0,05			<0,05
Toxicity			< 50 %**			collection experiance

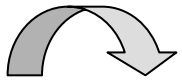
Assessment

parameter	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]	remark	ko condition
DOC	> 20 / < 40		consideration EOX	
	> 40			x
EOX				EOX > 100 mg/kg
Zn*	> 0,5		consideration Zn acid leachat	
	> 1			x
		> 20		x

* synthetic turf areas

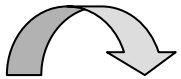
Relevant Parameters according to DIN 18035

- complex spectrum of organic compounds

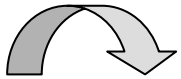
  lump parameter DOC

- Chlorinated paraffin and other halogenated organic compounds

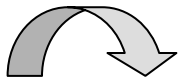
  lump parameter EOX

- Long-range soluble heavy metals

  acid elution (CO2-gassing)

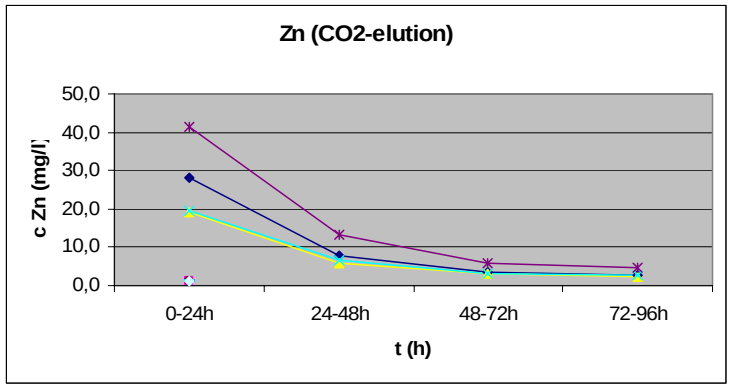
- easily available Zinc cations

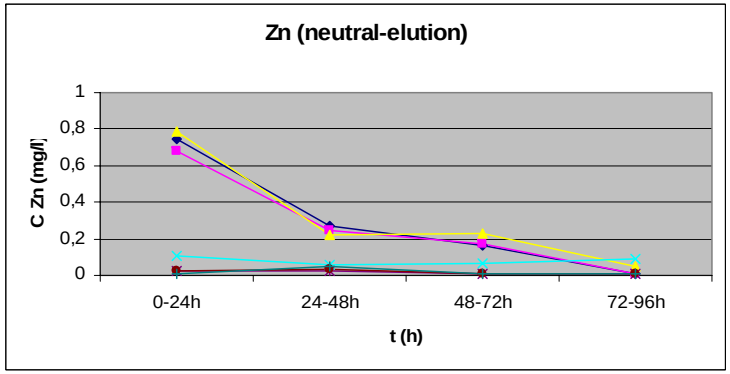
  neutral elution L/S ratio 10:1

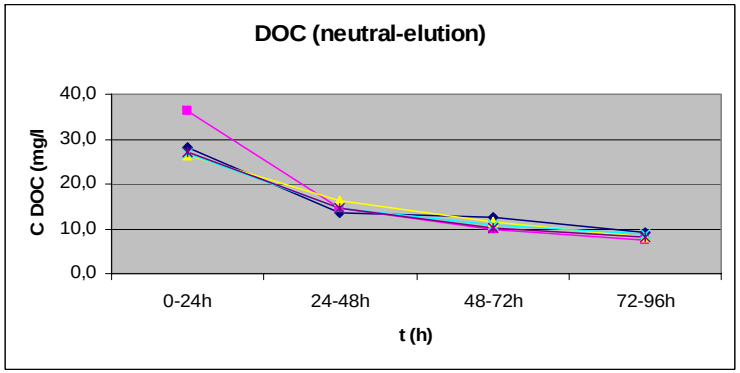
Elution Method

Differences between 24 - 48 h elution from the commonly applied 24 h-elution



Recording of the mobilisation of dangerous compounds





Toxicity Test

- Nitrification test or luminescence bacteria test in the 24-48 h neutral elution
- Only assessments for elastic baselayers and synthetic turf
- Experiences are collected in the field of toxicity by synthetic surfaces and infill materials in synthetic turf surfaces

.

Basis of the Assessment

Assessment is based on the German Legislation

- German Soil Protection Law (Groundwater is the point of compliance)
- the Guide for Recycling of Mineral Product

  (Groundwater is the point of compliance)

LAGA

Länderarbeitsgemeinschaft Abfall

General Findings

Synthetic turf areas

- Turf

  toxicity << 50 %,

  exception – enhanced values for DOC, Zn
- Base layer all requirements fulfilled
- Infill material
  - SBR

    toxicity in 75 % all samples < 50%

    in general Zn requirements fulfilled
  - EPDM (S) always toxic (benzothiazols)
  - EPDM (P) all requirements fulfilled
  - TPE all requirements fulfilled

Synthetic surfaces –

all requirements fulfilled

Points of Criticism

- Relation between extraction methods and existing release
- Extraction with CO2 saturated water
- Preparation method of test bodies
- Importance of toxicity tests

Outlook

- Change elution method (CEN/TS 14405 as well as the batch test such as EN 12457)
- Change saturated CO2 Elution test into pH dependence test such as prEN 14429
- The use of tank test for synthetic surfaces is recommended
- No necessity to exceed the parameter list
- Luminescence bacteria test with an attenuation level GL 8, if the DOC exceeds the 10 ppm level

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Investigation and Assessment of Synthetic Sports Surfaces in Switzerland

Including Athletic & Soccer Facilities

Hans J. Kolitzus, IST Switzerland

Investigation and Assessment of Synthetic Sports Surfaces in Switzerland Including Athletic and Soccer Facilities

Hans J. Kolitzus, IST Switzerland

Switzerland had developed a concept for synthetic Surfaces (athletic) in respect to environment similar to Germany. Partly, the two committees had common meetings. The result was published in the mid 90ies as a recommendation “Kunststoffbeläge und Umwelt (Synthetic Surfaces and Environment) by BASPO, the Swiss Federal Authority of Sports at Magglingen. The Swiss document (BASPO 105) was more complicated than the German document (first RAL later DIN 18035-6). The use of this document was not obligatory, but more incidental acc. to the deliberation of the various States of Switzerland.

Unfortunately, the document was applied to Artificial Turf also although its scope was limited to synthetic athletic surfaces. The application was done without modification and considerations. When it was realized that there was a discrepancy or inadequate use of the document, BASPO decided to completely reconsider the issue. A new committee was founded including experts from various Swiss authorities, companies and lab experts. As discussions and activities are still going on I can only report the design of the programme and first results. I am authorized to do this but cannot publish any data available today.

The common view of the committee is that the real effect of sports surfaces on site to the environment cannot be determined by using lab tests as used by the former concept or the DIN. They are regarded totally non suitable for assessment of artificial turf. In order to receive real data, a practical study programme has been prepared and started. The aim is to get data of what is really released from sports surfaces to water running off the surfaces and probably contaminating rivers or the underground. The test program was started last year and will be continued until spring time of next year.

For this, a variety of typical sports surfaces have been installed in so called Lysimeters (see appended pictures). These are well known in horti- and agriculture to

investigate the exchange of nutrients of plants. These are reinforced Polyester tubes. They are about 1m wide and 1.5m high. They are equipped with an automatic water sampling system. Thus, the total amount of rain water seeping through or running off the sports surface can be collected and analyzed.

In Bern, 10 such Lysimeters are equipped with the following set of surfaces:

List of surfaces

1. Artificial Turf with EPDM infill and Quartz sand on a permeable asphalt base and elastic layer 25mm
2. Artificial Turf with SBR rubber and Quartz sand infill on mineral sub base
3. Artificial Turf with EPDM infill and Quartz sand on mineral subbase and elastic layer
4. Artificial Turf without infill on mineral sub base
5. Permeable Synthetic Surface EPDM 12mm on an asphalt base + elastic layer
6. Permeable Synthetic Surface EPDM + SBR (6mm + 9mm) with Spray Coat 1.5kg/m2
7. Sandwich Surface PUR coating + SBR (5mm + 10mm)
8. Mineral Supporting Layer = 0-sample no. 1
9. Bituminous Supporting Layer on mineral subbase = 0-sample no. 2
10. Elastic Layer of recycled SBR granules 25mm on mineral subbase

All containers were filled with an unbound (mineral) supporting layer as commonly used in Switzerland. Only the upper 65cm are used. Beneath an impermeable layer (concrete) is installed so that the water can flow into the collection containers. The design of the surfaces is rather similar to real surfaces. The analysis of the collected water is performed after 300mm precipitation.

Searched Substances

- Rubber chemicals: various aromatic Amines and Benzothiazoles
- Polycyclic aromatic hydrocarbons (16 PAH)
- Sum of organic nitrogen compounds (total N-org)
- Sum of dissolved organic substances (DOC)
- Zinc

Progress of Investigation

Due to adverse weather conditions the main test series could not be started until May 2006 . Thus, test data are available for the time from May to September.

The Lysimeter device was checked in December 2005 already with the installation of an artificial turf filled with EPDM granules and Quartz sand on top of a permeable asphalt sub base and an elastic layer.

It is intended to observe the substances released to the run-off water for a minimum of 1 year. Special interest is drawn on the decrease of their concentrations over time.

Zinc

With all surface types, including the 0-sample no. 1 consisting of the mineral supporting layer, Zinc was found in concentrations of 0.009 to 0.003 mg/l. In rain water which was also investigated a concentration of 0.02 mg/l was found. We will see how the Zinc concentration will change in the course of time.

Polycyclic Aromatic Hydrocarbons (PAH)

In all samples, also in the 0-sample no. 1 which consists of the unbound supporting layer only, the various PAHs were determined in the range of analytic determination limit which is 0.02 µg/l, whereas the sum of all 16 PAHs is about 0.1 to 0.3 µg/l. None of the surface systems including the surfaces with recycled granules showed any noticeable PAH concentration. PAHs are ubiquitous substances in the environment and in water. They are present in any street sewage and also in purified sewage from communal sewage purification plants as well as sewage sludge in partly much higher concentrations.

DOC

Reliable conclusions about DOC concentrations are not possible yet. Especially not because the 0 sample (i.e. unbound supporting layer without a sports surface) had a

DOC concentration of 6 mg/l. Due to the results of the pre-test it is expected that the DOC concentration will decrease in the course of time.

Various Substances

In surface systems with EPDM and recycled rubber infill several aromatic Amino complexes and Benzothiazoles were determined in the range of 10 – 300 µg/l. According to the results of the pre-test it is expected that similar concentrations will be found in all street sewage waters as a consequence of abrasion of car tires. These complexes and substances are also ubiquitous in the aquatic environment.

Already today, BASPO has notified the communities and states of Switzerland that the BASPO document 105 is not relevant any longer and should especially not be applied to artificial turf.

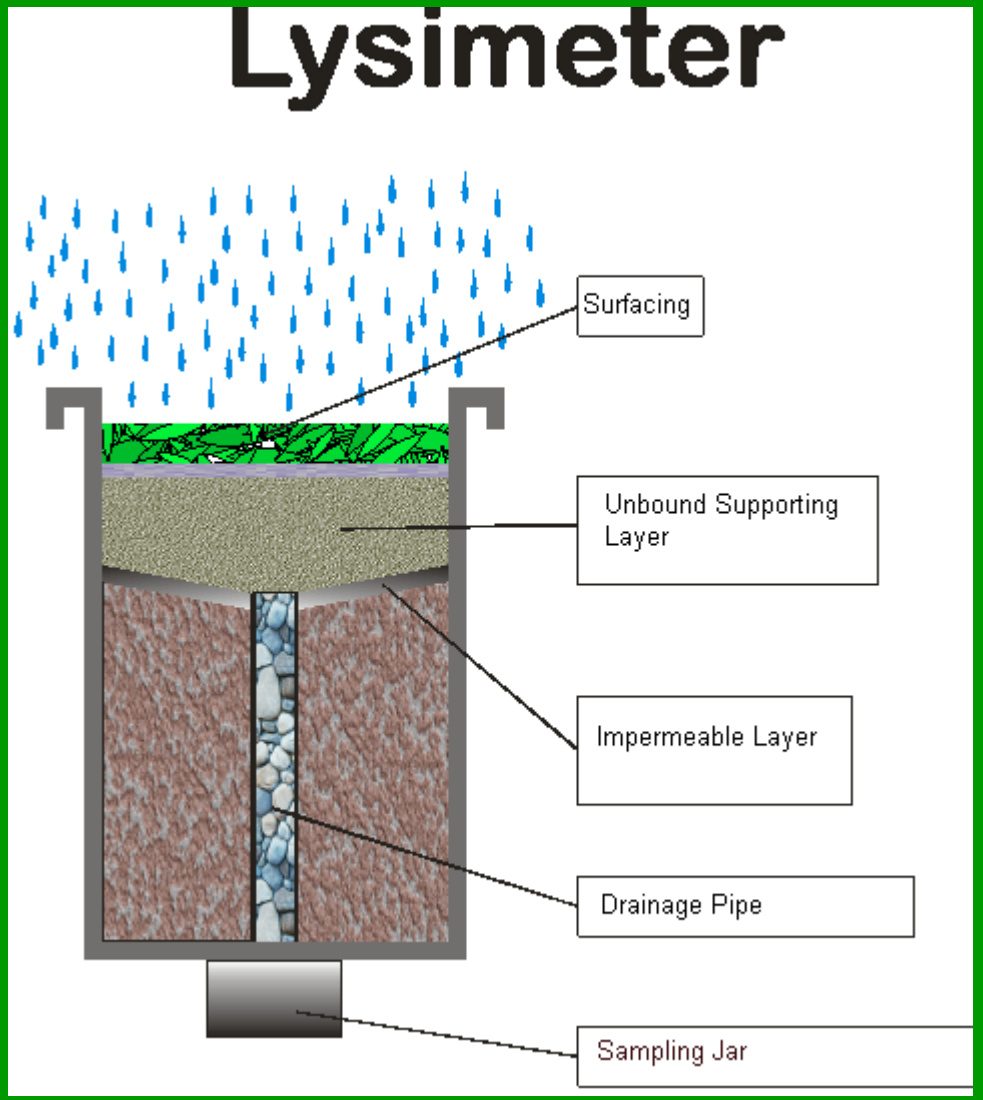
Swiss Federal Authority of Health July 6, 2006

This authority was challenged to provide a statement regarding health risk caused by PAH in artificial turf. The issue refers to recycled rubber granules i.e. SBR granules from car tires. It is considered the question of abraded particles being inhaled as dust and being washed out and ending up in waters and in the subsoil. PAHs can be substances added to softeners of tires, but are also generated by burning processes, from traffic exhaust fumes and heating systems; they also come from tobacco smoking and chimneys.

Assessment and Recommendation for Switzerland

Although a final assessment of the health risks is not possible acc. to the data available today, the estimatable PAH stress is low even in worst case scenarios compared with stress from other sources. The health risk for players and spectators is classified low. Thus, from the health point of view no urgent need of action is seen.

Lysimeter



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Spring 2006 - SPECIAL REPORT
A PARK POLICY PAPER

New Yorkers for Parks
The Arthur Ross Center for Parks and Open Spaces

NEW YORKERS FOR PARKS

Ensuring greener, safer, cleaner parks, together.

Spring 2006

SPECIAL REPORT

A PARK POLICY PAPER



A New Turf War

Synthetic Turf in New York City Parks



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Executive Summary

New York City's Department of Parks & Recreation (DPR) has become increasingly reliant on synthetic turf as a replacement for asphalt and natural grass athletic fields across the city. Through the installation of the "new generation" of synthetic turf, DPR seeks to increase community access to fields as well as to solve the maintenance challenges of grass and the aesthetic and safety problems associated with asphalt. This surface offers all-weather playability and lower maintenance costs than grass; however, synthetic turf has some negative environmental impacts and requires a significant capital investment. The important environmental benefits of natural turf, such as its ability to absorb and filter rainwater and pollutants, and to decrease the impact of the urban heat island effect, must be considered in the debate. In addition, DPR's current process for evaluating the appropriateness of synthetic turf installation requires increased community input. New Yorkers for Parks (NY4P), the only citywide parks advocacy organization, conducted interviews with practitioners, community members, academics and representatives from the Parks Department in researching synthetic turf. This in-depth, independent analysis will examine the financial and environmental costs of natural vs. synthetic turf, as well as the implications for usage, maintenance, health and safety. Finally, the report will assess the current community input processes and offer policy recommendations toward the best use of this new technology.

NY4P offers the following recommendations to more effectively use and evaluate synthetic and natural turf on athletic fields:

- Continue and expand the Neighborhood Parks Initiative to improve the performance of natural turf fields, lawns and gardens.
- Formally mitigate the installation of synthetic turf by creating new green space elsewhere in the neighborhood.
- Develop a targeted maintenance strategy for natural turf baseball fields in order to boost their performance.
- Install irrigation systems to enhance the DPR's capacity to maintain natural turf baseball fields.
- Include maintenance plans and cost-benefit analyses in requests for capital funding for athletic fields so that educated funding decisions are made.
- Include safety information on signage at synthetic turf fields.
- Take advantage of recent turf installations—engage in formal studies that may support the benefits of synthetic turf.
- Form a task force of experts to develop criteria for consideration by community boards facing athletic field renovations.
- Before fiscal appropriations occur, present to the community board all possibilities for athletic field renovations.

Introduction—Synthetic Turf: A Growing Trend

In 1998, the Parks Department began using synthetic turf to replace asphalt and grass athletic fields throughout the city and has since become the largest municipal buyer of turf in the country.[1] Citing benefits such as decreased maintenance requirements, all-weather play, and lower long-term costs than natural turf, the Parks Department is embracing the new generation of synthetic turf. Opponents of this initiative argue that the installation costs of synthetic turf are too high, placing an undue burden on the city's capital budget. Environmental arguments play a key role in the debate, with opponents stressing the ecological and psychological benefits of natural grass.

Community groups on both sides of this debate have brought the issue to the media and raised it in park policy discussions. As the only citywide advocacy group for New York City's parks, New Yorkers for Parks (NY4P) offers an independent, in-depth analysis of synthetic turf in this report. This paper will examine the financial and environmental costs of natural vs. synthetic turf and the implications for usage, maintenance, health and safety, assess the current community input processes, and offer policy recommendations toward the best use of this new technology.



COLUMBUS PARK, MANHATTAN
This synthetic turf field opened during the summer of 2005 after much community debate.

[1] Berger, Joseph. "Falling (Safely) for Artificial Turf." *The New York Times*. 20 March 2004. Retrieved Nov. 2005 from www.nytimes.com

The Parks Department: 1986-2006

New York City's Department of Parks and Recreation (DPR) manages 28,800 acres of municipal parkland, comprising 14% of New York City's land cover. As a city agency, the Parks Department is largely dependent on public funds for its operations. In recent decades, during good fiscal times and bad, DPR's budget has been repeatedly cut, forcing the Department to manage a growing park system with diminishing funds. Even with the recent budget increases under Mayor Bloomberg, DPR's budget has been cut by approximately 20% and its staffing by close to 60% since 1986.[2]

The impacts of these budget cuts pervade the Parks Department. Decreased funding has forced DPR to cut back on vital maintenance and important programs. In NY4P's 2005 *Report Card on Parks*, 40% of neighborhood parks received a C, D or F, reflecting the poor conditions in many city parks and the need for improved maintenance. Many communities look back fondly on the days of the "parkie in the park"—when regular full-time employees were stationed in parks to carry out maintenance, supervise children and provide programming. Unfortunately, the Department no longer has the resources for this type of staffing.

As a partial solution to this dilemma, the Parks Opportunity Program (POP) was introduced in 2001 to provide public assistance recipients with paid employment maintaining New York City parks. The program has relieved some of the pressure on full-time employees to reduce litter and remove graffiti. Now called Job Training Participants (JTPs), these staff are employed for 6 months at the end of their assistance eligibility and are frequently the only Parks personnel in our city's parks. Though their presence is valuable, due to their short-term employment status and limited training, they often do not know how to navigate the Parks system in order to report or address maintenance needs in city parks. POP is an innovative program that serves parks and their users, but it does not satisfy the need for full-time staffing.

In NY4P's 2005 *Report Card on Parks*, 40% of neighborhood parks received a C, D or F, reflecting the poor conditions in many city parks and the need for improved maintenance.

The increase in private funding for park projects and management represents another partial solution to the Parks Department's limited budget. Groups like the Central Park Conservancy and the Bryant Park Restoration Corporation use privately raised dollars to make up 85% and 100% of those parks' maintenance budgets, respectively.[3] Alternate models of park management include the Hudson River Park Trust and the Brooklyn Bridge Park Development Corporation, both of which are state-city partnerships whose business plans include funding maintenance through revenues generated within the park. Though these entities have enacted positive change in public spaces, their impressive work illustrates the wide disparity between these and smaller neighborhood parks that cannot access private money and are left to rely solely on public funding.

[2] Reflects changes in Adopted Budgets between Fiscal Years 1986 -2006. New York City Office of Management and Budget; Adopted Budget Expense, Revenue, Contract: Fiscal Years 1986 -2006.

[3] "About the Central Park Conservancy," CPC. Retrieved Dec. 2005 from www.centralparknyc.org/aboutcpc and "Park Management," Bryant Park Restoration Corporation. Retrieved Dec. 2005 from www.bryantpark.org.

Maintenance Challenges of Athletic Fields

With a limited budget, an increasingly diminished staff, and a heavily used park system, DPR has faced a challenge in keeping up with maintenance. Properly maintained natural grass fields require the following: regular mowing and spraying for weeds, irrigation, and daily trash and glass pick-ups. Ideally, they should be closed for a period of time to allow the grass to rest. (One of the few benefits of asphalt fields is that they are easily maintained, needing only occasional patching of cracks and holes.) The growing popularity of soccer—a particularly punishing sport when it comes to grass—has intensified the need for regular maintenance of grass fields.

Park managers and horticulturalists agree that a natural turf field must be closed to the public at regular intervals in order to keep the grass healthy. The debate of access vs. green fields presents a challenge for policy makers. The Central Park Conservancy closes fields all winter until April, and during the spring and summer, fields are closed on a rotating basis for rehabilitation.[4] The Prospect Park Alliance also closes their fields during winter, the most damaging season for grass. But DPR is hesitant to close fields at neighborhood parks for any amount of time due to the demand for play time and the impracticality of securely closing the fields.

DPR has stated that the number of requested permits for baseball and softball fields has doubled over the past six years[5], showing tremendous growth in the popularity of recreational sports. The debate over closing athletic fields pits public access against sufficient maintenance, presenting a tough decision for park managers. Grass fields that are open to the public year-round for sports—particularly soccer—are virtually guaranteed to wear out.



LEIF ERICSON PARK, BROOKLYN
Keeping up with maintenance of ballfields has been a challenge for the Parks Department's limited staff.

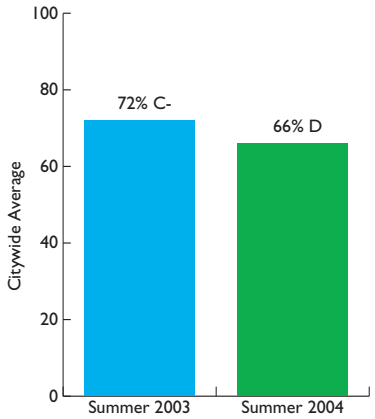
4 Personal Interview. Doug Blonsky, President, Central Park Conservancy. 7 Dec. 2005.
5 Williams, Timothy. "Fine Diamonds, Locked Away." *The New York Times* 26 Oct. 2005.

Constant use and limited park staff have led to inadequately maintained athletic fields. In NY4P's *Report Card on Parks*, an independent assessment of 200 neighborhood parks (1-20 acres), the performance of athletic fields has been consistently poor (See Figure 1). In the summer of 2003, athletic fields throughout the city earned an average score of 72% (C-). By the following summer, the score had dropped to 66% (D). During the summer of 2005, athletic fields at 14 randomly selected neighborhood parks[6] were evaluated monthly from June through August to track changes over time. That survey yielded an average score of 53% (F) for the summer. Conditions declined as the summer went on, due in large part to bare, discolored or overgrown fields. Other common problems included excessive litter and glass and damaged bleachers, benches and fencing. These results primarily reflect the conditions of natural turf baseball fields, as few soccer fields were chosen by the random selection process.

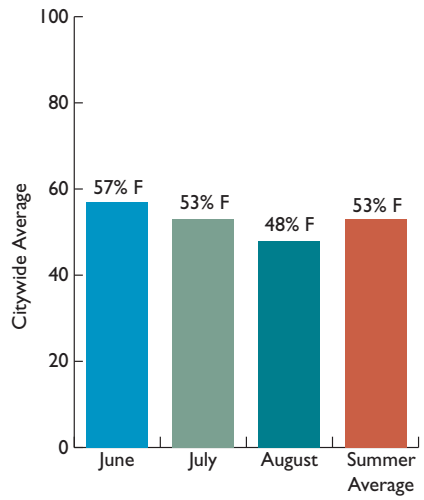
To improve athletic field conditions, DPR sometimes relies on the strategy of renovating natural turf fields by resodding them and installing irrigation systems to ease maintenance. But in recent years, synthetic turf has frequently been looked to as an alternative to grass fields that are heavily used and difficult to keep up, as well as asphalt fields that are unsafe and unpleasant to play on.

Figure 1:

Peformance of Athletic Fields
Report Card on Parks / Summer 2003 & 2004



Peformance of Athletic Fields
Mini Report Card on Parks / Summer 2005



[6] This randomly selected sample was drawn from all of the 200 neighborhood parks that have athletic fields—81 parks—and represents 1/6 of the *Report Card* survey universe. For the complete *Mini Report Card on Parks* or to see any *Report Card on Parks*, visit www.ny4p.org.

Synthetic Turf—A New Alternative

Since Chelsea Park in Manhattan became home to New York City's first synthetic field in 1998, DPR has installed the surface at an increasing number of parks each year. In 2001, Mayor Bloomberg pledged to address the shortage of athletic facilities by seeking out asphalt fields that could be replaced with synthetic turf.[7] The Parks Department expanded this initiative to include not only asphalt but also natural turf ballfields that were heavily used and difficult to maintain. As of August 2005, the Department had installed synthetic turf at 44 parks, with plans for installations at 35 more.[8]

Since beginning its synthetic turf program, the Parks Department has been contracting primarily with the manufacturers FieldTurf and AstroPlay for synthetic turf installations. These surfaces were designed to replicate the look and feel of natural grass and represent a giant leap forward from traditional AstroTurf, which was a hard, carpet-like surface developed in the 1960s.[9] AstroTurf produced new injuries to athletes such as "turf toe", caused by a player's cleat getting caught in the turf, which had virtually no give.[10] FieldTurf is widely praised as a great improvement over traditional AstroTurf and, judging from its popularity, has largely been able to



Mafera Park, Queens
Asphalt ballfield



Paerdegat Park, Brooklyn
Natural grass field

[7] "2004 Campaign Accountability Statement. Michael R. Bloomberg, Mayor, City of New York", City of New York. Retrieved Oct. 2005 from www.nyc.gov/html/om/pdf/campaign_accountability_report.pdf
[8] Marritz, Ilya. "'Turf' War Erupts Over So-Called Dust Bowl in Cadman Plaza." *New York Sun* Aug 11, 2005. Retrieved Oct. 2005 from www.nysun.com
[9] "AstroTurf", Wikipedia. Retrieved Nov. 2005 from en.wikipedia.org/wiki/AstroTurf
[10] Ibid.

overcome AstroTurf's bad reputation. AstroPlay, created by the makers of AstroTurf, has also grown its market share in the past few years. In 1998, AstroPlay had only five fields in the country, but by 2003, the number was up to 300.[11]

DPR cites numerous benefits of synthetic turf: year-round use due to its drainage capabilities, decreased maintenance costs, versatility of the types of sports it can accommodate, and environmental benefits, since it requires no pesticides, herbicides, mowing or watering. Synthetic turf also has aesthetic benefits—it never suffers during dry seasons or storms, and it is uniformly green.

From Seattle to Howard County, Maryland, municipal governments are turning to synthetic turf for its low maintenance and continual play. The NYC Department of Parks and Recreation is now the number one municipal purchaser of synthetic turf in the country, with the number of fields growing exponentially each year.[12] Over the next two years, Parks Commissioner Benepe's "commitment to ballfields" will devote $50 million to renovate and construct athletic fields.[13] Many of these projects will include synthetic turf.



CHELSEA PARK, MANHATTAN
"Old generation" of synthetic turf installed in 1998



THOMAS JEFFERSON PARK, MANHATTAN
"New generation" of FieldTurf installed in 2003

11 Chan, Erin. "Cows Can't Eat It, But Ball Fields Are Getting It." *The New York Times* 26 Oct. 2003. Retrieved Oct. 2005 from www.wirednewyork.com
12 Berger, Joseph. "Falling (Safely) for Artificial Turf." *The New York Times*, 20 March 2004. Retrieved Nov. 2005 from www.nytimes.com.
13 "Parks and Recreation Announces an Unprecedented Commitment to New Ballfields". DPR Press Release. 15 Sept. 2005. Retrieved Oct. 2005 from www.nycgovparks.org/sub_newsroom/press_releases

Analysis—A New Turf War

This discussion focuses on the comparison of the environmental, financial, maintenance, use, health, safety and community effects of synthetic vs. natural turf athletic fields. In order to foster the most relevant and robust discussion, the analysis takes for granted two assumptions: 1. The superiority of synthetic turf over asphalt; and 2. The use of synthetic turf surfacing on athletic fields rather than lawns or other passive areas. Thus far, DPR has focused on athletic fields as the primary venue for synthetic turf.

The Parks Department began using synthetic turf in 1998 as a strategy to replace its inventory of aging asphalt fields. NY4P agrees that this represents a practical and positive use of synthetic turf and supports this strategy for future asphalt field renovations. Asphalt is neither safe nor environmentally friendly, and its hard surface invites injuries and neither absorbs nor filters rainwater. One of the few benefits of asphalt is that it requires almost no maintenance, aside from regular trash and glass pick-ups and sporadic patching of holes and cracks. Synthetic turf offers a surface that is safer than asphalt for children. It doesn't filter rainwater, but it is pervious, which prevents large puddles and offers more regular play.

Environmental Impacts

Perhaps the most contested aspect of synthetic turf is its potential impact on the environment. The Parks Department states the following ecological benefits of synthetic turf: the crumb rubber base is made from recycled tires (the average soccer field uses 27,000 tires); synthetic fields do not require the pesticides, herbicides or fertilizers that grass needs to stay healthy; and resources are conserved by the avoidance of mowing (use of fossil fuels) and watering.[14] However, synthetic turf contributes to the urban heat island effect by absorbing sunlight and emitting heat. Additionally, removing grass takes away habitats that serve birds and plant life in the city.

The environmental benefits of synthetic turf may not be as significant as DPR claims. Though grass needs to be watered to stay healthy, synthetic turf also performs better when watered. Watering decreases static cling, helps to wash away bacteria and fluids that may be on the fields[15], and helps to cool the often high temperatures of synthetic turf, at least temporarily.[16] DPR uses pesticides and herbicides sparingly on natural grass, so the conservation of chemicals through the use of synthetic turf likely has minimal effects.[17]

14 Personal letter from Commissioner Benepe to Christian DiPalermo, Executive Director, NY4P. 16 Sept. 2005.

15 Personal Interview. Dr. A.J. Powell, Jr., Extension Specialist, Turf; Plant and Soil Science Department, University of Kentucky. 28 Nov. 2005.

16 McNitt, Andrew S. and Dianne Petrunak. "Evaluation of Playing Surface Characteristics of Various In-Filled Systems." Pennsylvania State University, Department of Crop and Soil Sciences. 2006.

17 Department of Parks & Recreation document. "Synthetic Turf Ballfields – 2004", courtesy of DPR, Operations. 15 Dec. 2005.

Urban Heat Island Effect

The replacement of natural turf with synthetic contributes to the urban heat island effect. Urban heat islands are created when grass and trees are replaced by impervious surfaces like rooftops and asphalt, which absorb heat.[18] Summer temperatures in New York City are approximately seven degrees higher than surrounding areas due to this effect.[19] Urban heat islands increase demand for energy (particularly air conditioning), intensify air pollution, and increase heat-related health problems.[20] A 2005 study of mitigation strategies found that increasing vegetation has a great effect on reducing temperatures and recommends planting street trees to provide the greatest cooling potential by area.[21]

Not only does removing natural turf exacerbate the urban heat island effect – synthetic turf fields absorb rather than reflect sunlight, causing them to emit heat. In 2002, Brigham Young University undertook a preliminary study comparing temperatures at two newly installed fields—one FieldTurf and one sand-based natural turf. Initial results showed that the surface temperature of the synthetic field was, on average, 39 degrees higher than the natural turf and 8 degrees higher than asphalt. At its hottest point, the synthetic turf was 86.5 degrees hotter than grass. The study also found that cooling the synthetic turf with water had very little effect on its temperature.[22] Similar results were found by researchers at Penn State, who examined the surface temperatures of several different brands of synthetic turf. On FieldTurf, the difference between surface and air temperatures was 37 degrees.[23]

Synthetic turf fields absorb rather than reflect sunlight, causing them to emit heat.

Cadman Park Community Council, a Brooklyn group who unsuccessfully fought the installation of a synthetic turf soccer field on a neglected lawn, conducted a less rigorous but very compelling study of the temperature of several grass and synthetic turf fields in New York City. The group found that on a hot summer day when the air was 91 degrees, the temperature at the synthetic turf field at Van Voorhees Park in Brooklyn was 122 degrees with similar results found at the synthetic field at the Prospect Park Parade Grounds. The grass lawn at Cadman Plaza Park, however, registered 87 degrees — four degrees cooler than the air.[24] These high temperatures not only impact the environment, but could affect the health and safety of athletes and children as well.

[18] Rosenzweig, Cynthia. "Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces," Columbia University and Hunter College, New York, NY; and W. Solecki, L. Parshall, S. Gaffin, B. Lynn, R. Goldberg, J. Cox, and S. Hodges. Presented 31 Jan. 2006.

[19] Ibid.

[20] Ibid, and "Heat Islands", ScienCentralNews. Retrieved Dec. 2005 from sciencentral.com

[21] Ibid.

[22] Williams, C. Frank, and Gilbert E. Pulley. "Synthetic Surface Heat Studies", Brigham Young University, 2002. Retrieved Nov. 2005 from turf.nmsu.edu

[23] McNitt, Andrew S. and Dianne Petrunak. "Evaluation of Playing Surface Characteristics of Various In-Filled Systems." Pennsylvania State University, Department of Crop and Soil Sciences. 2006.

[24] Cadman Park Community Council. "Cadman Plaza Park: A Report for Councilman David Yassky". 23 Aug. 2005.

Habitat

Natural turf not only cools the city; it offers habitats for insects, plants, and other organisms, and provides food for birds. Hundreds of birds migrate through New York City and depend on parks for resources. Many municipal parks are recommended bird-watching sites by NYC Audubon[25], and the organization has publicly opposed the proposal to install synthetic turf at Cadman Plaza Park, citing the harmful effects it would have on the food supply for birds and other wildlife.[26] Removing natural turf, no matter how deteriorated it has become, is damaging to the environment and to the city's ecosystem. Though synthetic fields have drainage systems, they do not contain microorganisms that can break down pollutants. Additionally, rainwater is not absorbed—it simply drains through the field and runs into storm sewers.

Removing natural turf, no matter how deteriorated it has become, is damaging to the environment and to the city's ecosystem.

Clearly, well-maintained natural turf benefits the environment by reducing the urban heat island effect, filtering rainwater and pollution, and providing habitats for birds and insects. Synthetic turf offers none of these benefits.

NY4P offers the following recommendations to address the potential environmental impacts of synthetic turf and to boost the performance of natural grass fields:

❖ Continue and expand the Neighborhood Parks Initiative to improve the performance of natural turf fields, lawns and gardens.

The Neighborhood Parks Initiative (NPI), a public-private partnership that has brought funding and a full-time gardener to 30 of the neediest parks across the city, aims in part to remediate neglected fields. Gardeners are on site during the busy summer months to ensure that baseball and soccer fields stay safe and green and to address maintenance issues that arise throughout the park. This program has had a significant impact on the health and conditions of natural and synthetic turf fields, as well as enhancing the performance of lawns and gardens. The natural turf baseball fields at Thomas Jefferson Park in Manhattan benefited greatly from the constant watering and attention provided by the NPI gardener at that site. Fields that were dry and weedy during the early part of the summer were lush and green in August. During the summer of 2005, the first year of NPI, 2 synthetic and 18 natural turf fields benefited from the program. We call for the expansion of NPI to at least one park in each of the 51 City Council districts.

❖ Formally mitigate installation of synthetic turf by creating new green space elsewhere in the neighborhood.

When synthetic turf is slated for installation, mitigate the removal of green space by planting trees or otherwise creating and maintaining new green space. New vegetation will help filter air pollutants and contribute to the cooling of the city, decreasing the effects of the urban heat island. This strategy will also mitigate the removal of wildlife habitats.

[25] New York City Audubon. "Places to Bird," Retrieved Dec. 2005 from www.nycaudubon.org/getinvolved/birding/places/
[26] Personal letter from E.J. McAdams, Executive Director, NYC Audubon, to Commissioner Benepe. 16 Dec. 2005

Is Synthetic Turf Cost-Effective?

Several factors must be considered when planning the renovation or installation of an athletic field, including the types and costs of surfacing materials, the use or sport that the field will accommodate, and the community's desired access to the field. This section illustrates that: 1. The annual costs of synthetic and natural turf fields do not differ significantly assuming the current Parks Department maintenance levels; and 2. Synthetic turf is sometimes appropriate for soccer but is not appropriate for baseball. Community access will be discussed in a subsequent section.

Surface Types

Park managers have several options when seeking to upgrade their athletic fields: soil-based natural turf, sand-based natural turf, or synthetic turf. A soil-based field is simply a natural grass field that may or may not include installed irrigation. Sand-based fields, developed in the 1990s, consist of an 8-12-inch sand foundation with an organic mixture on top so that grass can grow. These fields include installed drainage systems, which offer more play time but high installation costs.[27] Sand-based fields were popular in college and professional sports arenas when first introduced. The NYC parks system includes some sand-based fields, such as those at the Great Lawn in Central Park. The third option is synthetic turf. As FieldTurf defines it, the material consists of an installed drainage system and what the corporation calls "synthetic earth"—a crumb rubber base made from recycled tires and mixed with sand. This base is embedded with polyethylene blades colored a grass-like shade of green.[28] Other manufacturers, such as AstroPlay and Nexturf, produce turf consisting of a rubber base with no sand[29], an alternative that, though cheaper, bears less resemblance to natural grass in terms of playability.

Soccer Fields: Annual Costs

Figure 2 is the Parks Department's cost comparison chart for synthetic and natural turf (soil-based) soccer fields. In examining this chart, it is important to remember that these costs pertain to soccer and not to baseball fields, which are normally cheaper and easier to maintain. The installation costs for natural grass detailed in Figure 2 include the price of an installed irrigation system, though DPR does not indicate the exact cost of such a system. In addition, built-in irrigation must have a water source and is not always an option. The lifespan of natural grass is highly dependent on the maintenance and wear it receives. The chart projects costs based on a five-year lifespan for natural grass, though according to DPR, a heavily used soccer field can last as few as two years. Battery Park City Parks Conservancy opts to close athletic fields for four months during the winter and adheres to a strict maintenance plan, and therefore does not need to reinstall grass fields, avoiding this cost. It is important to note that exact installation and maintenance costs vary based on the particulars of individual sites.

[27] Personal Interview. Dr. A.J. Powell, Jr., Extension Specialist, Turf; Plant and Soil Science Department, University of Kentucky. 28 Nov. 2005.
[28] "Product Overview," FieldTurf. Retrieved Dec. 2005 from www.fieldturf.com
[29] Northwest Parks Foundation. "Athletic Field Surfaces in the Pacific Northwest: A Comparison of Synthetic and Natural Grass Fields," Retrieved Oct. 2005 from www.nwparks.org

Soccer Fields: Maintenance Costs

The difference in the annualized cost of the two types of fields is not a sizeable one—according to the Parks Department, synthetic fields save $14,714 per year. Because maintenance and installation requirements are site-specific, synthetic turf could end up costing more than natural grass in some locations. In addition, this chart details only the cost of the initial investment and does not calculate the cost of replacing either field at the end of its expected lifespan. (Synthetic fields typically come with an eight-year warranty, but beyond that, the purchaser must bear the full replacement cost.) The quoted cost of installing a natural grass field includes the cost of an irrigation system, which would not be incurred again once the system was in place. Similarly, a synthetic turf field contains a drainage system whose cost would only be incurred once. Opportunity costs should also be included - for example, this analysis does not include the value of all-weather playability provided by synthetic turf. A break out of these figures would be helpful in determining the cost-efficiency of the two types of fields.

It should be noted that this cost analysis assumes the Parks Department's current level of maintenance attention to fields, comparing what the Department is presently funded to spend on each type of field. As noted earlier, the conditions of the city's baseball and soccer fields, under this level of funding, are mediocre. In other sections of this report, Parks Department maintenance standards and practices are compared to other park management entities, such as the Central Park Conservancy and the Battery Parks City Park Conservancy. Were these costs of maintaining fields available for this analysis, the difference in the cost of maintaining a turf field versus a synthetic field would be significantly more substantial.



Sara D. Roosevelt Park, Manhattan
The amount of maintenance that a synthetic turf field requires depends heavily on its usage.

Figure 2 - Cost Comparison, Multi-use/Soccer Field [30]

		Synthetic Turf	Natural Grass
Installation Costs (capital)	Per Field	$1,365,000	$690,000
	Expected Life Span (yrs)	10	5
	Installation Costs per Year (distributed over the projected lifetime of the field)	$136,500	$138,000
Annual Maintenance	Materials[31]	$0	$750
	Lawn Mowing (equipment)	$0	$107
	Field Maintenance (equipment)	$31	$59
	Lawn Mowing (staff)	$0	$826
	Field Maintenance (staff)	$1,239	$10,864
	Staff Supervision	$255	$2,133
	Total Maintenance Cost	$1,525	$14,739
Total Cost per Field per Year		$138,025	$152,739

Figure 2 details the significantly higher up-front costs of installing synthetic turf, but the Department argues that low maintenance costs more than make up for this. The difference in maintenance costs for the two surfaces is largely a result of the staff time required to care for natural grass. The maintenance schedule for a natural grass field generally includes the following: weekly mowing and watering; daily cleaning of trash and glass; fertilizer, pesticide and herbicide applications; and line painting. Maintaining a synthetic turf field requires daily cleaning of trash and glass; daily removal of substances such as gum with a solvent; and grooming with a special vacuum to "fluff up" the field.[32]

The need for vacuuming partially depends on the frequency of use, which varies by park. However, the amount of grooming seems to have an effect on the field's surface. The former sports field manager for the New York Jets, who maintained FieldTurf at the stadium, was told by FieldTurf's staff to groom twice a year. After receiving complaints from coaches about hardness and compaction of the field, FieldTurf staff recommended increasing grooming to every two weeks. With this frequency, the sports field manager noticed that fibers came loose, which the FieldTurf staff had not predicted.[33] Consistent maintenance standards have yet to be determined.

[30] Figure 2 courtesy of the Department of Parks & Recreation, Operations, 15 Dec. 2005. Costs were figured in 2004 and vary depending on site.
[31] Materials include fertilizer, grass seed, clay, and lime for painting lines on the fields. Lines on synthetic fields are sewn in at the time of installation.
[32] Personal Interview. Keith Kerman, Chief of Operations, Department of Parks & Recreation. 15 Dec. 2005.
[33] Personal Interview. Robert Hansen, Ballfield Turfgrass Specialist, Battery Park City Parks Conservancy. 2 May 2006.

While the Parks Department recommends vacuuming between once every two weeks and once a month, at Prospect Park's Parade Grounds, which contain heavily used baseball, soccer and football fields, workers vacuum two to three times per week.[34] If DPR projected this level of maintenance, costs of synthetic turf would increase. An additional, though irregular, maintenance cost is incurred when repairing loose seams or burns on the turf. If a portion of the synthetic field becomes damaged, a large swath of turf is required to replace it.

Some hidden maintenance costs exist within the installation of synthetic turf. With year-round play comes more frequent use of the park itself and its other features, such as bathrooms, drinking fountains, and playgrounds. While parks are typically used most heavily in the warmer months, synthetic turf ensures that the public will depend on these features year-round, highlighting the Department's need for increased maintenance funding.

Useful Lifetime

The use of synthetic turf in NYC parks is new enough that deterioration and replacement cycles require more time for assessment. Though synthetic fields have a projected lifetime of 8–10 years, their functionality and appearance after a decade of use remains to be seen. The Parks Department will rely on capital funding to replace the turf on an as-needed basis, and because the base and drainage system would already be in place, replacement costs are projected at $500,000, or half of the original installation fee.[35] Since synthetic grass technology is so new, these costs are simply estimates. Depending on economic effects and other factors, replacement costs could be higher than predicted.

Another environmental and financial challenge is the disposal of synthetic turf. At the end of their useful lifetime, the reused tires must be disposed of, and the EPA has not addressed whether or not they can be recycled. Tear-out and disposal costs range from $1.75 to $2.25 per square foot, not including transportation or other ancillary charges.[36]

Maintenance money saved through the use of synthetic turf can be applied toward the maintenance of other critical park features, which is an important benefit. But installing synthetic turf requires DPR to take on large capital costs, contributing to the city's debt. While capital funding is fairly easy to obtain, maintenance funding must be dedicated to support large investments and prevent them from physical decline. City Council members often allocate capital funds for projects that their constituents support, but, unfortunately, budget additions that would provide continued care for these projects are more difficult to come by. The good news is that, so far, synthetic turf seems to be performing well. Prospect Park's first synthetic turf project, a football field, opened three years ago, and the Prospect Park Alliance has faced no significant wear issues.[37] Though, the Parks Department has had to replace one melted portion of turf due to a fire on a field. They have also noted at least one instance of a seam ripping loose on a soccer field.

[34] Personal Interview. Tupper Thomas, President, Prospect Park Alliance. 17 Nov. 2005.

[35] Northwest Parks Foundation. "Athletic Field Surfaces in the Pacific Northwest: A Comparison of Synthetic and Natural Grass Fields," Retrieved Oct. 2005 from www.nwparks.org.

[36] Sports Turf Managers Association. "A Guide to Synthetic and Natural Turfgrass for Sports Fields – Selection, Construction and Maintenance Considerations", http://www.sportsturfmanager.org/_Files/_Items/STMA-MR-TAB2-1416/Docs/STMA%20SyntheticTurfGuideHI.pdf

37 Personal Interview. Tupper Thomas, President, Prospect Park Alliance. 17 Nov. 2005.

Use: Baseball vs. Soccer

Commissioner Benepe has stated that grass soccer fields are more quickly turned to dust due to the nature of the game and, therefore, are more frequent candidates for synthetic turf.[38] However, the Department has increasingly looked to synthetic turf when planning baseball field renovations as well. As most of the activity in a baseball game takes place along the dirt baselines, the players have limited impact on natural grass. Some argue that DPR relies on synthetic turf too heavily as an easy way out when seeking to renovate these fields. Unfortunately, evidence of cost savings is not available for baseball fields, as the costs illustrated in Figure 2 apply to multi-use/soccer fields.

NY4P believes that while the use of synthetic turf can address some of the challenges of maintaining a soccer field, it should not be used on baseball fields, which are easier to keep up. Although DPR has faced challenges in maintaining baseball fields, synthetic turf is not necessarily the solution. Instead, the Department should design a targeted maintenance program and install irrigation systems to ensure that natural turf baseball fields get the care that they need.

NY4P offers the following recommendations to provide for more efficient allocations of funding to enhance field use and access:

❖ Develop a targeted maintenance strategy for natural turf baseball fields in order to boost their performance.
Presumably, not every field is a candidate for replacement, nor will every community want synthetic turf. In order to ensure the availability of natural turf, use the model of "Operation Relief", DPR's targeted maintenance program that has improved the conditions of bathrooms, to develop a targeted program to keep baseball fields green and clean. Increased trash and glass pick-ups as well as more frequent watering by Parks staff could be included in such a program.

❖ Install and manage irrigation and drainage systems to enhance the capacity to maintain natural turf fields.
Despite the environmental benefits of natural turf, many existing fields have been neglected and consist solely of dust and dirt, with virtually no plant life. As new fields are installed, they should receive irrigation systems when possible so that consistent maintenance will be less challenging. Barren fields do not provide the same benefits that grass fields offer. When possible, existing natural fields should be retrofitted with irrigation systems.

38 Berger, Joseph. "Falling (Safely) for Artificial Turf." *The New York Times.* 20 March 2004. Retrieved Nov. 2005 from www.nytimes.com

Health and Safety Effects

Though studies have compared the safety of synthetic fields to natural grass fields, most are outdated, relying on data from the days of AstroTurf. One of the few studies applicable to this report was published in the *American Journal of Sports Medicine* and compares high school football injuries over a five-year period on FieldTurf and natural grass. Results show that similarities exist between the two surfaces, but that athletes experienced different types of injuries, necessitating further study. For example, FieldTurf players had higher incidences of non-contact injuries, surface (skin) injuries, muscle-related trauma, and injuries during warmer temperatures. Natural turf players had higher incidences of ligament injuries, long-term injuries, and head and neural trauma.[39]

Some of those who oppose synthetic turf fear that the use of crumb rubber in the base, aside from posing an environmental challenge when it comes to disposal, could lead to the leaching of dangerous chemicals.[40] Results thus far are inconclusive. An additional concern is the sand that is mixed with crumb rubber to create the base of some synthetic turf fields. Sprinturf, one leading manufacturer of synthetic turf, commissioned an independent study that found that bacteria counts of infill containing sand and rubber were 50,000 times higher than infill containing only rubber. The company has offered free lifetime sanitization to those customers who have purchased the rubber and sand infill and is starting a new line of synthetic turf called "SandFree".[41]

Though FieldTurf has not proven to be unsafe, it is still a young technology.

While new signage has been developed describing the rules of synthetic fields, the public is generally unaware of which problems to look out for on an artificial surface. Athletes and children typically know when a natural grass field is unsafe by the presence of holes or broken glass. Signs at the entrances to synthetic turf fields should describe potential hazards to look out for, such as turf that has begun to come up at the seams, and direct users with questions or issues to 311.

Though FieldTurf has not proven to be unsafe, it is still a young technology. No precedent exists to show how FieldTurf will behave when it begins to deteriorate. Whether this funding will come out of the expense or capital budget depends on how the fields decline and how quickly they are replaced. Because the Parks Department's budget varies with the political cycle, the availability of funding to replace decaying fields is not guaranteed.

Proponents of synthetic turf fields tout the reduction of allergy and asthma triggers. The removal of natural pollens and grasses may be beneficial to children and adults with these afflictions. However, the opposing side points to the potential toxicity of recycled tires and silicon. These health impacts need to be studied further in order to draw decisive conclusions.

[39] Meyers, Michael C., PhD, FACSM and Bill S. Barnhill, MD. "Incidence, Causes and Severity of High School Football Injuries on FieldTurf Versus Natural Grass: A Five Year Prospective Study," *American Journal of Sports Medicine* 32: 1626-1638. 2004.
[40] Chalker-Scott, Linda, PhD. "Rubber – The Reality." Ransfords Equestrian Surfaces. Retrieved April 2006 from www.ransfords.co.uk
[41] "Sprinturf goes sand-free; offers decontamination free to existing customers." Athletic Turf News. 20 Mar 2006. Retrieved April 2006 from http://www.athleticturf.net

NY4P offers the following recommendations to ensure that synthetic turf remains a safe option:

❖ Include maintenance plans and cost-benefit analyses in requests for capital funding for athletic fields so that educated funding decisions are made.

The safety of athletes and children is compromised when synthetic turf is allowed to deteriorate. Provide City Council and other entities that appropriate moneys for athletic field projects with a specific cost-benefit analysis so that educated funding decisions are made. Fold maintenance plans into capital requests for athletic fields so that funding will be available to replace turf segments as needed.

❖ Take advantage of recent turf installations—engage in formal studies that examine the benefits and challenges of synthetic turf.

DPR is in a good position to lead the way with studies of the long-term viability of synthetic turf technology. With the recent installation of these fields, DPR can seek funding to evaluate the multiple issues this report addresses—the health, safety, maintenance and other potential impacts of synthetic turf use. Partner with a university in undertaking such a study.

❖ Include safety information on signage at synthetic turf fields.

Many athletes are unfamiliar with the "new generation" of synthetic turf. Improve safety by notifying users what dangers to look out for before using synthetic fields, such as loose seams that could create a trip hazard. Users with questions or issues should be directed to 311.



JAMES J. WALKER PARK, MANHATTAN
Safety must be the first priority at athletic facilities, including synthetic fields like this one.

Community Input and Issues

Community preference should be a major deciding factor when planning athletic field renovations. While synthetic turf offers more playable hours, installing this surface removes the opportunity to create new—or retain existing—green space. Natural turf requires more care and, especially in the case of soccer fields, needs to be closed periodically for maintenance in order to remain healthy. Community members should be aware of the advantages and disadvantages of all options and encouraged to participate in the discussion.

Several park organizations have formed around the synthetic turf debate. Though there are groups on both sides of the issue, these debates have highlighted the need for improved evaluation processes and increased community outreach by the Parks Department.

Cadman Plaza Park, Brooklyn

The Cadman Park Community Council (CPCC) led one of the most high-profile of these fights against a proposed synthetic turf field that would take the place of a lawn at a park in Brooklyn Heights. The Parks Department found the lawn to be a good candidate for synthetic turf because it is frequently used by soccer players and is heavily worn, with little grass.

The neighborhood of Brooklyn Heights in City Council District 33 is already underserved by green space. Only 4% of the acreage in District 33 is devoted to parkland, while the citywide average is 11%.[42] As a spokeswoman for CPCC said of the lawn slated for replacement: "Yes, it is really ugly now, but we need to preserve the park space we have because there is so little."[43] The group also argued that the placement of a synthetic soccer field is not appropriate in front of the Brooklyn War Memorial building—a monument that honors veterans and should face a natural grass lawn that can be used for reflection or recreation. The turf, they said, would put parameters on such usage of this space.

The group did not have an easy fight ahead of them. The community board voted to approve the project, which, though not binding, increased DPR's leverage. CPCC feels that DPR's presentation to Community Board 2 was unfair because they offered only two options for the field: its dustbowl state or synthetic turf. The community was not given the option to vote for the rehabilitation of the field.

[42] NY4P. City Council District Profiles 2005: Brooklyn City Council District 33, available www.ny4p.org. Data courtesy Department of Parks & Recreation, 2004.
[43] Lepeska, David and Elizabeth Hays. "Fake Grass, Real Fight: Foes out to mow down 2.5m overhaul of park." *The New York Daily News.* 19 Aug. 2005.

Columbus Park, Manhattan

Residents living near Columbus Park in Chinatown were divided over a Parks Department proposal to convert an expansive asphalt yard, which hosted a variety of games, including basketball, volleyball and baseball, to synthetic turf. Paul Gong, the President of Friends of Columbus Park, said that an all-synthetic turf field would limit the types of activities enjoyed at the park and also expressed concern that, in tough fiscal times, the Parks Department would not be able to maintain an artificial turf field.[44] In addition, the group believed that the neighborhood would not have access to the field because of the popularity of this park among corporate leagues.[45]

Community Board 3 voted down the proposal, although many residents supported the synthetic turf. Through discussions among community residents, DPR officials, and Manhattan Borough Commissioner Bill Castro, the decision was made to pave half of the surface with rubberized asphalt and to cover the rest with synthetic turf—providing a space that is no longer big enough for adult softball games but that can continue to accommodate sports like basketball. Predictably, community residents are split on this outcome, but this represents a better community input process.

Athletic Groups

The all-weather playability of synthetic turf is appealing to many athletic leagues. The West Side Little League and the West Side Soccer League assisted the Riverside Park Fund in raising $1 million in private funds for synthetic turf fields in that park.[46] A spokesperson for the West Side Soccer League said that, two years ago, half of the league's scheduled games were canceled due to heavy rains that had flooded the fields.[47] However, Downtown Little League President Vincent Licata, who grew up playing baseball on asphalt and concrete, voiced his relative indifference on the issue of synthetic versus natural grass: "A place to play is a place to play, no matter what it looks like."[48]

Examples from Other Cities

While the Parks Department frequently presents field renovation projects to community boards and hears community desires via the City Council and other venues, looking to other cities as models could enhance DPR's work with the public. Seattle's Joint Athletic Facilities Development Program (JAFDP) is a partnership between Seattle Parks and the School District focused on relieving the demand for the city's athletic fields. On the program's website, the public can view trends in field usage in Seattle, technological developments in turf, JAFDP's policies that guide development of athletic fields, and a list of proposed sites to receive synthetic turf and a scope of work for each. JAFDP posts detailed minutes from community meetings so that all residents are informed.[49]

[44] Kaysen, Ronda. "Yer Out! Adult Softball Ejected in Park Plan," *Downtown Express*. Nov. 12 - 19, 2004. Retrieved Oct. 2005 from www.downtownexpress.com
[45] Bennett, Chuck. "Chinatown Battle Over Turf," *amNew York*. 12 Oct. 2004.
[46] Personal Interview. Bill Crain, Citizens for a Green Riverside Park. 15 Nov. 2005.
[47] Berger, Joseph. "Falling (Safely) for Artificial Turf." *The New York Times*. 20 March 2004. Retrieved Nov. 2005 from www.nytimes.com
[48] Personal Interview. Vincent Licata, President, Downtown Little League. 21 Nov. 2005.
[49] "Joint Athletics Facilities Development Program," City of Seattle. Retrieved Oct. 2005 from www.cityofseattle.net/parks/meetings/jafdp/jafdp.htm

The Vancouver Board of Parks and Recreation, in tandem with the School Board, held a public workshop to foster discussion about the location of synthetic fields throughout the city. Participants brainstormed and voted on criteria that would be necessary for candidate sites to be approved for synthetic field installation. The six criteria chosen included site-related issues such as ownership and size of the land as well as green space and use issues. For example, participants agreed that proposed sites should not be in communities already underserved by green space and that they should be supported by the surrounding neighborhood. After developing the list of criteria, participants brainstormed a list of schools and parks that might support a synthetic field.[50]

These are two examples of parks agencies that actively work with the community throughout the park renovation process. By truly engaging residents in the discussion, communities are more likely not only to support the projects but also to trust the agency and its motivations. In addition, a park plan that truly reflects the needs and inputs of the community is much more likely to foster positive use. A park that is well used and valued leads to other benefits, such as reduced crime rates and enhanced real estate values in surrounding areas.[51]

NY4P offers the following recommendations to improve Parks relations with the community and to effectively channel debate and conflict:

❖ Form a task force of experts to develop criteria for consideration by Community Boards facing athletic field renovations.

A task force of park experts should be formed to develop standard criteria regarding athletic field surfacing options. While DPR currently presents overall project plans to Community Boards for their approval, many communities would benefit from recommendations on how to evaluate the various options. We strongly recommend that the DPR include these in-depth analyses of the pros and cons of all surfacing options in all presentations. By making the criteria publicly known, neighborhoods can evaluate the needs of their community to make an informed choice regarding turf. The DPR should work to ensure a proper balance of synthetic and natural turf fields so that the benefits of both can be maximized.

❖ Before fiscal appropriations occur, present to the community board all possibilities for athletic field renovations.

Community members should be given an appropriate venue to discuss athletic field projects before fiscal commitments have been made. When planning athletic field renovations or installations, DPR should present to the parks committees of the neighboring community boards all surfacing options—whether these include synthetic turf, natural turf with or without irrigation, or rubberized asphalt—and their advantages and disadvantages. This will ensure that the community is sufficiently educated to discuss and vote on plans for its parks.

[50] "Notes from the Synthetic Field Location Public Workshop," Vancouver Park Board. Retrieved Oct. 2005 from 199.175.219.1/parks/info/planning/syntheticturf/index.htm

[51] Ernst & Young and NY4P. "How Smart Parks Investment Pays Its Way," 2003.

Summary—Achieving a Balance: Community Access, Environmental Success

New York City residents deserve athletic fields that are green, clean and safe. Synthetic turf offers significant advantages over asphalt fields, and provides some solutions to the challenges of grass fields: maintenance costs may be lower and fields are available for play in all weather. However, overall annual costs for synthetic and natural grass are not significantly different, and synthetic turf places a greater burden on the city's capital budget.

Due to the relative ease of maintaining baseball fields, NY4P believes that natural turf should be used in these renovations. The types of challenges that the Parks Department faces in the maintenance of baseball fields—such as aesthetic difficulties and insufficient staffing—do not provide adequate rationale for the conversion of a field from grass to synthetic. Natural turf soccer fields are more difficult to maintain due to the nature of the sport and are a more appropriate venue for synthetic turf.

Environmental concerns associated with synthetic turf demand that it be used sparingly until appropriate mitigation and management policies are in place. The surface contributes to the urban heat island effect, which causes temperatures in the city to rise and increases the demand on limited energy sources. In addition, natural grass is too precious in an urban environment to be torn out due to aesthetic challenges. Natural turf provides valuable environmental benefits, such as hosting birds and other small organisms and filtering air pollutants.

The true debate over synthetic turf lies with the issue of community access. Grass fields must be closed for a period of time in order to remain healthy; however, New Yorkers' demand for athletic fields exceeds the supply and continues to grow. The Parks Department should actively seek community input to create a comprehensive plan for athletic field renovations across the city to ensure that every community has access to a quality field and is equally served by green space. Community approval should be a major deciding factor in using synthetic turf.

The use of synthetic turf is not a panacea to maintenance concerns. The Parks Department must be provided with an increased staff and budget in order to appropriately maintain both natural and synthetic turf fields. With increased resources, natural grass can be better preserved from the impact of athletes. Built-in irrigation systems should be installed when possible, and dedicated maintenance programs should be developed to keep baseball fields green. These strategies will guarantee a longer life for fields, resulting in green, clean and safe athletic facilities for every New Yorker.

NYC Department of Parks and Recreation's Response

City of New York
Parks & Recreation

March 31, 2006

Christian DiPalermo
Executive Director
New Yorkers for Parks
The Arthur Ross Center for Parks and Open Space
355 Lexington Avenue, 14th Floor
New York, NY 10017

Dear Mr. DiPalermo:

Thank you for the opportunity to comment on "A New Turf War: Synthetic Turf in New York City Parks" prior to its release.

Despite the provocative title, the expanded use of synthetic turf in city parks has sparked a modest but healthy debate on how best to use this new product, not a "war." The new generation of synthetic surfaces has enabled us to provide more safe, high-quality playing fields to meet the explosive growth of youth and adult sports leagues and the extended (some would say "unlimited") playing seasons New Yorkers have come to expect. It is an approach that has been adopted by the sports field providers around the world at all levels, from small parks to huge professional sports arenas.

We do not, however, view it as a panacea or appropriate in every instance. In general, our management strategy for field development mirrors the approach suggested in the report. Renovating lightly used asphalt fields with synthetic turf is a smart way to meet local demand for active recreation in heavily developed neighborhoods, especially for youth sports. Similarly, soccer pitches, and fields that host multiple sports, as many of ours do, are safer, more attractive and available for play more often when converted to synthetic turf. Fields that are not heavily used (and believe it or not, there are some) and those that are used exclusively for baseball should remain natural turf when ever possible and be designed to include in-ground irrigation and fences to ensure that they can be maintained to a consistently high standard.

Although we agree in broad terms on how best to use this new technology, some of the conclusions of the "Analysis" section of the report warrant comment as noted below.

Environmental Impacts: Perhaps there should be a definitive study comparing synthetic and natural turf in terms of water, pesticide, fertilizer, and fossil fuel consumption and the effect of those chemical residues and by-products on the environment, but there is no question that synthetic turf fields use fewer of those resources, especially when compared to meticulously maintained natural turf. Furthermore, the benefit of providing a constructive use for an environmental headache like used tires should not be overlooked.

Additionally, grass ballfields have little habitat value and are more likely to harbor nuisances like Canada geese, gulls, Japanese beetles and invasive weeds than plants and animals that contribute to biodiversity. The loss of vegetative cover is a legitimate concern and there is no question the synthetic surfaces are hotter that natural turf or even bare dirt. We are working with manufacturers to find ways to make fields cooler. We are currently designing a pilot water retention system for one of our new soccer fields to address the issue of storm water management.

But over the last ten years fewer than 300 acres of parkland (and less than 10% of the grass ballfields) have been converted to synthetic surfaces, including all of the asphalt field renovations. Over that same period, Parks has acquired over 1,900 acres of mostly undeveloped natural areas, restored or improved hundreds of those acres, launched the Greenstreets program (which has converted approximately 165 acres of asphalt on 2,114 sites into plants and tree beds), preserved community gardens, and planted more than a hundred thousand trees. Our contributions to New York City's environment are so extensive and basic to our mission that it is unnecessary to specifically mitigate new synthetic turf installations.

Cost Effectiveness: The report contends that the annual savings of $14,714 we project for one synthetic turf field is "not a sizeable one". In fact, the savings per field are significant and are equivalent to the salary of a six-month seasonal park worker. Synthetic turf fields allow staff to devote more time to maintaining other grass fields, playgrounds, sitting areas and other park features.

The missing factor in the maintenance equation is the fact that for any grass field to survive it must be shut down for at least four or five months a year. Your analysis fails to account for the cost of preventing people from playing, nor does it factor in the lost/gained opportunity costs of allowing a field to remain open seven days a week, twelve months a year.

The report also recommends improving the maintenance of natural turf fields by using more fixed or dedicated staff. We see that ideal park maintenance is a combination of fixed and mobile crews. For ballfield maintenance, we do our cost estimates based on a mobile crew maintenance strategy, which is less expensive than dedicated staff. Nothing, including synthetic turf, is maintenance-free, but it is clear to us that synthetic surfaces use fewer resources and provide up to 50 percent more (safe) playing time for New Yorkers. That's cost effective!

City of New York
Parks & Recreation

Community Input: Parks has a long-standing practice of involving the community in capital renovations and responding to local input as illustrated by the Columbus Park case study included in the report. Community support will always be an important component of our decision-making process; all of our projects are the subjects of on-site scope meetings and formal community board review, and most of the ballfield projects are specifically requested by community groups or sports leagues and funded by local elected officials. A citywide committee that determines "which sites and neighborhoods are suited to synthetic turf and which are more appropriate for natural turf," will be difficult to achieve as we do not want a committee making recommendations for a community that is not represented in the group.

As you know, synthetic turf is being used by high schools, colleges, municipalities, and professional sports leagues across the country and around the world, and even where cost is no object, these organizations are demonstrating a preference for synthetic turf, even in professional baseball stadia. There are also a number of local organizations, Take the Field among them, colleges, and professional teams whose experience with synthetic turf fields would be a valuable addition to the report and could form a committee that makes general recommendations. The report does not seem to include any input from the teams and leagues that play on synthetic turf fields. The response we have received from them has been overwhelmingly positive. Their voice should be part of the debate and we would be happy to provide you with a list of contacts.

Park management is, as you imply, something of a balancing act. Access, cost, environmental impacts, and community input are all elements of the equation we seek to solve on behalf of the public who look to us to fulfill their need for playing fields. As we know, there is always room for improvement but we are confident that synthetic turf when used appropriately is a creative addition to our tool kit and while it will never eliminate natural turf, it does expand significantly our options for meeting the recreation needs of all New Yorkers.

Sincerely,

Adrian Benepe
Commissioner

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Environmental Risk Assessment of Artificial Turf Systems

Norwegian Institute for Water Research

NIVA REPORT LNR 5111-2005

Environment Risk Assessment of Artificial Turf Systems

Norwegian Institute for Water Research **REPORT**

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Summary
An assessment of environmental risk linked to run-off from artificial turf pitches has been carried out on the basis of studies of the concentration of hazardous substances in materials used in artificial turf pitches and their potential for leaching into water. The risk assessment was carried out in accordance with standard procedures for the risk assessment of chemicals within the EU. The results show that there is a risk of environmental effects in small recipients which receive surface run-off from artificial turf pitches. The factor which contributes most to the environmental risk is zinc, but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits for environmental effects. Other components which were not studied could also provide an additional contribution to the environmental risk. The concentrations of chemicals in run-off from artificial turf pitches are predicted to decrease slowly so that environmental effects may occur over many years. The total quantities of hazardous substances which are leached from an artificial turf pitch are however modest, so that any environmental effects will only be localised.

Four Norwegian keywords	Four English keywords
1. Kunstgress	1. Artificial turf
2. Miljøfarlige kjemikalier	2. Hazardous chemicals
3. Gifteffekter	3. Toxic effects
4. Risikovurdering	4. Risk assessment

(Signature)	(Signature)	(Signature)
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Project Manager	Research Manager	Responsible

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Environmental Risk Assessment of Artificial Turf Systems

Foreword

The Norwegian Pollution Control Authority (SFT) commissioned the Norwegian Institute for Water Research (NIVA) to carry out an assessment of environment risk linked to artificial turf pitches. The risk assessment was carried out on the basis of a study of materials used for such pitches undertaken by the Norwegian Building Research Institute (Plesser & Lund 2004).

The risk assessment was carried out by Torsten Källqvist with assistance from August Tobiesen, NIVA.

Oslo, 19 December 2005

Torsten Källqvist

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Translated Norwegian Summary

A simple assessment of environmental risks relating to artificial turf systems has been carried out. The assessment is based on a study of the concentrations and leaching potential of hazardous chemicals used in artificial turf pitches carried out by the Norwegian Building Research Institute. It is assumed that the greatest environmental risk is linked to the leaching of chemicals through surface water run-off in connection with precipitation. In the risk assessment, the effects on the biota in the water phase and in the sediment in a small stream which receives run-off from an artificial turf pitch has been assessed. The degree of dilution in the stream is assumed to be a factor of ten. The assessment shows that there is a risk of environmental effects in both the water phase and the sediment. The factor which contributes most to the environmental risk is zinc, but alkylphenols, and octylphenol in particular, are also predicted to exceed the limits for environmental effects. The leaching of chemicals from the material is predicted to occur slowly, so that environmental effects may take place over many years. The total quantities of hazardous substances which are leached from an artificial turf pitch are modest however, and any environmental effects will only be local.

Original English Summary (*unedited*)

Title: Environmental Risk Assessment of Artificial Turf
Year: 2005
Author: Torsten Källqvist
Source: Norwegian Institute for Water Research, ISBN No.: ISBN 82-5777-4821-8

An environmental risk assessment of artificial turf for sports grounds have been performed, based on an investigation of content and leaking potential of hazardous substances in the materials used. It was found that recycled rubber was the major source of potentially hazardous substances. An exposure scenario where the runoff from a football field is drained to a small creek showed a positive risk of toxic effects on biota in the water phase and in the sediment. The risk was mainly attributed to zinc, but also for octylphenol the predicted environmental concentration exceeded the no environmental effect concentration. The total annual amounts of hazardous substances leaching from a normal sports ground are fairly low which means that any environmental effects are expected to be local only.

1. Background

Artificial turf sports pitches are becoming increasingly widespread in Norway. According to the Norwegian Football Association, there were approximately 300 artificial turf pitches in existence at the end of 2004 and 100 new pitches will be laid during 2005 (www.fotball.no). Because the materials used in artificial turf systems contain hazardous chemicals, questions have been raised as to whether such pitches could cause a health hazard for users and an environmental hazard concerning the distribution of pollution components to the surroundings.

The potentially harmful effects linked to artificial turf systems have been studied by the Norwegian Building Research Institute, Byggforsk (15). In the study, samples of synthetic turf fibre and rubber granulates were analysed for metals and organic toxins. Leaching tests were also carried out in water using fibres and rubber granulates. The results showed that the artificial turf fibres contained copper, zinc, phthalates, alkylphenols, among other things. In the leachate from fibres, zinc was identified as the most important pollution component.

The studies of rubber granulates based on recycled rubber showed considerable variation in the chemical composition of different samples from the same manufacturer. This is probably due to differences in the raw materials used. A number of metals (lead, cadmium, copper, mercury and zinc) and organic pollutants (polycyclic aromatic hydrocarbons (PAH), phthalates, 4-t-octylphenol and iso-nonyphenol) was demonstrated in rubber granulates and many of these components were also found in leachate. Rubber granulate of the EPDM (ethylene propylene diene monomer) rubber type had lower concentrations of hazardous components.

In the report from the Norwegian Building Research Institute, concentrations of hazardous chemicals in fibres and rubber granulate were compared with the Norwegian Pollution Control Authority's normative values for polluted ground and corresponding limits for agricultural soil in Canada. Concentrations in leachate from rubber granulate were compared with limits in the Norwegian Drinking Water Regulation, the Norwegian Pollution Control Authority's classes for environmental quality in freshwater, Canadian Environmental Quality Guidelines and "Predicted No Effect Concentrations (PNEC)" from risk assessments carried out within the EU's programme for existing chemicals. The results showed that the leachate exceeded limits or normative values for a number of components and it was concluded that "An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the extent to which the concentrations of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols in the leachate actually are harmful to people and the environment" (15).

This report contains a simple assessment of environmental risk linked to artificial turf systems, based on the documentation in the abovementioned report from the Norwegian Building Research Institute.

2. Methodology

The environmental risk assessment was carried out in accordance with the "Technical Guidance Document" (TGD), which is used in connection with risk assessments for new and existing chemicals within the EU (EC 2003).

The method is based on the calculation of two concentrations of an individual chemical:

- PEC – "Predicted Environmental Concentration", i.e. the predicted concentration in the environment, and
- PNEC – "Predicted No Effect Concentration", i.e. the highest concentration which does not result in harmful effects on the environment.

Finally, the PEC/PNEC ratio was calculated. PEC/PNEC risk quotients of > 1 indicate a risk of environmental effects.

Separate PEC/PNEC calculations can be performed for five "compartments": treatment works, surface water, sediments, terrestrial environment and air.

Risk assessments can be carried out for local scenarios linked to specific pollution sources and recipients or regional scenarios which show the general risk for larger regions.

As regards the environmental effects of artificial turf pitches, spreading via run-off to surface water is predicted to cause the greatest potential risk. It is therefore appropriate to perform a risk assessment which covers water and sediments in watercourses which receive run-off from artificial turf pitches. Input to water treatment works is not assumed to be a problem area, and where it does occur, the degree of dilution of run-off water from artificial turf pitches in the total drainage flow is expected to be so high that the environmental risk is assumed to be insignificant. Input to the terrestrial environment is predicted in the TGD to occur through the use of sludge from municipal treatment works as a soil preparation agent. This scenario has not been assessed for the same reason as that mentioned for treatment works. Some spreading to surrounding areas through the airborne transport of particles and with floodwater could occur. No information is however available on the extent of such spreading, preventing realistic calculations of the risk from being carried out. It is however assumed that the exposure concentrations and the risk of environmental effects in the terrestrial environment will be lower than in sediments in the aquatic environment.

The environmental risk assessment is based on a local scenario, where run-off from an artificial turf pitch is drained to a nearby stream. The water flow in the stream will of course be of significance to the resulting concentrations of chemicals in the recipient. Here, the dilution has been set to a factor of ten, which is the recommended default value for calculating PEC_{local} in the TGD.

The quantity of run-off has been calculated for an artificial turf pitch with an area of $7200m^2$ and annual precipitation of 800 mm[1]. This gives a total run-off of $5760m^3$ per year. As dilution in the recipient is set to a factor of ten, the mean water flow in the recipient is 110 l/min.

The quantities of fibre turf and rubber granulate are assumed to be 0.8 and 18 kg per square metre respectively (Thale et al. 2004), i.e. a total of 5760 kg artificial turf fibre and 129,600 kg rubber granulate.

The concentrations of various pollution components in the run-off water were taken from the Norwegian Building Research Institute's study of leachate from artificial turf fibre and rubber granulate. Where data was available for a number of samples, the highest concentration for each component was chosen. In the Norwegian Building Research Institute's study, the leachate was investigated by shaking 1 kg of material (fibre or rubber granulate) in 10 litres of water for 24 hours. The water was then filtered and the filtrate analysed. The leachate procedure is based on pr EN 124567-4 and NT ENVIR 005. In the risk assessment it is assumed that the concentrations found in the filtrate represent equilibrium concentrations, i.e. they are independent of the material/water quantity ratio.

3. PEC_{water}

[1] The quantity of precipitation will not affect the risk assessment, as it is assumed that the dilution of run-off is constant at a factor of ten. It will however be of importance for the total quantities of substances which are leached out. 800 mm/year is slightly higher than normal for Blindern, Oslo (763 mm).

Predicted concentrations in surface water (PEC_{water}) have been calculated for the pollution components which were demonstrated to be above the detection level in analyses of leachate of artificial turf fibre and rubber granulate.

These components are listed in Table 1. Maximum concentrations which were found in the study and the samples from which the results originate are also given in this table.

PEC_{water} is calculated from the concentration in the run-off, the dilution in the recipient and the predicted reduction in the water phase as a result of adsorption to suspended particles in water:

$$PEC_{water} = \frac{C_{run-off}}{(1 + Kp_{susp} \times SUSP_{water} \times 10^{-6}) \times DILUTION}$$

Where:

Kp_{susp}	Distribution co-efficient (solid/water) in suspended material	[l•kg^{-1}]	Calculated from K_{OC}
$SUSP_{water}$	Concentration of suspended material in the recipient	[mg•l^{-1}]	= 15*

* 15 mg/l is the default value for suspended material in the TGD. It is a realistic value for small watercourses in Norway, but can vary considerably.

Kp_{susp} is calculated from the distribution coefficient organic carbon/water (K_{OC}) and the concentration of organic carbon in the suspended material which is set to 10% (the default value in the TGD). The K_{OC} values for the various compounds are taken from the EU's risk assessment reports or, if no such reports are available, calculated from the distribution coefficient octanol/water (K_{OW}) with the quantitative structure/activity equations from the TGD (Table 5, Chapter 4).

$PEC_{sediment}$ is calculated from PEC_{water} using the formula:

$$PEC_{sediment} = \frac{K_{susp-water}}{RHO_{susp}} \times PEC_{water} \times 1000$$

Where:

$K_{susp\text{-}water}$	Volume-based distribution coefficient suspended material/water	[m^3•m^{-3}]	Calculated in EUSES
RHO_{susp}	Density of suspended material	[kg•m^{-3}]	= 1150*

* default value in the TGD

$K_{susp\text{-}water}$ was calculated using EUSES, a model tool that is used in the TGD.

PEC values for water and sediment are listed in Table 2. $PEC_{sediment}$ cannot be calculated for the most nonpolar phthalates (log K_{OW} > 8) with the model which was used. This does not however represent a

problem, as the biological availability of these substances on exposure via water and sediment is so low that PNEC values cannot be calculated.

Table 1. Concentrations of chemicals in water determined in leachate tests on artificial turf fibres and rubber granulates (From Plesser & Lund 2004).

Parameter	Unit	Concentration	Sample
Zinc (Zn)	mg/l	2.29 + 1.00	Granulate 1 + Fibre 3
Total PAH (16)	µg/l	0.87	Granulate 1
Naphthalene	µg/l	0.15	Granulate 1
Acenaphtylene	µg/l	0.27	Granulate 1
Acenaphthylene	µg/l	0.03	
Fluorene	µg/l	0.04	
Phenanthrene	µg/l	0.17	Granulate 2
Anthracene	µg/l	0.03	Granulates 1 and 2
Fluoranthene	µg/l	0.06	Granulates 1 and 2
Pyrene	µg/l	0.13	Granulates 1
Dimethylphthalate (DMP)	µg/l	1.6	Granulate 2
Diethylphthalate (DEP)	µg/l	8.3	Granulate 2
Dibutylphthalate (DBP)	µg/l	3.3	Granulate 1
Benzylbutylphthalate (BBP)	µg/l	0.3	Granulate 2
Diethylhexylphthalate (DEHP)	µg/l	5.6	Granulate 2
Di-n-octylphthalate (DOP)	µg/l	4.4	Granulate 2
Diisononylphthalate (DINP)	µg/l	2.7	Granulate 1
Diisodecylphthalate (DIDP)	µg/l	1.0	Granulate 2
4-t-octylphenol	ng/l	3600	Granulate 1
4-n-nonylphenol	ng/l	43	Granulate 1
iso-nonylphenol	ng/l	1120	Granulate 1

The calculated PEC values in water and sediment are shown in Table 2. The K_{OC} values which were used to calculate $K_{susp\text{-}water}$ are taken from the EU's risk assessments for naphthalene, "Coal Tar Pitch, high temperature" (acenaphthylene, fluorene, phenanthrene, fluoranthene and pyrene), anthracene, dibutylphthalate, benzylbutylphthalate, diethylhexylphthalate, octylphenol and nonylphenol. For other substances, K_{OC} was calculated using a QSAR model for "predominantly hydrophobic chemicals" in accordance with the TGD.

It should be noted that K_{OC} for naphthalene was calculated using a different QSAR model than the other PAHs.

Table 2. Estimated exposure concentrations for water (PEC_{water}) and sediment ($PEC_{sediment}$)

Parameter	**Concentration in run-off (µg/l)**	**Log K_{OW}**	**K_{OC}**	**Kp_{susp} (l/kg)**	**PEC_{water} (µg/l)**	**$K_{susp-water}$ (m^3/m^3)**	**$PEC_{sediment}$ (µg/kg wet weight)**
Zinc (Zn)	3290	-	-	11000[a]	124	27501[a]	2969000
Total PAH (16)	0.87						
Naphthalene	0.15	3.7	1250	125	0.015	32.2	0.42
Acenaphthylene	0.27	3.62	2570	257	0.027	65.2	1.52
Acenaphthene	0.03	4.0	6166	617	0.003	155	0.40
Fluorene	0.04	4.2	9772	977	0.004	245	0.84
Phenanthrene	0.17	4.68	18197	1820	0.017	456	6.56
Anthracene	0.03	4.54	21380	2138	0.003	151	0.38
Fluoranthene	0.06	4.98	58884	5888	0.006	1470	7.05
Pyrene	0.13	5.2	97724	9772	0.011	2440	24.06
Dimethylphthalate (DMP)	1.6	1.66	28	3	0.160	1.04	0.14
Diethylphthalate (DEP)	8.3	2.65	176	18	0.830	5.5	3.97
Dibutylphthalate (DBP)	3.3	4.57	6334	633	0.327	159	45.20
Benzylbutylphthalate (BBP)	0.3	4.84	10481	1048	0.030	315	8.09
Diethylhexylphthalate (DEHP)	5.6	7.6	1803018	180302	0.151	54000	7098
Di-n-octylphthalate (DOP)	4.4	8.54	10408784	1040878	0.026	*	
Diisononylphthalate (DINP)	2.7	8.8	16904409	1690441	0.010	*	
Diisodecylphthalate (DIDP)	1	8.8	16904409	1690441	0.004	*	
4-t-octylphenol	3.6	4.12	2737	274	0.36	69.4	21.64
4-n-nonylphenol	0.043	4.48	5355	536	0.00	135	0.50
iso-nonylphenol	1.12	4.48	5355	536	0.11	135	13.04

a) Values taken from the RA document for Zn (8).

* The values cannot be calculated as K_{OW} is outside the model's area of validity.

4. PNEC

PNEC values for surface water and sediment are taken from the EU's risk assessment documents for the chemicals that have been subjected to such an assessment (see references). For the phthalates DMP and DEP, the preliminary $PNEC_{water}$ values were calculated from available toxicity data in the database of the European Chemicals Bureau (IUCLID). $PNEC_{sediment}$ values were calculated from $PNEC_{water}$ in accordance with the TGD using the following equation:

$$PNEC_{sediment} = \frac{K_{susp-water}}{RHO_{susp}} \times PNEC_{water} \times 1000$$

The results are compiled in Table 3. It should be noted that the assumptions for calculating the PNEC values for sediment differed in each of the risk assessment documents from which they were taken. In some cases, they are based on toxicity data for sediment-inhabiting organisms and in others through the equilibrium equation from $PNEC_{water}$. In addition, the same method was not used for the equilibrium equation in all the documents. For two PAHs (naphthalene and anthracene), PNEC values are available from risk assessments concerning the individual compounds and from the risk assessment for "Coal Tar Pitch, High temperature". The PNEC values for water are fairly similar in the two documents, whilst they differ by a factor of up to 10 for $PNEC_{sediment}$. In this report, the PNEC values for naphthalene and anthracene were taken from the EU's specific risk assessment reports for these substances.

5. Risk quotients

Risk quotients for water and sediment are shown in Table 4. For all the chemicals with the exception of zinc and octylphenol, PEC/PNEC < 0.6 in both water and sediment. The analysis shows that zinc represents the biggest risk with a risk quotient of 40 in water and 341 in sediment.

For octylphenol, the risk quotient was calculated at 2.9 for water and sediment, indicating a risk of toxic effects in both media.

If it is assumed that the toxic effects of related chemicals are additive, the total risk for the three categories PAH, phthalates and alkylphenols can be calculated by summing the risk quotients. This can of course only be done for components present in concentrations above the detection limit in the leachate and for which PNEC values have been determined. For the PAH group, where the risk quotients for the individual substances is < 1, the sum of the risk quotients for water is 1.13, indicating that the collective effect of PAHs could represent a risk for the biota in the water phase.

For the phthalates group, the total of the risk quotients is < 1. For alkylphenols, where octylphenol alone represents a risk, the nonylphenols contribute to the risk quotient for water and sediment of 3.3.

Table 3. PNEC values for water and sediment

Parameter	**Log K_{OW}**	**$PNEC_{water}$ (µg/l)**	**$PNEC_{sediment}$ (µg/kg wet weight)**	**Source (see references)**
Zinc (Zn)		3.1[a]	8000[b]	8
Total PAH (16)				
Naphthalene	3.7	2.4	67.2	6
Acenaphthylene	3.62	0.64	37[c]	10
Acenaphthene	4	3.8	608[c]	10
Fluorene	4.2	2.5	973[c]	10
Phenanthrene	4.68	1.3	1900[c]	10
Anthracene	4.45	0.12	11.9	11
Fluoranthene	4.45	0.12	365[c]	10
Pyrene	5.2	0.023	532[c]	10
Dimethylphthalate (DMP)	1.66	960[d]	868[f]	IUCLID
Diethylphthalate (DEP)	2.65	900[e]	4304[f]	IUCLID
Dibutylphthalate (DBP)	4.57	10	1200	7
Benzylbutylphthalate (BBP)	4.84	7.5	1715	9
Diethylhexylphthalate (DEHP)	7.6	n.d.	100000	12
Di-n-octylphthalate (DOP)	8.54			
Diisononylphthalate (DINP)	8.8	No effect	No effect	5
Diisodecylphthalate (DIDP)	8.8	No effect	No effect	4
4-t-octylphenol	4.12	0.122	7.4	2
4-n-nonylphenol	4.48	0.33	39	3
iso-nonylphenol	4.48	0.33	39	3

[a] $PNEC_{add}$ for water with low hardness, i.e. in addition to the natural background concentration
[b] $PNEC_{add}$, i.e. in addition to the natural background concentration
[c] Calculated from $PNEC_{sediment}$ dry weight with the assumption that the solid phase makes up 20% of the sediment and that the density of the solid phase is 2.5 g/cm^3 (TGD).
[d] calculated from the lowest NOEC in IUCLID (Daphnia, 9.6 mg/l) and Assessment factor = 10
[e] calculated from the lowest NOEC in IUCLID (Algae, 9 mg/l) and Assessment factor = 10
[f] calculated from $PNEC_{water}$

Table 4. Risk quotients (PEC/PNEC) for water and sediment.

Parameter	**$PEC/PNEC_{water}$**	**$PEC/PNEC_{sediment}$**
Zinc (Zn)	40	371
Total PAH (16)		
Naphthalene	0.006	0.006
Acenaphthylene	0.042	0.041
Acenaphthene	0.001	0.001
Fluorene	0.002	0.001
Phenanthrene	0.013	0.003
Anthracene	0.024	0.032
Fluoranthene	0.551	0.019
Pyrene	0.493	0.045
Total PAH	**1.132**	**0.149**
Dimethylphthalate (DMP)	0.0002	0.0002
Diethylphthalate (DEP)	0.001	0.001
Dibutylphthalate (DBP)	0.033	0.038
Benzylbutylphthalate (BBP)	0.004	0.004
Diethylhexylphthalate (DEHP)	0.000	0.071
Di-n-octylphthalate (DOP)		
Diisononylphthalate (DINP)	0.0000	0.0000
Diisodecylphthalate (DIDP)	0.0000	0.0000
Total phthalates	**0.038**	**0.114**
4-t-octylphenol	2.939	2.924
4-n-nonylphenol	0.013	0.013
iso-nonylphenol	0.337	0.334
Total alkylphenols	**3.288**	**3.271**

6. Discharge quantities

The total quantities of the various substances leached from an artificial turf pitch with an area of 7200 m^2 over a period of one year were calculated from the concentrations in the leachate water and the quantity of water which is input through precipitation (800 mm/year = 5760 m^3). The results of these calculations are shown in Table 5. With the exception of zinc, of which approximately 19 kg is leached out over one year, the total quantities of the various substances analysed are low.

Table 5. Estimated total quantities of substances leached from an artificial turf pitch with an area of 7200 m^2 over a period of one year with 800 mm precipitation.

Parameter	**Leachate (µg/l)**	**Leached/year (g)**
Zinc (Zn)	3290	18950*
Total PAH (16)	0.87	5.01
Naphthalene	0.15	0.86
Acenaphthylene	0.27	1.56
Acenaphthene	0.03	0.17
Fluorene	0.04	0.23
Phenanthrene	0.17	0.98
Anthracene	0.03	0.17
Fluoranthene	0.06	0.35
Pyrene	0.13	0.75
Dimethylphthalate (DMP)	1.6	9.22
Diethylphthalate (DEP)	8.3	47.81
Dibutylphthalate (DBP)	3.3	19.01
Benzylbutylphthalate (BBP)	0.3	1.73
Diethylhexylphthalate (DEHP)	5.6	32.26
Di-n-octylphthalate (DOP)	4.4	25.34
Diisononylphthalate (DINP)	2.7	15.55
Diisodecylphthalate (DIDP)	1.0	5.76
4-t-octylphenol	3.60	20.74
4-n-nonylphenol	0.043	0.25
iso-nonylphenol	1.12	6.45

* Of this amount, 14091 g originates from rubber granulate and 4859 g originates from turf fibre.

7. Discussion

The most problematic pollution components from artificial turf pitches originate from rubber granulates based on recycled rubber. The rubber material which is used comes from car tyres. There has long been a focus on the concentrations of hazardous substances in car tyres and the spreading of such substances through the wearing of and leaching from tyres. In a recent study, acute toxicity to water fleas (*Daphnia magna*) was demonstrated in water samples to which 0.5g/l of fine-grained car tyre rubber had been added. Another study demonstrated zinc as the cause of the toxic effects of car tyres (13). There is however considerable variation in the concentrations of toxic components between different types of car tyre. It is therefore not possible to transfer these results directly to the material that is used as rubber granulate in artificial turf pitches, but the results do show that car tyres have the potential to leak toxic compounds.

The risk assessment shows that zinc is the component which represents the greatest risk for environmental effects. The estimated exposure concentrations of zinc in water and sediment are far higher than the preliminary limits for environmental effects (PNEC) proposed in the EU's risk assessment for zinc (8). The amount by which the limit is exceeded is greatest for sediment (PEC/PNEC = 370). There has been some discussion as to whether the $PNEC_{sediment}$ value which is proposed in the most recent version of the risk assessment document for zinc is too low and it is possible that the value will be adjusted. An alternative method of calculation, where $PNEC_{sediment}$ is calculated from $PNEC_{water}$ (normal hardness) through an equilibrium equation gives a $PNEC_{sediment}$ = 187 mg/kg, which is a factor of 23 higher than that used in this risk assessment. With this higher PNEC value, the risk quotient for sediment becomes 16, which still indicates a clear risk of environmental effects.

The toxicity of zinc in water depends on the hardness of the water. In this risk assessment, a $PNEC_{water}$ of 3.1µg/l above the background concentration was used, which applies to water with low hardness (< 24 mg $CaCO_3$/l). Even using a PNEC value for water with a hardness of over 24 mg/l ($PNEC_{water}$ = 7.8 µg/l above the background concentration), the estimated concentration in water ($PNEC_{water}$ = 124 µg/l) clearly exceeds the limit. Calculations of the environmental risk relating to zinc were performed without taking into account the background concentration of zinc. This background concentration will however be so low that it will only have a marginal effect on the risk quotients. The median value for zinc in lakes in Norway has been calculated at 1.1 µg/l (16).

According to the results from the Norwegian Building Research Institute's study, the leaching of zinc from artificial turf pitches will originate from both turf fibre (30%) and rubber granulate (70%). Zinc has previously been demonstrated as being the cause of toxic effects in leachate from car tyres, which is the source material for the rubber granulate (13).

Octylphenol is the organic compound which represents the greatest risk (PEC/PNEC = 2.9). The rubber granulate which was used in the leaching test had a concentration of 33.7 mg/kg, giving a concentration of 3.6 µg/l in the leachate water. The content of octylphenol in car tyres could be considerably higher. In a report by OSPAR (14), it is specified as 0.3%, i.e. 3000 mg/kg. If such a high concentration can occur in the rubber granulate used for artificial turf pitches it is possible that the leachate and the environmental risk could be higher than estimated in this report. There is also some uncertainty as to whether the proposed PNEC values for octylphenol are sufficiently conservative to protect against hormone-disruptive effects. No hormone-disruptive effects caused by octylphenol have however been demonstrated at concentrations lower than $PNEC_{water}$ (0.122 µg/l) (2).

In the leaching test which was carried out by the Norwegian Building Research Institute, 100 g rubber granulate/l was used. No toxicity tests were carried out on the water samples, but in the light of previous studies concerning car tyres it is probable that the leachate could have had acute toxic effects – even after dilution by a factor of 10, which is an assumption in the discharge scenario used in this report. The outcome of the risk assessment is therefore not surprising. It is however possible that components other than those analysed in the rubber granulate and the leachate could also contribute to toxic effects.

In the risk assessment, it has been assumed that the concentrations of various components in filtered water samples from the leachate test are representative of run-off water from an artificial turf pitch. This presupposes that it can be assumed that equilibrium exists between the concentrations in the water phase and in the solid phase (rubber granulate), which is independent of the quantity ratio between granulate and water. In the case of a precipitation episode involving 10 mm of precipitation for example, a total of 72m^3 of rainwater would come into contact with 144 tonnes of rubber granulate and the granulate/water ratio would be a factor of 18 higher than in the leachate test. It is however reasonable to assume that this will not result in a corresponding increase in the concentrations of the various pollution components in the run-off.

In the study conducted by the Norwegian Building Research Institute, the degree of mobilisation, i.e. the proportion of the pollution components which are leached out into the water phase when the water/granulate mixing ratio is 10 l/kg, was calculated. It would appear that the mobilisation values reported are consistently too low by a factor of ten. Granulate sample no. 1 contained 7500 mg Zn/kg. In the leachate test, the total quantity of zinc was 750 mg/l. Of this, 2.29 mg/l was found in the water phase. This gives a mobilisation of 0.31%. For 4-t-octylphenol, 0.11% of the content in the granulate was mobilised to the water phase.

Annual precipitation of 800 mm over a 7200m^2 pitch with 18 kg rubber granulate/m^2 gives a water/granulate ratio = 44l/kg. If the equilibrium concentrations in water are assumed to be constant, less than 1.4% of the zinc content and 0.5% of the octylphenol in the granulate will have been leached out after one year. This indicates that the leaching of zinc and organic chemicals could take place over a long period of time. As mentioned in the Norwegian Building Research Institute's report however, potential changes in leaching properties over time should be investigated.

It is stressed that the risk assessment is based on analysis of a limited number of samples of turf fibre and rubber granulate. It is known that the leaching of toxic components varies between different types of car tyre and the representativeness of the available data is therefore uncertain. Although the highest concentrations of chemicals which were found in analyses of leachate water were used as a basis for the risk assessment, the possibility that even higher concentrations could occur in other granulate sections cannot be eliminated. In addition, it is possible that components other than those which were determined through analysis, and which are known constituents in car tyres, could contribute to the risk of environmental effects in recipients which receive run-off from artificial turf pitches.

The risk assessment that was carried out is based on a simplified scenario, where it is assumed that equilibrium exists between concentrations of chemicals in the artificial turf material and water which has been in contact with this material. It is also assumed that the run-off occurs directly to a watercourse and not through infiltration into the ground, which could retain some of the pollution components through adsorption.

Another factor which is not included in this risk assessment is the significance of the spreading of pollution components through fine particles from the artificial turf material being transported with the drainage water. The significance of the particle fraction is not known. In the Norwegian Building Research Institute's study, the samples were filtered before analysis, and the concentrations of chemicals in the particle fraction were not quantified. The concentration of suspended material in the leachate from the rubber granulate was 1.3-2.9 mg/l. If the suspended material had the same composition as the granulate, the concentration of zinc linked to suspended material would be 22 µg/l, whilst the dissolved fraction in the leachate was 2290 µg/l. This indicates that the spreading to water of chemicals bound to fine-grained particles is of little significance for pitches made from recycled rubber granulate. One cannot however ignore the fact that a fine-grained fraction of the rubber granulate is created through erosion as a result of activity on artificial turf pitches, making the leaching of particles more important as the material is exposed to wear.

With the scenario which was used for the risk assessment, in which it is assumed that the run-off from an artificial turf pitch drains into a small stream with a constant dilution factor of ten, the calculations show a risk of environmental effects in water and sediment downstream of the section where the run-off drains into the stream. The extent of the area over which environmental effects can be anticipated will depend on the hydrological conditions in the stream downstream of the artificial turf pitch. As a general rule, the water

flow will increase down a watercourse as a result of run-off from a large area, and the concentrations of the substances which are expected to give environmental effects will decrease through dilution, so that the risk quotients will be reduced. The concentrations of degradable organic substances will also be reduced through degradation. The relatively small quantities which are leached out with the run-off over the course of a year (Table 5) indicate that artificial turf pitches are not an important source of pollution and that environmental effects can only be anticipated locally, as shown in the scenario which was used for the risk assessment. The scope of effects from an individual artificial turf pitch will depend on local conditions.

In order to provide a better basis on which to assess the environmental effects of artificial turf pitches, measurements should be made of drainage water from existing pitches. The study should include toxicity tests in order to identify any effects of chemicals which were not covered by the analysis programme in the limited studies which have been carried out.

8. Conclusion

The risk assessment shows that the concentration of zinc poses a significant local risk of environmental effects in surface water which receives run-off from artificial turf pitches. In addition, it is predicted that concentrations of alkylphenols and octylphenol in particular exceed the limits for environmental effects in the scenario which was used (dilution of run-off by a factor of ten in a recipient). The leaching of chemicals from the materials in the artificial turf system is expected to decrease only slowly, so that environmental effects could occur over many years. The total quantities of pollution components which are leached out into water from a normal artificial turf pitch are however relatively small, so that only local effects can be anticipated.

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

NYSDEC
Soil Clean-up Objectives

New York State Department of Environmental Conservation

New York State Department of Environmental Conservation
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Bureau of Technical Support, 11th Floor
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Alexander B. Grannis
Commissioner

August 13, 2007

Mr. Phil M. Stricklen, Ph.D
Director of R&D
Sportexe
197 Boling Industrial Way
Calhoun, GA 30701

RE: NYSDEC Soil Clean-up Objectives

Dear Dr. Stricklen:

Thank you for your letter regarding the applicability of the NYSDEC Soil Clean-up Objectives to synthetic turf installed on athletic playing fields. The New York State Department of Environmental Conservation, Division of Environmental Remediation, does not regulate the use of your product and cannot provide any information relative to its safety.

Exposure evaluation for the crumb rubber in your product is different than exposure evaluation for soil. Comparison of the Departments Soil Clean-up Objectives to an analysis of components of synthetic turf would serve no useful purpose.

The NYSDEC Soil Clean-up Objectives were developed to address the most common compounds, that are considered contaminants, at the Petroleum Spill, State Super Fund, Brownfield Clean-up Program and Environmental Restoration Program sites under the jurisdiction of the Department. These clean-up objectives can be found in NYSDEC Technical and Administrative Guidance (TAGM) 4046, and 6 NYCRR Part 375.

The Soil Clean-up Objectives were developed using the methodologies in the Technical Support Document (http://www.dec.ny.gov/docs/remediation_hudson_pdf/techsuppdoc.pdf). The formulas and modifying considerations are presented in sections 5.3 through section 10, the exposure assessment parameters are contained in section 5.2.

The default assumptions and exposure parameters used in the development of NYSDEC's Soil Clean-up Objectives would not be representative of the proper use of an artificial turf athletic field, therefor, use of the clean-up objectives as a measure of your products acceptability, or its effect on the environment, would not be appropriate.

Sincerely,

Christopher Magee
Engineering Geologist
Bureau of Technical Support

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SYNTHETIC TURF
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An Assessment of Chemical Leaching, Releases to Air and Temperature at Crumb-Rubber Infilled Synthetic Turf Fields

New York State Department of Environmental Conservation (DEC) and the Department of Health (DOH)

AN ASSESSMENT OF CHEMICAL LEACHING, RELEASES TO AIR AND TEMPERATURE AT CRUMB-RUBBER INFILLED SYNTHETIC TURF FIELDS

New York State Department of Environmental Conservation

New York State Department of Health

May 2009

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Preface

From the Spring of 2008 to the Fall of 2008, the New York State Department of Environmental Conservation conducted a series of studies to assess some potential impacts from the use of crumb rubber as infill material in synthetic turf fields. Crumb rubber samples were obtained from New York State manufacturers and evaluated to determine the potential for release of pollutants into the air and by leaching. Field sampling was conducted at two New York City fields to evaluate the release of airborne chemicals, release of particulate matter and measurements of heat. Ground and surface water was evaluated at other fields to assess potential impacts. The New York State Department of Health assessed the air quality monitoring survey data. This report addresses some aspects of the use of crumb rubber infill in synthetic turf fields and is not intended to broadly address all synthetic turf issues, including the potential public health implications associated with the presence of lead-based pigments in synthetic turf fibers. Information about lead in synthetic turf fibers is available in a Centers for Disease Control and Prevention Health Advisory available at http://www2a.cdc.gov/han/archivesys/ViewMsgV.asp?AlertNum=00275.

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Appendix D – Reserved for Appendices for Section 5
none

Appendix E – Appendices for Section 6
E1 - Assessment of the risks to aquatic life from leachate from crumb rubber, based on the SPLP test results for zinc, aniline and phenol

Appendix F – Appendices for Section 7
F1 - Field notes recorded by RTP for Thomas Jefferson Field
F2 - Field notes recorded by RTP for John Mullaly Field
F3 – RTP's workplan
F4 - Target list of analytes
F5 – Chemistry and Laboratory Services Section data review report
F6 – VOC, SVOC, TICs data for Thomas Jefferson Park
F7 – VOC, SVOC, TICs data for John Mullaly Park
F8 – Microscopy Lab report
F9 – PM data for Thomas Jefferson Park
F10 – PM data for John Mullaly Park

Appendix G – Reserved for Appendices for Section 8
none

Appendix H – Appendices for Section 9
H1 – Temperature Field Measurement Protocol
H2 – TJP summary of all heat parameters
H3 – JMP summary of all heat parameters

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Executive Summary

This report presents the findings from a New York State Department of Environmental Conservation (NYSDEC) study, designed to assess potential environmental and public health impacts from the use of crumb rubber as infill material in synthetic turf fields. The New York State Department of Health (NYSDOH) evaluated the potential public health risks associated with the air sampling results. The study focused on three areas of concern: the release and potential environmental impacts of chemicals into surface water and groundwater; the release and potential public health impacts of chemicals from the surface of the fields to the air; and elevated surface temperatures and indicators of the potential for heat-related illness ("heat stress") at synthetic turf fields.

The study included a laboratory evaluation, applied to four types of tire-derived crumb rubber (car, truck, a mixture of car and truck, and a mixture cryogenically produced), to assess the release of chemicals using the simulated precipitation leaching procedure (SPLP). The results of this evaluation indicate a potential for release of zinc, aniline, phenol, and benzothiazole. Zinc (solely from truck tires), aniline, and phenol have the potential to be released above groundwater standards or guidance values. No standard or guidance value exists for benzothiazole. However, as leachate moves through soil to the groundwater table, contaminant concentrations are attenuated by adsorption and degradation, and further reduced by dilution when contaminants are mixed with groundwater. An analysis of attenuation and dilution mechanisms and the associated reduction factors indicates that crumb rubber may be used as an infill without significant impact on groundwater quality, assuming the limitations of mechanisms, such as separation distance to groundwater table, are addressed.

Analysis of crumb rubber samples digested in acid revealed that the lead concentration in the crumb rubber samples were well below the federal hazard standard for lead in soil and indicate that the crumb rubber from which the samples were obtained would not be a significant source of lead exposure if used as infill material in synthetic

turf fields. The evaluation of volatile and semi-volatile organic compounds by off-gassing proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples but the results did provide useful information for additional analytes in the ambient air field investigation.

A risk assessment for aquatic life protection performed using the laboratory SPLP results, found that crumb rubber derived entirely from truck tires may have an impact on aquatic life due to the release of zinc. For the three other types of crumb rubber, aquatic toxicity was found to be unlikely. When the results of the column tests are used in this risk assessment model, no adverse impacts are predicted for any of the crumb rubber types evaluated. Although the SPLP results predict a greater release of chemicals, the column test is considered more representative of the field conditions.

The study also included a field sampling component for potential surface and groundwater impacts. This work has not been fully completed at the time of this report. The groundwater sampling that was conducted shows no impact on groundwater quality due to crumb rubber related compounds, but this finding should not be considered as conclusive due to the limited amount of data available. Additional sampling of surface and groundwater at crumb-rubber infill synthetic turf fields will be conducted by NYSDEC. The results will be summarized in a separate report.

A field evaluation of chemical releases from synthetic turf surfaces was conducted at two locations using an air sampling method that allowed for identification of low concentration analytes and involved the evaluation of the potential releases of analytes not previously reported. Few detected analytes were found. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in an urban environment. A number of analytes found in previous studies evaluating crumb rubber were detected at low concentrations (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

A public health evaluation was conducted on the results from the ambient air sampling and concluded that the measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields.

The ambient air particulate matter sampling did not reveal meaningful differences in concentrations measured on the field and those measured upwind of the field. This may be explained by the lack of rubber dust found in the smaller size fraction (respirable range) through the application of aggressive sampling methods on the surface of the fields. Overall, the findings do not indicate that these fields are a significant source of exposure to respirable particulate matter.

The results of the temperature survey show significantly higher surface temperatures for synthetic turf fields as compared to the measurements obtained on nearby grass and sand surfaces. While the temperature survey found little difference for the indicators of heat stress between the synthetic turf, grass, and sand surfaces, on any given day a small difference in the heat stress indicators could result in a different guidance for the different surface types. Although little difference between indicators of heat stress measurements was found, the synthetic turf surface temperatures were much higher and prolonged contact with the hotter surfaces may have the potential to create discomfort, cause thermal injury and contribute to heat-related illnesses. Awareness of the potential for heat illness and how to recognize and prevent heat illness needs to be raised among users and managers of athletic fields, athletic staff, coaches and parents.

This assessment of certain aspects of crumb-rubber infilled synthetic turf fields was designed to collect data under conditions representative of "worst case" conditions (e.g., summer-time temperatures that should maximize off-gassing of chemicals). However, samples collected under different conditions, using different methods or at different fields could yield different results. For example, the results of measurements may be different for fields of other ages or designs (e.g., different volumes of crumb rubber infill, non-crumb rubber infill) or for indoor fields. This report is not intended to

broadly address all synthetic turf issues, including the potential public health implications associated with the presence of lead-based pigments in synthetic turf fibers. Information about lead in synthetic turf fibers is available in a Centers for Disease Control and Prevention Health Advisory available at http://www2a.cdc.gov/han/archivesys/ViewMsgV.asp?AlertNum=00275

1. Introduction

Background

Crumb rubber, also referred to as ground rubber, is finely ground rubber derived from recycled or scrap tires. Over 20 million scrap tires are generated annually in New York State (NYS). The R.W. Beck consulting firm estimated that in 2004, about 22.5 percent of NYS generated scrap tires were used to produce ground rubber (Beck 2006). Ground rubber and ground rubber products derived from scrap tires have a wide range of customers, both inside and outside NYS, including: molded product producers, schools, sports stadiums, landscape firms, road construction firms and new tire manufacturers. Growth in ground rubber production is largely centered on its use in mulch products, playground materials, and sports field markets. Crumb rubber is a common infill material for synthetic turf fields providing cushion and ballast for the playing surface. The benefits claimed for choosing crumb rubber over natural grass fields include reduced water needs and maintenance, avoided need for pesticides, herbicides or fertilizer, reduced injuries, and an "all-weather" playing surface. Out of the 850 synthetic turf fields in the United States, NYS has about 150 fields (Katz 2007).

Governmental agencies in Norway, New York City and California have conducted evaluations of the potential health issues associated with the use of crumb rubber as infill at playgrounds and synthetic turf fields. Their assessments did not find a public health threat (NIPHRH 2006, NYCDOHMH 2008b, CIWMB 2007). However, several recent preliminary studies by Zhang et al. (2008), Mattina et al. (2008) and RAMP (2007) indicated the presence of organic compounds, such as polycyclic aromatic hydrocarbons and heavy metals, such as zinc, and raise concerns that these substances could have potential adverse impacts on the environment and public health, especially for children playing on these synthetic turf fields for extended time periods. Additionally, studies have reported high surface temperatures on synthetic turf fields and raised concern about potential heat-related illness ("heat stress") during play (DeVitt et al. 2007, Williams and Pulley 2006).

Under New York State Environmental Conservation Law, § 27-1901 (ECL), crumb rubber is not considered a solid waste and therefore its use is not regulated as a

solid waste under the NYSDEC solid waste regulations or the ECL. However, in response to public concerns about the safety of crumb rubber used at synthetic turf fields, the NYSDEC initiated a study to assess the potential environmental and health impacts from the use of crumb rubber as an infill material in synthetic turf fields.

NYSDEC completed a study protocol in the spring of 2008 (NYSDEC 2008). The protocol included both laboratory evaluations and field sampling components. The objective was to collect data to assess potential impact to both surface and ground waters due to leaching of chemicals, assess potential public health impact from air release of chemicals and evaluate surface temperature and indicators of heat stress.

The laboratory evaluations began in the late spring. The field sampling components began in the summer at two fields in New York City. A field in the Bronx at the John Mullay Park was selected since the field had been installed less than a year at the time of sampling. The second field sampled was in Manhattan at Thomas Jefferson Park and the synthetic turf was approximately 4 years old at the time of sampling. Two different fields were selected to potentially provide information on whether contaminant releases would differ relative to the age of the field.

Upon collection of the laboratory data from the surface water and groundwater assessment, NYSDEC staff evaluated potential environmental and aquatic life impacts. Upon collection of the laboratory data from the ambient air monitoring survey, NYSDOH staff evaluated potential public health impacts.

Synthetic turf composition

Crumb rubber is finely ground rubber manufactured from scrap tires with a size typically of about 1/16 inch (about 2-3 mm) and one of its current uses is as infill material at synthetic turf fields. The infill material consists of either all crumb rubber or a mix of coarse sand and crumb rubber. The infill is brushed into the artificial grass fibers to keep the fibers upright and to cushion and provide ballast to the playing surface.

Figure 1.1 depicts a typical cross section of a synthetic turf field. Although specific field construction varies, most new fields are generally comprised of three layers and use crumb rubber as infill material. The top layer usually consists of nylon or polyethylene fibers attached to a polypropylene or polyester plastic woven fabric

backing. The fabric backing supports the infill material and has holes for drainage of water. The infill material, between the fibers typically is either crumb rubber, flexible plastic pellets, sand, rubber-coated sand or a combination of sand and crumb rubber. Below the woven fabric backing is a layer of crushed stone with plastic tubing for drainage and rubber padding for shock absorbance. The final layer is commonly comprised of a permeable fabric placed over a stable soil foundation.

If the application rate of crumb rubber is approximately two to three pounds per square foot (NYSDOH 2008), for a typical sport field of 230 by 360 feet, about 83 to 120 tons of crumb rubber are used. Assuming 48 inches annual rainfall (NRCC 2000), the average runoff flow rate across the entire turf field is about 7,000 gallons per day.

Laboratory evaluation

The objectives of this portion of the study were to evaluate leaching and air releases of chemicals from randomly selected crumb rubber samples obtained from four scrap tire processing facilities in NYS. The crumb rubber samples were split for each of the laboratory evaluations. Aggressive laboratory testing methods, not necessarily translatable to environmental conditions, were used in this portion of the study to fully evaluate all potential releases of chemicals.

The crumb rubber samples were subjected to two sequential, aggressive leach tests. Another type of test was conducted, intended to simulate acid rain conditions. The crumb samples also were subjected to an acid digestion test to evaluate the lead concentration in the samples.

In addition to evaluating release of chemicals in the water environment, the release of chemicals to the air also was evaluated. In this portion of the study, sometimes called an off-gassing evaluation, crumb rubber samples were evaluated at three different temperature levels to assess chemical releases under a range of environmental temperatures.

The information gathered from these analyses was used to determine the potential parameters of concern for the field evaluation of surface water, groundwater and ambient air. Additionally, these data were used to estimate potential impacts on surface water, groundwater and aquatic life.

Field sampling approach and evaluation of potential environmental and public health impacts

The field sampling portion of the study was comprised of a surface water and groundwater assessment, an air quality survey and a temperature and indicators of heat stress evaluation.

The objectives of the surface water survey were to collect runoff samples from drainage pipes at two synthetic turf fields during rainfall events and to measure the concentration of metals and organic compounds that may leach from the crumb rubber. The objectives of the groundwater survey were to collect samples from down gradient wells at existing synthetic turf fields and to measure the concentration of metals and organic compounds that may leach from the crumb rubber.

The air quality monitoring survey was conducted to determine if organic compounds and particulate matter concentrations above the field surface were different from those found upwind of the fields. An evaluation of the potential health risks from exposure to chemicals found in the air survey was conducted by the NYSDOH. Surface samples were collected to assess particle size and composition and grass samples also were obtained to determine composition.

Finally, a temperature survey, which included measuring surface temperatures and indicators of heat stress above the surface in comparison to a nearby grass and sand surfaces, was performed.

2. Laboratory Analysis of Crumb Rubber Samples

2.1 Objective and Design

The objectives of this portion of the study were to evaluate leaching and air releases of chemicals from randomly selected crumb rubber samples obtained from four scrap tire processing facilities in New York State (NYS). Although crumb rubber generated from these facilities may not necessarily be used at existing turf fields in New York State, it is anticipated that the crumb rubber from these facilities would be representative of crumb rubber generated at out-of-state facilities. Aggressive laboratory testing methods were used in this portion of the study which may overestimate releases from the samples as compared to releases in the ambient setting. The information gathered from these analyses was used to determine potential parameters of concern in the evaluation of the groundwater and ambient air surveys conducted in this study.

The leaching portion of the study evaluated the release of semi-volatile organic compounds (SVOCs), including rubber-related compounds such as benzothiazole, and 23 metals, including arsenic, cadmium, chromium, copper, lead, mercury, vanadium, and zinc, from the crumb rubber under an acid rain conditions. To determine if the release rate changes over time, a second SPLP test on the same sample was performed. The crumb rubber samples also were subjected to an acid digestion test to evaluate the total lead concentration in the samples.

The objective of the air release (off-gassing) portion of the study was to develop a list of analytes to inform the field evaluation portion of the study. Crumb rubber samples were evaluated at three different temperature levels: 25°C (77°F), 47°C (117° F) and 70°C (158°F) to assess a range of environmental temperature conditions. The lower value (25°C) represents a temperature for an indoor field. The center value (47°C) was the average surface temperature recorded in a study conducted at Brigham Young University (Williams and Pulley 2006) for an outdoor field. Finally, 70°C was considered a potential high surface temperature that could be achieved at NYS fields (Willams and Pulley 2006, Fresenburg and Adamson 2005). In addition to identifying rubber related chemicals reported in previous studies, the laboratory also reported the top 20 tentatively identified compounds (TICs).

2.2 Sample Collection

NYS has four crumb-rubber processing facilities and their production rates range from 0.5 million to 10 million pounds of crumb rubber per month. In January 2008, crumb rubber samples were collected (in 500 mL laboratory certified clean glass jars) from the facilities and sent to NYSDEC's contract laboratory for analysis. Table 2.1 provides information on each facility's production rate, sample type, and number of samples obtained from that facility. Crumb rubber is derived from truck and passenger car tires and is produced by both ambient and cryogenic grinding processes. Ambient grinding occurs at room temperature when tire chips are finely ground to desired particle sizes. In the cryogenic grinding process, whole tires first are reduced to tire chips of approximately 3-inch size. These chips are then frozen using liquid nitrogen at -195°C (-319°F). Freezing converts the rubber to a brittle, glassy state in which it is easily shattered into tiny smooth-sided particles and separated from any adhering wire or fabric (Snyder 1998). Facility #1 processes crumb rubber from both truck tires and passenger tires in an ambient grinding process. Crumb rubber is derived from whole tires and separated by type (truck versus passenger car) at this facility. Facility #2 also applies an ambient grinding process for whole tires, but mixes the truck and passenger car tires together with a greater proportion coming from car tires. Facilities #3 and #4 produce crumb rubber from a mixture of car and truck tire chips (the tires are preprocessed into chips approximately 2-3 inches long prior to grinding). Facility #3 uses an ambient grinding process, while Facility #4 applies a cryogenic process.

Thirty-one samples of crumb rubber were randomly collected. One of the samples was split for quality control purposes for a total of 32 samples. The samples were split and sent to NYSDEC's contract laboratory for the leaching and off-gassing analysis.

Information about each sample, including the processing facility and crumb rubber type, was recorded and each sample was assigned a unique identification code.

2.3 Laboratory

The samples were shipped to NYSDEC's contract laboratory, Columbia Analytical Services, which is certified by the NYSDOH Environmental Laboratory Approval Program (ELAP).

2.4 Laboratory Leaching Test

2.4.1 Test Methods and Test Parameters

EPA SW-846 Method 1312 (USEPA 2009), the Synthetic Precipitation Leaching Procedure (SPLP) test, was used to evaluate the leaching potential of the crumb rubber samples. The analysis involves the mixing of 100 grams of crumb rubber in two liters of water at pH 4.2 to simulate acidic rainwater. The mixture is then rotated for 18 hours. After the agitation period, the leachate is filtered and analyzed for semi-volatile organics (SVOCs) and 23 metals. To determine if the release rate changes over time, a second SPLP test on the same sample was performed.

EPA SW-846 Method 6010B (USEPA 1996a), an acid digestion method used to determine metals in ground waters and solid materials, was used to evaluate the lead content in the crumb rubber samples.

2.4.2 Data Review

All data received from the laboratory were subjected to a comprehensive review for data completeness and compliance following the criteria in the USEPA's Contract Laboratory Program National Functional Guidelines for inorganic (USEPA 2004) and organic (USEPA 1999a) data review. The review for these data indicates the data are useable for the purpose of this study which is to develop a list of chemicals for analysis in the field portion of the study. Appendix A1 reports the results of this review conducted by NYSDEC's Chemistry and Laboratory Services Section.

2.4.3 Test Results

Appendix A2 provides the laboratory leaching test results. Tables 2.2 and 2.3 present a summary of the results for metals and SVOCs, respectively. These tables have been arranged by the frequency that the analytes were detected in the samples. As shown

in Table 2.2, three metals were detected above the Groundwater Standard (NYSDEC 1999). Zinc was the only metal that leached from crumb rubber for every sample tested, with an average concentration close to the groundwater standard. Iron and copper were detected above the groundwater standard in a small percentage of the samples, primarily from crumb rubber derived from truck tires. The remaining analytes detected were below the groundwater standard. Manganese and barium were detected at low concentrations with barium being detected in a low percentage of the samples (19.4%). Lead was detected at half the groundwater standard in a low percentage of the samples, primarily derived from truck tires. Table 2.2 also includes metals that were not detected in the SPLP leachate, along with detection limits.

Figure 2.1 depicts the concentration of zinc in the leachate separated by facility and crumb rubber type. Crumb rubber from truck tires at Facility #1 produced the highest concentration of zinc in the leachate (approximately three times higher than the groundwater zinc guidance value (NYSDEC 1998a). A substantial reduction in zinc leachate concentration is noted for the subsequent SPLP test on these samples. In contrast, the subsequent SPLP tests conducted on the crumb rubber for Facilities #2 and #3 resulted in minimal change in zinc concentration. Finally, the results for Facility #4 (cryogenically produced crumb rubber), show a slight increase in zinc concentration as compared to the first SPLP test. In summary, this figure illustrates that the release of zinc is not uniform and is highly dependent on the type of crumb rubber.

Table 2.3 summarizes the SPLP test results for SVOC analysis. Fifteen SVOCs were detected in the SPLP leachate. Aniline had the highest concentration of the detected compounds and was detected in all samples (for both SPLP passes). For the first SPLP pass, the average concentration of aniline is approximately 20 times higher than the groundwater standard and the subsequent SPLP pass also was above the groundwater standard. Phenol, detected in all samples (for both SPLP passes) was detected at an average concentration 13 times the groundwater standard. The second pass was slightly above the groundwater standard. 4-Methylphenol (detected 94% in the first SPLP and 48% in the second SPLP) had an average concentration marginally above the standard. The combined concentration for all phenols is approximately 18 times higher than the groundwater standard. The remaining analytes were detected infrequently, but found at

concentrations less than the corresponding groundwater standard or there is no groundwater standard available. Therefore, the potential impact of these analytes would be considered insignificant. In summary, the SPLP leach tests report results for aniline and phenol above the groundwater standard and should be considered for further review in the surface and groundwater portion of this study.

Figure 2.2 provides more detail on the levels of aniline found in the different types of crumb rubber. The results for crumb rubber from truck tires were 40 times the groundwater standard. All other types of crumb rubber had lower aniline levels, but well above the groundwater standard of 5 μg/L.

Figure 2.3 displays phenol concentrations for the different types of crumb rubber. It is interesting to note that crumb rubber from truck tires has the lowest phenol concentration, while the cryogenic crumb generated the highest phenol concentration in the leachate – approximately 20 times the groundwater standard. All types of crumb rubber had phenol levels exceeding the groundwater standard of 1 μg /L.

In addition to the above detected SVOCs, Table 2.4 lists the highest detected TICs found in the leachate. Since the instrument was not calibrated for these compounds, the TIC results have been reported as estimated concentrations.

Previous studies report benzothiazole is commonly found in crumb rubber and this was found to be the most prominent compound in the TIC list. Figure 2.4 displays the estimated concentration of benzothiazole in the SPLP leachate for the different types of crumb rubber. Crumb rubber made from truck tires had the highest leaching results for benzothiazole. Benzothiazole and the remaining TICs are further examined in Section 3 (Laboratory Column Test) where the study design more closely resembles ambient conditions.

The lead results from the acid digestion test can be found in Appendix A3. The lead concentrations range from 5.6 – 116 ppm with an average of 30.8 ppm. In the absence of an applicable lead standard for crumb rubber, a comparison of the results to the USEPA hazard standard for lead in bare residential soil (400ppm) (USEPA 2001) was conducted. All results were below the hazard standard of 400 ppm.

2.4.4 Conclusions

Based on this test method aniline, phenol and zinc (for samples derived solely from truck tires) were found above groundwater standards or guidance values. It is important to consider that this test method may result in an overestimate of the release of pollutants under actual field conditions. Additionally, the results indicate that the leaching potential is dependent on the type of crumb rubber, with truck tires typically having the highest leaching potential. The results obtained in the leaching analysis and from the column testing (Section 3) were used to develop a list of analytes for the surface and groundwater portion of the study.

The lead concentration in the crumb rubber samples are below the USEPA hazard standard for lead in bare residential soil and below applicable standards that have been used by others evaluating lead concentrations on synthetic turf fields (NYCDOHMH, 2008a). These data indicate that these samples of crumb rubber would not be a significant source of lead exposure if used as infill material in synthetic turf fields.

2.4.5 Limitations

The leaching method provided a conservative scenario for the following reasons: 1) the method pH 4.2 is slightly lower (more acidic) than the pH of rain water recorded in New York State which runs from 4.35 to 4.76 (NYSDEC 2006); and 2) the method includes 18 hours of agitation, while in practice, crumb rubber is tightly packed as an infill and not agitated as aggressively. Therefore, the method may overestimate the release of compounds of interest. This method, however, will be useful to compare the release rates for different types of crumb rubber under a controlled laboratory setting. Additionally, it provides data for a conservative scenario evaluation for potential surface and groundwater impacts.

It is unknown whether synthetic turf fields in New York State were installed with crumb rubber obtained from production facilities in the State.

2.5 Laboratory Off-gassing Test

2.5.1 Test Methods and Parameters

Upon receipt of the samples for the off-gassing analysis, the laboratory split two different samples for additional quality control evaluation. The crumb rubber samples were heated for 50 minutes to three different temperatures. A modified TO-15 method was used to evaluate VOC and SVOCs released from the samples. A modification was necessary due to the high sorbent properties of crumb rubber. When internal standards were applied to the crumb rubber off-gasses, they were irreversibly adsorbed onto the crumb rubber matrix. Therefore, an external standard technique was used and response factors with units of area counts per nanogram were used for all calibration curves. Additionally, to prevent the off-gasses from contaminating the analytical system, 0.1 gram samples were analyzed yielding a dilution factor of 10, thereby raising the practical quantitation limit from 5.5 to 55 μg/kg.

2.5.2 Data Review

The laboratory was not provided any information regarding the type of crumb rubber in the samples. Field and laboratory, split samples were compared and combined (by averaging) if both samples yielded results. If one of the split samples was found as a non-detect and the other sample was reported as an estimated value, the second sample was consider as a non-detect to allow for the combining of the split samples.

A quality control/quality analysis review of the laboratory results for the samples evaluated at the three temperature levels was conducted by staff in NYSDEC's Chemistry and Laboratory Services Section. The review and comments are provided in Appendix A4 (samples at 25°C and 47°C) and Appendix A5 (samples at 70°C). A recommendation was made by the reviewing chemist to treat all results qualitatively. It was noted by the chemist that the surrogate recoveries were low due to the high adsorptivity that the crumb rubber has for VOCs. Therefore, it was recommended that all analytical results from the off-gassing experiments be regarded as estimated quantities, in the correct proportions.

2.5.3 Test Results

The number of analytes detected increased with increasing temperatures. At 25°C, 47°C and 70°C, the number of compounds detected was 47, 54, and 60,

respectively. The full list of analytes detected by temperature and subdivided by crumb rubber type can be found in Appendix A6.

The laboratory off-gassing data provided information on analytes detected and relative concentrations to allow development of a list of additional analytes for the ambient air survey portion of the study. Unknown compounds and mixed isomers were not considered for evaluation in the ambient air field sampling evaluation. Analytes which were detected in at least 50% of the samples for each crumb rubber type (i.e., car, truck, mixture of car and truck, and cryogenic) were selected. From this subset, analytes were selected for consideration if they were detected in more than 50% of all the samples collected. A total of 18 analytes were identified for further consideration. Analytes that were already proposed for evaluation by the laboratory evaluating the ambient air field samples have not been included in this total count. Additional criteria were applied as detailed in a memo attached as Appendix A7 and a final list of analytes was developed and submitted to the laboratory that conducted the analysis of the ambient air survey samples.

2.5.4 Conclusions

Although the laboratory off-gassing portion of the study proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples for VOCs, the results did provide useful information for additional analytes to be included in the laboratory analysis of the ambient air field samples. Five additional analytes were selected for inclusion in the ambient air survey, based on the results of the crumb rubber off-gassing study. Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnaphthalene (90-12-0). Two analytes were selected because of high frequency of detects and high relative concentrations found in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9). Finally, it is uncertain what effect the absorptive nature of the crumb rubber, as noted in the laboratory setting, may have in the field setting.

2.5.5 Limitations

The strong absorptive nature of the crumb rubber samples prevented a quantitative analysis of the results in this portion of the study. Additionally, laboratory conditions do not mimic the environmental setting. Other factors such as compression and degradation of the crumb rubber during field use and changes attributable to solar radiation may affect the release of chemicals in the ambient environment.

It is unknown whether synthetic turf fields in New York State were installed with crumb rubber obtained from production facilities in the State.

3. Laboratory Column Test

3.1 Objective and Design

The objectives were to evaluate the leaching potential of crumb rubber using a laboratory method that more closely represents field conditions than the SPLP test and to compare the results with the more aggressive SPLP tests described in Section 2. The test simulates the release of chemicals from crumb rubber by exposing the crumb to synthetic rainwater in a column designed to closely mimic ambient conditions at synthetic turf fields. The crumb rubber was exposed to an equivalent of one year's rainfall in NYS (48 inches (NRCC 2000)) using simulated rainwater at pH 4.2, which is slightly more acidic than the low end of the pH range found in NYS (4.35 to 4.76). The selection of pH 4.2, which is equal to the pH of the SPLP test, will facilitate the comparison between the results of the column test and SPLP test. The simulated rainfall that passed through the tire crumb columns, without being agitated as in the SPLP test, was collected at 12 inch rainfall intervals. Two types of crumb rubber were selected for the leaching experiment, a truck tire crumb (Facility #1) and a cryogenically prepared mixed crumb (Facility #4) because the SPLP leaching analysis indicated that more analytes and higher relative proportions were released from these types of crumb rubber. The laboratory column test was conducted by staff in NYSDEC's Division of Solid and Hazardous Materials laboratory. The resultant leachate was sent to NYSDEC's contract laboratory with ELAP certification for this analysis.

3.2 Equipment

The column system was designed by staff at NYSDEC. The pump system was a Cole Palmer System, consisting of Master Flex L/S Computerized Drive (P/N 7550-50), with 7519-16 4 roller pumphead. The pumphead drove 7519-80 peristaltic cartridges, up to eight cartridges could be run off of one pumphead. The system was interfaced (RS-232) to a Dell GX280 PC running MasterFlex WinLin Linkable Instrument Networking Software (V2.0) for instrument control. The peristaltic tubing used was Masterflex silicone platinum tubing, L/S-14. The silicone tubing was run from the simulated rainfall reservoir and passed through the peristaltic pump cartridges. The silicone tubing was

then connected to 1/8 inch OD Teflon tubing using an Upchurch P-798 conical adapter. From that point, 1/8 inch OD Teflon tubing was used to connect to the chromatography columns, and from the chromatography columns to the collection bottles.

The chromatography columns were Kontes P/N 820830-1520 Chromaflex Glass Columns – 4.8 cm ID x 15 cm L. An adjustable bed support (P/N 420836-0040) was used to provide minimal (2.2 inch gravity packed to 2.0 inch compressed) bed compression of the tire crumb to maintain reproducible elution conditions. The bed supports utilized a 20 micron polyethylene screens and Teflon/propylene seals.

3.3 Reagents

Table 3.1 reports the reagents used and supplier. The production of rainwater (Serkiz et al. 1999) was modified through the use of an acetic acid/acetate buffer system (0.0003M) adjusted to pH 4.2 with 0.5M HNO_3/H_2SO_4 to simulate an aggressive acid rain scenario. Final pH determinations were made using a Thermo Orion 920A+ pH meter with an Orion Ross Ultra combination pH electrode. For the final determination of pH, the simulated rainfall solution was allowed to equilibrate with the electrode overnight, in a covered beaker. The pH of the simulated rainfall solution was checked at the end of the leachate study and found to be stable.

3.4 Column Test Procedures

Crumb rubber was gravity packed into a glass chromatography column to a depth of approximately 2.2 inches. The amount of crumb used to pack the column was weighed for each column preparation. To ensure even flow of the eluent throughout the crumb bed, and to aid in consistency, the crumb column was compressed to 2.0 inches using the adjustable bed support. Following preparation of the column, the crumb was then eluted with simulated rainfall in an intermittent manner, with flow through the columns for half an hour, followed by no flow for half an hour, with the sequence maintained until the equivalent of 12 inches of rain passed through the crumb. The nominal flow through the column was 2 mL/min, with the equivalent of 12 inches of rain being passed through the column in a total of 300 minutes of flow time, or 600 minutes of total run time. The simulated rainfall eluent was collected in tared 1 liter I-Chem Series

300 bottles held in an ice/water bath. To minimize potential effects from atmospheric cross contamination, the collection bath was covered during the time of eluent collection. At the end of the collection of the simulated 12 inch of rainfall, the bottles were removed from the ice bath, dried, and then weighed to determine the total volume of eluent passed through the crumb. A portion (about 30 mL) of the eluent was then placed into a nitric acid preserved bottle for total zinc analysis, both bottles were sealed, and shipped on ice to the laboratory for analysis using next day courier. The column then sat for approximately 14 hours, before the crumb was subjected to a fresh elution sequence.

Two types of crumb rubber were selected for the leaching experiment, a truck tire crumb (Facility #1) and a cryogenically prepared mixed crumb (Facility #4). Each of the crumb rubber samples subjected to the elution experiment was run in triplicate over 4 days, for a total of 24 samples sent for analysis. In addition, a blank column was prepared and run with each sample set consisting of an identical column set-up without tire crumb added to the column. This provided a method of assessing any potential for contamination that might have occurred during the leaching experiment. Calibration of the column flow rates and peristaltic pump cartridges was done by passing ASTM type I water through the columns using the flow program for 5 days prior to the experiment. The empty column set-ups were then equilibrated with pH 4.2 simulated rainwater for three days prior to the start of the experiment, also checking on flow calibration. At the beginning of the experiment, the calibrated, flushed, and equilibrated columns were packed with the tire crumb samples, and the experiment started with immediate collection of eluent, thus mimicking field events following placement of the tire crumb.

3.5 Eluent Analysis - Test Method and Test Parameters

The eluent samples were analyzed for total zinc by SW-846 Method 6010, and selected SVOCs by SW-846 Method 8270C (USEPA 2009). The laboratory instrumentation was calibrated, using reference standard materials, for selected SVOCs listed in Table 3.2.

3.6 Data Review

Appendix B1 includes the data review summary conducted by NYSDEC's Chemistry and Laboratory Services Section for the column test results. Overall, the data are usable though some of the results must be considered as estimated due to Quality Control deficiencies.

3.7 Test Results

Appendix B2 contains the laboratory column test results. Table 3.3 summarizes the results for zinc and detected SVOCs only. The average concentrations are compared with the NYS Groundwater Quality Standards (NYSDEC 1998b). As illustrated in Table 3.3, aniline was found at the highest concentration relative to the standard, found at more than five times the groundwater standard.

Figures 3.1, 3.2 and 3.3 display a comparison of zinc, aniline, and phenol concentrations, respectively, between the SPLP and the column tests for two types of crumb rubber. The concentrations of these analytes in the column tests are measured after 12, 24, 36, and 48 inches of simulated rainfall. As expected, these concentrations are all lower than the ones in the SPLP tests, but at different ratios. For example, as noted in Figure 3.1, the average zinc concentration in the leachate of the truck crumb for the column test is approximately 16 times lower than the SPLP test concentration. In comparison, for the cryogenic crumb zinc is only three times lower in concentration. The zinc leachate concentration is well below the groundwater guidance value. Figure 3.2 indicates the average aniline concentration of the truck crumb in the column test is approximately six times lower than the SPLP test concentration. In comparison, for the cryogenic crumb aniline is five times lower in concentration. The aniline leachate concentration is above the groundwater standard. In Figure 3.3, it is noted that the average phenol concentration of the truck crumb in the column test is approximately eight times lower than the SPLP test concentration, while the cryogenic crumb is 16 times lower in concentration.

3.8 Conclusions

The column test procedure is considered more representative of field conditions and as expected, the concentration of all chemicals of concern was lower than that of the

SPLP for the two types of crumb rubber evaluated. Phenol and aniline leachate results were above the groundwater standards and these analytes will be included in the surface water and groundwater evaluation.

3.9 Limitations

Although the laboratory column test was more representative of actual ambient field conditions as compared to the SPLP analysis, observations noted by the chemist conducting the laboratory column test indicate that some variability may exist in the data results due to limitations such as flow channeling and clogging of the effluent.

4. Water Quality Survey at Existing Turf Fields

4.1 Surface Water Survey

4.1.1 Objectives and Design

The objectives of surface water survey were to collect runoff samples from drainage pipes at existing turf fields during rainfall events and to measure the concentration of metals and organic compounds that may be present in the runoff. The concentrations of these compounds were compared with the NYS Water Quality Standards Surface Waters and Groundwater (NYSDEC 1999).

The original study design called for sampling two synthetic turf fields selected for the overall study design. After a few rainfall events in August and September 2008, no samples were collected at these fields, due to problems such as clogging and insufficient runoff volume in the drainage collection pipes. Therefore, another field (installed in 2007) was identified where the drainage pipes were easily accessible and sufficient volume of surface runoff could be collected. Staff were able to collect only one surface runoff sample from this site before the water sampling effort was halted due to NYSDEC budget restrictions.

4.1.2 Test Methods and Test Parameters

Test parameters include volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) and metals using Methods 624, 625, and 200.7. The NYSDEC contract laboratory H2M Labs, Inc. conducted the analysis. The laboratory holds an ELAP certification for these methods. The analysis of this sample did not include chemicals related to crumb rubber, such as aniline and benzothiazole. Future sampling activities and subsequent analysis will include the crumb rubber related compounds.

4.1.3 Data Review

Appendix C1 includes data review findings for the surface runoff test results, which indicates the data are usable.

4.1.4 Test Results

Tables 4.1, 4.2, and 4.3 include test results for the surface runoff sample. These results show no organics were detected. Since all results for the organics were below detection limits, a comparison to surface water standards was not conducted. For metals, zinc was detected at 59.5 μg/L which is below the surface water standard. Several other metals also were detected (chromium, copper, lead, nickel) but at concentrations below the surface water standards. Appendix C2 provides the laboratory results.

4.2 Groundwater Survey

4.2.1 Objectives and Design

The objectives of the groundwater survey were to collect samples from downgradient wells at existing synthetic turf fields and to measure the concentrations of SVOCs that may leach from the crumb rubber. The concentrations of these compounds were compared to the NYS Groundwater Quality Standards (NYSDEC 1998b). To obtain samples in a timely manner, the survey focused on areas where sandy soil is predominant. In 2008, four turf fields were selected ranging from ≤1 - 7 years old. Table 4.4 provides the field characteristics. Two to three downgradient wells were installed at each field and samples were collected at various depths by staff from the Suffolk County Department of Health Services (SCDOHS). The samples were sent to the NYSDEC contract laboratory. The thirty-two groundwater samples at these sites have a depth to the groundwater table ranging from 8.3 ft to 70 ft as shown in Table 4.4. NYSDEC will perform additional sampling in 2009 at different sites that have depth to groundwater less than 8.3 ft to further characterize potential groundwater impacts.

4.2.2 Test Methods and Test Parameters

SVOCs, including aniline and benzothiazole were assessed by SW-846 Method 8270C.

4.2.3 Data Review

Appendix C3 includes data review findings for the SVOC groundwater test results, which indicates the data are usable.

4.2.4 Test Results

All test results were below the limit of detection for all groundwater samples analyzed. Table 4.5 reports the detection limits for the specific compounds associated with crumb rubber, aniline, phenol, and benzothiazole. Table 4.6 reports the detection limits for all SVOCs evaluated. A comparison of the results to applicable groundwater standards was not conducted, since all were below the detection limit. Appendix C4 provides the laboratory results.

4.3 Conclusions

Surface water

No organics were detected and several metals were detected at low levels for one sample analyzed. The NYSDEC will perform additional sampling of surface water runoff in 2009. The additional test results will be included in a separate report.

Groundwater

Based on test results of 32 groundwater samples, no organics or zinc were detected at the turf fields. The NYSDEC will perform additional sampling of groundwater at sites with shallower groundwater levels in 2009 to better represent potential impacts and will present test results in a separate report.

4.4 Limitations

Surface water

Results for the surface water quality survey are based on one sample and have very limited application to other fields. Additionally, the initial surface water survey did not include chemicals related to crumb rubber, such as aniline and benzothiazole. The surface water sample was analyzed by a different NYSDEC contract laboratory than the other water samples obtained and evaluated in this study. The laboratory used reported

higher detection limits when compared to the results for the groundwater sample analysis. Future sampling activities will include the crumb rubber related compounds and standardized laboratory analyses.

Groundwater

Although the results from the downgradient wells show no impact on groundwater quality due to crumb rubber related compounds, this finding should not be considered as conclusive, due to limited data available. NYSDEC will perform additional sampling of groundwater at sites having different characteristics, such as shorter separation distance to groundwater table, to further evaluate potential impacts. The additional sampling will also include an expanded list of parameter for analysis.

5. Potential Groundwater Impacts

5.1 Dilution-Attenuation Factor (DAF)

One method to determine the potential for groundwater impacts is through the application of a dilution-attenuation factor (DAF). As leachate moves through soil to the groundwater table, contaminant concentrations are attenuated by adsorption and degradation. After entering the groundwater table, a chemical is mixed with groundwater and the resultant concentration is further diluted. The DAF is used to account for these mechanisms and is often called a correction factor. The higher the DAF, the greater the attenuation needed to achieve the groundwater standard.

The NYSDEC's soil cleanup guidance for hazardous remediation sites was first established in 1992. The DAF is used in guidance for the remediation program, found in the Technical Support Document for NYSDEC's 6 NYCRR Part 375 soil cleanup objectives (NYSDEC and NYSDOH 2006). In developing the soil cleanup objectives, a DAF of 100 was used for organics and 40 for inorganics because experience has shown that when a site is cleaned up using these DAFs, the groundwater quality is protected.

Table 5.1 presents the predicted groundwater concentrations calculated by using the SPLP results for the three most prominent organic compounds: aniline, phenol, and benzothiazole with a DAF of 100, and zinc with a DAF of 40. A conservative approach was taken and a comparison to the 95th percentile of the SPLP test (results reported in Section 2 Laboratory Leaching Test) with the groundwater standards was conducted. This evaluation was limited to the two types of crumb rubber with the greatest leaching potential, truck tires and the cryogenic crumb rubber. As shown in Table 5.1, all predicted groundwater concentrations are lower than groundwater standards or guidance values.

5.2 Conclusions

The dilution-attenuation factor (DAF) from the NYSDEC's soil cleanup program is one method to determine if leachate will impact groundwater. Application of the DAF to the leachate results in this study demonstrates that crumb rubber can be used as an infill without significant impact on groundwater quality.

5.3 Limitations

Use of the DAF 100 for organics is presented in the remediation guidance with a note of caution for situations where the contamination source is close (three to five feet) to the groundwater table. The soil cleanup guidance also assumes one percent organic carbon content of soil when organic pollutants are evaluated. Therefore, for areas where organic carbon content is less than the desired level, such as in sandy soils, care should be taken to ensure that the groundwater quality is protected by a sufficient buffer (separation distance) to the groundwater table. The groundwater survey in a sandy soil area presented in Section 4 indicates that no groundwater impacts at sites where the minimum depth to groundwater is 8.3 feet. NYSDEC will perform additional groundwater sampling with shallower groundwater levels to better document potential impacts and needed buffer zones.

6. Potential Surface Water Impacts

6.1 Surface Water Standards

Table 6.1 lists the surface water standards (NYSDEC 1998b) for four most prominent compounds in crumb rubber from Facility #1 (truck tires) and Facility #4 (mixed tires) and a comparison of these standards to the SPLP and the column test results. As mentioned in Section 3, the results from the column test, much lower than the ones obtained from SPLP tests, are considered more representative of field conditions, because the column test does not involve 18 hours of agitation as included in the SPLP test. A conservative approach was applied by using the upper limits for the SPLP and column test results. Zinc concentrations are higher than the surface water standards. For phenol, the concentrations in the column test are lower than the surface water standards. Both aniline and benzothiazole do not have surface water standards. Comparison of the laboratory leaching results directly to surface water standards does not represent what will happen under field conditions. The actual concentration in the surface water body will be lower due to dilution and attenuation. To determine actual impact on the surface water body, the impact can be modeled mathematically and/or actual quality measurements can be taken.

6.2 Risk Assessment on Aquatic Life

Appendix E1 provides a mathematical assessment of the risks to aquatic life from leachate from crumb rubber, based on the SPLP test results for zinc, aniline and phenol. The risk assessment was conducted by NYSDEC's Division of Fish, Wildlife and Marine Resources and concludes that there may be a potential aquatic life impact due to zinc release from crumb rubber solely derived from truck tires, but an impact is unlikely for the mixed tires.

6.3 Conclusions

A risk assessment for aquatic life protection was performed and found that crumb rubber made derived entirely from truck tires may have an impact on aquatic life based on the impacts that zinc may have on aquatic life pathway. For the crumb rubber made

from mixed tires, the potential impacts are insignificant. However, this assessment is based on the SPLP test results which predict a greater the release of chemicals as compared to the column test which is considered more representative of field conditions. If the results of the column test in Table 6.1 are used in the risk assessment model, no adverse impacts are expected.

6.4 Limitations

The dilution factor used in the assessment of potential surface water impact will depend on site-specific information and it is difficult to assume all potential scenarios. The exposure model describes in Section 6.2 addresses one potential scenario which may not be applicable in all cases. As outlined in Section 4, the NYSDEC will perform additional field testing of surface water quality near crumb-rubber infilled synthetic turf fields.

7. Air Quality Monitoring Survey at Existing Fields

7.1 Objectives and Design

The air quality monitoring survey was conducted to determine if volatile organic compounds (VOC), semi-volatile organic compounds (SVOC), and particulate matter concentrations (PM) above the field surface were different than concentrations measured upwind (intended to represent background air quality) of the fields and if the measured concentrations are of public health concern. A goal of this portion of study was to collect samples on summer days when temperatures were above 80°F and the VOC and SVOC releases would be anticipated to be higher than other times of year. To determine the relevance of particulate matter monitoring, surface wipe and microvacuum sampling was conducted to evaluate the type and size of the smaller particles liberated through aggressive sampling. Synthetic grass samples also were obtained to determine composition. Finally, meteorological data were collected to facilitate comparisons to upwind air samples.

This portion of the survey was conduced on the two synthetic turf fields selected for the overall study. These two fields differ in age which may help identify whether chemical releases differ by age of field.

To measure potentially low chemical concentrations in air, field sample collection methods and laboratory analytical techniques were employed to provide minimum detection limits on the order of nanogram (billionth of a gram) per cubic meter levels. Sampling locations included upwind of the fields as well as in the center and at the downwind edge of fields to examine the horizontal profile of contaminant release concentrations. Samples at the center and downwind edge were collected at three different heights to examine a vertical profile of release. A comparison of the upwind and on-field/downwind sample results provided an indication of chemicals potentially released from the field itself.

7.2 Sample Collection

RTP Environmental Associates, Inc. was awarded the contract to conduct the field sampling. Field sampling involved ambient air sampling, surface wipe sampling, surface

microvacuum sampling, ambient particulate matter monitoring and meteorological monitoring.

The field notes recorded by RTP for the Thomas Jefferson Field, detailing field conditions and equipment setup, have been included in this report as Appendix F1. The field notes recorded by RTP for the John Mullaly Field are included as Appendix F2.

7.2.1 Date Selection

Samples for each field were collected over a two-day time period. The following criteria were developed to assist with the selection of the sampling date: two consecutive days with no precipitation including the day prior to sampling, forecast winds from the same direction for at least 4-6 hours on each day of sampling at light to moderate speeds and forecast day temperature above 80°F. These conditions were assumed to maximize measurable quantities of VOCs and SVOCs released from the fields and allowed for the comparison of upwind to on-field and downwind samples.

On August 21, 2008, RTP made final preparations to perform tests and was given final approval to proceed with testing at the Thomas Jefferson Park field by New York City Department of Parks and Recreation (NYCDPR) representatives. On August 22, 2008, RTP collected samples at the field. On September 1, 2008, RTP made final preparations to perform tests and was given final approval to proceed with testing at the John Mullaly Park field by NYCDPR representatives. On September 2, 2008, RTP collected samples at the field.

7.2.2 VOC and SVOC Sampling

Samples were collected using sorbent sample collection media. The VOC samples were collected using "active" sampling, pumping large volumes of air through the media. Tenax cartridge and Tenax/Anasorb® cartridge in series were used. One-hundred twenty liters of air were drawn through the sampling media over a period of two hours. The SVOC samples were collected using PUF/XAD cartridges and samples were collected over a two hour time period drawing in 4.0 liters per minute. More details on the sampling methods can be found in Appendix F3, RTP's work plan to perform the ambient air quality monitoring survey.

Figure 7.1 shows the sampling locations for Thomas Jefferson Park and Figure 7.2 shows the sampling locations for John Mullaly Park. These maps also show the location of the wipe, microvacuum and particulate matter monitoring. Nine samples were collected at each field. Table 7.1 reports information on sample location and heights. For quality control and quality assurance purposes, VOC and SVOC field blanks were collected and duplicate samples were obtained at two locations. A lab blank also was analyzed.

For both fields, some modifications to the field sampling protocol were necessary. The SVOC inlets for the field surface samples were placed vertically, approximately 2 mm above the turf surface. The VOC inlets for the field surface samples were placed 1 mm above the turf surface, pointing into the wind. Upwind and downwind edge surface samples were not on the field, and therefore, were placed 1-2 cm above the surface to avoid contact with the soil in these areas.

7.2.3 Wipe Samples

Wipes samples were collected at three locations: on field in the center, on field in shade and at the downwind edge of field, shown in Figures 7.1 and 7.2. For both fields, a duplicate wipe sample was obtained to determine consistency of sampling collection efficiency. Eight samples were submitted to the laboratory for analysis.

Wipe sampling was performed in accordance with the sampling methods outlined in American Society for Testing and Materials (ASTM) E1728 and in the Housing and Urban Development (HUD) guidelines (HUD 1995). Precut templates were used to mark each sampling location and wiping was performed following the HUD guidance. A clean wipe (field blank) was included in the samples sent to the laboratory for analysis. The turf temperature was recorded using an infrared thermometer (recorded by Extech 42510A infrared thermometer) at the time of wipe sample collection.

7.2.4 Microvacuum Samples

Microvacuum samples were collected in accordance with ASTM D 5755-95. Sampling techniques, materials and equipment used followed the HUD guidelines (HUD

1995). Samples were collected in three locations: on field in the center, on field in shade and at the downwind edge of field, shown in Figures 7.1 and 7.2. At one of the locations, a duplicate microvacuum sample was obtained to assess collection efficiency. Seven samples were submitted to the laboratory for evaluation. Samples were collected utilizing 25 mm particulate filter cassettes with a 0.45 μm filter coupled with Buck BioAire sampling pump.

7.2.5 Ambient PM_{10} and $PM_{2.5}$ Monitoring

Particulate matter concentrations were obtained in real-time using a Thermo DataRam (DR) 4000 aerosol monitor with size collectors for $PM_{2.5}$ (particulate matter with an aerodynamic diameter of 2.5 microns (μm) or less) and PM_{10} (particulate matter with an aerodynamic diameter of 10 μm or less). Two Thermo DR-4000 units were used for sampling simultaneously at the upwind location. Samples were collected in four locations: upwind of the field, at the center of field, and at two downwind locations, shown in Figures 7.1 and 7.2. Samples were collected during actual field use. Monitoring was conducted at three feet from the ground and one minute averaged values were recorded for time intervals lasting approximately ten minutes. Prior to field sampling, collocated calibration was conducted with both monitors.

7.2.6 Meteorological Monitoring

On-site meteorological data were collected during the VOC, SVOC and particulate matter sampling. Meteorological parameters measured include wind speed, wind direction, temperature, relative humidity, turbulence and barometric pressure. Data were collected using a Climatronics All-in-One compact weather unit mounted to a ten-foot meteorological tower. Ambient (recorded by Testo 615 temperature meter or weather unit) and surface temperatures (recorded by Extech 42510A infrared thermometer) were also periodically taken at the sampling locations.

7.2.7 Synthetic Grass Sample

During a site visit in July 2008, several blades of the synthetic grass were collected from each field.

7.3 Test Parameters and Methods

7.3.1 Ambient Air Samples

The target list of analytes shown in Appendix F4 was developed based on modifications to the Volatile Organic Sampling Train (VOST) sampling methods 5041A/8260B (USEPA 2009a) and a modified TO-13A (2009b). The laboratory agreed to report the top 20 TICs utilizing surrogates also listed in Appendix F4. TICs are those analytes which were detected but cannot be positively identified or quantified without additional analytical testing. The laboratory also evaluated the presence of five additional analytes identified by the crumb rubber off-gassing study (Section 2). Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnaphthalene (90-12-0). Two analytes were selected because of high frequency of detects and high relative concentrations in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9).

7.4 Laboratory Analysis

7.4.1 Ambient Air Samples:

Air Toxics Ltd. laboratory in Folsom, California analyzed the VOC and SVOC samples. This laboratory holds a New York State Environmental Laboratory Approval Program certification.

VOC analysis: Tenax and Tenax/Anasorb® cartridges were used for the VOC analysis. The laboratory performed the analysis via EPA SW-846 Method 5041A (USEPA 2009a) using gas chromatography/mass spectrometry (GC/MS) in the full scan mode. The tubes were thermally desorbed at 180°C for ten minutes by ultra high purity (UHP) helium carrier gas. The gas stream was then bubbled through 5 mL of organic free water and trapped on the sorbent trap of the purge and trap system. The trap was thermally desorbed to elute the components into the GC/MS system for further separation. See Appendix F4 for the reporting limits for each compound.

The VOC samples collected for the Thomas Jefferson Field and John Mullay Field, twelve VOST Tube pairs for each field, were received by Air Toxics Ltd. on August 23, 2008 and September 3, 2008, respectively, at the recommended temperature ($4 \pm 2°C$).

SVOC analysis: PUF/XAD Cartridge-Low Volume samples were used for the SVOC analysis and the samples were extracted using Pressurized Fluid Extraction (PFE) by EPA Method 3545A (USEPA 2009a). A modified EPA Method TO-13A (USEPA 2009b) was used to analyze for SVOCs. The sample extract was then concentrated to 1.0 mL and analyzed by GC/MS in the full scan mode. See Appendix F4 for the reporting limits for each compound. Method modifications are detailed in Table 7.2.

The SVOC samples collected at the Thomas Jefferson Field and John Mullaly Field, twelve PUF/XAD Cartridge-Low Volume samples for each field, were received on August 23, 2008 and September 3, 2008, respectively.

7.4.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

The particle size distribution and morphology were evaluated by staff in the Microscopy Laboratory in NYSDEC's Bureau of Air Quality Surveillance. Samples were shipped overnight to the laboratory. All samples were received in good condition.

Samples were analyzed microscopically with an Olympus SZX12 Stereomicroscope and a JEOL JSM-6490LV Scanning Electron Microscope (SEM). Fourier Transform Infrared (FTIR) analysis was performed with a Smiths Detection IlluminateIR. Images were collected with either the Olympus Stereomicroscope or the JEOL Scanning Electron Microscope.

7.4.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

Since the DR-4000, used to obtain $PM_{2.5}$ and PM_{10} measurements, reports measurements on-site in the field (real-time reporting), laboratory analysis was not necessary.

7.5 Data Review Procedures

7.5.1 Ambient Air Samples:

A review of the laboratory results for the VOC and SVOC data for both fields was conducted by staff in NYSDEC's Chemistry and Laboratory Services Section. The chemist conducting the review noted that results were appropriately qualified when sample results fell outside their respective control limits. A spot check for a particular sample showed that the results were calculated correctly from the values found in the raw data. The chemist noted that all samples were received by the laboratory in "Good" condition and all analytical holding times and temperature storage requirements were met. All blank results were non-detect indicating the absence of any system contamination, which can bias results upwards. All surrogate recoveries fell within the 100 ± 30% control limits indicating that the laboratory was capable of performing the analyses as per method specifications. For more details, the report summarizing this review can be found in Appendix F5.

Descriptive sample location information was matched to sample identifiers in each of data sets received from Air Toxics Ltd.

The VOC, SVOC and TIC results and supporting information (e.g., percent quality match for TICs and field sampling information prepared by RTP) were submitted to NYSDOH for review and analysis. See Section 8. "Assessment of Air Quality Monitoring Survey Data" for additional data review conducted by NYSDOH.

For the Thomas Jefferson field, the ambient temperature during field sampling was 77.2ºF, slightly lower that the goal of 80°F. RTP recorded high surface temperatures throughout the sampling period (118-146 ºF).

For the John Mullaly field, the ambient temperature during field sampling was 84.2ºF and RTP recorded high surface temperatures (121-148ºF) throughout the sampling period.

7.5.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

Data reported are qualitative. No further evaluation was conducted.

7.5.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

See Section 8. “Assessment of Air Quality Monitoring Survey Data” for data review conducted by NYSDOH.

7.6 Test Results

7.6.1 Ambient Air Samples:

Appendix F6 reports the raw data results for the VOC and SVOC analysis and TICs identified for the samples from the Thomas Jefferson Park. Appendix F7 reports the raw data results for the VOC and SVOC analysis and TICs identified for the samples from the John Mullay Park. See Section 8, “Assessment of Air Quality Monitoring Survey Data” for the data evaluation conducted by NYSDOH.

An evaluation was conducted on the horizontal and vertical concentrations on the fields selecting analytes not commonly found in the urban environmental and those generally found in other studies or reports (NILU 2006, NYCDOHMH 2008b) evaluating releases from crumb rubber infill material. Among those associated with crumb rubber infill, only those analytes found in at least seven locations were retained for this evaluation.

For the Thomas Jefferson Field, the analytes used in the evaluation were 1-ethyl-4-methyl-benzene, decane, nonanal, nonane, and undecane. For the horizontal profile, a linear regression was conducted on the concentrations at the three foot height collection site. The f-statistic for the slope was not significant (α=0.05) for any of the analytes evaluated. An evaluation of the vertical profile was conducted at the downwind location, since this location consistently reported a result for the five analytes evaluated. The f-statistic for the slope was not significant for any of the analytes evaluated**.** Finally, the upwind concentrations for these analytes were compared with the concentrations obtained on-field and downwind. Analysis results, using a Wilcoxon two-sample test indicates no difference ($p>0.05$) in upwind and on-field measurements for these analytes.

For the John Mullaly Field, the analytes used in the evaluation were 2-methyl-butane, ethyl-cyclohexane, nonane, octane, and undecane. The f-statistic for the slope was not significant (α=0.05) for any of the analytes evaluated in the horizontal profile linear regression analysis at locations three feet above the surface. The f-statistic for the

slope was significant (α=0.05) for two analytes (nonane and octane) in the vertical profile analysis. A linear regression was conducted on the vertical profile for these two analytes in samples collected at the center of the field. The f-statistic for the slope at this location for these two analytes was not significant. Finally, the upwind concentrations for these analytes were compared with the concentrations obtained on-field and downwind. Analysis results, using a Wilcoxon two-sample test indicates no difference ($p>0.05$) in upwind and on-field measurements for these analytes.

7.6.2 Wipe/Microvacuum Samples and Synthetic Grass Analysis:

A full copy of the report detailing the results for this analysis can be found in Appendix F8. A summary is presented below.

Blanks: All blanks were characterized as clean and free of particulate.

Duplicate Samples: Duplicate samples consistently matched in collection efficiency.

Particle size and composition: Particle analysis for the wipe and microvacuum samples for both fields revealed a bi-modal distribution of the material collected. Both very large (mm size) and very small particles (micron size) were observed. The large particles were rubber, grass, and cord material. The very small particles were primarily crustal minerals (quartz and calcite) and biologicals (plant material such as pollen or mold). Rubber dust was not found in the smaller particle size range. The large particles were in the several mm range, while the small ones averaged about 5-7 microns. Reported size distributions for the small ones were based on a minimum of 50 particles. In most cases it was difficult for the microscopist to find the minimum of 50 particles. The number of particles available for large particle counting was dependant on the individual filter.

Microvacuum filter particle size analysis of the large (mm size) and small particles (micron size) at the Thomas Jefferson Field revealed that in both cases,

site F1 (the center of the field) had the largest particles, followed by F2 (Northwestern corner of field) and the smallest was F3 (the Southern edge of field).

Microvacuum filter particle size analysis of the large particles (mm size) at the John Mullaly Field revealed that the largest particles were collected at site F2 (Northeastern side of field), followed by F3 (Southern edge of field), and the smallest were observed at F1 (center of the field).

Microvacuum filter particle size analysis of the smaller particles (micron size) at the John Mullaly Field revealed that the largest of the small particles (micron size) were collected at F3 (Southern edge of field), followed by F1 center of the field, and the smallest were observed at F2 (Northeastern side of field).

Synthetic grass: FTIR analysis on the synthetic grass from both fields identifies the fibers as Olefin. Most of the grass fibers were green with a few black fibers contained in the sample. Grass blades varied but were approximately 1 mm in width.

7.6.3 Ambient PM_{10} and $PM_{2.5}$ Monitoring

The results of the particulate matter monitoring conducted at the Thomas Jefferson field can be found in Appendix F9. The results for the particulate matter monitoring conducted at the John Mullaly field can be found in Appendix F10. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for the data evaluation conducted by NYSDOH.

7.7 Conclusions

7.7.1 VOC and SVOC:

An air sampling method was used that allowed for identification of analytes in the nanogram range. Additionally, the laboratory evaluating the samples was asked to

provide results for analytes detected in the crumb rubber off-gassing analysis and to provide results for tentatively identified compounds. With this approach, intended to look for low level concentrations and analytes not previously reported, few analytes were detected and no clear cumulative impact across the horizontal or vertical profile of sampling locations was observed. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in the urban environment. A number of analytes detected at low concentrations have also been found in previous studies (Mattina 2007, NYCDOHMH 2008b) evaluating crumb rubber (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

Although ambient air temperatures during sampling at the Thomas Jefferson field were slightly lower (77.2ºF) than the goal of 80°F, RTP recorded fairly high surface temperatures (118ºF- 146ºF) throughout sampling. Additionally, the types of analytes detected and range of concentrations were similar for this field as compared to the results for the John Mullaly field which was sampled during an ambient temperature of 84.2ºF.

Overall, this study design was sufficient to evaluate chemical releases from these two fields. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

7.7.2 Particulate Matter (Surface Wipe, Microvacuum and Ambient PM_{10} and $PM_{2.5}$ Monitoring):

Rubber dust was not found in the respirable range (particles in the micron size diameter range which are able to travel deeply into the respiratory tract, reaching the lungs) through aggressive surface sampling methods (vacuuming of the surface) and by wipe sampling. The respirable particles identified in these samples are primarily crustal or biological in nature. Additionally, the particulate matter sampling ($PM_{2.5}$ and PM_{10}) did not reveal meaningful differences in concentration between the results for the samples collected upwind and those on the field (for the John Mullaly field). This may be explained by the lack of rubber dust found in the smaller size fraction (micron diameter range). See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

7.8 Limitations

7.8.1 Ambient Air Samples:

The results of this survey are only applicable to fields constructed in the same fashion and with the same type of crumb rubber as those in this study. The results of this survey are not applicable to fields constructed with other types of infill material, nor are they applicable to indoor fields. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional limitations reported by NYSDOH.

7.8.2 Ambient PM_{10} and $PM_{2.5}$ Monitoring:

Although fields of different ages were sampled to potentially provide information concerning the relationship between age of the field and PM levels measured above the field, other factors, such as field use and condition, may also influence PM concentrations above synthetic turf fields. An evaluation of these other factors was not conducted. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional limitations reported by NYSDOH.

8. Assessment of Air Quality Monitoring Survey Data

The objectives of this assessment were to estimate potential health risks associated with chemical-specific ambient air concentrations measured at the Thomas Jefferson and John Mullaly Fields, and to evaluate the measured particulate matter (PM) concentrations to determine if the fields are a potential source of PM exposure. This section describes the methods used to evaluate the data, the results of the evaluation and limitations of the assessment.

8.1 Volatile and Semi-volatile Organic Chemicals

8.1.1 Data Evaluated

Laboratory analytical results were reported for volatile organic chemicals (VOCs) in 11 air samples and semi-volatile organic chemicals (SVOCs) in 12 air samples, collected at each of the two playing fields. A list of the 140 target chemicals is provided in Appendix F4. The data include results for samples from upwind, on-field and downwind locations, as well as results for laboratory blank samples and field blank samples. The blank sample results help to identify chemicals that may be associated with the laboratory (*e.g.*, common laboratory contaminants) and those that may be associated with the transportation and handling of the samples or with the air sampling equipment. The analytical laboratory also reported estimated concentrations for chemicals that were not on the target chemical list. These chemicals are referred to as "tentatively identified compounds" or TICs. Because the analytical laboratory was not specifically testing for these chemicals, there is some uncertainty as to the precise identity of each TIC. For each TIC, the laboratory reported a "match quality percent" reflecting the extent to which (as estimated by the laboratory computer) the analytical spectrum ("fingerprint") for the chemical in the sample matched a standard reference spectrum. All of the results from the analytical laboratory are provided in Appendix F6 for the Thomas Jefferson field and Appendix F7 for the John Mullaly field. DEC staff performed a quality assurance/quality control review of the data and found it to be acceptable (see Appendix F5).

The analytical laboratory reported data for all chemicals on the target chemical list. Because the reported concentrations for each target chemical are based on comparisons to laboratory standards for that chemical, there is a high level of confidence in the chemical identity and the concentrations reported. The analytical laboratory did not report data for all of the TICs. Only the 20 TICs with the largest chromatographic peaks (*i.e.*, highest estimated concentration) were reported for each sample. The absence of a TIC in a sample does not mean that it was not present, only that it was not among the 20 largest peaks that were reported. However, because neither the identity nor the reported concentrations for TICs are based on comparisons to authentic laboratory standards, there is a lower level of confidence in both the identities and the reported concentrations of TICs than for the target chemicals.

8.1.2 Selecting Chemicals of Potential Concern

This evaluation began by identifying all target chemicals with detectable concentrations for any sample and all TICs for which an estimated concentration value was reported for at least one on-field or downwind sample. Criteria, listed below were applied to focus the health risk evaluation on those chemicals most likely to be associated with the playing fields.

- Chemicals identified in field and laboratory blanks that did not meet the criteria described in the US Environmental Protection Agency's (US EPA) Superfund guidance were eliminated from further evaluation (US EPA, 1989). That guidance indicates that sample results should only be considered positive if concentrations exceed ten-times the concentration of a common laboratory contaminant in a blank, or five-times the concentration of a chemical that is not considered a common laboratory contaminant.

- Chemicals with on-field and downwind concentrations that were not at least 35 percent higher than the concentration in the corresponding upwind sample were

eliminated from further evaluation.[1] If the upwind measurement was reported as not detected, results for on-field and downwind samples were retained.

- TICs that met the previous criterion, but which had a match quality below 85 percent for all samples, were eliminated from further evaluation (US EPA, 1999b).[2]

For TICs that did not meet the 85 percent match quality criterion, the New York City Department of Health and Mental Hygiene report (NYCDOHMH, 2008b) was reviewed to determine if any should be included as a chemical of potential concern because the chemical has been associated with tire rubber or crumb rubber. No additional TICs were included based on this review.

Table 8.1 (Thomas Jefferson Field) and Table 8.2 (John Mullaly Field) summarize the monitoring results for detected target chemicals and TICs. These tables show the reported levels of all target chemicals that were detected in at least one of the samples on each field (27 chemicals for the John Mullaly Field and 21 chemicals for the Thomas Jefferson Field). The tables also show the TICs that were reported for each field, excluding those did not meet the laboratory/field blank criterion described above. Table 8.3 provides a list of the TICs that were present in the blanks (no target chemicals were reported as being detected in the blanks). The majority of target chemicals were not detected in the samples collected at either field.

Tables 8.4 (Thomas Jefferson Field) and 8.5 (John Mullaly Field) present the final list of chemicals that were selected, based on the criteria listed above, for the health risk evaluation.

The chemicals listed in the tables (beginning with Table 8.4) were separated into four categories:

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1 The threshold value of 35 percent (%) was selected based on an analysis of the distribution of percent differences among target compound concentrations reported for paired (co-located) air samples. That review indicated that percent differences among paired samples ranged from 0% to 181%, with a mean of 35%.

- Chemicals detected in the field survey that were also detected in the DEC laboratory off-gassing study.
- Chemicals on the target analyte list detected in the field survey that were not included in the DEC laboratory off-gassing study.
- Chemicals detected in the field survey that were reported as non-detects in the DEC laboratory off-gassing study.
- Chemicals that were detected in the fields survey as TICs.

8.1.3 Approach for Identifying Health-based Inhalation Comparison Values

Chemicals associated with crumb-rubber infilled synthetic turf have the potential to cause non-cancer and (for some chemicals) cancer health effects. Therefore, non-cancer and cancer toxicity values were used to evaluate potential health risks from inhalation exposures. The toxicity value used to evaluate non-cancer effects is the reference concentration, which, as defined by US EPA (2002), is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups such as children) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure (US EPA, 2002). The toxicity value used to evaluate cancer effects is the chemical concentration in air that is associated with an estimated excess lifetime human cancer risk of one per one-million people (1×10^{-6}). This value is often referred to as the one-in-one-million (or 1×10^{-6}) air concentration. Both kinds of toxicity values are usually used to evaluate continuous, long-term (*e.g.*, lifetime) exposures. Possible chemical exposures that people may have at synthetic turf fields will not be continuous and will be of relatively short duration for any given event. Long-term ("chronic") toxicity values were used to evaluate possible exposures because these values will either be lower than or the same as values that would be used to evaluate shorter-term exposures.

[2] The US EPA recommends that any chemical with a "match quality percent" less than 85 percent be treated as an "unknown" chemical (US EPA, 1999).

Toxicity values for some of the chemicals identified in the previous section have been derived by state, national or international regulatory or advisory public health organizations. An evaluation of these toxicity values and selected reference concentrations and a 1 x 10^{-6} air concentrations for use in this analysis was conducted. These chemical-specific toxicity values and the sources of the values are shown in Table 8.6.

For chemicals without an existing reference concentration or a 1 x 10^{-6} air concentration, each chemical was placed into a chemical class based on its chemical structure, and a surrogate chemical (with a toxicity value) was identified in that class sharing a similar chemical structure. The chemical classes, surrogate chemicals, and toxicity values for these chemicals are shown in Table 8.6.

8.1.4 Approach for Evaluating Potential Non-cancer and Cancer Risks

An evaluation of possible health risks was conducted by comparing the measured air concentrations to the toxicity value(s) for each chemical. To evaluate potential non-cancer effects, a "hazard quotient" was calculated by dividing the measured air concentration by the reference concentration. A hazard quotient that is equal to or less than one is generally not considered to be a significant public health concern. If the measured air concentration of a chemical exceeds the reference concentration, there may be concern for potential non-cancer health effects. Generally, the greater hazard quotient, the greater the level of concern.

To evaluate potential cancer risks, cancer risk estimates were calculated using the measured air concentrations and the 1 x 10^{-6} air concentration as shown in the following equation:

$$\text{estimated risk level} = \frac{(\text{measured air concentration } (\mu g/m^3)) \times (1 \times 10^{-6})}{1 \times 10^{-6} \text{ air concentration } (\mu g/m^3)}$$

($\mu g/m^3$ = micrograms of chemical per cubic meter of air)

There is general consensus in the scientific and regulatory communities that an increased lifetime cancer risk of one per one-million (10^{-6}) or less is not a significant public health concern and that an increased cancer risk level of greater than one per ten-thousand (10^{-4}) may warrant measures to reduce the risk (*e.g.*, exposure reduction measures). Risk levels that fall between 10^{-4} and 10^{-6} usually warrant further evaluation (*e.g.*, the actual potential for exposure, "background" exposure, and the strength of the toxicological data), with the need for risk reduction measures depending on where in that range the risk estimate falls. There usually is greater concern for risk estimates close to 10^{-4} than for estimates close to 10^{-6}.

8.1.5 Results and Discussion

The results of this evaluation of potential non-cancer risks are shown in Table 8.7 (Thomas Jefferson Field) and Table 8.9 (John Mullaly Field). As shown in these tables, the hazard quotients for all chemicals (target chemicals and TICs) at all sampling locations are below (and in most cases well-below) a value of one. This means that none of the measured concentrations exceed the reference concentrations that were used to evaluate non-cancer health risks. The highest hazard quotients ranged from 0.2 to 0.6 for 1,3-pentadiene, (E)-1,3-pentadiene and 1,4 pentadiene on the Thomas Jefferson Field and from 0.1 to 0.3 for 2-methyl-1,3-butadiene and 1,3-pentadiene on the John Mullaly Field. All of these chemicals are TICs and, as the tables show, there is no consistent pattern in the measurements of these chemicals on the fields. These results do not indicate a public heath concern for non-cancer effects.

The results of the evaluation of potential cancer risks are shown in Table 8.8 (Thomas Jefferson Field) and Table 8.10 (John Mullaly Field). At the Thomas Jefferson Field, the only target chemical with an estimated cancer risk greater than one-in-one-million (10^{-6}) is benzene, and the estimated risks for the on-field samples are essentially no different than the estimated cancer risk for the upwind sample. At the same field, the measured concentrations of the three TICs (1,3-pentadiene, (E)-1,3-pentadiene and 1,4-pentadiene) correspond to estimated cancer risks that range from two-to-four in one hundred thousand (2×10^{-5} to 4×10^{-5}). For 1,3-pentadiene, the cancer risk estimate for

the upwind sample is 2 x 10^{-5}, which is not substantially different than the risk estimates for the on-field samples. (E)-1,3-pentadiene and 1,4-pentadiene were reported in only one of eight of the downwind samples, both of which were collected off of the field. This suggests that the athletic field may not have been the source of these chemicals in air. At the John Mullaly Field, the estimated cancer risks for methylene chloride and chloroform (both of which are target chemicals) are less than 10^{-6}. At the same field, the measured concentrations of the two TICs (2-methyl-1,3-butadiene and 1,3-pentadiene) correspond to estimated cancer risks that range from 8 x 10^{-6} to 2 x 10^{-5}. For 1,3-pentadiene, the estimated cancer risks at the on-field/downwind concentrations are the same as for the upwind concentration at the Thomas Jefferson Field (2 x 10^{-5}). 2-Methyl-1,3-butadiene was only reported in one of the eight downwind samples and the estimated cancer risk for the measured concentration is 8 x 10^{-6}. There is no consistent pattern in the measurements of any of the TICs at either field. These results, combined with the consideration that any exposures at the fields will neither be continuous nor of lifetime duration, do not indicate a public heath concern for cancer effects.

8.2 Particulate Matter (PM)

8.2.1 Data Evaluated

The survey data also included real-time air monitoring results for $PM_{2.5}$ (particulate matter with an aerodynamic diameter of *2.5* microns (μm) or less) and PM_{10} (particulate matter with an aerodynamic diameter of *10* μm or less) at each playing field. Particulate matter was measured at upwind and downwind locations at both fields using DataRAM particle monitors.

At each field, both monitors were initially placed side-by-side for a period of time at the upwind location to obtain a baseline comparison of their responses. After the baseline monitoring period was complete, one of the monitors (referred to as the downwind monitor) was moved to downwind (on-field) monitoring locations.

Both $PM_{2.5}$ and PM_{10} were measured using the same monitors but with different inlet size cutoff devices to measure the two different size fractions. Particulate matter measurements were averaged over one-minute intervals and the monitoring duration at each downwind location was approximately ten minutes. At the Thomas Jefferson Field, $PM_{2.5}$ and PM_{10} were alternately measured at each location. At the John Mullaly Field, all $PM_{2.5}$ measurements were completed prior to measuring PM_{10}. At both fields, sampling staff simulated play with a soccer ball during the monitoring period.

All of the PM monitoring data are available in Appendix F8 for Thomas Jefferson field and Appendix F9 for John Mullaly field.

8.2.2 Approach for Evaluating PM Data

The PM data evaluated consisted of upwind and downwind measurements of $PM_{2.5}$ and PM_{10} at both athletic fields. The real-time instruments used in this study (DataRAMs) differ from the instruments used for air quality monitoring for compliance with the National Ambient Air Quality Standards (NAAQS). Therefore, comparisons between the PM monitoring results in this study and the NAAQS for particulate matter are not appropriate.

To evaluate these data graphs were prepared shown in Figures 8.1-8.3. These figures show the results of the initial baseline (side-by-side) monitoring and the upwind/downwind monitoring. The concurrent side-by-side PM concentrations were evaluated to determine whether the monitors responded similarly to local PM. Additionally, the upwind/downwind concentrations were evaluated to determine if there are meaningful differences in upwind vs. downwind PM measurements.

8.2.3 Results and Discussion

Thomas Jefferson Field

The PM data for Thomas Jefferson Field are shown in Figure 8.1. Examination of this figure shows that the two monitoring instruments differed in their response to PM concentrations during the initial side-by-side upwind monitoring of PM_{10}. Given the short duration of this side-by-side monitoring, an assessment on how the responses of the instruments might or might not vary over time could not be reliably conducted. Therefore, the response variability between the two monitors in evaluating the upwind/downwind results could not be explained. The high initial PM_{10} concentrations for both monitors may have been a result of initial instability in monitor response or because of interaction with the monitors by field staff (*e.g.*, field staff activity in the vicinity of the monitor). For the remaining five minutes in the side-by-side monitoring period, the PM_{10} concentrations measured with the downwind monitor were about two to three micrograms per cubic meter higher than the concentrations measured with the upwind monitor. Initial side-by-side $PM_{2.5}$ monitoring was not conducted at this field.

A notable observation about the sampling results is that $PM_{2.5}$ concentrations sometimes appear to be higher than PM_{10} concentrations, even though the samples were collected minutes apart. Since the PM_{10} size fraction includes $PM_{2.5}$, PM_{10} measurements would generally be expected to be higher than $PM_{2.5}$. Additionally, the PM sampling method at this field involved switching the sample inlet heads for each of the two size fractions monitored. For example, when samples were collected in the center of the field, PM_{10} was measured first (for about 10 minutes) and then the inlet head was changed and $PM_{2.5}$ was measured at the same location. Based on NYSDOH staff experience with this kind of monitor, physical interaction of field staff with the monitors (*e.g.,* changing inlet heads and moving monitors) can result in spikes in the data. In some instances, it appears that the inlet change may have affected the measured PM concentrations, but this was not always the same in both monitors. There may also have been synchronization issues involved in changing the inlets on the two monitors (*i.e.*, the inlet head on one monitor may have been changed at a slightly different time than on the other monitor) that may also account for peaks at the beginning and end of some of the monitoring periods, as observed at times 17:09 and 17:48 in Figure 8.1. Given the similarity in PM concentrations measured by the two monitors and the short duration of monitoring

periods, it is difficult to determine whether the differences in the measurements were due to actual differences PM concentrations or to perturbations in operation of the instruments. The results shown in Figure 8.1 do not show consistent differences between the upwind and downwind results for either $PM_{2.5}$ or PM_{10}, although the data suggest that the downwind levels of $PM_{2.5}$ may have been somewhat higher than upwind levels while activity was occurring on the field. Also, downwind PM_{10} levels appear to be somewhat higher than upwind levels after activity ended. However, for the reasons described above it has been concluded that these data are inadequate for reliably evaluating differences between upwind and downwind measurements.

John Mullaly Field

The PM data for the John Mullaly Field are shown in Figures 8.2 and 8.3. Figure 8.2 shows the results of the initial side-by-side $PM_{2.5}$ monitoring that was conducted for almost 90 minutes. Generally, the two monitors responded similarly, although the $PM_{2.5}$ concentrations measured by the upwind monitor were slightly higher than the concentrations measured by the downwind monitor. The differences (upwind result minus downwind result) ranged from –2 to 5.9 $\mu g/m^3$ with a median value of 1.4 $\mu g/m^3$. No initial side-by-side PM_{10} monitoring was conducted at this field.

Figure 8.3 shows the measured PM levels during on-field deployment. The $PM_{2.5}$ concentrations measured by the upwind monitor were always higher than the concentrations measured by the downwind monitor. The difference in the concentrations ranged from 1 to 6 $\mu g/m^3$. There were only 5 out of 40 data points in the PM_{10} data where the concentrations measured by the downwind monitor exceeded the concentrations measured by the upwind monitor. The difference in the concentrations for these five measurements was always less than 2 $\mu g/m^3$, and on average the measurements at the upwind monitor were higher than at the downwind monitor. While no initial side-by-side PM_{10} monitoring was performed, the differences in the five measurements are within the variability seen during the $PM_{2.5}$ side by side monitoring. Based on these data, there is no indication of meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$ at the John Mullaly Field.

8.3 Air Quality Monitoring Survey Conclusions

The measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields. Although the particulate matter data for the Thomas Jefferson Field were found to be inadequate for evaluation, data from the John Mullaly Field do not show meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$.

8.4 Air Quality Monitoring Survey Limitations

The results of this survey do not identify a public health concern for the levels of chemicals or particulate matter measured at the two turf fields. While the survey was designed to collect data under conditions representative of "worst case" conditions (*e.g.*, summer-time temperatures that should maximize off-gassing of chemicals), samples collected under different conditions, using different methods or at different fields could yield different results. For example, concentration measurements may be different for fields of other ages or designs (*e.g.*, different volumes of crumb rubber infill, non-crumb rubber infill) or for indoor fields.

9. Temperature Survey

9.1 Objectives and Design

The temperature survey was performed to gain a better understanding of the surface temperature of synthetic turf fields and the potential for field users to suffer from heat-related illness ("heat stress"). The indicators of heat stress used in this survey are the wet bulb globe temperature and heat index. These indicators and surface temperature were measured above the surface of the synthetic turf and as comparison these measurements were made above a nearby grass and sand surface. The initial objective of the survey was to capture a range of surface temperatures and above surface heat stress indicator measurements throughout changing ambient summer temperatures and humidity levels.

Synthetic turf fields absorb solar radiation; therefore, the field measurements were conducted in areas that are subject to direct solar radiation. Discrete temperature measurements over these surfaces were conducted at short-time intervals as opposed to a continuous evaluation over time. Measurements were generally made from, noon to 2:00 PM, which other studies identified as the time of day with the highest surface temperatures (DeVitt et al. 2007, Williams 1991).

Surface temperatures were measured using an infrared thermometer. The potential for heat stress was assessed by measuring the wet bulb globe temperature (WBGT) since the American Academy of Pediatrics (AAP) has issued a policy statement addressing heat stress and exercising children and adolescents based on this index (AAP 2000). The AAP uses the WBGT since it can be measured in the field and incorporates factors (i.e., radiant heat, humidity, wind and temperature) that influence heat illness for an individual. The WBGT was compared to the AAP guidance on heat stress for exercising children and adolescents to assess the potential for heat stress. The National Federation of State High School Associations also recommends the use of the WBGT to assess potential heat stress during sports participation (NFSHSA 2001).

9.2 Measurements and Collection Methods

9.2.1 Measurement Locations and Protocol

Because the surface temperature of synthetic turf is dependent on the amount of sunlight received, the edge of the field should have cooler temperatures due to shade cover from nearby trees, while the center should have warmer temperatures because it was subject to full sun. Therefore, for each field in this study, the center and a shaded edge area were selected for measurements and both areas were comprised of green-colored synthetic grass. For the Thomas Jefferson field, an additional center location was selected consisting of white synthetic grass.

Measurements on each synthetic turf field were immediately followed by measurements on a nearby grass area and sand surface of a baseball field – both areas in full sun. All parameters recorded on the synthetic turf fields were recorded for the nearby comparison areas.

To account for instrument variability and rapid changes in cloud cover, three sequential measurements per area were obtained.

The Field Measurement Protocol – Temperature and Heat Stress (attached as Appendix H1) provides details for the collection of field measurements. As stated in the Protocol, if weather conditions changed between the synthetic turf and comparison area measurements, the synthetic turf would be re-measured to obtain field measurements under similar conditions for all areas. During actual field measurements, the cloud cover changed fairly rapidly, albeit subtly, making it difficult for field staff to obtain measurements under identical conditions for the different areas (synthetic turf versus comparison areas).

9.2.2 Instrumentation for Collection of Surface Temperature and Heat Stress Measurements

Surface temperature was recorded using an infrared thermometer (DeltaTrak Thermo Trace, Model #15006). Wet bulb globe temperature was recorded using a thermal environmental and heat stress monitor (Quest Technologies QUESTemp°36). The temperatures used to calculate WBGT (wet bulb (WB), dry bulb (T), and globe (G)) and the relative humidity were also recorded. The instrument reports the wet bulb globe temperature based on the following formula: WBGT = 0.7 WB + 0.2 G + 0.1 T. WB is a

measure of evaporative cooling and integrates the effects of wind, humidity and radiant heat. In the presence of solar radiation, G integrates the effects of radiant heat, wind and air temperature. T is the ambient air temperature.

The heat index (HI), another indicator of potential heat stress, was calculated from the dry bulb temperature and relative humidity[3] (NOAA 2009). The WBGT instrument also has the capability of recording wind speed but during field deployment the instrument malfunctioned and this value was not recorded. General meteorological observations such as cloud cover and qualitative information about field conditions such as whether or not the grass was recently watered or cut also were recorded.

9.2.3 Measurement Dates

Field measurements were conducted in August (11 days) and September (6 days). Meteorological data from the New York City Central Park monitor for the years 2000 – 2007 were used to derive a historical profile of average, and 50^{th} and 90^{th} percentile temperature and relative humidity values for each of the two months. Information on daily maximum temperature, and daily minimum relative humidity and rain events for the dates of sampling from this data source also was obtained. A goal of the study was to conduct field measurements representative of high ambient conditions, therefore field temperatures were measured when the ambient temperature was above the 90^{th} percentile and relative humidity was expected to be above the 50^{th} percentile based on historical data. A second target scenario to capture field measurements was during average temperature conditions for the month.

9.3 Data Review Procedures

The three sequential measurements per area were averaged together. The heat index was calculated from dry bulb temperature and relative humidity. The WBGT index was calculated from the individual measures to verify instrument reporting of this value.

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[3] The formula for heat index is: $-42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783x10^{-3}T^2 - 5.481717x10^{-2}R^2 + 1.22874x10^{-3}T^2R + 8.5282x10^{-4}TR^2 - 1.99x10^{-6}T^2R^2$, where T = ambient dry bulb temperature degrees Fahrenheit and R = relative humidity

Meteorological data from a monitor in Central Park were used to determine whether the measurement dates were representative of high ambient conditions and average scenario goals stated previously[4]. Daily maximum temperature and minimum relative humidity data, summarized for the years 2000-2007, were used to evaluate the conditions on the dates of the field measurements.

9.4 Analysis Methods

A graphical display was used to facilitate comparisons of the surface temperature measurements between the synthetic turf and comparison locations. Tests for normality and autocorrelation were conducted and the appropriate statistical comparison was performed. Coefficient of variation was calculated to facilitate comparison between surface and ambient temperature. In the absence of a formal established peer-reviewed guideline value, the surface temperature measurements were compared to a guideline value issued by Brigham Young University (BYU). BYU has set a surface temperature guideline of 120°F (Williams, 2002) as the limit for conducting activities on synthetic turf fields. The BYU Safety Office based this value on studies relating temperature to skin damage and not on data related to synthetic turf fields and potential injury (Ed Jackson BYU Safety Office, personal communication, 12/16/08).

The WBGT indicator of heat stress was compared with the AAP guidelines (AAP, 2000) which are shown in Table 9.1. Additionally, the HI was compared with guidelines issued by the National Weather Service (NWS 2005). The NWS has developed a set of guidelines to warn people about conditions that may lead to heat stress at various HI levels and employs alert procedures when the HI is expected to exceed 105°F. Tests for normality and autocorrelation were conducted and statistical tests were performed to compare surface temperatures and the indicators of heat stress for the different surfaces.

[4] Comparison data for 2008 from the Central Park monitor were only available in summary format of daily average, minimum and maximum values for temperature and relative humidity and total daily rainfall. Since field measurements were taken a warm part of the day (40% of the measurements were taken at 1:00 PM), it was recommended (John Kent, Air Pollution Meteorologist, NYSDEC, personal communication 11/21/08) to use the daily maximum for temperature and minimum relative humidity to best represent the actual field measurement conditions.

The rain event data was reviewed and was found not to be useful for examining the effects of field watering on surface temperature, and humidity and indicators of heat stress measurements.

9.5 Results and Discussion

General meteorological and environmental observations were recorded by field staff during each site visit. On many occasions, field staff noted a rapid decline in surface temperature when incident solar radiation was interrupted by cloud cover and the opposite, a rise in temperature when cloud cover passed. All field measurements were collected within a short period of time. For the Thomas Jefferson field, all measurements were collected within 41 minutes, on average. For the John Mullaly field, all measurements were collected within 26 minutes, on average. A summary of all parameters measured for the Thomas Jefferson field can be found in Appendix H2 and for the John Mullaly field in Appendix H3.

9.5.1 Meteorological Data

Table 9.2 shows the average, range 50th and 90th percentiles of daily maximum temperature and daily minimum relative humidity for 2000-2007 and the dates of field measurements. The average daily maximum ambient temperatures during the dates of field measurements are nearly identical to the average daily maximum 2000-2007 temperatures. The minimum daily relative humidity profile appears to be lower for the dates of measurements as compared to previous years. Measurements greater than or equal to the 90th percentile (for the summarized years of 2000-2007) of daily maximum temperature for the month of August were not obtained, although this goal was achieved for the month of September. Overall, the goal of capturing measurements during typical August and September days was met based on daily maximum temperature but the daily minimum relative humidity measurements are lower than previous years.

9.5.2 Surface Temperatures

Thomas Jefferson Field

Figure 9.1 illustrates the surface temperatures for measurement dates at all five locations (three on synthetic turf and two comparison areas) for the Thomas Jefferson field. The graph shows that the surface temperatures of the synthetic turf were typically higher and were more variable than the surface temperatures of the comparison areas. In general, the surface temperatures in September are lower than the surface temperatures in August (on average, eight degrees lower for green sections). The figure also shows the BYU guideline temperature. At least one location on the turf field was above 120°F guideline for 12 out of 17 dates of measurements (70%), while the comparison areas never exceeded 110°F.

The dry-bulb temperatures (recorded with the QUESTemp°36 monitor at a 3ft height) at all locations on the synthetic turf field, grass and sand was compared with the temperatures obtained from the nearest meteorological station, located in Central Park. On average, all values were within 1 % (Central Park data not shown, dry-bulb measures from the field can be found in Appendix H2) of each other as demonstrated by comparison ratios, with maximum differences of approximately 8.0%. This evaluation reveals little difference between the ambient temperatures above these surfaces and the nearest meteorological station. This comparison also indicates little difference in dry-bulb temperature above the synthetic turf field versus the comparison areas. The ambient temperature obtained from the measurements over the center green section of the synthetic turf is displayed in Figure 9.1.

The coefficient of variation (CV) was calculated across dates for surface temperatures at the center section and the corresponding ambient temperature measured above that location. The average CV for surface temperature was 0.19, whereas the CV for ambient temperature was 0.074. Because the variability was significantly lower for the dry-bulb temperature above these surfaces, a direct relationship between ambient air temperature and synthetic surface temperature (which is highly variable) cannot be readily inferred from these data.

A summary of the temperature differences between the synthetic turf and grass and synthetic turf and sand is illustrated in Table 9.3. Surface temperatures for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 132, 87, and 86°F, respectively and geometric mean temperatures of 126,

87, and 88°F. The average synthetic turf surface was 42°F higher than the grass surface temperature and 40°F higher than the sand surface temperature. The Durban-Watson test statistic indicates the surface temperature data are not autocorrelated. The mean log-transformed surface temperature for the synthetic turf field was significantly higher ($p<0.0001$) than that of the natural grass and sand using paired Student's t-test. Statistical comparisons between the grass and sand showed little differences ($p>0.10$).

John Mullaly Field

Figure 9.2 illustrates the surface temperatures at all four measurement locations (two synthetic turf, one grass, one sand) along with the BYU guideline value of 120°F. Nine out of 17 dates of measurements (53%) had at least one location on the synthetic turf field above 120°F. Also displayed is the ambient temperature recorded by the dry-bulb thermometer above the synthetic turf field.

The coefficient of variation (CV) was calculated across dates for surface temperatures at the center section and the corresponding ambient temperature measured above that location. The average CV for surface temperature was 0.16, whereas the CV for ambient temperature was 0.085. Because the variability was significantly lower for the dry-bulb temperature above these surfaces, a direct relationship between ambient air temperature and synthetic surface temperature (which is highly variable) cannot be readily inferred from these data.

Comparisons between the synthetic turf, grass and sand surface temperatures for the same day are illustrated in Table 9.4. Surface temperatures for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 119, 80 and 90°F, respectively and geometric mean temperatures of 114, 80, and 89°F. The average synthetic turf surface was 26°F higher than the grass surface temperature and 35°F higher than the sand surface temperature. The Durban-Watson test statistic indicates the surface temperature data are not autocorrelated. The mean log-transformed surface temperature for the synthetic turf field was significantly higher ($p<0.0001$) than that of the natural grass and sand using paired Student's t-test. Statistical comparisons between the grass and sand surface also were statistically different ($p<0.001$).

9.5.3 Heat Stress Indicators

Thomas Jefferson Field

Figure 9.3 shows the results of the WBGT measurements for all locations. Little variability in WBGT values (compared to surface temperature) is noted across the three surface types for each measurement date. Across dates of measurements (inclusive of all surface types), the average CV for WBGT was 0.020, whereas the average CV for surface temperature was 0.21. WBGT measurements for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 76, 78, and 78°F, respectively and geometric mean temperatures of 76, 76, and 76°F. The comparisons of the mean log-transformed WBGT measurement between all surface types (synthetic turf, grass and sand) were not statistically different ($p>0.05$) using paired Student's t-test.

Threshold values that correspond to the AAP guidelines for exercising children are also shown in Figure 9.3. The highest WBGT recorded was 85°F on the synthetic turf. Following the AAP guidelines, a recommendation could have been made to cancel all activities when this heat stress level was reached. For the same date, the WBGT values for the other locations were within in the range of 79 - 84°F. At these levels, the AAP guidelines recommend stopping activities for unacclimatized persons and limiting activities for all other individuals (e.g., disallow long-distance races, reduce amount of time spent exercising). On eight days, the maximum WBGT values for one or more surfaces were also within the range of 79 - 84°F. On three days the maximum WBGT values for one or more surfaces were within the range of 75 - 79°F. At these levels, the AAP guidelines recommend longer rest periods in the shade and an increase in fluid intake. Use of the AAP guidelines could have led to the recommendation of some activity limitation on one or more of the surfaces for 12 of the 17 days of measurements. All the surfaces appear to be similarly impacted and similar recommendations could apply to all surfaces.

The heat index values are reported in Appendix H2. Following guidelines issued by the NWS, approximately 56% of the heat index values (across all measurement locations) are above 80°F and the NWS warns that fatigue is possible with prolonged

exposure and/or physical activities. There was little difference in the HI measurements between the synthetic turf and comparison areas.

John Mullaly Field

Figure 9.4 illustrates the WBGT recorded for John Mullaly Park. The figure shows little variability in WBGT values for each measured date across the three surface types. Across dates of measurements, the average CV for WBGT was 0.020, whereas the average CV for surface temperature was 0.19. WBGT measurements for the synthetic turf field, grass and sand approximated log-normal distributions, with median temperatures of 77, 76, and 76°F, respectively and geometric mean temperatures of 75, 75, and 75°F. The comparisons of the mean log-transformed WBGT measurement between all surface types (synthetic turf, grass and sand) were not statistically different ($p>0.05$) using paired Student's t-test.

Threshold values that correspond to the AAP guidelines for exercising children are also shown in Figure 9.4. The highest WBGT recorded on the synthetic turf was 82°F. For the same date, the WBGT values for the other locations were also within in the range of 79 - 84°F. At these levels, the AAP guidelines recommend stopping activities for unacclimatized persons and limiting activities for all other individuals.

On ten of the 17 days of measurements, the maximum WBGT value for at least one of the surfaces fell within the range of 79 - 84°F. On two days, the maximum WBGT value for all of the surfaces fell within the range of 75 - 79°F. At these levels, the AAP guidelines recommend longer rest periods in the shade and an increase in fluid intake. All of the surfaces had a WBGT that exceeded 75ºF on multiple occasions during the 17 days of measurements.

The heat index values are reported in Appendix H3. Following guidelines issued by the NWS, approximately 65% of the heat index values (across all measurement locations) are above 80°F and the NWS warns that fatigue is possible with prolonged exposure and/or physical activities. There was little difference in the HI measurements between the synthetic turf and comparison areas.

9.6 Conclusions

9.6.1 Surface Temperatures

These results show significantly ($p<0.0001$) higher surface temperatures for both synthetic turf fields compared to the grass and sand surfaces. The average differences between synthetic turf and grass were 42°F and 35°F for the Thomas Jefferson field and John Mullaly field, respectively. The average differences between synthetic turf and sand (measured at a baseball field) were 40°F and 26°F for the Jefferson and Mullaly fields, respectively.

Buskirk et al. (1971) reported that the interior of a shoe can reach high temperatures when in contact with synthetic turf of elevated temperature. However, peer-reviewed studies reporting thermal burns attributable to contact with these types of synthetic turf surfaces were not identified and NYSDEC and NYSDOH staff are not aware of widespread reports of people receiving thermal burns from these surfaces. Staff acknowledge that direct contact with surfaces of elevated temperature has the potential to create discomfort and may cause thermal injury.

9.6.2 Heat Stress

Relatively little difference was found for WBGT levels across the different surface types, however, on any given day; a small difference in WBGT could result in different guidance for the different surface types under the AAP guidelines. Following the AAP guidelines for limitations on activities at different WBGT levels, approximately 70% of the measurement dates at the Thomas Jefferson field and 70% of the measurement dates at the John Mullaly Field could have warranted some type of guidance for exercising children and adolescents for one or more of the surface types evaluated in this survey. The AAP guidelines are shown in Table 9.1.

This survey also found that the calculated heat indices exceeded the level at which the NWS issues advice regarding the potential for heat stress.

The WBGT is one indicator of heat stress and is based on three factors; humidity, solar radiation and ambient temperature. The heat index is based on two factors; relative humidity and ambient temperature. Many other factors (e.g., an individual's activity level and skin resistance to heat transfer) contribute to elevating body temperatures

(Steadman 1979a, Steadman 1979b). Although little difference between heat stress indicator measurements for the synthetic turf, grass, and sand were found, the surface temperatures recorded were much higher for the synthetic turf suggesting a greater potential for heat stress might exist since the body could be in prolonged contact with a surface of elevated temperature. Additionally, high metabolic activity generated during active play, in addition to the heat input from the surfaces, could produce a situation leading to greater potential for heat stress on these surfaces.

9.7 Limitations

Surface temperature measurements were not recorded during the warmest summer month, July (Fisk, 2009) and an evaluation of the environmental conditions (such as presence of shade trees, different field configurations) which may lead to lower surface temperatures was not conducted.

The two common indicators of potential heat stress measured are based on a limited number of factors (e.g., humidity, solar radiation and ambient temperature). But a number of other factors, not assessed in this survey could contribute to heat related-illness. External factors such as contact with a heat source and the amount and type of clothing worn by an individual as well as internal factors including decreased ability to sweat, hydration, lack of acclimatization and less efficient heat dissipation affect the body's ability to maintain a normal range in core temperature. The indicators of heat stress reported in this survey do not include these other factors.

Finally, this survey was not intended to determine the factors contributing to the elevation in surface temperatures for synthetic turf fields. Measurements taken on other synthetic turf surfaces constructed differently or in different locations might yield different findings.

10. Conclusions

10.1 Laboratory Analysis of Crumb Rubber Samples

10.1.1 Laboratory SPLP

The results of this evaluation, using aggressive leaching methods, indicate a potential for release of zinc, aniline, phenol, and benzothiazole. Zinc (solely from truck tires), aniline, and phenol have the potential to be released above groundwater standards or guidance values. No standard or guidance value exists for benzothiazole. It is important to note that this test method may not be representative of actual field conditions, and therefore may result in an overestimate of the release of pollutants under these conditions. Additionally, the results indicate that the leaching potential is dependent on the type of crumb rubber, with truck tires reporting the highest leaching potential.

10.1.2 Laboratory Total Lead Analysis (Acid Digestion Method)

The lead concentration in the crumb rubber samples are below the USEPA's hazard standard for lead in bare soil and below applicable standards used by others evaluating lead concentrations on synthetic turf fields (NYCDOHMH, 2008a). These data indicate that the crumb rubber from which the samples were obtained would not be a significant source of lead exposure if used as infill material in synthetic turf fields.

10.1.3 Laboratory Off-gassing Test

Although the laboratory off-gassing portion of the study proved difficult to conduct quantitatively due to the strong absorptive nature of the crumb rubber samples for VOCs, the results did provide useful information for additional analytes to be included in the laboratory analysis of the ambient air field samples. The five additional analytes were selected for inclusion in the ambient air survey based on the results of the crumb rubber off-gassing study. Three analytes were selected for inclusion in the air survey because of high toxicity (i.e., low reference concentration): aniline (CAS# 62-53-3), 1,2,3-trimethylbenzene (526-73-8), and 1-methylnapthalene (90-12-0). Two analytes

were selected because of high frequency of detects and high relative concentrations found in the off-gassing study: benzothiazole (95-16-9), and tert-butylamine (75-64-9). Finally, it is uncertain what effect the absorptive nature of the crumb rubber, as noted in the laboratory setting, may have in the field setting.

10.2 Laboratory Column Test

The column test procedure was considered to be more representative of field conditions and, as expected, the concentration of all elements of concern were lower than of the concentrations measured in the more aggressive SPLP for the two types of crumb rubber evaluated. Phenol and aniline leachate results were above the groundwater standards and these analytes were included in the surface water and groundwater evaluation.

10.3 Water Quality Survey at Existing Fields

10.3.1 Surface Water Sampling

Only one surface water runoff sample was collected during the study period presented in this report. Based on test results of this sample, no organics were detected and several metals were detected at low levels. One sample is not sufficient to draw a conclusion, so additional analyses will be performed in 2009 and presented in a separate report.

10.3.2 Groundwater Sampling

Thirty-two samples of groundwater were collected during the study period presented in this report. Based on test results of these samples, no organics or zinc were detected. The NYSDEC will perform additional sampling of groundwater at sites with shallower groundwater levels in 2009 to better represent potential impacts and will present test results in a separate report.

10.4 Potential Groundwater Impacts

The dilution-attenuation factor (DAF) from the NYSDEC's soil cleanup guidance for hazardous remediation sites was applied and demonstrates that crumb rubber may be used as an infill without significant impact on groundwater quality.

10.5 Potential Surface Water Impacts

A risk assessment for aquatic life protection was performed and found that crumb rubber derived entirely from truck tires may have an impact on aquatic life based on the impacts that zinc may have on aquatic life pathway. For the crumb rubber made from mixed tires, the potential impacts are insignificant.

10.6 Air Quality Monitoring Survey at Existing Fields

10.6.1 VOC and SVOC Conclusions

An air sampling approach, intended to look for low level concentrations was used and few detected analytes were found with no clear cumulative impact across the horizontal or vertical profile of sampling locations. Many of the analytes detected (e.g., benzene, 1,2,4-trimethylbenzene, ethyl benzene, carbon tetrachloride) are commonly found in the urban environment. At low concentrations a number of analytes were detected that have been found in previous studies evaluating crumb rubber (e.g., 4-methyl-2-pentanone, benzothiazole, alkane chains (C4-C11)).

The types of analytes detected and range of concentrations were similar at both fields, even though surface and ambient temperatures differed at the time of sampling.

See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

10.6.2 Particulate Matter

Rubber dust was not identified in the respirable range (particles in the micron size diameter range which are able to travel deeply into the respiratory tract, reaching the lungs) through aggressive sampling methods (vacuuming of the surface) and by wipe sampling. The small size particles identified were primarily crustal or biological in

nature. See Section 8, "Assessment of Air Quality Monitoring Survey Data" for additional conclusions reported by NYSDOH.

10.7 Assessment of Air Quality Monitoring Survey Data

The measured levels of chemicals in air at the Thomas Jefferson and John Mullaly fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields. Although the particulate matter data for the Thomas Jefferson Field were found to be inadequate for evaluation, data from the John Mullaly Field do not show meaningful differences between upwind and downwind levels of either PM_{10} or $PM_{2.5}$. Therefore, these synthetic turf fields are not important contributors of exposure to particulate matter.

10.8 Temperature Survey

10.8.1 Surface Temperatures

The results show significantly ($p<0.0001$) higher surface temperatures for both synthetic turf fields compared to the grass and sand surfaces. The average differences between synthetic turf and grass were 42°F and 35°F for the Thomas Jefferson field and John Mullaly field, respectively. The average differences between synthetic turf and sand (measured at a baseball field) were 40°F and 26°F for the Jefferson and Mullaly fields, respectively.

Although this survey reported significantly high surface temperatures and previous research indicates that the interior of the shoe can reach high temperatures when in contact with synthetic turf of elevated temperature (Buskirk et al. 1971), peer-reviewed studies reporting thermal burns attributable to contact with these types of synthetic turf surfaces were not identified. NYSDEC and NYSDOH staff acknowledge that direct contact with the surfaces of elevated temperature has the potential to create discomfort and may cause thermal injury.

10.8.2 Heat Stress

Relatively little difference for WBGT levels was found across the different surface types, however, on any given day, a small difference in WBGT could result in different guidance for the different surface types under the AAP guidelines. Following the American Academy on Pediatrics (AAP) guidelines for limitations on activities at different WGBTs, approximately 70% of the measurement dates could require some type of advice for exercising children and adolescents for both the synthetic turf and natural grass surfaces.

Although little difference between heat stress indicator measurements for the synthetic turf, grass, and sand were found, the surface temperatures recorded were much higher for the synthetic turf suggesting a greater potential for heat stress might exist since the body could be in prolonged contact with a surface of elevated temperature.

11. Follow-up Actions

11.1 Water Releases from Synthetic Turf Fields

- NYSDEC will perform additional sampling of surface water and groundwater near synthetic turf fields with crumb-rubber infill and present its findings in a separate report.

11.2 Surface Temperature and Heat Stress

- NYSDOH will continue to identify and implement measures to make the public, including users and managers of synthetic turf fields, aware of the following:
  (1) the dangers of heat-related illness,
  (2) symptoms of heat-related illness,
  (3) settings or conditions that increase the risk of heat-related illness, and
  (4) measures that can be taken to reduce the potential for heat-related illness.

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Tables

Table 2.1 Description of Crumb Rubber Samples

Facility Number	Production Rate (Million lbs per month)	Sample Type	Number of Samples
#1	10	Ambient/Truck	7
		Ambient/Car	7
#2	0.5	Ambient/Mixed	5
#3	0.6	Ambient/Mixed	5
#4	3	Cryogenic/Mixed	7

Table 2.2 Summary of SPLP Leaching Test Results for Metals (All 31 Crumb Rubber Samples)

	1st SPLP		2nd SPLP		Groundwater Standard/ Guidance Value, µg/L
	% Detected	Average [a], µg/L	% Detected	Average [a], µg/L	
Detected metals					
Zinc	100	1947.4 ± 419.3	100	1150.1 ± 95.4	2000
Calcium	96.8	2443.5 ± 251.8	29	1736.1 ± 286.3	No Standard
Manganese	77.4	20.7 ± 1.8	22.6	13.9 ± 1.4	300
Barium	19.4	30.4 ± 3.6	3.2	22	1000
Iron	12.9	1704.8 ± 717.8	3.2	105	300
Copper	9.8	296.3 ± 120.7	0	0	200
Lead	9.7	12.8 ± 1.2	0	0	25
Non-detected metals [b]					
Aluminum	0	< 100			
Antimony	0	< 60			
Arsenic	0	< 10			
Beryllium	0	< 5			
Cadmium	0	< 5			
Chromium	0	< 10			
Cobalt	0	< 50			
Magnesium	0	< 1000			
Mercury	0	< 0.2			
Molybdenum	0	< 25			
Nickel	0	< 40			
Potassium	0	< 2000			
Selenium	0	< 10			
Silver	0	< 10			
Sodium	0	< 1000			
Thallium	0	< 10			
Vanadium	0	< 50			

[a] Average ± standard error for detected results only
[b] Not detected at detection limit

Table 2.3 Summary of SPLP Leaching Test Results for SVOCs (All 31 Crumb Rubber Samples)

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (µg/L)
		% Detect	Average[a] (µg/L)	% Detect	Average[a] (µg/L)	
Detected Compounds						
Aniline	62-53-3	100	103.4 ± 15.5	100	62.7 ± 6.4	5
Phenol	108-95-2	100	12.8 ± 1.1	100	4.1 ± 0.6	1
N-Nitrosodiphenylamine	86-30-6	100	3.6 ± 0.3	100	3.3 ± 0.3	50
Isophorone	78-59-1	97	3.6 ± 0.3	45	1.4 ± 0.1	50
4-Methylphenol	106-44-5	94	3.2 ± 0.3	48	1.4 ± 0.2	1
Acetophenone	98-86-2	74	2.3 ± 0.2	19	1.6 ± 0.1	No Standard
Diethyl Phthalate	84-66-2	71	1.7 ± 0.2	39	1.6 ± 0.1	50
Benzoic Acid	65-85-0	29	19.8 ± 5.7	0	0	No Standard
Bis(2-ethylhexyl) Phthalate	117-81-7	28	1.6 ± 0.2	19	1.1 ± 0.1	5
2-Methylphenol	95-48-7	19	1.4 ± 0.2	0	0	1
Naphthalene	91-20-3	16	1.4 ± 0.2	16	1.3 ± 0.1	10
Di-n-butyl Phthalate	84-74-2	6	1.2 ± 0.3	1	1.8	50
Carbazole	86-74-8	6	1.4 ± 0.1	6	1.2 ± 0.1	No Standard
2,4-Dimethylphenol	105-67-9	6	2.6 ± 0.4	0	0	1
Benzyl Alcohol	100-51-6	3	2.8	0	0	No Standard
Non-detected Compounds						
Acenaphthene	83-32-9	0	< 10[b]			
Acenaphthylene	208-96-8	0	< 10			
Anthracene	120-12-7	0	< 10			
Benz(a)anthracene	56-55-3	0	< 10			
Benzo(a)pyrene	50-32-8	0	< 10			
Benzo(b)fluoranthene	205-99-2	0	< 10			
Benzo(g,h,i)perylene	191-24-2	0	< 10			
Benzo(k)fluoranthene	207-08-9	0	< 10			
Butyl Benzyl Phthalate	85-68-7	0	< 10			
Indeno(1,2,3-	193-39-5	0	< 10			

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (μg/L)
		% Detect	Average[a] (μg/L)	% Detect	Average[a] (μg/L)	
cd)pyrene						
4-Chloroaniline	106-47-8	0	< 10			
Bis(2-chloroethoxy)methane	111-91-1	0	< 10			
Bis(2-chloroethyl) Ether	111-44-4	0	< 10			
2-Chloronaphthalene	91-58-7	0	< 10			
2-Chlorophenol	95-57-8	0	< 10			
Bis(1-chloroisopropyl) ether	108-60-1	0	< 10			
Chrysene	218-01-9	0	< 10			
Dibenz(a,h)anthracene	53-70-3	0	< 10			
Dibenzofuran	132-64-9	0	< 10			
1,3-Dichlorobenzene	541-73-1	0	< 10			
1,2-Dichlorobenzene	95-50-1	0	< 10			
1,4-Dichlorobenzene	106-46-7	0	< 10			
3,3'-Dichlorobenzidine	91-94-1	0	< 10			
2,4-Dichlorophenol	120-83-2	0	< 50			
Dimethyl Phthalate	131-11-3	0	< 10			
2,4-Dinitrophenol	51-28-5	0	< 10			
2,4-Dinitrotoluene	121-14-2	0	< 10			
2,6-Dinitrotoluene	606-20-2	0	< 10			
Fluoranthene	206-44-0	0	< 10			
Fluorene	86-73-7	0	< 10			
Hexachlorobenzene	118-74-1	0	< 10			
Hexachlorobutadiene	87-68-3	0	< 10			
Hexachlorocyclo-pentadiene	77-47-4	0	< 10			
Hexachloroethane	67-72-1	0	< 10			
2-Methylnaphthalene	91-57-6	0	< 10			
4,6-Dinitro-2-methylphenol	534-52-1	0	< 50			
4-Chloro-3-methylphenol	59-50-7	0	< 10			
2-Nitroaniline	88-74-4	0	< 50			
3-Nitroaniline	99-09-2	0	< 50			
4-Nitroaniline	100-01-6	0	< 50			
Nitrobenzene	98-95-3	0	< 10			

Analytes	CASRN	1st SPLP		2nd SPLP		Ground-water Standard/ Guidance Value (μg/L)
		% Detect	Average[a] (μg/L)	% Detect	Average[a] (μg/L)	
2-Nitrophenol	88-75-5	0	< 10			
4-Nitrophenol	100-02-7	0	< 10			
N-Nitrosodimethylamine	62-75-9	0	< 10			
Di-n-octyl Phthalate	117-84-0	0	< 10			
Pentachlorophenol (PCP)	87-86-5	0	< 50			
Phenanthrene	85-01-8	0	< 10			
4-Bromophenyl phenyl Ether	101-55-3	0	< 10			
4-Chlorophenyl phenyl Ether	7005-72-3	0	< 10			
N-Nitro0sodi-n-propylamine	621-64-7	0	< 10			
Pyrene	129-00-0	0	< 10			
1,2,4-Tri0chlorobenzene	120-82-1	0	< 10			
2,4,6-Tric0hlorophenol	88-06-2	0	< 10			
2,4,5-Trich0lorophenol	95-95-4	0	< 10			

[a] Average ± SE (standard error) for detected results only

[b] < 10 = Not detected at 10 μg/L detection limit

Table 2.4 TICs Found in SPLP Leaching Test Results (All 31 Crumb Rubber Samples)

Detected Compounds	CAS #	1st SPLP		Groundwater Standard/Guidance Value, µg/L
		% Detected	Average,[a] µg/L	
Benzothiazole	95-16-9	100	526.3 ± 47.6	No Standard
Cyclohexanamine, N-cyclohexyl	101-83-7	100	208.1 ± 37.4	No Standard
Methyl Isobutyl Ketone	108-10-1	100	173.5 ± 24.3	No Standard
2(3H)-Benzothiazolone	934-34-9	100	261.9 ± 11.1	No Standard
Phthalimide	85-41-6	100	108.6 ± 11.3	No Standard
2-Mercaptobenzothiazole	149-30-4	87	52.4 ± 6.9	50
Cyclohexane, isothiocyanato-	1122-82-3	39	129.6 ± 22.9	No Standard
Methane, diethoxy-Cyclohexane	462-95-3	3	330.0	No Standard

[a] Average ± standard error.

Table 3.1 Reagents Used in Column Test

Reagent	Source
Water - ASTM Type I, provided by a Barnstead 18megohm water purification system	Nanopure Infinity
NH_4Cl - USP Grade	Fisher
$CaSO_4$ - ACS Grade	MP Biochemicals
KNO_3 - ACS Grade	Fisher
$NaNO_3$ - ACS Grade	Fisher
$Mg(NO_3)_2$ - ACS Grade	Fisher
Simulated Rainwater (pH 4.2)	Prepared by the method of Serkiz, et. al. 1999 (5)

Table 3.2 Selected SVOCs and CASRN

Name	CASRN
Aniline	62-53-3
Phenol	108-95-2
2,4-Dimethylphenol	105-67-9
Benzothiazole	95-16-9
Dicyclohexylamine	101-83-7
2-Hydroxybenzothiazole	934-34-9
Phthalimide	85-41-6
Formaldehyde Diethyl Acetal	462-95-3
Cyclohexyl Isothiocyanate	1122-82-3
2-Mercaptobenzothiazole	149-30-4

Table 3.3 Summary of Column Test Results for Zinc and Detected SVOCs

Analytes	Average Concentration[a] (μg/L)		Groundwater Standard/ Guidance Value (μg/L)
	Facility #1 Truck/Ambient	Facility #4 Mixed/Cryogenic	
Zinc	291.9 ± 72.0	214.1 ± 80.3	2000
Aniline	37.5 ± 7.4	21.5 ± 2.2	5
Phenol	0.7 ± 0.1	1.4 ± 0.2	1
Benzothiazole	215.3 ± 25.1	92.7 ± 6.3	No Standard
Phthalimide	107.5 ± 28.7	23.0 ± 2.5	No Standard

[a] Average ± standard error.

Table 4.1 Surface Runoff Test Results for VOCs

Analyte	CASRN	Concentration (μg/L)
1,1,1-Trichloroethane	71-55-6	< 1
1,1,2,2-Tetrachloroethane	79-34-5	< 1
1,1,2-Trichloroethane	79-00-5	< 1
1,1-Dichloroethane	75-34-3	< 1
1,1-Dichloroethene	75-35-4	< 1
1,2-Dichlorobenzene	95-50-1	< 1
1,2-Dichloroethane	107-06-2	< 1
1,2-Dichloropropane	78-87-5	< 1
1,3-Dichlorobenzene	541-73-1	< 1
1,4-Dichlorobenzene	106-46-7	< 1
2-Chloroethylvinyl ether	110-75-8	< 1
Benzene	71-43-2	< 1
Bromodichloromethane	75-27-4	< 1
Bromoform	75-25-2	< 1
Bromomethane	74-83-9	< 1
Carbon tetrachloride	56-23-5	< 1
Chlorobenzene	108-90-7	< 1
Chloroethane	75-00-3	< 1
Chloroform	67-66-3	< 1
Chloromethane	74-87-3	< 1
cis-1,3-Dichloropropene	10061-01-5	< 1
Dibromochloromethane	124-48-1	< 1
Ethylbenzene	100-41-4	< 1
Methylene chloride	75-09-2	< 1
Tetrachloroethene	127-18-4	< 1
Toluene	108-88-3	< 1
trans-1,2-Dichloroethene	156-60-5	< 1
trans-1,3-Dichloropropene	10061-02-6	< 1
Trichloroethene	79-01-6	< 1
Trichlorofluoromethane	75-69-4	< 1
Vinyl chloride	75-01-4	< 1

Table 4.2 Surface Runoff Test Results for SVOCs

Analyte	CASRN	Concentration (μg/L)
1,2,4-Trichlorobenzene	120-82-1	< 5
1,2-Dichlorobenzene	95-50-1	< 5
1,3-Dichlorobenzene	541-73-1	< 5
1,4-Dichlorobenzene	106-46-7	< 5
2,2′-oxybis(1-Chloropropane)	108-60-1	< 5
2,4,6-Trichlorophenol	88-06-2	< 5
2,4-Dichlorophenol	120-83-2	< 5
2,4-Dimethylphenol	105-67-9	< 5
2,4-Dinitrophenol	51-28-5	< 10
2,4-Dinitrotoluene	121-14-2	< 5
2,6-Dinitrotoluene	606-20-2	< 5
2-Chloronaphthalene	91-58-7	< 5
2-Chlorophenol	95-57-8	< 5
2-Nitrophenol	88-75-5	< 5
3,3′-Dichlorobenzidine	91-94-1	< 5
4,6-Dinitro-2-methylphenol	534-52-1	< 10
4-Bromophenyl-phenylether	101-55-3	< 5
4-Chloro-3-methylphenol	59-50-7	< 5
4-Chlorophenyl-phenylether	7005-72-3	< 5
4-Nitrophenol	100-02-7	< 10
Acenaphthene	83-32-9	< 5
Acenaphthylene	208-96-8	< 5
Anthracene	120-12-7	< 5
Benzidine	92-87-5	< 50
Benzo(a)anthracene	56-55-3	< 5
Benzo(a)pyrene	50-32-8	< 5
Benzo(b)fluoranthene	205-99-2	< 5
Benzo(g,h,i)perylene	191-24-2	< 5
Benzo(k)fluoranthene	207-08-9	< 5
Bis(2-chloroethoxy)methane	111-91-1	< 5
Bis(2-chloroethyl)ether	111-44-4	< 5
Bis(2-ethylhexyl)phthalate	117-81-7	< 5
Butyl benzyl phthalate	85-68-7	< 5
Chrysene	218-01-9	< 5
Dibenzo(a,h)anthracene	53-70-3	< 5
Diethylphthalate	84-66-2	< 5
Dimethylphthalate	131-11-3	< 5
Di-n-butyl phthalate	84-74-2	< 5
Di-n-octyl phthalate	117-84-0	< 5
Fluoranthene	206-44-0	< 5
Fluorene	86-73-7	< 5

Analyte	CASRN	Concentration (µg/L)
Hexachlorobenzene	118-74-1	< 5
Hexachlorobutadiene	87-68-3	< 5
Hexachlorocyclopentadiene	77-47-4	< 5
Hexachloroethane	67-72-1	< 5
Indeno(1,2,3-cd)pyrene	193-39-5	< 5
Isophorone	78-59-1	< 5
Naphthalene	91-20-3	< 5
Nitrobenzene	98-95-3	< 5
N-Nitrosodimethylamine	62-75-9	< 5
N-Nitroso-di-n-propylamine	621-64-7	< 5
N-Nitrosodiphenylamine	86-30-6	< 5
Pentachlorophenol	87-86-5	< 5
Phenanthrene	85-01-8	< 5
Phenol	108-95-2	< 5
Pyrene	129-00-0	< 5
2(3H)-Furanone, dihydro-4-hydroxy- [a]	5469-16-9	2

[a] Tentatively identified compound – reported based on presumptive evidence and reported as estimated concentration

Table 4.3 Surface Runoff Test Results for Metals [a]

Analyte	CASRN	Concentration (µg/L)	Surface water standard [b] (µg/L)
Antimony	7440-36-0	< 2.3	3
Arsenic	7440-38-2	< 1.8	50
Beryllium	7440-41-7	< 0.096	1100
Cadmium	7440-43-9	< 0.35	5
Chromium	7440-47-3	2.2	50
Copper	7440-50-8	5.4	200
Lead	7440-92-1	1.7	50
Mercury	7440-97-6	< 0.13	0.7
Nickel	7440-02-0	8.8	100
Selenium	7440-49-2	< 1.9	10
Silver	7440-22-4	< 0.54	50
Thallium	7440-28-0	< 1.9	8
Zinc	7440-66-6	59.5	82.6

[a] Results based on one sample collected
[b] Assume water hardness = 100 ppm

Table 4.4 Groundwater Field Information

Turf Field #	Turf Field Area (ft^2)	Depth to groundwater (ft)	Age of Field	# Samples	# Wells
1	531,000	68.5 - 70.0	4-5 years	6	2
2	120,000	11.3 - 12.0	< 1 year	8	2
3	82,300	36.8 - 38.0	4-7 years	10	3
4	77,400	8.3 - 8.9	2-4 years	8	2

Table 4.5 Groundwater Test Results for Selected SVOCs

Analyte	CASRN	Concentration (µg/L)
Aniline	62-53-3	< 0.39
Phenol	108-95-2	< 0.59
Benzothiazole	95-16-9	< 0.83

Table 4.6 Groundwater Test Results for all SVOCs

Analyte	CASRN	Concentration (µg/L)
Acenaphthene	83-32-9	< 0.38
Acenaphthylene	208-96-8	< 0.72
Aniline	62-53-3	< 0.39
Anthracene	120-12-7	< 0.5
Benz(a)anthracene	56-55-3	< 0.24
Benzo(a)pyrene	50-32-8	< 0.5
Benzo(b)fluoranthene	205-99-2	< 0.36
Benzo(g,h,i)perylene	191-24-2	< 0.3
Benzo(k)fluoranthene	207-08-9	< 0.33
Benzothiazole	95-16-9	< 0.83
Benzyl Alcohol	100-51-6	< 0.55
Butyl Benzyl Phthalate	85-68-7	< 0.64
Di-n-butyl Phthalate	84-74-2	< 0.65
Carbazole	86-74-8	< 0.42
Indeno(1,2,3-cd)pyrene	193-39-5	< 0.44
4-Chloroaniline	106-47-8	< 0.63
Bis(2-chloroethoxy)methane	111-91-1	< 0.66
Bis(2-chloroethyl) Ether	111-44-4	< 0.63
2-Chloronaphthalene	91-58-7	< 0.66
2-Chlorophenol	95-57-8	< 0.32
Bis(1-chloroisopropyl) Ether	108-60-1	< 0.67
Chrysene	218-01-9	< 0.6
Dibenz(a,h)anthracene	53-70-3	< 0.32
Dibenzofuran	132-64-9	< 0.49
1,3-Dichlorobenzene	541-73-1	< 0.6
1,2-Dichlorobenzene	95-50-1	< 0.86
1,4-Dichlorobenzene	106-46-7	< 0.28

Analyte	CASRN	Concentration (μg/L)
3,3'-Dichlorobenzidine	91-94-1	< 0.46
2,4-Dichlorophenol	120-83-2	< 0.59
Diethyl Phthalate	84-66-2	< 0.55
Dimethyl Phthalate	131-11-3	< 0.7
2,4-Dimethylphenol	105-67-9	< 1.6
2,4-Dinitrophenol	51-28-5	< 21
2,4-Dinitrotoluene	121-14-2	< 0.68
2,6-Dinitrotoluene	606-20-2	< 0.75
Bis(2-ethylhexyl) Phthalate	117-81-7	< 0.27
Fluoranthene	206-44-0	< 0.44
Fluorene	86-73-7	< 0.55
Hexachlorobenzene	118-74-1	< 0.42
Hexachlorobutadiene	87-68-3	< 0.6
Hexachlorocyclopentadiene	77-47-4	< 0.53
Hexachloroethane	67-72-1	< 0.7
Isophorone	78-59-1	< 0.56
2-Methylnaphthalene	91-57-6	< 0.42
4,6-Dinitro-2-methylphenol	534-52-1	< 0.86
4-Chloro-3-methylphenol	59-50-7	< 0.72
2-Methylphenol	95-48-7	< 0.54
4-Methylphenol	106-44-5	< 0.78
Naphthalene	91-20-3	< 0.49
2-Nitroaniline	88-74-4	< 14
3-Nitroaniline	99-09-2	< 9.3
4-Nitroaniline	100-01-6	< 10
Nitrobenzene	98-95-3	< 0.59
2-Nitrophenol	88-75-5	< 0.76
4-Nitrophenol	100-02-7	< 6.2
N-Nitrosodimethylamine	62-75-9	< 0.43
N-Nitrosodiphenylamine	86-30-6	< 0.47
Di-n-octyl Phthalate	117-84-0	< 0.63
Pentachlorophenol (PCP)	87-86-5	< 16
Phenanthrene	85-01-8	< 0.31
Phenol	108-95-2	< 0.59
4-Bromophenyl Phenyl Ether	101-55-3	< 0.67
4-Chlorophenyl Phenyl Ether	7005-72-3	< 0.4
N-Nitrosodi-n-propylamine	621-64-7	< 0.37
Pyrene	129-00-0	< 0.44
1,2,4-Trichlorobenzene	120-82-1	< 0.62
2,4,6-Trichlorophenol	88-06-2	< 0.43
2,4,5-Trichlorophenol	95-95-4	< 0.55

Table 5.1 Predicted Groundwater Concentrations for Crumb Rubber Derived from Truck and Mixed Tires Using a Dilution Attenuation Factor (DAF) of 100 for Organics.

Compound	Groundwater Quality Standards/ Guidance Values (µg/L)	Facility#1 Truck Tires		Facility #4 Mixed Tires	
		SPLP [a] (µg/L)	GW Conc. (µg/L)	SPLP [a] (µg/L)	GW Conc. (µg/L)
Aniline	5	347	3.5	124	1.2
Phenol	1	6	0.1	23	0.2
Benzothiazole	No Standard [b]	1,062	10.1	394	3.9
Zinc[c]	2000	7,700	192.5	1,400	35.0

[a] 95% Upper Confidence Limit
[b] Unspecified Organic Compound (UOC) standard of 50 µg/L is used for comparison purposes
[c] NYSDEC uses a DAF of 40 for metals.

Table 6.1 Surface Water Standards for Compounds of Concern

Compound	Facility #1 Truck Tires		Facility #4 Mixed Tires		Surface Water Standard (µg/L) for Stream Classes B, C, D
	SPLP Test [a]	Column Test [a]	SPLP Test [a]	Column Test [a]	
Zinc	7,700	436	1,400	375	117.2/82.6 [b]
Phenol	6	1	23	2	5
Aniline	347	52	124	26	No Standard
Benzothiazole	1,062	265	394	105	No Standard

[a] 95% Upper Confidence Limit
[b] For acute and chronic water quality standards for zinc, respectively, assuming hardness = 100 ppm. See Appendix E1 for calculations of surface water standards.

Table 7.1 Sampling Locations

Sampling Location	Sampling Height	Duplicate Sample
Upwind edge of field	3 feet	Yes
On field in shade	0.4-0.8 inches & 3 feet	No
On field in center	0.4-0.8 inches , 3 feet, 6 feet	No
Downwind edge of field	0.4-0.8 inches , 3 feet, 6 feet	Yes at 3 foot height

Table 7.2 Modifications to Method TO-13A

Requirement	TO-13A	ATL Modifications
Extraction Solvent	10% ether in hexane for PUF; methylene chloride (DCM) for XAD sorbent. Final extract in hexane.	DCM for PUF/XAD cartridge and XAD sorbent. Final extract in DCM.
Glassware Cleaning	Muffle furnace is utilized.	Solvent cleaning procedure is used.
Extraction technique	Soxhlet extraction	Soxhlet extraction or pressurized fluid extraction (PFE).
Calibration range	0.10 to 2.5 μg/mL	1.0 μg/mL to 160 μg/mL
Field surrogates	Deuterated polycyclic aromatic hydrocarbons (PAHs) are spiked on media prior to sampling.	Performed by client request only.
Solvent Process Blank	Required each analytical batch.	Not performed; each solvent lot is certified prior to use.
Method Blank	<Method Detection Limit	<Reporting Limit

Table 8.1 Chemicals Detected in Air Samples Collected at the Thomas Jefferson Field* Concentrations are μg/m^3

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1,2,4-Trimethylbenzene	0.28	0.22	0.17	0.17	0.16	0.16	0.11	0.17	0.098
1,4-Dichlorobenzene	0.12	0.18	0.12	0.15	0.12	0.14	0.092	0.13	0.1
4-Methyl-2-pentanone	ND	ND	ND	1.2	ND	ND	ND	ND	ND
Acetone	0.48	0.48	ND	ND	ND	ND	ND	ND	ND
Benzene	0.4	0.4	0.44	ND	0.48	0.54	0.37	0.41	0.27
Carbon Tetrachloride	0.27	0.26	0.34	0.29	0.26	0.34	0.3	0.31	0.23
Chloroform	ND	0.1	0.15	ND	ND	0.14	ND	0.084	ND
Ethyl Benzene	0.23	0.18	0.18	0.18	0.16	0.17	0.14	0.19	0.11
Freon 11	0.34	0.22	0.69	0.33	0.31	0.52	0.37	0.4	0.3
Freon 113	0.085	ND	0.13	0.095	ND	0.12	0.087	0.1	ND
Freon 12	0.81	0.39	1.1	0.74	0.68	1	0.77	0.79	0.7
Hexane	0.44	0.36	0.4	ND	0.29	0.34	0.33	0.32	0.3
m,p-Xylene	0.72	0.56	0.54	0.52	0.5	0.5	0.38	0.52	0.32
Methylene Chloride	0.11	ND	0.17	0.16	0.13	0.16	0.29	0.096	0.099
o-Xylene	0.26	0.22	0.19	0.17	0.18	0.17	0.13	0.19	0.1
Tetrachloroethene	0.28	0.34	0.3	0.3	0.26	0.29	0.27	0.29	0.2
Toluene	1.5	1.4	1.3	1.3	1.2	1.4	1.1	1.3	0.82
1,2-Butadiene, 3-methyl-	-	-	-	-	0.42 J (81%)	-	-	-	-
1,3-Butadiene, 2-methyl-	-	-	0.89 J (81%)	-	-	-	-	-	-
1,3-Pentadiene	0.46 J (94%)	0.51 J (94%)	-	-	-	1.1 J (94%)	0.53 J (91%)	0.58 J (94%)	-
1,3-Pentadiene, (E)-	-	-	-	-	-	-	-	0.62 J (90%)	-
1,3-Pentadiene, (Z)-	0.48 J (83%)	-	-	0.64 J (96%)	-	-	-	-	-
1,4-Pentadiene	-	-	-	-	-	-	-	-	0.52 J

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
									(93%)
1H-Benzotriazol-5-amine, 1-methyl-	-	-	-	-	-	9.2 J (47%)	8.5 J (43%)	13 J (32%)	9.1 J (43%)
1-Heptene	-	-	-	1 J (49%)	-	-	-	-	-
1-Iodo-2-methylundecane	-	-	-	0.76 J (72%)	-	-	-	-	-
2-Dibenzofuranamine	-	-	11 J (38%)	-	-	-	-	-	-
2-Hexen-1-ol, (Z)-	-	-	-	-	-	-	-	-	22 J (43%)
2-Octen-1-ol, (E)-	-	0.64 J (35%)	-	-	-	-	-	-	-
3-Dibenzofuranamine	-	-	-	-	-	-	-	8.6 J (38%)	-
4-Dibenzofuranamine	-	-	-	8.4 J (46%)	-	8.6 J (50%)	-	8.7 J (38%)	-
5-Hexen-2-ol, (.+/-.)-	-	-	-	-	-	-	24 J (40%)	-	-
Benzene, 1-ethyl-2-methyl-	0.64 J (76%)	-	-	-	-	-	-	-	-
Benzene, 1-ethyl-4-methyl-	0.41 J (70%)	0.67 J (91%)	0.54 J (76%)	-	0.52 J (93%)	0.43 J (76%)	0.42 J (76%)	0.55 J (80%)	0.33 J (70%)
Benzenemethanol, ar-ethenyl-	-	-	10 J (62%)	-	13 J (68%)	-	-	8.9 J (52%)	-
Butane	-	-	-	-	-	0.45 J (64%)	0.3 J (64%)	-	-
Butane, 2-methyl-	-	-	0.48 J (86%)	0.32 J (80%)	-	-	0.34 J (80%)	0.29 J (80%)	0.26 J (80%)
Cyclohexanol	23 J (32%)	-	-	21 J (22%)	19 J (22%)	27 J (16%)	-	23 J (46%)	-
Cyclopentane	-	-	-	-	-	-	0.3 J (78%)	-	-
Cyclopentanone, 2-	10 J (72%)	-	-	-	-	10 J (53%)	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
methyl-									
Decanal	-	-	-	0.46 J (90%)	-	-	-	-	-
Decane	1.2 J (53%)	-	1.2 J (64%)	1.4 J (87%)	1.2 J (64%)	1.3 J (64%)	1 J (64%)	1.3 J (64%)	0.93 J (64%)
Decane, 2,5,6-trimethyl-	0.89 J (42%)	-	-	-	-	-	-	-	-
Decane, 2,9-dimethyl-	-	1.4 J (64%)	-	-	-	-	-	-	-
Decane, 5-methyl-	0.28 J (50%)	-	-	-	-	-	-	-	-
Decane, 6-ethyl-2-methyl-	-	-	-	-	-	-	-	1.2 J (64%)	-
Dodecanal	0.38 J (72%)	-	-	-	-	-	-	0.37 J (59%)	-
Heptane	0.31 J (91%)	0.43 J (86%)	-	0.36 J (74%)	-	-	-	0.3 J (87%)	-
Heptane, 2,3,4-trimethyl-	-	-	0.38 J (50%)	-	-	-	-	-	-
Hexane, 3-methyl-	0.29 J (87%)	-	-	-	-	-	-	-	-
Methanimidamide, N,N-dimethyl-N'-phenyl-	-	-	-	-	9.6 J (72%)	-	-	-	-
Nonanal	0.59 J (72%)	0.88 J (58%)	0.54 J (56%)	-	0.76 J (72%)	-	0.5 J (64%)	0.75 J (59%)	0.34 J (53%)
Nonanamide	-	-	-	-	-	13 J (50%)	-	-	-
Nonane	1.1 J (72%)	1.4 J (45%)	1 J (76%)	1 J (90%)	0.99 J (70%)	2.5 J (90%)	0.81 J (47%)	0.99 J (66%)	2.3 J (91%)
Octane, 2-methyl-	-	-	-	-	-	-	-	-	0.26 J

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
									(72%)
Pentadecane	0.46 J (90%)	-	-	-	-	-	-	-	-
Pentanamide, 4-methyl-	-	-	-	-	15 J (50%)	-	-	-	-
Pentane, 2,2,3,4-tetramethyl-	-	-	-	-	0.31 J (72%)	-	-	-	-
Pentane, 2-methyl-	0.4 J (91%)	-	-	-	-	-	-	0.28 J (90%)	-
Propane, 2-methyl-	-	-	0.4 J (4%)	-	-	-	-	-	-
Tetradecane, 1-chloro-	-	-	-	-	-	0.42 J (74%)	-	-	-
Undecane	0.51 J (91%)	0.58 J (90%)	0.42 J (91%)	-	0.49 J (90%)	0.45 J (81%)	0.41 J (76%)	0.49 J (91%)	0.33 J (81%)
Undecane, 2,6-dimethyl-	-	-	-	-	-	-	-	-	0.26 J (50%)
Undecane, 3-methyl-	1.1 J (53%)	-	-	-	-	-	-	-	-
Undecane, 5,6-dimethyl-	-	-	-	-	-	-	-	0.34 J (50%)	-

ND = not detected
J = estimated concentration of a tentatively identified compound (TIC)
- = not reported
(%) = match quality
* Chemicals that did not meet the laboratory/field blank criterion are not included.

Table 8.2 Chemicals Detected in Air Samples Collected at the John Mullaly Field* Concentrations are μg/m^3.

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1,2,4-Trimethylbenzene	0.26	0.26	0.24	0.19	0.10	0.21	0.22	0.27	0.22
1,3,5-Trimethylbenzene	0.089	ND	ND	ND	ND	ND	ND	ND	ND
1,4-Dichlorobenzene	0.46	0.52	0.49	0.40	0.24	0.41	0.46	0.55	0.48
4-Methyl-2-pentanone	ND	0.78	ND	0.67	ND	ND	ND	ND	ND
Acetone	ND	0.55	0.55	ND	0.56	0.53	ND	ND	ND
Benzene	0.39	0.34	0.35	0.14	ND	0.22	0.33	ND	0.35
Benzothiazole	ND	ND	ND	6.5	ND	ND	ND	ND	ND
Carbon Tetrachloride	0.26	0.33	0.34	0.14	ND	0.19	0.34	0.2	0.32
Chloroform	ND	0.096	0.092	ND	ND	ND	0.15	0.087	0.087
Chloromethane	ND	0.10	ND	ND	ND	ND	0.10	ND	0.11
Ethyl Benzene	0.29	0.28	0.28	0.18	0.11	0.24	0.24	0.27	0.27
Freon 11	0.4	0.62	0.69	0.20	0.16	0.26	0.56	0.44	0.70
Freon 113	0.092	0.22	0.20	ND	ND	ND	0.16	0.13	0.14
Freon 12	0.74	1.0	1.0	0.32	0.24	0.43	1.0	0.85	1.1
Hexane	0.38	0.35	0.37	0.12	ND	0.16	0.37	0.32	0.41
m,p-Xylene	0.83	0.82	0.80	0.55	0.33	0.71	0.72	0.80	0.80
Methylene Chloride	0.19	2.3	0.81	0.95	ND	0.12	3.0	0.35	0.17
o-Xylene	0.26	0.28	0.27	0.16	0.088	0.21	0.22	0.27	0.24
Tetrachloroethene	1.2	1.2	1.2	0.74	0.38	0.91	0.88	0.84	0.83
Toluene	1.4	1.3	1.5	0.72	0.43	1.3	1.0	0.75	1.6
1,3-Butadiene, 2-methyl-	-	-	-	-	-	0.23 J (94%)	-	-	-
1,3-Pentadiene	-	0.52 J (96%)	0.51 J (94%)	-	-	-	0.53 J (94%)	0.44 J (95%)	0.45 J (94%)
1-Butanol, 4-methoxy-	50 J (23%)	-	-	-	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
1-Hexene, 3,4,5-trimethyl-	1.5 J (59%)	0.45 J (59%)	-	-	-	-	-	-	-
1-Hexene, 4,5-dimethyl-	-	-	-	-	-	-	0.33 J (64%)	-	-
1-Propene, 2-methyl-	-	-	-	0.46 J (80%)	0.33 J (80%)	1.0 J (50%)	-	-	-
2-Butene, (E)-	-	1.8 J (52%)	-	-	-	0.54 J (80%)	-	0.56 J (59%)	-
2-Butene, (Z)-	2.8 J (50%)	-	2.7 J (50%)	0.55 J (64%)	0.23 J (59%)	-	0.88 J (42%)	-	1.1 J (53%)
2-Dibenzofuranamine	-	-	-	-	-	-	-	12 J (38%)	-
3-Dibenzofuranamine	-	10 J (38%)	-	-	-	-	11 J (38%)	9.9 J (38%)	-
3H-Indazol-3-one, 1,2-dihydro-2-methyl-	14 J (53%)	-	-	-	-	-	-	-	12 J (53%)
4-Dibenzofuranamine	9.0 J (46%)	-	-	10 J (44%)	8.9 J (43%)	9.1 J (35%)	-	-	11 J (43%)
Benzaldehyde, ethyl-	-	9.6 J (91%)	-	-	-	-	-	-	-
Benzene, 1,3-dimethyl-	9.2 J (53%)	-	-	-	-	-	-	-	-
Benzene, 1-ethyl-2-methyl-	1.8 J (80%)	-	-	-	-	-	-	0.59 J (86%)	0.51 J (55%)
Benzene, 1-ethyl-3-methyl-	-	-	0.51 J (55%)	-	-	-	-	-	-
Benzene, 1-ethyl-4-methyl-	0.48 J (60%)	0.56 J (87%)	-	-	-	-	0.49 J (86%)	-	-
Benzene, 1-methoxy-4-(1-propenyl)-	-	-	-	-	9.9 J (52%)	-	9.7 J (45%)	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
Benzene, 2-methoxy-1,3,4-trimethyl-	-	-	-	2.1 J (17%)	-	-	-	-	-
Benzo[b]thiophene, 6-methyl-	-	-	-	-	-	8.7 J (53%)	-	-	-
Butane	-	0.50 J (38%)	0.43 J (38%)	-	-	-	0.42 J (52%)	0.33 J (56%)	0.41 J (64%)
Butane, 2-iodo-2-methyl-	0.34 J (72%)	-	-	-	-	0.35 J (64%)	-	-	-
Butane, 2-methyl-	0.42 J (80%)	0.65 J (80%)	0.61 J (80%)	0.22 J (80%)	-	-	0.50 J (80%)	0.31 J (80%)	0.42 J (80%)
Cycloheptane	-	-	-	-	-	-	-	0.23 J (27%)	-
Cyclohexane, 1,1,3-trimethyl-	-	-	0.60 J (86%)	-	-	-	-	-	-
Cyclohexane, 1,3-dimethyl-, cis	0.94 J (94%)	-	-	-	-	0.47 J (95%)	0.44 J (95%)	0.42 J (94%)	0.48 J (94%)
Cyclohexane, 1,4-dimethyl-	-	-	1.1 J (91%)	-	-	-	-	-	-
Cyclohexane, ethyl-	1 J (87%)	1.3 J (64%)	-	0.38 J (87%)	-	0.55 J (90%)	0.47 J (68%)	0.52 J (86%)	0.59 J (90%)
Cyclopropane, 1-chloro-2-ethenyl-1-methy	-	-	17 J (59%)	-	-	-	23 J (64%)	18 J (59%)	-
Decane	3.3 J (53%)	1.1 J (64%)	-	-	0.64 J (64%)	-	1.1 J (59%)	1.2 J (64%)	1.1 J (64%)
Decane, 2,3,8-trimethyl-	1.5 J (53%)	-	-	-	-	-	-	-	-
Decane, 2,9-dimethyl-	-	-	-	0.92 J (59%)	-	-	-	-	-
Dodecane, 2,6,11-	0.66 J	-	-	0.23 J	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
trimethyl-	(78%)			(78%)					
Dodecane, 2,7,10-trimethyl-	-	-	-	-	-	-	0.36 J (78%)	-	-
Ethane, 1,1,2,2-tetrachloro-	12 J (95%)	-	-	-	-	-	-	-	-
Heptane	0.42 J (91%)	-	-	0.23 J (91%)	-	0.32 J (91%)	-	0.30 J (80%)	-
Heptane, 2,2-dimethyl-	-	0.51 J (64%)	-	-	-	-	-	-	-
Heptane, 2,4-dimethyl-	1.5 J (86%)	1.5 J (78%)	-	-	-	0.85 J (78%)	0.62 J (86%)	0.76 J (64%)	-
Heptane, 2,5-dimethyl-	0.82 J (68%)	0.72 J (68%)	0.77 J (68%)	-	-	-	-	-	-
Heptane, 2,6-dimethyl-	-	-	1.6 J (72%)	-	0.37 J (59%)	-	-	-	-
Heptane, 2-methyl-	0.98 J (72%)	0.76 J (53%)	1.0 J (80%)	0.32 J (64%)	-	0.68 J (86%)	-	-	0.62 J (50%)
Heptane, 3-methyl-	0.45 J (83%)	0.49 J (72%)	0.62 J (83%)	-	-	0.38 J (83%)	-	-	0.36 J (72%)
Heptane, 4-(1-methylethyl)-	-	-	-	0.30 J (64%)	-	-	-	-	-
Heptane, 4-ethyl-2,2,6,6-tetramethyl-	-	-	-	-	-	0.54 J (56%)	-	-	-
Hexane, 2,2,4-trimethyl-	0.61 J (64%)	-	-	-	-	-	-	-	-
Hexane, 2,2,5-trimethyl-	2.1 J (72%)	-	0.51 J (72%)	-	-	-	0.47 J (72%)	0.60 J (72%)	0.47 J (72%)
Hexane, 3,3-dimethyl-	0.44 J (59%)	-	-	-	-	-	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
Hydroxylamine, O-decyl-	-	-	-	-	-	-	-	-	0.88 J (64%)
Methanimidamide, N,N-dimethyl-N'-phenyl-	16 J (50%)	-	-	8.7 J (50%)	-	-	-	-	-
Nonanal	1.28 J (68%)	-	0.54 J (72%)	0.47 J (50%)	0.45 J (72%)	0.51 J (78%)	-	-	0.42 J (53%)
Nonane	3.2 J (91%)	2.6 J (91%)	3.2 J (91%)	2.1 J (87%)	1.7 J (87%)	2.8 J (94%)	1.8 J (91%)	2.3 J (91%)	2.7 J (83%)
Nonane, 3-methyl-5-propyl-	-	-	-	-	-	-	-	0.33 J (72%)	-
Octane	6.3 J (90%)	4.5 J (45%)	6.2 J (46%)	3.4 J (74%)	3.0 J (49%)	5.9 J (94%)	3.1 J (70%)	4.7 J (38%)	6.0 J (76%)
Octane, 2-methyl-	-	-	0.41 J (72%)	-	-	-	-	-	-
Octane, 3-methyl-	0.64 J (64%)	-	-	-	-	0.42 J (90%)	-	0.39 J (80%)	0.44 J (91%)
Pentane	-	0.46 J (86%)	0.40 J (86%)	-	-	-	-	-	-
Pentane, 2,2,3,4-tetramethyl-	-	-	-	0.42 J (53%)	0.30 J (53%)	-	-	-	-
Pentane, 2-methyl-	-	-	-	-	-	-	0.35 J (80%)	0.31 J (91%)	0.32 J (91%)
Pentane, 3,3-dimethyl-	-	-	-	-	-	0.40 J (50%)	-	0.44 J (64%)	-
Propane, 2-methyl-	-	-	-	-	-	-	-	0.25 J (45%)	-
Tetradecane, 1-chloro-	-	-	-	0.56 J (74%)	-	-	-	-	-
Tridecane	0.96 J	-	-	-	-	0.96 J	-	-	-

CHEMICAL NAME	Upwind of field @ 3 feet above surface	On-field in shade @ surface	On-field in shade @ 3 feet above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 feet above surface	Center of field in the sun @ 6 feet above surface	Downwind of field @ surface	Downwind of field @ 3 feet above surface	Downwind of field @ 6 feet above surface
	(59%)					(53%)			
Undecane	2.2 J (80%)	0.93 J (90%)	0.95 J (91%)	0.78 J (91%)	0.65 J (83%)	0.79 J (87%)	0.91 J (90%)	1.0 J (90%)	0.77 J (90%)
Undecane, 4,6-dimethyl-	-	-	-	0.23 J (64%)	-	-	-	-	-
Undecane, 4-methyl-	-	-	-	0.28 J (64%)	-	-	-	-	-

ND = not detected
J = estimated concentration of a tentatively identified compound (TIC)
- = not reported
(%) = match quality
* Chemicals that did not meet the laboratory/field blank criterion are not included.

Table 8.3 TICs Detected in Laboratory and/or Field Blank Samples. Concentrations are μg/m^3

Tentatively Identified Compound	Laboratory Blank Concentration		Field Blank Concentration	
	Thomas Jefferson Field	John Mullaly Field	Thomas Jefferson Field	John Mullaly Field
2-Cyclohexen-1-ol	32J	34J	38J	40J
2-Cyclohexen-1-one	33J	35J	35J	42J
7-Oxabicyclo[4.1.0]heptane	35J	25J	32J	30J
Benzene, 1-methoxy-4-(1-propenyl)-	NR	12J	NR	NR
Benzene, 2,4-diisocyanato-1-methyl-	13J	15J	9.1J	10J
Bi-2-cyclohexen-1-yl	24J	NR	18J	NR
Cyclohexanol	18J	15J	NR	18J
Cyclohexanol, 2-chloro-, trans-	21J	30J	20J	33J
Cyclopentene, 1,5-dimethyl-	NR	12J	NR	15J
Cyclohexanone	NR	NR	9.2J	NR
Benzene, 1,2-dimethyl-	NR	NR	NR	10J
Cyclopentanol, 2-methyl-	NR	NR	19J	NR
Tetradecane	NR	NR	NR	0.63J
Undecane, 2,3-dimethyl-	NR	NR	0.29J	NR

NR = not reported
J = estimated concentration

Table 8.4 Thomas Jefferson Field – Measured Air Concentrations (μg/m^3) for Chemicals Selected for Health Risk Evaluation

Name	Air Concentration (μg/m^3)*								
	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study									
1,4-Dichlorobenzene	0.12	0.18	0.12	0.15	0.12	0.14	0.092	0.13	0.1
4-Methyl-2-pentanone	ND	ND	ND	1.2	ND	ND	ND	ND	ND
Benzene	0.4	0.4	0.44	ND	0.48	0.54	0.37	0.41	0.27
Benzene, 1-ethyl-4-methyl-	0.41 J (70%)	0.67 J (91%)	0.54 J (76%)	-	0.52 J (93%)	0.43 J (76%)	0.42 J (76%)	0.55 J (81%)	0.33 J (70%)
Nonane	1.1 J (72%)	1.4 J (45%)	1 J (76%)	1 J (90%)	0.99 J (70%)	2.5 J (90%)	0.81 J (47%)	0.99 J (66%)	2.3 J (91%)
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study									
Freon 11	0.34	0.22	0.69	0.33	0.31	0.52	0.37	0.4	0.3
Freon 113	0.085	ND	0.13	0.095	ND	0.12	0.087	0.1	ND
Methylene Chloride	0.11	ND	0.17	0.16	0.13	0.16	0.29	0.096	0.099
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study									
Chloroform	ND	0.1	0.15	ND	ND	0.14	ND	0.084	ND
Chemicals Detected in Field Survey as TICs									
1,3-Pentadiene	0.46 J (94%)	0.51 J (94%)	-	-	-	1.1 J (94%)	0.53 J (91%)	0.58 J (94%)	-
1,3-Pentadiene, (E)-	-	-	-	-	-	-	-	0.62 J (90%)	-
1,4-Pentadiene	-	-	-	-	-	-	-	-	0.52 J (93%)
Butane, 2-methyl-	-	-	0.48 J (86%)	0.32 J (80%)	-	-	0.34 J (80%)	0.29 J (80%)	0.26 J (80%)
Decanal	-	-	-	0.46 J (90%)	-	-	-	-	-
Heptane	0.31 J (91%)	0.43 J (86%)	-	0.36 J (74%)	-	-	-	0.3 J (87%)	-

*ND = not detected; - = not reported; J = estimated concentration; (percentage) = degree of statistical match between the mass spectrum of a suspect chemical and the mass spectrum of a known chemical from a computer-based "library" of mass spectra. The suspect chemical is tentatively identified as the chemical with the highest match quality. A match of 85% or higher is necessary for reliable identification (US EPA, 1999b).

Table 8.5 John Mullaly Field – Measured Air Concentrations (μg/m^3) for Chemicals Selected for Health Risk Evaluation

Name	Air Concentration (μg/m^3)*								
	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study									
4-Methyl-2-pentanone	ND	0.78	ND	0.67	ND	ND	ND	ND	ND
Benzothiazole	ND	ND	ND	6.5	ND	ND	ND	ND	ND
Acetone	ND	0.55	0.55	ND	0.56	0.53	ND	ND	ND
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study									
Freon 11	0.40	0.62	0.69	0.20	0.16	0.26	0.56	0.44	0.70
Freon 113	0.092	0.22	0.20	ND	ND	ND	0.16	0.13	0.14
Freon 12	0.74	1.0	1.0	0.32	0.24	0.43	1.0	0.85	1.1
Methylene Chloride	0.19	2.3	0.81	0.95	ND	0.12	3.0	0.35	0.17
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study									
Chloroform	ND	0.096	0.092	ND	ND	ND	0.15	0.087	0.087
Chloromethane	ND	0.10	ND	ND	ND	ND	0.10	ND	0.11
Chemicals Detected in Field Survey as TICs									
1,3-Butadiene, 2-methyl-	-	-	-	-	-	0.23 J (94%)	-	-	-
1,3-Pentadiene	-	0.52 J (96%)	0.51 J (94%)	--	-	-	0.53 J (94%)	0.44 J (95%)	0.45 J (94%)
Benzaldehyde, ethyl-	-	9.6 J (91%)	-	-	-	-	-	-	-
Cyclohexane, 1,1,3-trimethyl-	-	-	0.60 J (86%)	-	-	-	-	-	-
Cyclohexane, 1,4-dimethyl-	-	-	1.1 J (91%)	-	-	-	-	-	-
Pentane	-	0.46 J (86%)	0.40 J (86%)	-	-	-	-	-	-
Pentane, 2-methyl-	-	-	-	-	-	-	0.35 J (80%)	0.31 J (91%)	0.32 J (91%)

*ND = not detected; - = not reported; J = estimated concentration; (percentage) = degree of statistical match between the mass spectrum of a suspect chemical and the mass spectrum of a known chemical from a computer-based "library" of mass spectra. The suspect chemical is tentatively identified as the chemical with the highest match quality. A match of 85% or higher is necessary for reliable identification (US EPA, 1999b)

Table 8.6 Toxicity Values for Chemicals Selected for Health Risk Evaluation.

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration μg/m^3 (Effect)	Air Concentration (μg/m^3) at 1 x 10^{-6} Risk Level	Source of Toxicity Values
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study						
1,4-Dichlorobenzene (106-46-7)	chemical-specific	NA	NA*	800 (increased liver weights in rats)	0.32	NYS (2006)
Acetone (67-64-1)	chemical-specific	NA	NA*	30,000 (neurological effects in humans)	none available**	NYS (2006)
Benzene (71-43-2)	chemical-specific	NA*	NA*	30 (decreased lymphocyte count in humans)	0.13	NYS (2006)
Benzene, 1-ethyl-4-methyl- (622-96-8)	surrogate-chemical	dimethyl benzenes (xylenes) (1330-20-7)	all are alkyl benzenes with substitutions at two positions of the benzene ring & differ only in the structure of one of the alkyl groups attached to benzene ring; xylenes have a peer-reviewed RfC	100 (impaired motor coordination in rats)	none available**	NYS (2006)
Benzothiazole (95-16-9)	chemical-specific	NA*	NA*	18*** (none reported)	none available**	***
4-Methyl-2-pentanone (108-10-1)	chemical specific	NA*	NA*	3000 (reduced fetal body wt, skeletal variations, & increased fetal death in mice; skeletal variations in rats	none available**	US EPA IRIS#
Nonane (111-84-2)	surrogate-chemical	hexane (110-54-3)	both are straight-chain alkanes; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study						
Freon 11 or trichloromonofluoromethane (75-69-4)	surrogate chemical	chlorodifluoro-methane (HCFC 22) (75-45-6)	all are halogenated methanes that differ only in the number of chlorines or fluorines attached to carbon atom; HCFC 22 has a peer-reviewed RfC	50,000 (increased kidney, adrenal & pituitary weights in rats)	none available**	US EPA IRIS#
Freon 12 or dichlorodifluoromethane (1275-71-8)						

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration μg/m^3 (Effect)	Air Concentration (μg/m^3) at 1 x 10^{-6} Risk Level	Source of Toxicity Values
Freon 113 or CFC-113 or 1,1,2-trichloro-1,2,2-trifluoroethane (76-13-1)	chemical-specific	NA*	NA*	190,000 (psychomotor impairment in humans)	none available**	US EPA IRIS#
Methylene Chloride (75-09-2)	chemical-specific	NA*	NA*	400 (blood carboxyhemoglobin above 2% in humans)	27	NYS (2006)
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study						
Chloroform (67-66-3)	chemical-specific	NA*	NA*	50 (liver & kidney toxicity in mice)	14.8	NYS (2006)
Chloromethane (74-87-3)	chemical-specific	NA*	NA*	90 (cerebellar lesions in mice)	none available**	US EPA IRIS#
Chemicals Detected in Field Survey as TICs						
Benzaldehyde, ethyl- (53951-50-1)	surrogate-chemical	benzaldehyde (100-52-7)	both are aldehydes with a benzene ring & differ only in the ethyl group of the TIC; benzaldehyde has a peer-reviewed RfD	350**** (forestomach lesions, kidney toxicity in rats)	none available**	US EPA IRIS#
1,3-Butadiene, 2-methyl- (78-79-5)	surrogate-chemical	1,3-butadiene (106-99-0)	both are conjugated dienes & differ only in the methyl groups of the TIC; 1,3-butadiene is a highly potent chemical and has peer-reviewed toxicity values	2 (ovarian atrophy in mice)	0.03	US EPA IRIS#
Butane, 2-methyl (92046-46-3)	surrogate-chemical	hexane (110-54-3)	both are straight-chain alkanes & differ only in the methyl group attached to the carbon chain; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Cyclohexane, 1,4-dimethyl- (589-90-2)	surrogate-chemical	cyclohexane (110-82-7)	all are cycloalkanes & differ only in the methyl groups attached to the cyclohexane ring of the TICs; cyclohexane has a peer-reviewed RfC	6000 (reduced pup weights in F1 and F2 generations in rats)	none available**	US EPA IRIS#
Cyclohexane, 1,1,3-trimethyl- (3073-66-3)						

Name (CASRN)	Basis for Toxicity Value	Surrogate Chemical (CASRN)	Rational	Reference Concentration μg/m^3 (Effect)	Air Concentration (μg/m^3) at 1 x 10^{-6} Risk Level	Source of Toxicity Values
Decanal (112-31-2)	surrogate-chemical	propanal (propionaldehyde) (123-38-6)	both are aldehydes & differ only in the number of carbon atoms; propanal has peer-reviewed RfC	8 (atrophy of olfactory epithelium in rats)	none available**	US EPA IRIS#
Heptane (142-82-5)	surrogate-chemical	hexane (110-54-3)	all are straight-chain alkanes; hexane among most potent alkanes & has a peer-reviewed RfC	700 (peripheral neuropathy in rats)	none available**	US EPA IRIS#
Pentane (109-66-0)						
1,3-Pentadiene (504-60-9)	surrogate-chemical	1,3-butadiene (106-99-0)	all are conjugated dienes & differ in the number of carbon atoms; 1,3-butadiene is a highly potent chemical & has peer-reviewed toxicity values	2 (ovarian atrophy in mice)	0.03	US EPA IRIS#
1,3-Pentadiene, (E)- (2004-70-8)						
1,4-Pentadiene (591-93-5)						

***** NA = not applicable.

****** Chemicals may lack an estimate of the air concentration associated with a lifetime excess risk of one per million (1 x 10^{-6}), assuming continuous exposure, for several different reasons: because their potency to cause cancer has not been studied, because studies of their carcinogenic potency did not show a concentration-related increase in cancer incidence or because some evidence of carcinogenic potency has been observed, but the quality of the studies or the data do not allow quantitative estimation of the 1 x 10^{-6} air concentration.

*** Reference Concentration = [Reference dose (RfD) x Adult Body Weight]/Adult Inhalation Rate: RfC = [5 μg/kg-day x 70 kg]/20 m^3/day = 18 μg /m^3, where the draft reference dose is derived from a no-observed-effect level of 5 μg /kg-day in a 90-day study with rats (WHO, 2003) and the application of a 1000-fold uncertainty factor to compensate for interspecies difference, human variation, and the use of a subchronic study to estimate a chronic reference dose.

**** Reference Concentration = [Reference dose (RfD) x Adult Body Weight]/Adult Inhalation Rate: RfC = [100 μg /kg-day x 70 kg]/20 m^3/day = 350 μg/m^3.

#http://cfpub.epa.gov/ncea/iris/index.cfm

References for Table 6

NYS (New York State). 2006. New York State Brownfield Cleanup Program, Development of Soil Cleanup Objectives. Technical Support Document. Albany, NY: New York State Department of Environmental Conservation and New York State Department of Health.

WHO (World Health Organization). 2003. Safety Evaluation of Certain Food Additives / prepared by the Fifty-Ninth Meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA). WHO Food Additives Series: 50. Geneva, SZ: International Programme on Chemical Safety. [Last accessed on 12 01 08 on-line at http://www.inchem.org/documents/jecfa/jecmono/v50je01.htm]

Table 8.7 Thomas Jefferson Field – Ratio of Measured Concentration/Reference Concentration (Hazard Quotient) for Chemicals Selected for Health Risk Evaluation (see Table 8.4 for Measured Air Concentrations)

Name	Hazard Quotient (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
1,4-Dichlorobenzene	chemical-specific	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0001	0.0002	0.0001
4-Methyl-2-pentanone	chemical-specific	ND	ND	ND	0.0004	ND	ND	ND	ND	ND
Benzene	chemical-specific	0.01	0.01	0.02	ND	0.02	0.02	0.01	0.01	0.009
Benzene, 1-ethyl-4-methyl-	surrogate-chemical: xylenes (dimethyl benzenes)	0.004**	0.007**	0.005**	-	0.005**	0.004**	0.004**	0.006**	0.003**
Nonane	surrogate-chemical: hexane	0.002**	0.002**	0.001**	0.001**	0.001**	0.004**	0.001**	0.001**	0.003**
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Freon 11	surrogate-chemical: HCFC 22	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Freon 113	chemical-specific	< 0.0001	ND	< 0.0001	< 0.0001	ND	< 0.0001	< 0.0001	< 0.0001	ND
Methylene Chloride	chemical-specific	0.0003	ND	0.0004	0.0004	0.0003	0.0004	0.0007	0.0002	0.0002
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.002	0.003	ND	ND	0.003	ND	0.002	ND
Chemicals Detected in Field Survey as TICs										
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	0.2**	0.3**	-	-	-	0.6**	0.3**	0.3**	-
1,3-Pentadiene, (E)-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	0.3**	-

Name	Hazard Quotient (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
1,4-Pentadiene	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	-	0.3**
Butane, 2-methyl-	surrogate-chemical: hexane	–	-	0.0007**	0.0005**	-	-	0.0005**	0.0004***	0.0004**
Decanal	surrogate-chemical: propanal (propionaldehyde)	-	-	-	0.06**	-	-	-	-	-
Heptane	surrogate-chemical: hexane	0.0004**	0.0006**	-	0.0005**	-	-	-	0.0004**	-

*ND = not detected; - = not reported.

**** Based on estimated chemical concentration and tentative chemical identification.**

Table 8.8 Thomas Jefferson Field – Estimated Excess Cancer Risks from Continuous Lifetime Exposure at Measured Air Concentrations of Known or Potential Cancer-Causing Chemicals Selected for Health Risk Evaluation (see Table 8.4 for Measured Air Concentrations)

Name	Excess Lifetime Risk (rounded to one significant figure)*									
	Type of Toxicity Value	Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
1,4-Dichlorobenzene	chemical-specific	0.4×10^{-6}	0.6×10^{-6}	0.4×10^{-6}	0.5×10^{-6}	0.4×10^{-6}	0.4×10^{-6}	0.3×10^{-6}	0.4×10^{-6}	0.3×10^{-6}
Benzene	chemical-specific	3×10^{-6}	3×10^{-6}	3×10^{-6}	ND	4×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	2×10^{-6}
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Methylene Chloride	chemical-specific	0.004×10^{-6}	ND	0.006×10^{-6}	0.006×10^{-6}	0.005×10^{-6}	0.006×10^{-6}	0.01×10^{-6}	0.004×10^{-6}	0.004×10^{-6}
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.007×10^{-6}	0.01×10^{-6}	ND	ND	0.009×10^{-6}	ND	0.006×10^{-6}	ND
Chemicals Detected in Field Study as TICs										
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	2×10^{-5}**	2×10^{-5}**	-	-	-	4×10^{-5}**	2×10^{-5}**	2×10^{-5}**	-
1,3-Pentadiene, (E)-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	-	-	2×10^{-5}**	-
1,4-Pentadiene	surrogate-chemical 1,3-butadiene	-	-	-	-	-	-	-	-	2×10^{-5}**

** ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 8.9 John Mullaly Field – Ratio of Measured Concentration/Reference Concentration (Hazard Quotient) for Chemicals Selected for Health Risk Evaluation (see Table 5 for Measured Air Concentrations)

Name	Type of Toxicity Value	Hazard Quotient (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals Detected in Field Survey Also Detected in DEC Laboratory Off-gassing Study										
4-Methyl-2-pentanone	chemical-specific	ND	0.0003	ND	0.0002	ND	ND	ND	ND	ND
Acetone	chemical-specific	ND	0.00002	0.00002	ND	0.00002	0.00002	ND	ND	ND
Benzothiazole	default value	ND	ND	ND	0.4	ND	ND	ND	ND	ND
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Freon 11	surrogate-chemical: HCFC 22	< 0.00001	0.00001	0.00001	< 0.00001	< 0.00001	< 0.00001	0.00001	< 0.00001	0.00001
Freon 113	chemical-specific	< 0.00001	< 0.00001	< 0.00001	ND	ND	ND	< 0.00001	< 0.00001	< 0.00001
Freon 12	surrogate-chemical: HCFC 22	0.00001	0.00002	0.00002	< 0.00001	< 0.00001	< 0.00001	0.00002	0.00002	0.00002
Methylene Chloride	chemical-specific	0.0005	0.006	0.002	0.002	ND	0.0003	0.008	0.0009	0.0004
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.002	0.002	ND	ND	ND	0.003	0.002	0.002
Chloromethane	chemical-specific	ND	0.001	ND	ND	ND	ND	0.001	ND	0.001
Chemicals Detected in Field Survey as TICs										
1,3-Butadiene, 2-methyl-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	0.1**	-	-	-

Name	Type of Toxicity Value	Hazard Quotient (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	-	0.3**	0.3**	-	-	-	0.3**	0.2**	0.2**
Benzaldehyde, ethyl-	surrogate-chemical: benzaldehyde	-	0.03**	-	-	-	-	-	-	-
Cyclohexane, 1,1,3-trimethyl-	surrogate-chemical: cyclohexane	-	-	0.0001**	-	-	-	-	-	-
Cyclohexane, 1,4-dimethyl-	surrogate-chemical: cyclohexane	-	-	0.0002**	-	-	-	-	-	-
Pentane	surrogate-chemical: hexane	-	0.0007**	0.0006**	-	-	-	-	-	-
Pentane, 2-methyl-	surrogate-chemical: hexane	-	-	-	-	-	-	0.0005**	0.0004**	0.0005**

*ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 8.10 John Mullaly Field – Estimated Excess Cancer Risks from Continuous Lifetime Exposure at Measured Air Concentrations of Known or Potential Cancer-Causing Chemicals Selected for Health Risk Evaluation (see Table 5 for Measured Air Concentrations)

Name	Type of Toxicity Value	Excess Lifetime Risk (rounded to one significant figure)*								
		Upwind of field @ 3 ft above surface	On-field in shade @ surface	On-field in shade @ 3 ft above surface	Center of field in the sun @ surface	Center of field in the sun @ 3 ft above surface	Center of field in the sun @ 6 ft above surface	Downwind of field @ surface	Downwind of field @ 3 ft above surface	Downwind of field @ 6 ft above surface
Chemicals on Target List Detected in Field Survey Not Included in DEC Off-gassing Study										
Methylene Chloride	chemical-specific	0.007×10^{-6}	0.08×10^{-6}	0.03×10^{-6}	0.04×10^{-6}	ND	0.004×10^{-6}	0.1×10^{-6}	0.01×10^{-6}	0.006×10^{-6}
Chemicals Detected in Field Survey Reported as Non-Detects in DEC Laboratory Off-gassing Study										
Chloroform	chemical-specific	ND	0.006×10^{-6}	0.006×10^{-6}	ND	ND	ND	0.01×10^{-6}	0.006×10^{-6}	0.006×10^{-6}
Chemicals Detected in Field Survey as TICs										
1,3-Butadiene, 2-methyl-	surrogate-chemical: 1,3-butadiene	-	-	-	-	-	8×10^{-6}**	-	-	-
1,3-Pentadiene	surrogate-chemical: 1,3-butadiene	-	2×10^{-5}**	2×10^{-5}**	-	-	-	2×10^{-5}**	2×10^{-5}**	2×10^{-5} **

* ND = not detected; - = not reported.

** Based on estimated chemical concentration and tentative chemical identification.

Table 9.1 American Academy of Pediatrics
Limitations on Activities at Different Wet Bulb Globe Temperatures

WBGT		Limitations on Activities
°C	°F	
< 24	< 75	All activities allowed, but be alert for early symptoms of heat-related illness in prolonged events
24.0–25.9	75.0–78.6	Longer rest periods in the shade; enforce drinking every 15 minutes
26–29	79–84	Stop activity of unacclimatized persons and other persons with high risk; limit activities of all others (disallow long-distance races, reduce duration of other activities)
> 29	> 85	Cancel all athletic activities

Table 9.2 Central Park Monitor - Meteorological Data

	2000 - 2007		Dates of Measurements	
	Daily Maximum Temperature (°F)	Daily Minimum Relative Humidity (%)	Daily Maximum Temperature (°F)	Daily Minimum Relative Humidity (%)
August				
Average (range)	82 (59 – 102)	53 (24 – 90)	83 (73 – 87)	42 (34 – 60)
50th prctl	82	50		
90th prctl	92	76		
September				
Average (range)	75 (54 – 91)	53 (26 – 97)	75 (69 – 83)	45 (38 – 57)
50th prctl	76	51		
90th prctl	83	76		

Table 9.3 Thomas Jefferson Field
Comparison Between Synthetic Turf and Other Surfaces

Difference (°F)	Minimum	Mean	Maximum	Standard Deviation
Turf - grass	13	42	78	19
Turf - sand	8	40	63	19

Table 9.4 John Mullaly Field
Comparison Between Synthetic Turf and Other Surfaces

Difference (°F)	Minimum	Mean	Maximum	Standard Deviation
Turf - grass	8	35	63	17
Turf - sand	8	26	50	14

Figures

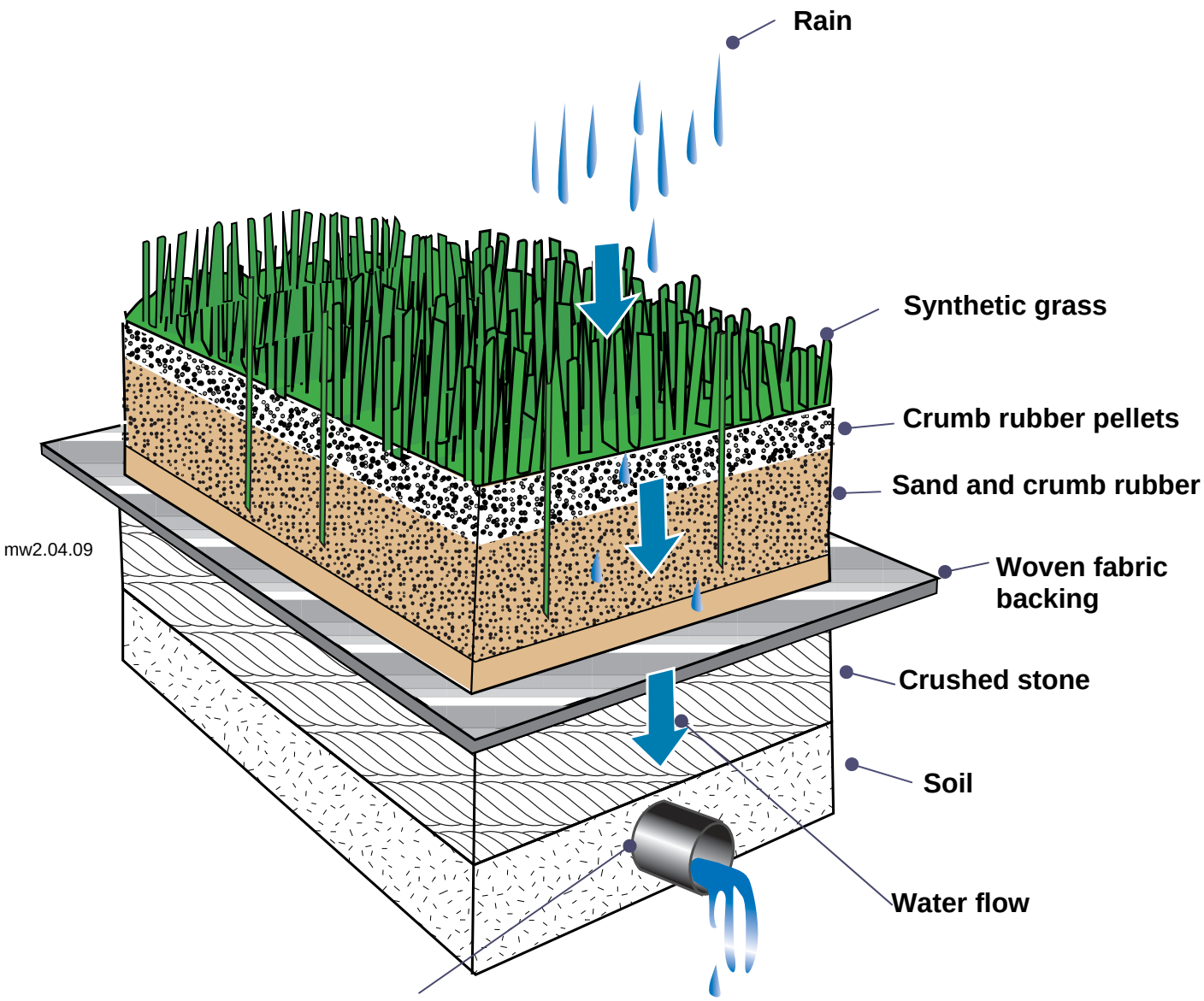


Figure 1.1 Cross-section of a typical synthetic turf field configuration

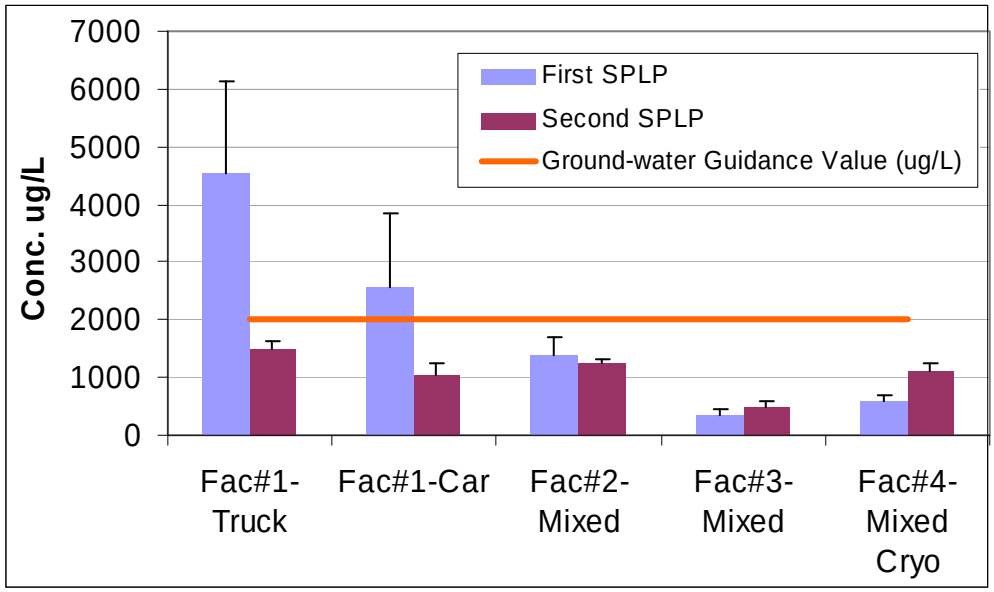


Figure 2.1 Zinc concentration in SPLP tests

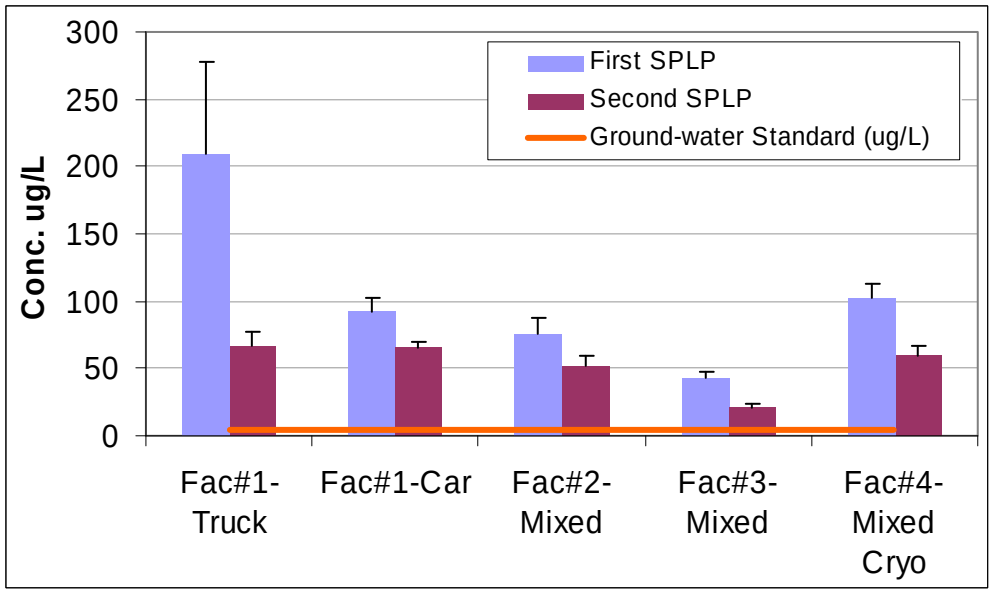


Figure 2.2 Aniline concentration in SPLP leachate

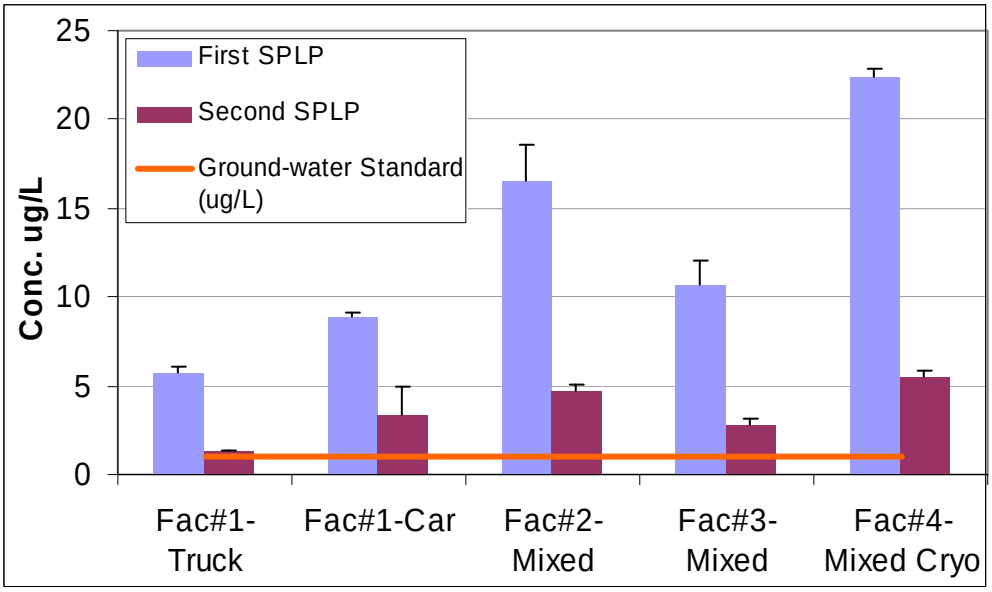


Figure 2.3 Phenol concentration in SPLP leachate

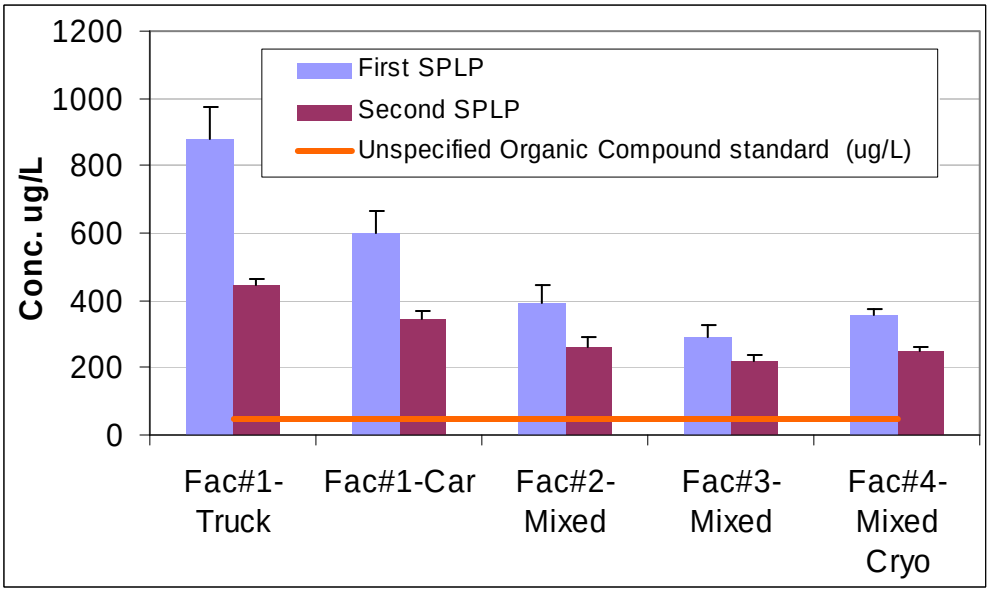


Figure 2.4 Benzothiazole in SPLP leachate

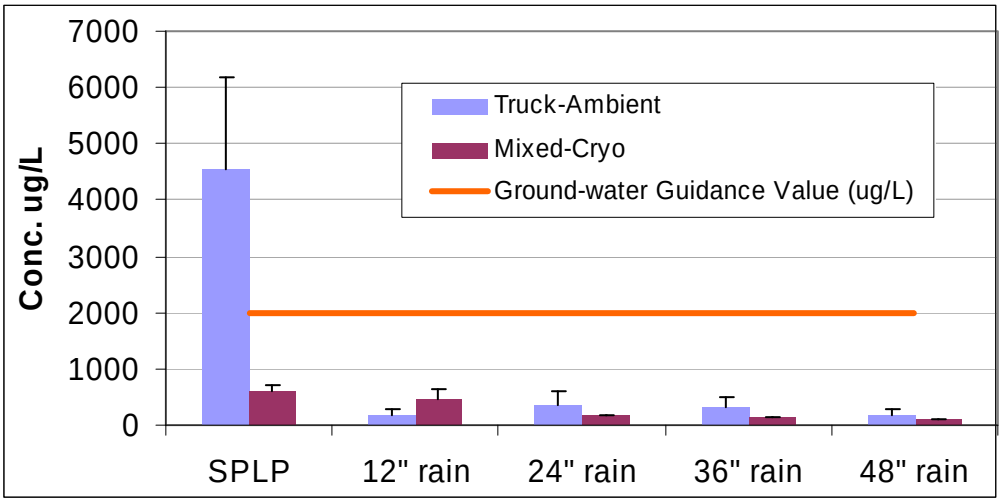


Figure 3.1 Comparison of zinc levels between SPLP and column tests

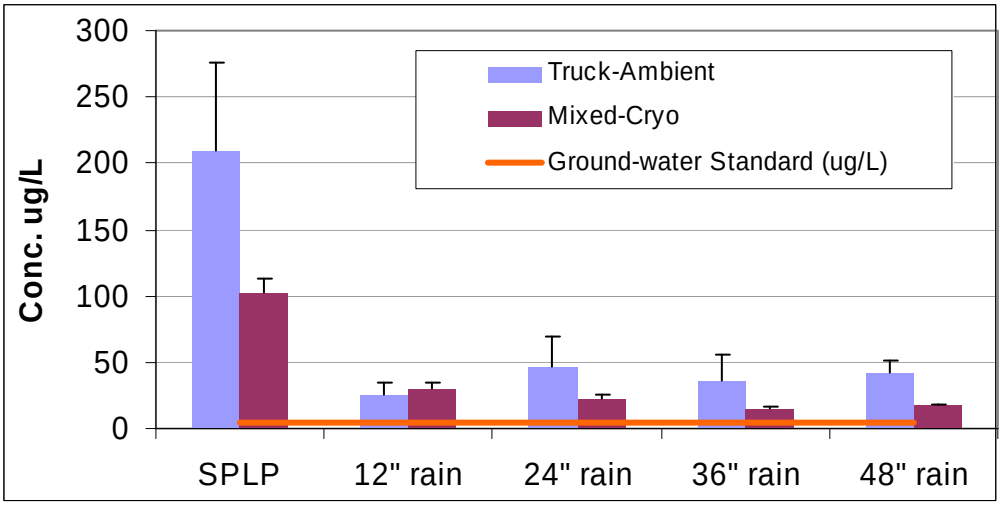


Figure 3.2 Comparison of aniline levels between SPLP and column tests

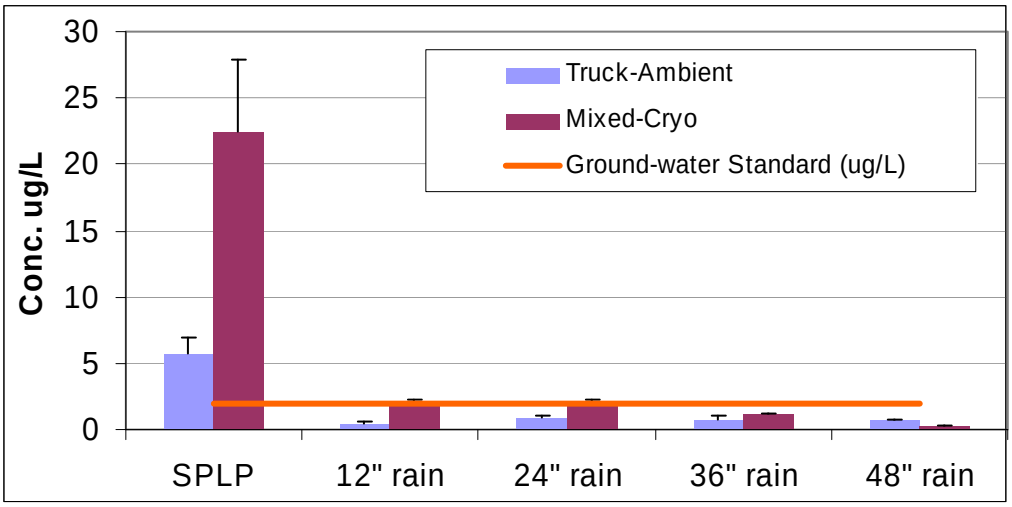


Figure 3.3 Comparison of phenol levels between SPLP and column tests

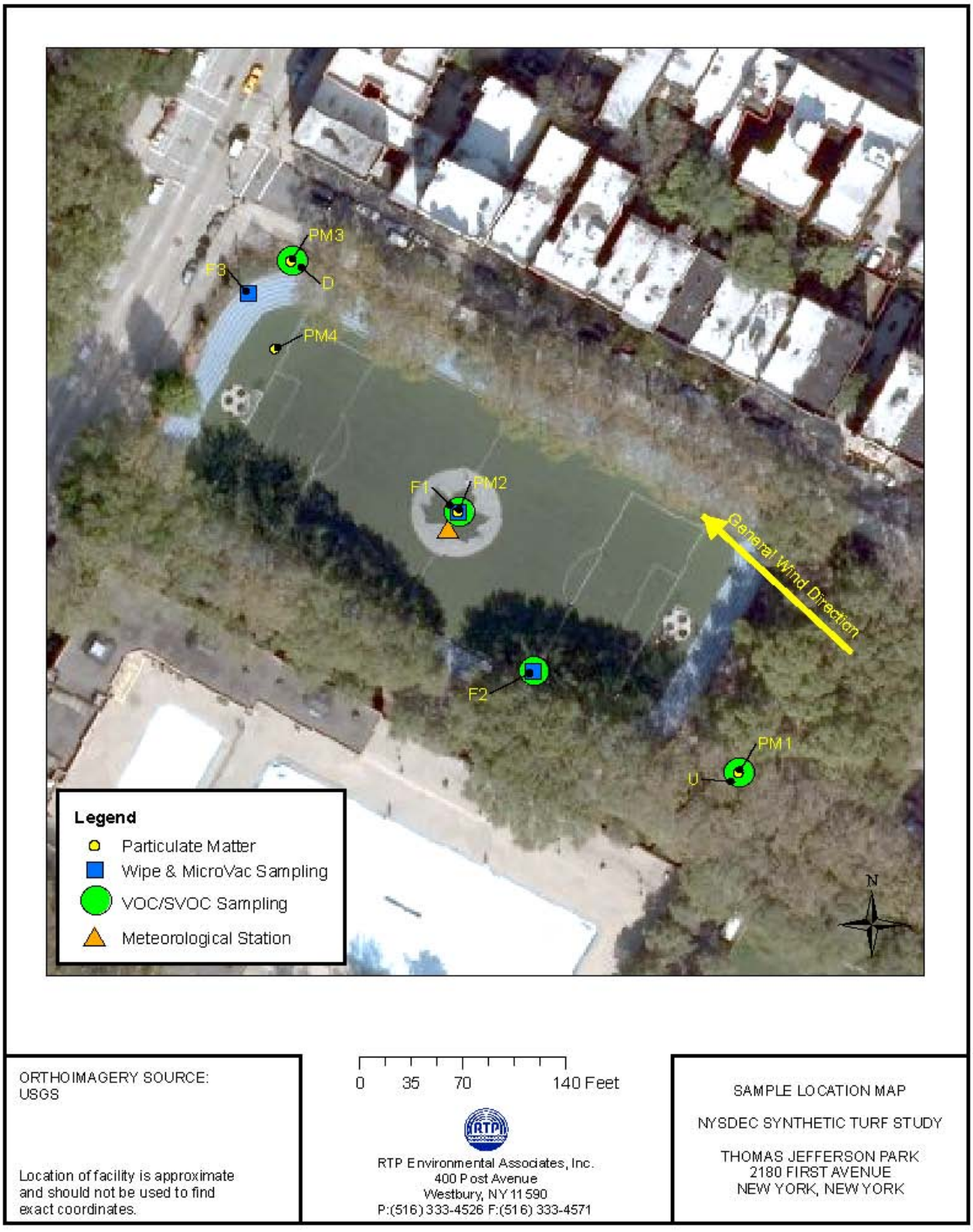


Figure 7.1 Thomas Jefferson Park Sampling Locations

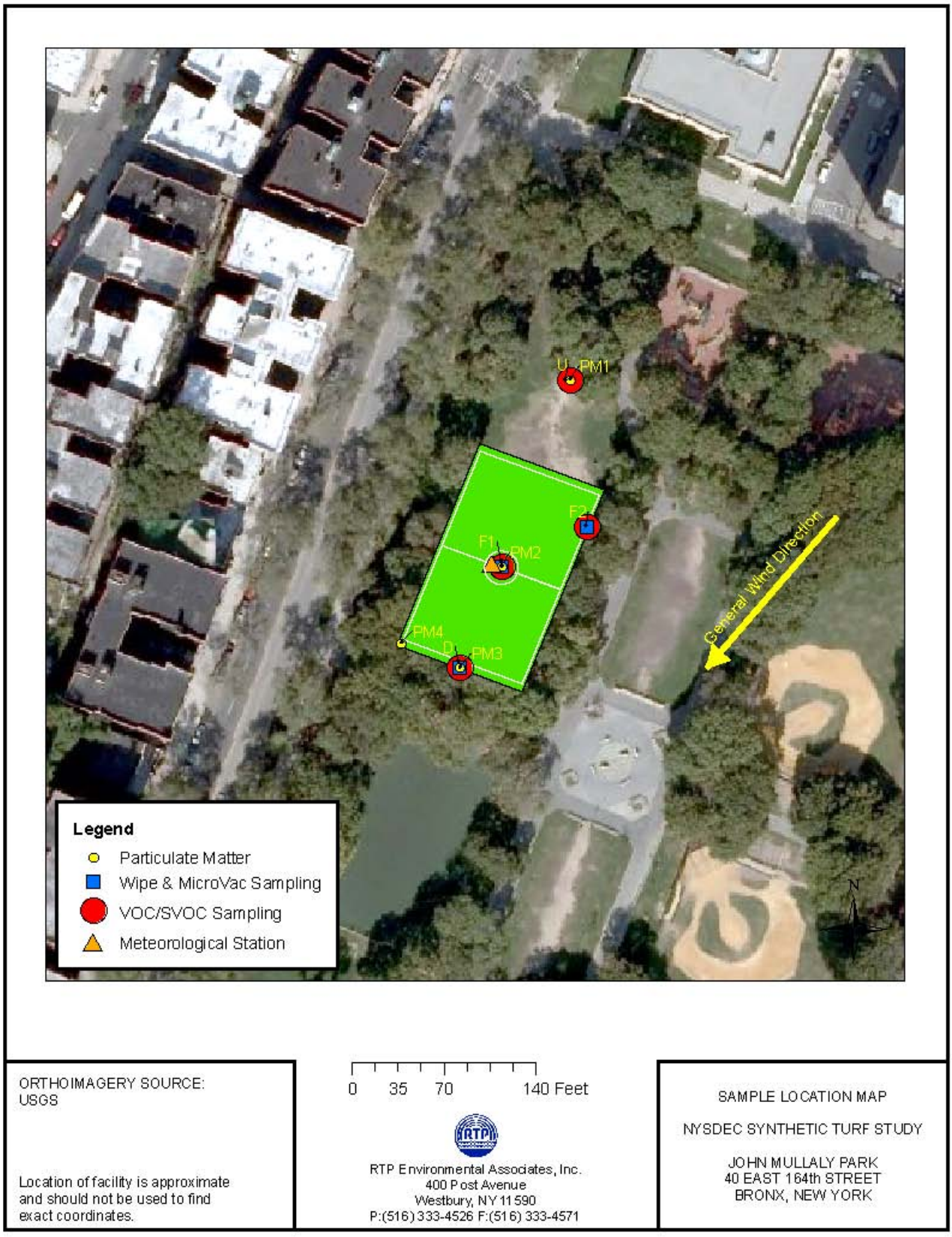


Figure 7.2 John Mullaly Park Sampling Locations

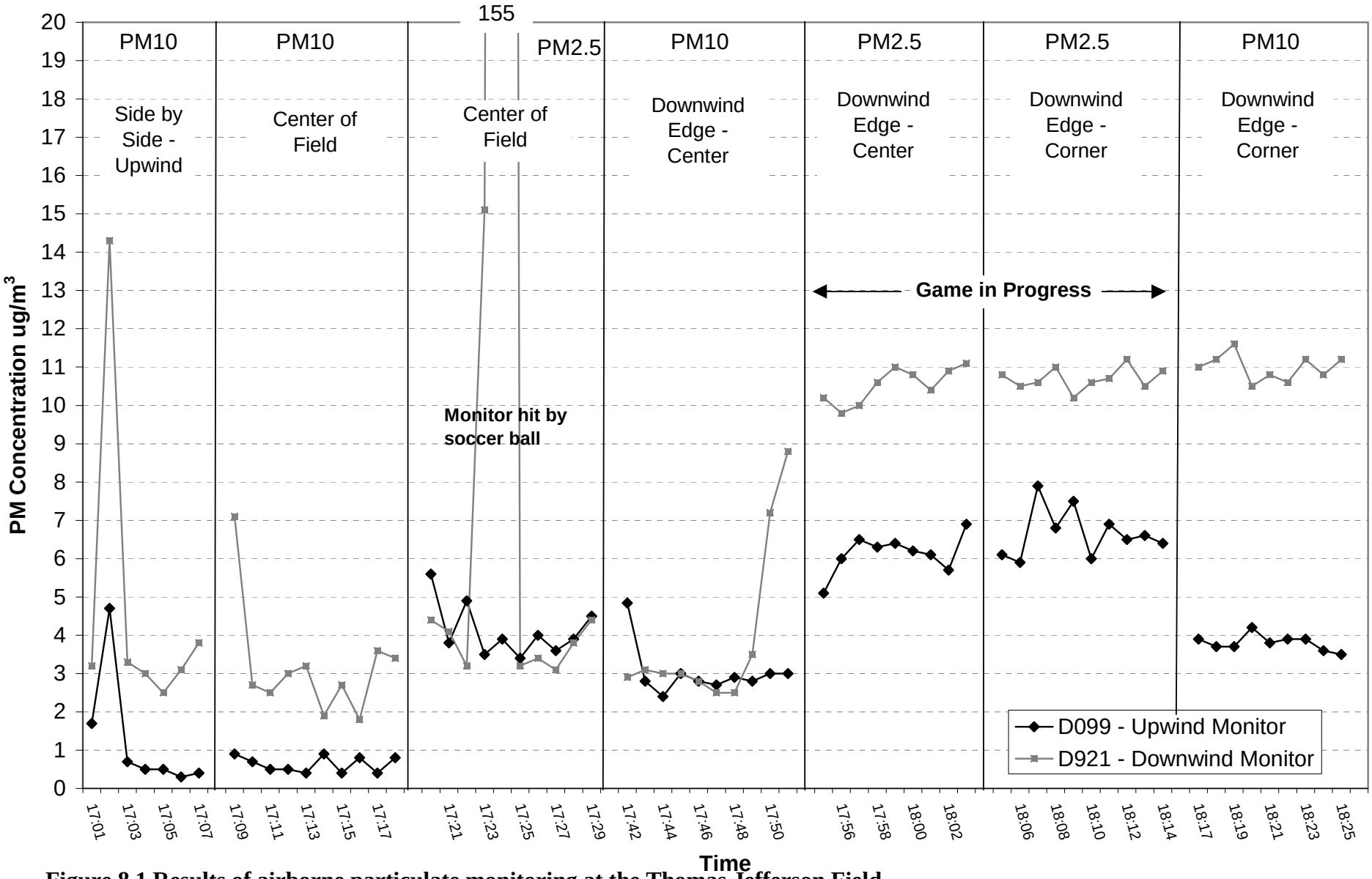


Figure 8.1 Results of airborne particulate monitoring at the Thomas Jefferson Field

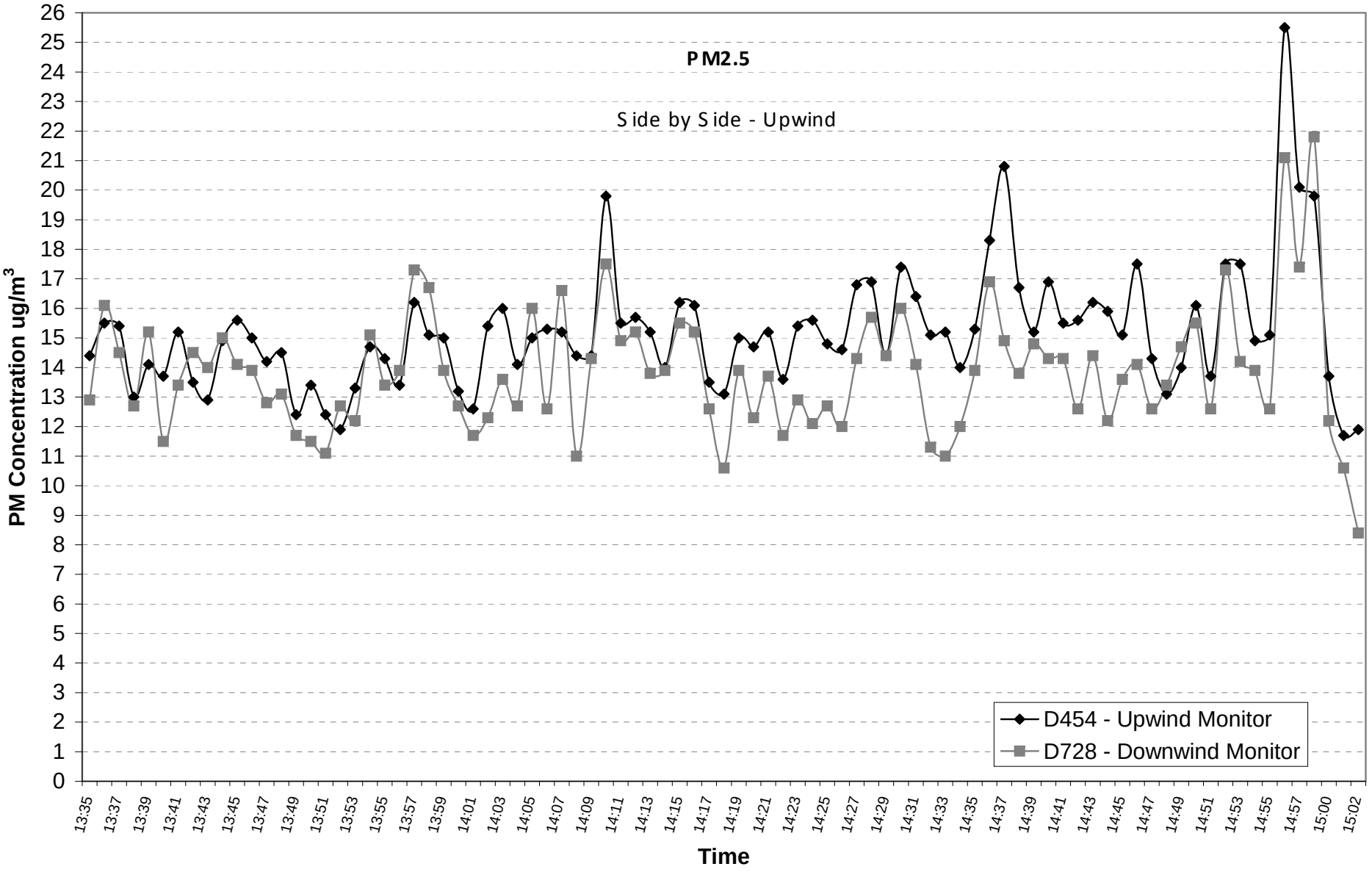


Figure 8.2 Results of side by side monitoring for airborne particulate monitoring at the upwind location on the John Mullaly Field

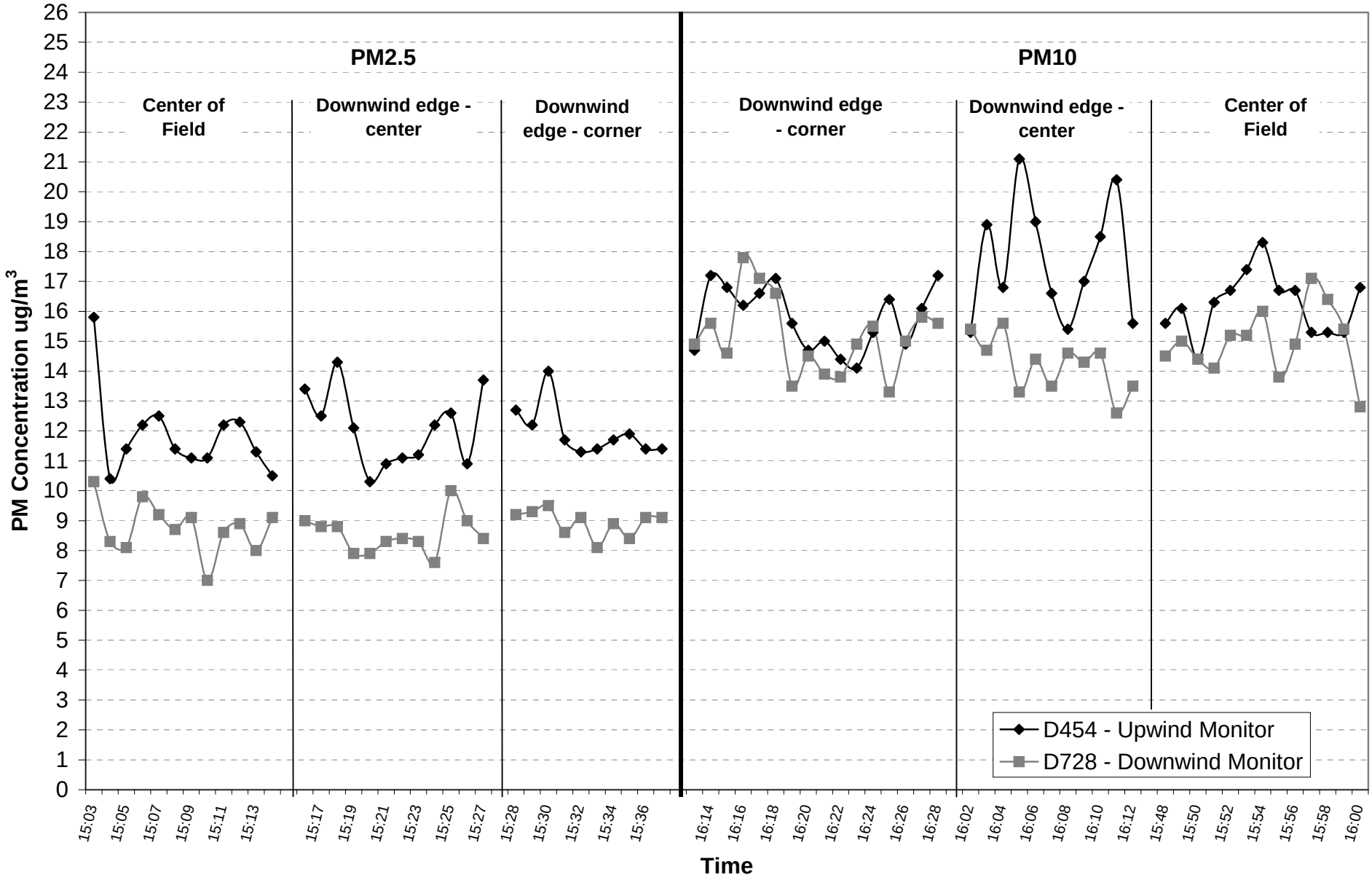


Figure 8.3 Results of airborne particulate monitoring at the John Mullaly Field

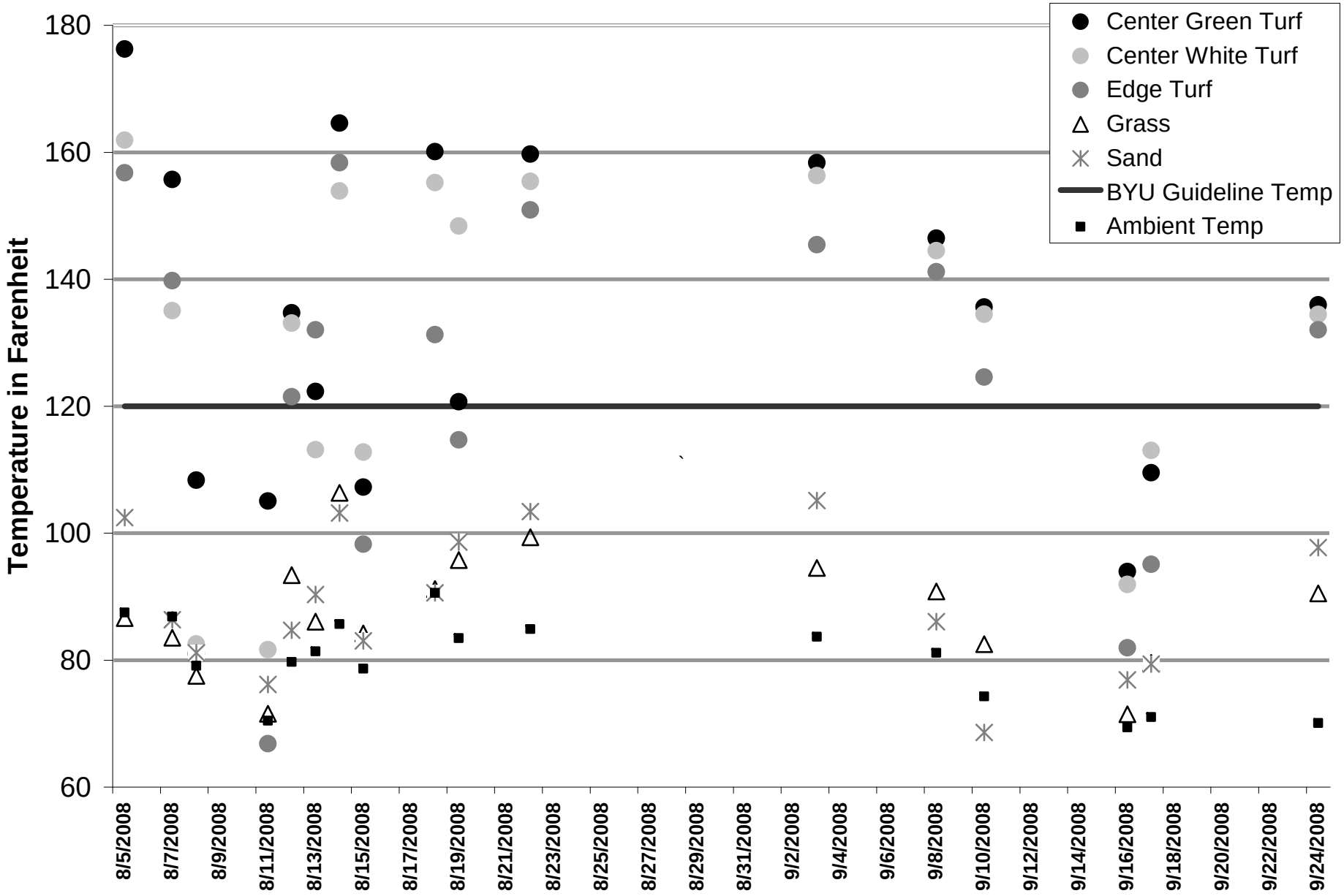


Figure 9.1 Thomas Jefferson field surface temperature measurements by date

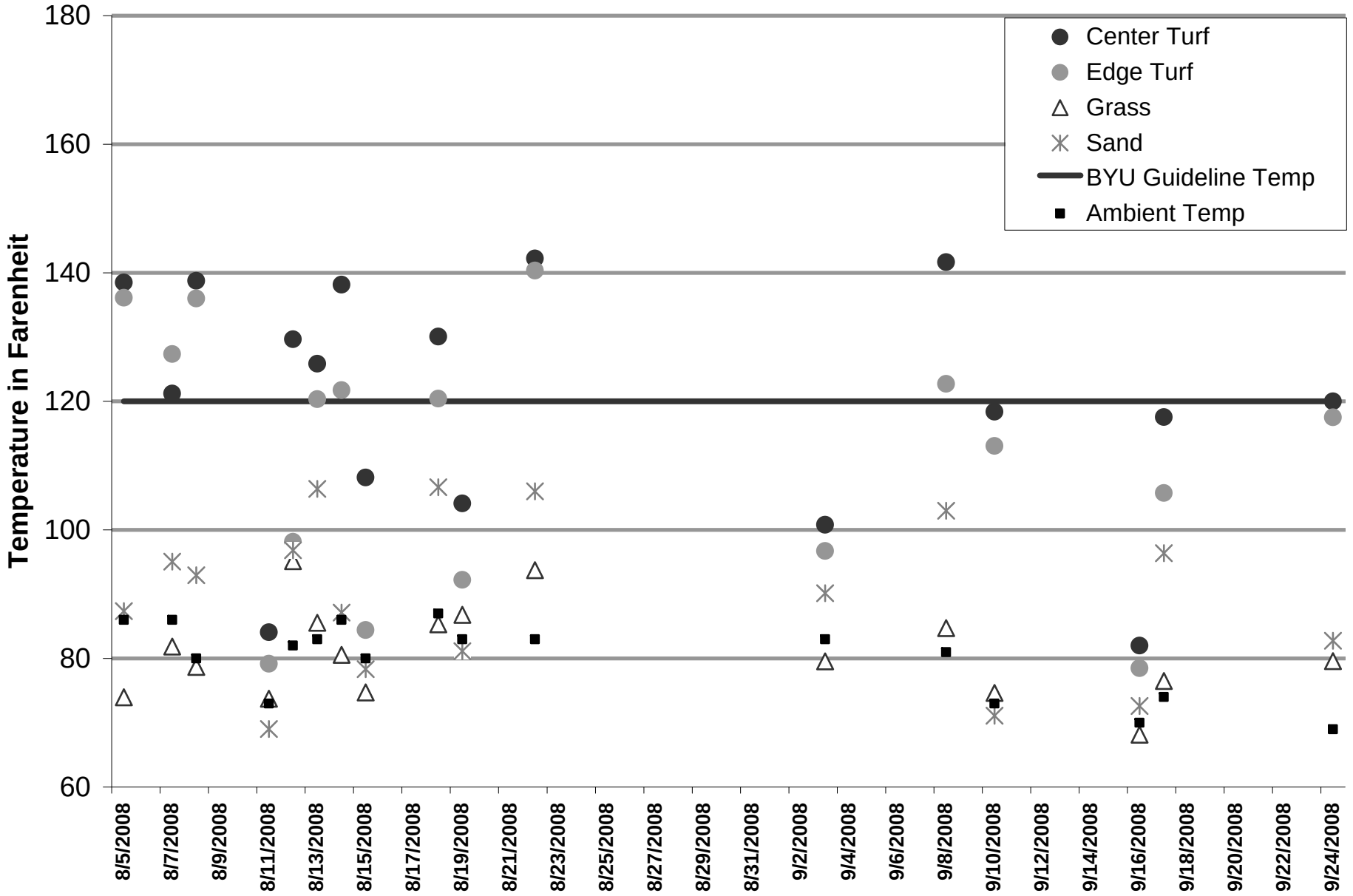


Figure 9.2 John Mullaly field surface temperature measurements by date

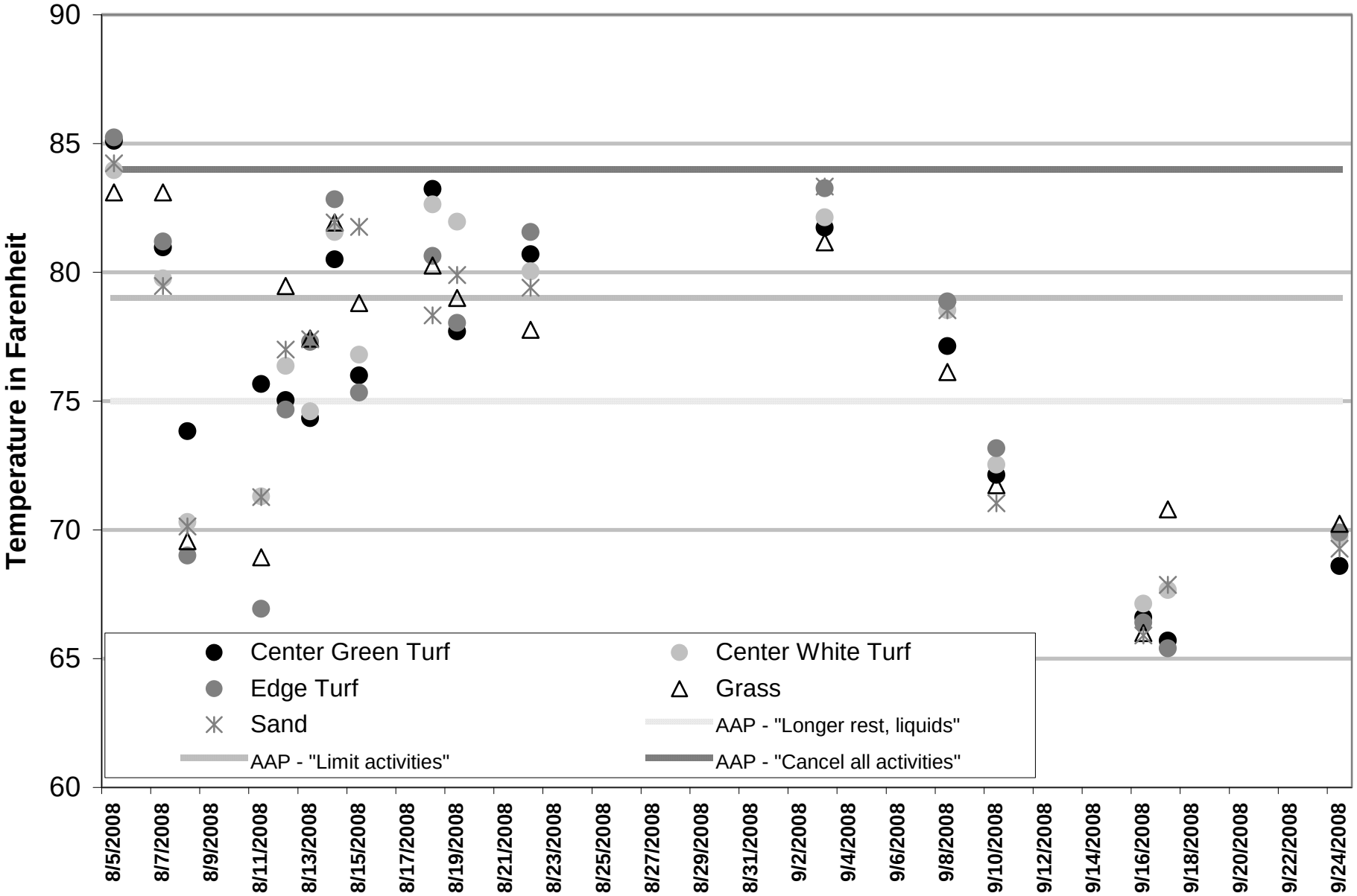


Figure 9.3 Thomas Jefferson field wet bulb globe temperatures by date

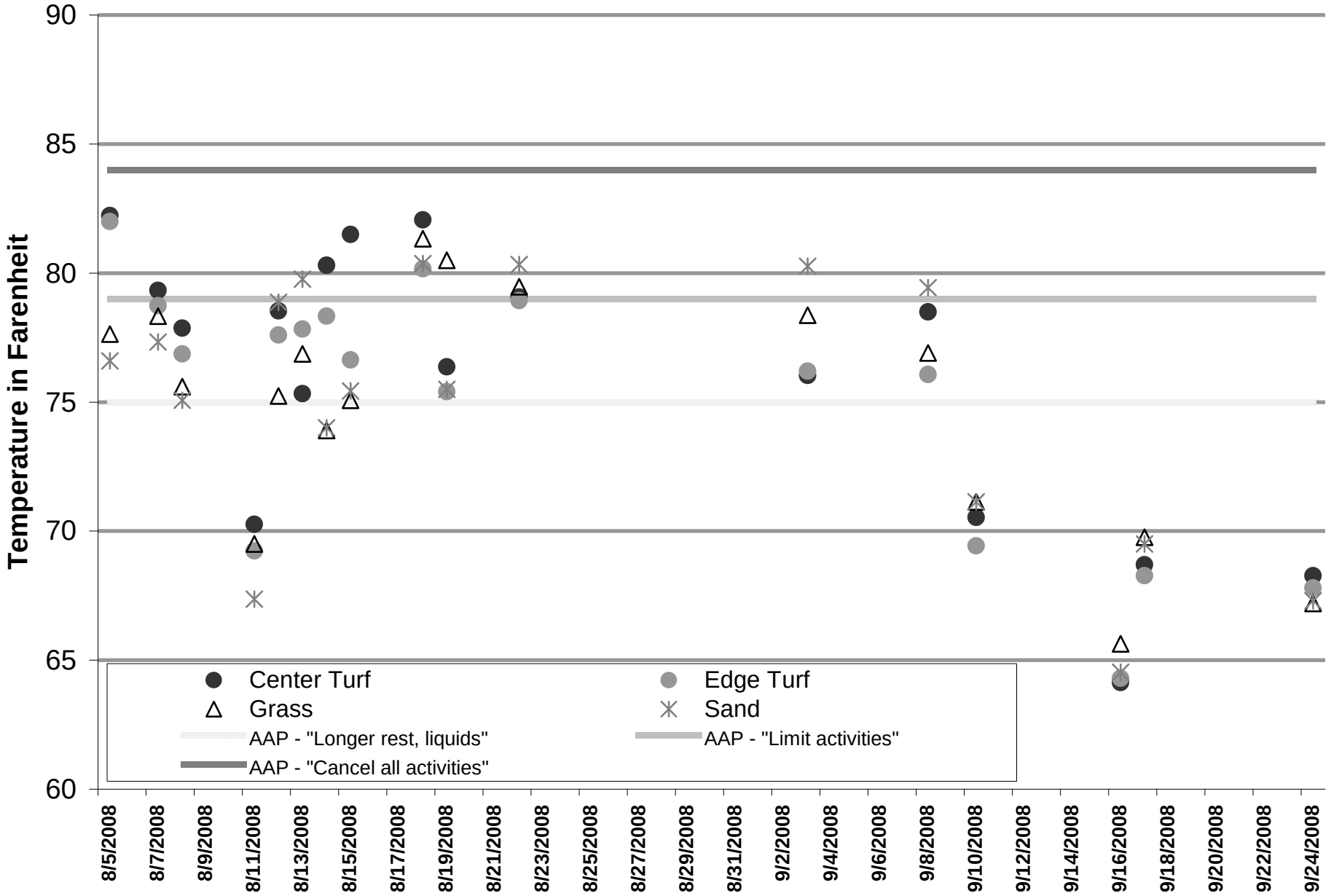


Figure 9.4 John Mullaly field wet bulb globe temperatures by date

Synthetic Turf Supplier Seeks to Set Record Straight

Athletic Turf News

ATHLETIC TURF

Synthetic turf supplier seeks to set record straight

Apr 25, 2007
Athletic Turf News

ATHLETIC TURF NEWS

Criticisms aimed at synthetic turf, including scattered complaints that the crumb rubber used as infill in new installations poses an environmental hazard as a leachate, drew a recent sharp response by John B. Giraud, managing director Target Technologies International. The Vancouover, Canada-based company is a major supplier of products and logistic solutions to the rubber mulch and sports turf industries.

The following is Giraud's response to recent environmental concern aimed at synthetic field installations:

The synthetic sports field is a system. What is a system related to leachates? The construction of a synthetic field is a filtration system. Normally most fields have specific drainage systems to move the water from the field: the sub base of the field is a layer of different aggregates while the synthetic grass and the infield all act as a filtration system. By the time the water moves a certain distance there will be little to no contamination.

When it comes to safety I see no value in their statements. I do agree children can bring in crumb rubber from their soles of their shoes into the house but they can also bring fertilizers from their shoes. I would suspect one can breath the harmful contaminates of fertilizers much easier than one can breath a 10- to 20-mesh crumb rubber particulate.

The writer suggests when it comes to the concern of silica sand — is the player really being exposed to silica? The sizing of the silica sand normally used for infields is a 20-40 mesh, which is impossible to breathe in. TTII has very strict specifications on the silica; the silica particle must not be agglomerated or crushed in the processing. When it comes to silica dust the silica provided from TTII is double washed, dried and screened to a very specific size. I would suggest any environmentalist that is concerned with silica dust not go to the beach; there is more silica dust exposure to humans at the local beach than you will ever find on any synthetic sports field. Obviously, proper protective clothing (such as approved air-filtration masks and safety glasses) should always be worn during field installs and renovations. Construction site safety and local regulations should never be compromised.

In this writer's opinion, synthetic sports field systems offer a much safer and ecological environment. We are not contaminating our ground water with fertilizers, pesticides, & operating equipment that spits toxic fumes applying fertilizers and pesticides weekly. Also, we aren't wasting a valued resource such as water on a daily basis.

When we examine a synthetic sports field vs natural grass fields, injuries are more prevalent with natural grass. With a natural grass field we face greater imperfections with elevations on the field as slight as they maybe. Ball players can twist and sprain their ankles due to these imperfections. There

are also fields, which we call all weather fields which are basically crushed sand or natural sand particles that are extremely dangerous when one falls on. At least with synthetic sports fields there is a cushion that supports fewer injuries to the athlete.

When it comes to nasty infections we now have introduced an anti-microbial product called TurfAide. This product has now been introduced to the synthetic sports field industry, and has a life span for the duration of the field (which normally is 8-10 years.) Once the product has been applied there is no leaching and contamination to the soil. This product has proven that it supports the prevention of harmful bacteria's attacking the athlete. This product is one of a kind and is not silver based.

Disposal not a problem

Our company has also recently introduced an environmental solution for the disposal of the synthetic turf fields, once they have gone through their life span. The disposal system is called STDF (Synthetic Turf Derivative Fuel) our company now has in place four cement factories that utilize not only the old synthetic carpet but also the infield materials such as crumb rubber for fuel. We now are saving the environment by not using fossil fuels, which is creating global warming. The temperature of kilns exceeds 3800 degrees F, which eliminates any toxic gases. This system has been approved by The Federal Environmental Protection Agency. Please visit our website, http://www.ttiionline.com/ for further information.

The disposal of tires in landfills is incorrect. There are many landfills that do accept tires but they are regulated by government agencies. The cement plants universally take in tires for fuel; they call this Tire Derivative fuel.

FIFA, one of the largest non profit organizations in the world came forth on July 12, 2006 and has made it clear that synthetic sports systems are environmentally friendly. I would suspect the problem with crumb rubber is the sizing of the product -- too many fines and too much fiber, which lends itself to environmental problems. Our company has taken the position to supply clean, well-graded crumb rubber that meets and exceeds normal industry standards. There is a lot of crumb rubber that is being supplied in the industry, which is sub-standard. TTII has taken great care evaluating suppliers that are capable of supplying good clean product.

TTII would suggest to any individual that speaks poorly of synthetic turf vs natural grass and ask if they drive a car or ride a bus — and if they do then I would suggest they consider a different mode of transportation. At the same time if these environmentalists wear a running shoe or any shoe that is made of rubber ultimately they are thrown in the trash; what then? Under these circumstances - by the writers thinking, they are a hypocrite to the environment. They should practice what they preach.

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

The Use of Recycled Rubber in Sports Surfaces

Sports And Play Construction Association (SAPCA)

The Use of Recycled Rubber in Sports Surfaces

Back

In conjunction with the British Standards Institute (BSI), the Sports and Play Construction Association (SAPCA) is helping to prepare new European (CEN) Standards for artificial sports surfaces. Through this work SAPCA has become aware of concerns being voiced in some European countries over the use of recycled rubber from vehicle tyres in sports surfaces. In response SAPCA has convened a working group of UK experts to investigate the situation. So far, SAPCA has carried out a substantial review of previous national and international studies undertaken by scientists on the risks from rubber aggregates in sporting contexts.

Waste rubber aggregate materials, derived primarily from vehicle tyres, are currently widely used in roads, railways, building construction, agriculture, packaging, bulk products, mining, automobiles and trucks, marine structures, landscaping and sports and play surfaces. The issue originates from some of the materials used in the manufacture of rubber. There are a number of organic and inorganic substances used in rubber manufacture that are potentially hazardous inviting caution. It has been suggested that there may be risks from leaching and therefore chemical pollution of soils and waters; there may also be possibilities of inhalation of volatile constituents, skin contact, ingestion, and abrasion of surfaces with particulate release.

SAPCA's opinion is that, because tyre rubber is designed to be strong, durable and substantially impermeable, it is unlikely that any losses could occur to air or water in concentrations that would pose serious human or environmental risk. This opinion is supported by the reports and academic studies reviewed, which have shown insignificant environmental effects of such chemicals or release of volatiles and particulates into the atmosphere. SAPCA is continuing with its investigations but subject to that our view is that there are negligible additional risks to humans based on theoretical extrapolation - indeed we have not identified from our initial investigation any evidence of reported symptoms or adverse health effects.

As with any health, safety or environmental concern, SAPCA will continue to maintain a watching brief on the situation. SAPCA has therefore initiated a dialogue with independent researchers and experts in this field. Where any avenues of further research are identified the Association will actively support necessary programmes to ensure that these materials continue to be used safely and meet the required standards for all concerned.

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Synthetic Turf Council Offers Clarity & Context to Concerns About New Jersey Fields

Synthetic Turf Council (STC)

NEWS RELEASE

DATE: April 15, 2008 **MEDIA CONTACT:** Shira Miller
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shira@shiramiller.com

Synthetic Turf Council Offers Clarity & Context to Concerns About New Jersey Fields

Atlanta, Ga. -- The Synthetic Turf Council, representing the U.S. synthetic turf industry, wants to offer some clarity and context to the concerns raised by the New Jersey Department of Health and Senior Services yesterday.

We offer this information as part of our corporate and community responsibility to not only promote health and safety, but also to act as an industry that relies on science, technology, research, engineering, testing and factual data. These standards have enabled our industry to develop cutting edge products that provide safe, environmentally sound sports and recreation facilities for communities throughout the country, contributing to the conservation of land and natural resources.

Based on the facts, chemical science, and research that is readily available, we believe the synthetic turf fields identified in New Jersey, and similar fields made with nylon fibers, are safe to use and pose no known risk to an individual's health or the environment.

Here are the facts:

The pigment used to color the nylon fiber contains lead chromate, a component used to extend the yarn color lifespan. Lead chromate is a highly insoluble compound with extremely low bioavailability, which is diluted, extruded with resins and microencapsulated within the nylon fiber. In fact, OSHA requires no protective measures when handling the turf fibers.

Extremely low bioavailability means that even if the compound were to be ingested, it is very difficult for the compound to be absorbed within the body. There is no known evidence that this poses any health risk.

The City of Newark recently conducted elemental analysis testing using EPA approved protocols on turf fibers from Ironbound Stadium, one of the fields identified in the New Jersey report. A separate independent test, supervised by Dr. Davis Lee, PhD of Chemistry with InnovaNet, was also conducted. Both tests concluded that under EPA approved test conditions, no leaching of heavy metals occurs. In other words – the lead chromate can't escape the nylon within which it is contained.

In addition, the City of Newark ordered an air monitoring test which was conducted by Weston Solutions at the Ironbound site during removal of the stadium's nylon surface. The test found no detectable levels of airborne lead or lead chromate. The technical data and summaries of these tests are available to the public and the media.

It's important to point out that the evaluation by the New Jersey DHSS of the safety of the material content of the synthetic turf in question is being made by using EPA residential soil safety standards. The EPA soil safety standard does not take into consideration the extremely low bioavailability of compounds that are bound and encapsulated in plastics such as synthetic turf. Given the serious nature of the report issued yesterday, it's critically important to point out the DHSS report itself acknowledges there is "a very low risk of exposure" to the users of the fields in question.

About the Synthetic Turf Council

Based in Atlanta, the Synthetic Turf Council was founded in 2003 to serve as an objective resource assisting buyers and end users with the selection, use, and maintenance of synthetic turf systems in sports field, golf, and landscape applications. The organization actively collects reputable studies and research, as well as official statements by governmental agencies and sports organizations, which address the impact of synthetic turf sports fields. STC members produce and install most of the synthetic turf sports fields in North America. Membership includes builders, landscape architects, testing labs, maintenance providers, installation contractors and other specialty service companies. For more information, visit www.syntheticturfcouncil.org.

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TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Synthetic Turf Sports Fields and the Environment

John Amato, P.E.

Synthetic Turf Sports Fields and the Environment

By John Amato, P.E.

I have been following the bantering back in forth regarding the proposed synthetic turf sports fields for Westford Youth Sports and find that there are a large portion of interested citizens that, although a first glance appear excellent at collecting data from internet sources, are having difficult time reading between the lines. To determine if infill synthetic turf sports fields are beneficial and if they should be funded using Community Preservation Funds you really need to dig past the negative marketing that is growing like a vine on the web.

First of all I feel it necessary to provide you with a little information about myself. I am a licensed civil engineer and have a sports facility design and consulting firm located here in Westford. In addition I am a committee member of the Sports Surface Committees on Natural Grass Fields, Tennis Courts and Running and Tracks and Synthetic Turf with the American Society of Testing Methods where we develop test methods and standards for the development and installation and safety of these venues. Beyond that I'm also on the Board of Directors of the Synthetic Turf Council. In these industry groups I spend equal time between natural and synthetic systems. We have developed standards for construction of running tracks, sand based sports fields, skinned infields and warning tracks, golf, tennis courts, synthetic turf. We have also developed test methods for the testing and evaluation of these venues with safety and performance as the primary goal.

Between my professional work and my industry related activities I have gained a solid knowledge base regarding these systems. I do not sell turf. I am not a carpet salesman. I have a natural lawn and not a synthetic one.

Both natural turf and synthetic turf have their places in the world of outdoor sports and recreation fields. Each situation needs to be evaluated to determine which surface type will best meet your needs. Natural turf, my preferred surface, is only suitable in cases where the projected hours of use per week can be limited and where you can spend the appropriate level of maintenance funds. For example, using a natural turf sports field more than 20 to 24 hours per week will compact the soil and damage the turf. This equates to between 680 and 816 hours per year over a three season window. Basically, grass is a living thing and can only handle limited use without destroying it. Unfortunately when using a natural turf sports field at these rates it needs to rest for a season and the recommended hours per year would be reduced. We do not have enough fields to rest any of them for a full season. Natural turf should not be used during the rain or when wet. This damages the turf. In most cases games and events are canceled and require rescheduling. Most times due to lack of available fields rescheduling is not possible. Overuse of natural turf fields almost always creates hard non-uniform unsafe surfaces and a reduction in the overall quality of programs offered on that surface.

Synthetic turf on the other hand can be used around 3,000 hour per year. Read the warranty. Because it s designed to be rapidly draining, play can take place in the rain and after the rain without damage to the turf. Synthetic fields are far more uniform and consistent than most natural turf fields and therefore a safer surface to practice and compete on. In addition they are made of resilient materials, much like a children's playground should be, and provide a level of impact attenuation that is difficult to obtain on hard over used natural turf fields.

The sports fields that are proposed for our Town are what are considered third generation infill synthetic turf. This is very different from the traditional plastic and nylon carpets most of us old folks played on. These third generation, and with the new monofilament technology forth

generation turf systems consist of a tall pile fiber simulating grass that is infilled with a mixture of resilient materials such as SBR rubber and sand. Basically the safety surface is located in simulated grass and not below the turf as in traditional systems. This creates a natural turf like texture that behaves much like natural turf grown in a soil. In fact based on testing by International Soccer organizations these surfaces are typically approved for all but the highest end competitions. Yes professional soccer players prefer natural grass but we will see our local Revolution playing on synthetic this season.

From a use standpoint these infill synthetic surfaces can survive easily three to four times the use of a natural grass field. So what does that mean for us? Well to develop a natural grass complex that provides the use benefit of one synthetic turf field we would need to develop at least three natural turf sports fields. Given that one field and the surrounding grading, safe zones, team areas and spectator areas takes up approximately three acres, we would need to build least nine acres of natural grass fields for the same net use as three acres for one synthetic field. By the way, the three acre space per field is not all field.

If you're a community with a need for six fields, I believe we actually need more, you need to obtain a site large enough to construct the six fields plus parking and any support program that you may need. That would require development of approximately 18 acres of buildable upland. Now if you could develop a complex that provides that same amount of use time using two synthetic turf sports fields in six acres and area able to "preserve" 12 acres does that constitute "preservation"? I believe that is serious preservation.

For those of you that follow the "Inconvenient Truth" philosophy, trees and shrubs tend to have at least twice the biomass as grasses. In grasses that are mowed you could expect even a larger difference. Therefore an acre of trees consumes at least twice the CO_2 as grass not to mention the other environmental benefits. Cutting an 18 acre forest to build 18 acres of grass fields cuts the potential CO_2 consumption in half. Clearing only six acres of the same 18 acre forest to build synthetic turf results in only a one-third decrease in CO_2 consumption potential. Basically two synthetic turf fields has a smaller CO_2 footprint than six natural grass fields. Again we "preserve" by using synthetic turf. Al Gore eat your heart out.

If you're still not convinced and decided to build the six natural turf sports fields you would need to consider that each field needs approximately 70,000 gallons of irrigation water each week. With six fields that is 420,000 gallons of water each week. That's just water. To maintain fields we need to fertilize them. A typical total yearly rate is approximately 15 to 20 pounds per 1,000 square feet of turf. This does not sound like much, however, with each of the six fields having 90,000 square feet of turf we need approximately four to five tons of fertilizer each year. The equipment, mowing, aeration, overseeding, turf repair, watering, application of fertilizer not to mention any herbicides and pesticides that could be required all add up to a substantial investment in man hours and materials. Reducing discharges into the environment is considered a method of "preserving" our natural resources and synthetic turf does just that.

A synthetic turf on the other hand does not need the amount of man hours and equipment needed for a natural turf sports field. A synthetic turf field needs to be groomed once every four to six weeks, dragged once a week and cleaned up at the same rate as a natural turf field. When it's hot outside these fields do heat up. Many use water as a means to cool the fields. Most do not. This water use is far less than that needed for irrigation of natural turf sports fields. Based on available data that I have reviewed, one can conclude dry areas with high elevation tend to the up more than low elevations. Comparing heat build up at Brigham Young, Penn State and New York City

one sees a heat build-up of as much as 100, 40 and 20 degrees Fahrenheit. These locations are all at the same latitude but differ in elevation and air moisture content.

Typical comparison of natural turf as compared to synthetic turf maintenance yields an investment of two or three to one on a per field basis. When you extrapolate this while considering that one synthetic turf field does the duty of three natural turf fields this becomes four to nine times the maintenance cost per hour of field use for a natural turf field over that of a synthetic turf. Data you may have seen on-line indicating $20,000 to $40,000 per year to maintain a synthetic turf field is for high-end Division I College and Professional fields not recreation fields located in Towns similar to our Town. Again, as with the savings on the amount of land indicates, the reduction in maintenance costs shows a large advantage. Clearly this is "preservation" of maintenance funds and manpower.

So why is there tons of data that says the opposite? This is big business. There have been approximately 4,000 synthetic turf sports fields constructed in the USA. This year there we will construct nearly 800 new synthetic turf sports fields in this country. In total that represents 4,800 fields that do not need sod, 4,800 fields that do not need fertilizer and 4,800 fields that do not need mowers, herbicides and other natural turf services. The natural turf business in loosing serious ground and they are fighting to maintain their ground, no pun intended. This is an industry loss in the order of hundreds of millions of dollars. This negative marketing is about money. Every owner they convince to keep it natural is money in their pocket. Check out the sources of most of the negative data. They are turf managers, turf scientists and others in the industry hurt most by the growth of synthetic turf. This is about money.

What about all of the data indicating that the rubber used is bad for the environment? Again, recent studies in Europe prompted by market competition put the scare into buyers to shift market trends. Most infill synthetic turf fields use recycled tire SBR crumb rubber as the resilient material. These recycled tires are not from stockpiles but from shops that replace tires. They take your old tires and send them to be granulated. Alternative material producers, far more expensive that the recycled tire rubber, would like to get into this hug market so a little miss information or partial information goes a long way and can create a lot of damage to an industry.

So here is some truthful information. The US EPA states that "scrap tires are not a hazardous waste." Scrap tires become a generator of hazardous materials when they are burned or exposed to temperatures over 400 degrees Fahrenheit. This information comes from the EPA and from Material Safety Data Sheets required by OSHA to ensure safety in the work place. Check out the following; http://www.epa.gov/garbage/tires/index.htm. The EPA, in fact, recommends using the crumb material from granulated tires for "playgrounds, running tracks and sports fields." These fields are a method to recycle tires. As we know recycling is a means to "preserve" our environment. As a country we generate approximately 350,000,000 tires each year. Recycling these is a good thing for the environment. The EPA would not tell us to use recycled tire rubber in playgrounds where our youngest children play if they were not sure it was safe. In fact, if you go beyond the many studies done over the past 30 years you will find consistently that the use of recycled tire SBR rubber in playgrounds and sports fields does not represent a risk. There is far more information that supports this EPA position than that presented by the negative marketers.

Now how does this fit into the use of infilled synthetic turf and funding by Community Preservation Committee Funds. First of all, Massachusetts General Law CHAPTER 44B. COMMUNITY PRESERVATION, Chapter 44B: Section 2. Definitions indicates:

"Recreational use", active or passive recreational use including, but not limited to, the use of land for community gardens, trails, *and noncommercial youth and adult sports, and the use of land as a park, playground or athletic field.* "Recreational use" shall not include horse or dog racing or the use of land for a stadium, gymnasium or similar structure.

In chapter 44B: Section 5 of this same law states;

(2) The community preservation committee shall make recommendations to the legislative body for the acquisition, creation and preservation of open space; for the acquisition, preservation, rehabilitation and restoration of historic resources; *for the acquisition, creation and preservation of land for recreational use*; for the acquisition, creation, preservation and support of community housing; *and for the rehabilitation or restoration of open space, land for recreational use* and community housing that is acquired or created as provided in this section. With respect to community housing, the community preservation committee shall recommend, wherever possible, the reuse of existing buildings or construction of new buildings on previously developed sites.

The law clearly states that Towns can use Community Preservation funds of active recreation. In fact they state "*creation and preservation"*. They include *"and the use of land as a park, playground or athletic field*" in their definition as well. Other Towns including Tyngsborough, Concord and Sandwich to mention a few have approved funding for synthetics. The installation of a crumb rubber infill synthetic turf sports field is an EPA recommended method to recycle scrap tires. It provides a substantial decrease in water demand for irrigation. It reduces discharge of pollutants into our natural resources and decreases man hours necessary to maintain a field. It results in a net decrease in land required to provide matching hours of use. It is safer than most natural turf fields due to its resilient surface and uniformity. In essence, it reduces the environmental impact of project that meets similar hours of demand, it reduces water demand, it eliminates the need for fertilizer, it decreases the amount of canceled games and practices, it can extend the months of play, and it is safer. It preserves the environment and preserves the health of our children. If that is not community preservation then nothing is.

Synthetic Turf Supplier Seeks to Set Record Straight

Athletic Turf News

Mark Nicholls

From: Joe Simpson **Sent:** Fri 4/27/2007 10:20 AM
To: Mark Nicholls
Cc: Jay Crider
Subject: FYI - excellent answer to rubber and sand safety issues.
Attachments:

ATHLETIC TURF

Synthetic turf supplier seeks to set record straight

Apr 25, 2007
Athletic Turf News

The *Brooklyn Eagle* and the Green Clinton Courier are reporting that a psychology professor and the city's Public Advocate are calling for additional testing on the crumb rubber used in the synthetic turf athletic fields being installed in New York city parks.

The city has installed 73 synthetic turf athletic fields and is planning as many as 43 additional synthetic installations in the next five years. But several people have been vocal in their opposition, and have gained the attention of the press.

City College Psychology Professor William Crain and Rutgers chemist Junfeng Zheng reportedly analyzed crumb rubber pellets collected from city parks and, they claim that preliminary testing indicated they contain polycyclic aromatic hydrocarbons (PAHs) above levels deemed safe by the state's Department of Environmental Conservation. Crain is one of several people requesting that the parks department send additional samples of the crumb rubber to an independent laboratory for more thorough testing before proceeding with plans to install more synthetic sports fields.

The city is reportedly the largest municipal buyer of synthetic turf in the United States and has "carpeted" 3 million square feet of fields with it between 1998 and 2004.

Supplier doesn't mince words

These and other criticisms aimed at synthetic turf, specifically a complaint that the crumb rubber used as infill in new installations poses an environmental hazard as a leachate, drew a recent sharp response by John B. Giraud, managing director Target Technologies International. The Vancouver, Canada-based company is a major supplier of products and logistic solutions to the rubber mulch and sports turf industries.

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When it comes to safety I see no value in their statements. I do agree children can bring in crumb rubber from their soles of their shoes into the house but they can also bring fertilizers from their shoes. I would suspect one can breath the harmful contaminates of fertilizers much easier than one can breath a 10--to 20-mesh crumb rubber particulate.

The writer suggests when it comes to the concern of silica sand — is the player really being exposed to silica? The sizing of the silica sand normally used for infields is a 20-40 mesh, which is impossible to breathe in. TTII has very strict specifications on the silica; the silica particle must not be agglomerated or crushed in the processing. When it comes to silica dust the silica provided from TTII is double washed, dried and screened to a very specific size. I would suggest any environmentalist that is concerned with silica dust not go to the beach; there is

more silica dust exposure to humans at the local beach than you will ever find on any synthetic sports field. Obviously, proper protective clothing (such as approved air-filtration masks and safety glasses) should always be worn during field installs and renovations. Construction site safety and local regulations should never be compromised.

In this writer's opinion, synthetic sports field systems offer a much safer and ecological environment. We are not contaminating our ground water with fertilizers, pesticides, & operating equipment that spits toxic fumes applying fertilizers and pesticides weekly. Also, we aren't wasting a valued resource such as water on a daily basis.

When we examine a synthetic sports field vs natural grass fields, injuries are more prevalent with natural grass. With a natural grass field we face greater imperfections with elevations on the field as slight as they maybe. Ball players can twist and sprain their ankles due to these imperfections. There are also fields, which we call all weather fields which are basically crushed sand or natural sand particles that are extremely dangerous when one falls on. At least with synthetic sports fields there is a cushion that supports fewer injuries to the athlete.

When it comes to nasty infections we now have introduced an anti-microbial product called TurfAide. This product has now been introduced to the synthetic sports field industry, and has a life span for the duration of the field (which normally is 8-10 years.) Once the product has been applied there is no leaching and contamination to the soil. This product has proven that it supports the prevention of harmful bacteria's attacking the athlete. This product is one of a kind and is not silver based.

Disposal not a problem

Our company has also recently introduced an environmental solution for the disposal of the synthetic turf fields, once they have gone through their life span. The disposal system is called STDF (Synthetic Turf Derivative Fuel) our company now has in place four cement factories that utilize not only the old synthetic carpet but also the infield materials such as crumb rubber for fuel. We now are saving the environment by not using fossil fuels, which is creating global warming. The temperature of kilns exceeds 3800 degrees F, which eliminates any toxic gases. This system has been approved by The Federal Environmental Protection Agency. Please visit our website, http://www.ttiionline.com/ for further information.

The disposal of tires in landfills is incorrect. There are many landfills that do accept tires but they are regulated by government agencies. The cement plants universally take in tires for fuel; they call this Tire Derivative fuel.

FIFA, one of the largest non profit organizations in the world came forth on July 12, 2006 and has made it clear that synthetic sports systems are environmentally friendly. I would suspect the problem with crumb rubber is the sizing of the product -- too many fines and too much fiber, which lends itself to environmental problems. Our company has taken the position to supply clean, well-graded crumb rubber that meets and exceeds normal industry standards. There is a lot of crumb rubber that is being supplied in the industry, which is sub-standard. TTII has taken great care evaluating suppliers that are capable of supplying good clean product.

TTII would suggest to any individual that speaks poorly of synthetic turf vs natural grass and ask if they drive a car or ride a bus — and if they do then I would suggest they consider a different mode of transportation. At the same time if these environmentalists wear a running shoe or any shoe that is made of rubber ultimately they are thrown in the trash; what then? Under these circumstances - by the writers thinking, they are a hypocrite to the environment. They should practice what they preach.

Score Board

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Strike Out 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 **Home Run**

resident geese

- Irrigation technology races ahead as water issues grow
- Toro announces new partnership with U.S. Soccer
- Toro joins effort to promote youth baseball, softball worldwide
- NFL grounds pros gather near Chicago
- The 'dirt' on infield skins
- Terraplas and Covermaster Inc. form alliance
- NFL grounds pros plan 2-day symposium
- Nicole Sherry returns to Camden Yard . . . this time as grounds boss

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TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

CPSC Staff Analysis and Assessment of Synthetic Turf "Grass Blades"

U.S. Consumer Product Safety Commission

CPSC Staff[1] Analysis and Assessment of Synthetic Turf "Grass Blades"

CPSC staff identified synthetic turf products for analysis of total lead content and accessible lead. Staff obtained samples of turf that had been left over after installation or that became available when a field was dismantled. Staff also visited in-service synthetic turf fields, and used portable X-ray Fluorescence (XRF) testing equipment to detect the presence of lead in the product, as well as a portable field wiping apparatus to measure the exposure potential to the lead.

The staff considered that exposure to the lead present in some synthetic turf products could occur if some of the lead gets on children's hands, perhaps when synthetic grass blades break or become worn and release small particles of lead-containing material. The lead on the children's hands may then get transferred from their hands to their mouths through normal hand-to-mouth activity during or after playing on the field.

Analytical Methods

Lead Content

Small pieces of synthetic grass blades were dissolved in concentrated nitric acid using a microwave digestion. The digested sample solutions were then analyzed for lead content using inductively coupled plasma atomic emission spectroscopy.

Accessible Lead (Wipe Sampling)

Products found to contain lead were tested for accessibility of the lead; *i.e.*, whether children using the product could be exposed to the lead that is present.

Staff adapted the approach for estimating exposure to lead from contact with lead-containing synthetic turf fields from the approach used to assess children's exposure to arsenic from playing on playground structures built using chromated copper arsenate (CCA) pressure-treated wood (Appendix A).

The wipe testing methodology developed for testing pressure-treated wood was used to measure transfer of lead from synthetic grass blades, with one modification. Ghost Wipe™ was used in place of the polyester cloth wipe used in the wipe sampling for wood. Ghost Wipe™ is a commercially available wiping material, 15 cm x 15 cm, pre-moistened with deionized water, and sold in individually sealed packets. Company literature indicates that the Ghost Wipe™ meets all ASTM E1792-96E[2] specifications for sampling materials for lead in surface dust.

The general method involves attaching a Ghost Wipe™ to a 1.1 kg weighted disk, 8 cm in diameter, installed in a device built to provide a standardized and consistent surface wiping. The disk is dragged down a 50-cm length of turf sample for 10 back and forth strokes. The wipe is then removed for analysis.

---

[1] These comments are those of the CPSC staff, have not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

[2] ASTM Standard E1792-96E, "Standard Specification for Wipe Sampling Materials for Lead in Surface Dust," ASTM International, West Conshohocken, PA, www.astm.org.

Results

Several of the products obtained by staff contained lead in the synthetic grass with concentrations ranging from 0.09 percent lead by weight to 0.96 percent. The testing showed that lead content varied between synthetic turf installations, and also within a field depending on color.

The data show that wiping of the surface of lead-containing synthetic turf with firm pressure results in transfer of some lead or lead-containing material to the wipe medium (Ghost Wipe™).

Exposure Assessment and Results

If it is assumed that transfer of lead-containing residue from the surface of synthetic turf has similar characteristics to transfer of arsenic-containing residue from wood (Appendix A) (*i.e.*, that the amount of residue collected does not increase infinitely, but plateaus at some point during play), then the amount of lead that might collect on the hands of children as they play on turf fields can be estimated from laboratory studies of synthetic turf.

As discussed in Appendix A, the experimental wipe method using polyester cloths overestimated the amount of residue that might be transferred to a person's bare skin by a factor of between five and 13 times, depending on whether a wet or dry cloth was used. Although the relationship between surface residue removal by a Ghost Wipe™ and bare skin has not been fully characterized, preliminary tests indicate that the Ghost Wipe™ overestimates to a similar degree the transfer of material from the turf surface to bare hands.

The staff believes that dividing the results obtained through use of using Ghost Wipes™ by five is a reasonable approximation of the amount of lead-containing material that may transfer to children's hands.

The exposure assessment described above concerns the accessibility of the lead. Another important point to consider is the bioavailability of the lead, which relates to the amount of lead that is absorbed by the body. The staff assumed, in this case, that the bioavailability of lead from the material that transfers to skin from contact with lead-containing synthetic turf is the same as the bioavailability of lead from food and drink in the epidemiological studies of lead exposure.

The staff's approach, based on the assessment of exposure to arsenic in pressure-treated wood, is that during play, lead-containing residue is transferred to a child's hands and then a portion of that "handload" is transferred to the mouth during the day. The staff practice for assessing whether exposure to a product would result in excessive lead exposure is to assume that about half of the residue that collects on a child's hands ends up in their mouths (*i.e.*, transfer efficiency is 50 percent).

The staff used the wipe-testing data to estimate transfer of lead to children's hands during contact with a synthetic turf surface during play. Each wipe value was divided by five to correct the overestimation of transfer using the Ghost Wipe™, and divided by two to account for the amount of lead that is transferred from the hands to the mouth.

CPSC staff recognizes a level of 10 micrograms of lead per deciliter of blood (10 µg/dL) as a level of concern with respect to lead poisoning. To prevent children from exceeding this level, the staff suggests that chronic ingestion of lead from consumer products should not exceed

15 µg lead/day[3]. This value was determined from epidemiological studies of ingestion of lead through food and drink (as discussed above with respect to bioavailability).

The results (Table 1) for this set of tested synthetic turf fields show no case in which the estimated exposure for children playing on the field would exceed 15 µg lead/day.

Study Limitations

This assessment is subject to a number of limitations including the accuracy of the wipe sampling method for estimating exposure to lead-containing residue from touching or other contact with the synthetic turf surface; the accuracy of the assumptions about the capacity of bare skin to collect surface residues during a typical play event at a field; and the accuracy of the assumptions related to hand-to-mouth transfer of lead-containing residues. Further, the staff did not make adjustments in its assessment to account for the non-uniformity of lead content of synthetic turf fields; *i.e.*, some fields had striped areas that contained lead that constitute only a small part of the total playing surface of the field that otherwise had no detectable lead levels. Children playing on such fields might have some contact with the lead-containing striped areas, but most of their contact with the surface would be expected to be with the other parts of the turf (not lead-containing). Finally, the bioavailability of lead from synthetic turf may not be the same as it is for the food and drink exposures that were the basis of the dose-response assessment used to determine the staff's recommended 15 µg/day exposure limit for lead.

[3] 16 C.F.R. § 1500.230. Codified Guidance Policy for Lead in Consumer Products (63 FR 70648; December 22, 1998).

Appendix A

The staff's previous assessment[4] of children's exposure to arsenic from playing on playground structures built using chromated copper arsenate (CCA) pressure-treated wood informed the current approach to analysis of synthetic turf surfaces and the assessment of potential exposure to the lead contained in the turf "grass" fibers. Lessons learned from the CCA studies include:

1) Development of a treated wood sampling method: A saline-wetted polyester cloth wipe was attached to a 1.1 kg weighted disk, 8 cm in diameter. The disk was dragged down a 50-cm length of wood for 10 back and forth strokes. When compared to results of residue transfer using volunteers with bare hands, the polyester cloths picked up approximately 13 times more residue; the experimental values were multiplied by a conversion factor of 0.076 to get human skin equivalent handloadings. When the polyester cloths were used dry, they picked up, on average, about 5 times more residue than the volunteer's bare hands did.

2) Understanding of some of the characteristics of treated wood surface residues: Removal of surface residue arsenic correlated with several experimental design features including the material used to wipe the surface, whether the material was wetted or dry, the amount of force applied during wiping, and the area wiped. A key observation was that the amount of dislodged residue did not necessarily simply increase with changes in method that would likely remove more residue. Rather, the amount of dislodged residue approached a plateau, *i.e.*, it appeared that the transfer of material depended on the capacity of the transfer medium (whether the skin of hands of volunteers or wipes made of cloth or other materials) to collect residue, which was not infinite.

3) Understanding of the nature of children's contact with playground structures and potential exposure to surface residues: The data, in conjunction with activity analysis of children playing on playgrounds, led to the conclusion that despite the large variability in children's playground activities and time spent at a playground, their hands would likely collect surface residues from the wood structures they happened to touch fairly quickly in a play session—what the staff termed "maximum handloading". For the exposure and risk analysis, then, the staff assumed that a child's hands would become contaminated with an amount of arsenic as determined by the experimental study of residue transfer. Data from cloth wipes were adjusted for the finding that the cloth wipes always picked up more residue from the wood surfaces than the bare skin of volunteers.

[4] Briefing Package, Petition to Ban Chromated Copper Arsenate (CCA)-Treated Wood in Playground Equipment (Petition HP 01-3), February 4, 2003.

Table 1. Turf Sample Exposure Results and Health Hazard Evaluation

Firm	Description	Subsample	Lead content (%)	Wipe Sampling Result (µg) *	Estimated daily ingestion of lead (µg) †‡
1	Green, installed 1999; removed 2008	1	0.54	65.8	6.6
		2	0.56	98.7	9.9
		3	0.55	39.9	4.0
		Average		68.1	6.8
1	Green, indoor field; installed 2000; in use		0.88	14.3	1.4
1	Green; new, 2008	1	0.1	1.2	0.12
		2	0.09	1.2	0.12
		3		0.9	0.09
		Average		1.1	0.11
1	Green; new, 2008	1	0.42	1.3	0.13
		2	0.47	0.4	0.04
		3		0.4	0.04
		Average		0.7	0.07
2	Green and other colors; installed 2005; in use		nd	nt	neg
2	Green; unused sample sent to lab for analysis		nd	nt	neg
2	Green; unused sample sent to lab for analysis		nd	nt	neg
2	Green; unused sample sent to lab for analysis		nd	nt	neg
2	Green; unused sample sent to lab for analysis		trace	nt	neg
2	Green; unused sample sent to lab for analysis		nd	nt	neg
2	Red; unused sample sent to lab for analysis		nd	nt	neg
2	Yellow stripes; field in use	Sideline,1	0.53	0.9	0.09
		Sideline,2		0.5	0.05
		Midfield		2.4	0.24
3	Green with yellow stripes; installed 2007; in use	Green	nd	nt	neg
		Yellow,18	0.96	0.7	0.07
		Yellow,19		1.4	0.14
		Yellow,20		0.8	0.08
		Yellow, Average		1.0	0.1
4	Green; white stripes; installed 2004; in use		nd	nt	neg

Note: nd = none detected; nt = not tested; neg = negligible

[*] Amount of lead collected on Ghost Wipe™ during wipe testing; if multiple wipes were conducted on a sample, the result of the first wipe is shown; all values are total lead removed during wipe.

[†] Laboratory wipe results divided by 5 to account for differences in lead residue removal efficiency of the Ghost Wipe™ and bare skin. The factor of 5 was taken from the staff's CCA studies; a similar trend was found in limited hand sampling of synthetic grass blades. Staff assumes that half of the residue that collects on a child's hands will be transferred to the mouth and ingested. Thus, the estimated daily ingestion of lead is the Ghost Wipe™ result divided by 5 divided by 2.

[‡] The estimated daily ingestion of lead is an estimate of exposure for children playing on a synthetic turf field. Each estimate in this analysis may be compared to the 15 µg/day level that CPSC staff suggests not be exceeded in order to prevent young children from exceeding the 10 µg/dL blood lead level of concern.

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Environmental and Health Study SBR Rubber Granulates

ISA - Instituut voor Sportaccommodaties

Instituut voor Sportaccommodaties

Environmental and Health Study SBR Rubber Granulates

The Netherlands

Nicole Salzmann

ISA Sport

ISA Sport - general

- Instituut voor Sportaccommodaties (started in 1959)
- 3 departments: research, field testing, consultancy

Laboratory:

- sports floors
- materials for sports floors
- attributes
- development

On-site:

- quality monitoring
- certification


Certificaat

INHOUD

Instituut voor Sportaccommodaties B.V.

ing. T.A. Jooston
Directeur

Sports facilities



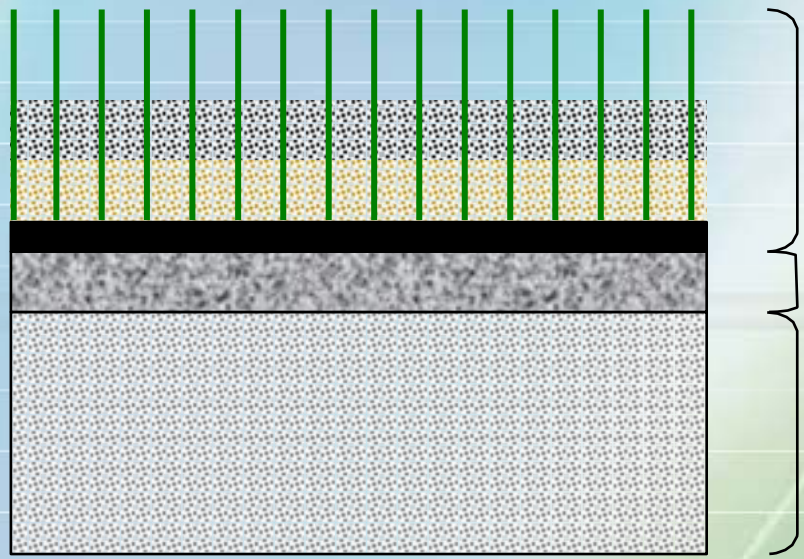
Instituut voor Sportaccommodaties

ISA Sport - Accreditations

- FIFA
- UEFA
- IAAF
- FIH
- ITF
- Quality:
  ISO 9001 : 2000
  ISO 17025: 2000

Artificial Turf for Football

Schematic view relevant layers:



sand / rubber filled turf

option: shock absorbing layer

base layer, e.g.:

- crushed stone
- asphalt
- lava stone
- lava / rubber crumb mixture

Artificial Turf - aims

Standards

- *Single countries*: dependent on local football associations

end 2006 (?): one CEN standard

- *International*:

UEFA and FIFA adopt one common standard

"FIFA Quality Concept"



March 2005

- *General (except Italy, Germany):*

no environmental or health requirements;

“local regulations”

Rumours…

“Giftige gassen boven kunstgrasvelden”



“mogelijk toch kankerverwekkend”

“Voetballen op kunstgras gevaarlijk”

Research needed



Steering committee

- contractors
- rubber recycling industry
- rubber producing industry
- Royal Dutch Football Association (KNVB)
- Dutch Olympic Committee * Sports Federation (NOC*NSF)
- Dutch ministries (VROM, VWS)

⇒ *independent research*

Research scope (1)

Research concentrated on:

- environmental risks
- health risks



- recycled tyre rubber granulates

  no virgin materials

- infill material in artificial turf football constructions

  no other applications (e.g. playgrounds)

- health risks for football player

  not for e.g. infill installers

Research scope (2)

Ultimate research goal:

- environmental
- health

} standard or directive for all infill materials



Certificaat

Betreft : kunstgras voetbalveld
type: sliding proof

Locatie : Sportpark De Eendracht
F.C. De Goatjes
Noorderhoek

Gerealiseerd door : Ingenieursbureau Sporters World

INHOUD

- het voetbalveld is onder keur van ISA Sport aangelegd
- het voetbalveld voldoet aan de normen van NOC*NSF, code ISA-KNVB2-15.2, maart 2002
- het voetbalveld voldoet aan het reglement van de KNVB
- geldigheidsduur certificaat: 2003 t/m 2005

maart 2003

Instituut voor Sportaccommodaties B.V.

ing. T.A. Joosten
Directeur

Certificaatnummer: T03.0006
Projectnummer : 28020000

Research execution

Independent experts on environment and toxicology:

- Intron (Project Manager)
- Industox (University of Nijmegen)
- National Institute for Public Health and Environment (RIVM)
- Kempeneers Environment and Management
- TNO
- DSM
- ISA Sport

Research content (1)

Research performed in 2 stages

<u>Stage 1:</u>

- literature study
- search for directives for judgement of results
- research on chemical composition of SBR rubber *)
- research on leaching behaviour of SBR rubber *)
- estimation health risks
- estimation environmental risks

*) *SBR rubber = recycled tyre rubber granulates*

Research content (2)

Stage 2:

- literature study continued
- research on leaching behaviour of SBR rubbers extended:
  - ageing due to use;
  - ageing in climatic chamber.
- research on health risks:
  - urine research on PAH exposure;
  - dermal exposure – PAH migration;
  - dermal exposure – local skin effects (literature).



Current status

Stage 1:

- Completed (June 2006)
- Report available via www.intron.nl

Stage 2:

- Running
- Report expected end of November



Results stage 1 (1)

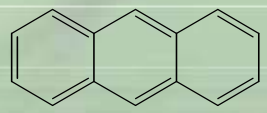


Literature study:

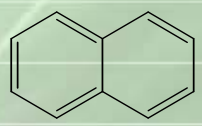
- Overview performed studies on tyres and granulates

  for summary: see report

- Chemical composition, leaching effects, air and waste water measurements, dermal exposure PAH*)
- No 100% “no risks” conclusion



*) *PAH = Polycyclic Aromatic Hydrocarbon*



Results stage 1 (2)

Search for directives:

- Tyres: European directive for reduction of PAH (from 2010)
- Toys: European guideline for heavy metals concentrations
- DIN V 18035-7: aims leaching of heavy metals, DOC, EOX *)

  "mild" test: with 2nd 24-hours eluate
- Dutch *Bouwstoffenbesluit (BSB)* for environment
- Infill rubber: no international guidelines

*) *DOC = Dissolved Organic Carbon*

EOX = Extracted Organic Halogens

Results stage 1 (3)

Search for directives:

- *BSB* = Resolution for Building Materials:
  - for stone-like materials (e.g. asphalt, lava, clay courts)
  - limit values for PAH and leaching of metals
  - minimum application height 20 cm
  - leaching tests: colomn experiments (NEN 7383/7344)

  ⟹ water, pH=7, 20ºC, 21 days



Results stage 1 (4)

<u>Research on chemical composition/leaching behaviour:</u>

Investigated samples:

- Production: samples taken at 3 granulate producers
- Field: samples taken at 5 football fields < 1 year old



Results stage 1 (5)

Research on chemical composition:

All compounds studied below maximum level of BSB

Results stage 1 (6)

Research on leaching behaviour:

- Leaching of PAH very low
- Zinc (Zn) concentration

Sample	Production [mg/kg]	Field [mg/kg]
1	4.6	*12*
2	4.0	*41*
3	*12* [1)]	*19*
4	-	*53*
5	-	*33*
mean	6.9	*32*
BSB	≤ 8.4 mg/kg [2)]	

[1)]: truck tyre granulates

[2)]: E_{max} = 130 mg/kg

Results stage 1 (7)

<u>Evaluation environmental risks:</u>

- Leaching of Zn: research to be extended
  - Field samples with truck tyre granulates
  - Effect of ageing:
    - × fields 3 years old;
    - × samples aged in climatic chamber.



Results stage 1 (8)

Evaluation health risks:

- SBR rubber contains hazardous components, but:
  - Heavy metal concentration meets toys standard
  - Available for football player?
  - Research to be extended:
    - × allergic and irritation effects?
    - × PAH-uptake via skin?
      - ⇒ migration research
      - ⇒ urine research

Urine research

- PAH uptake ⟹ 1-hydroxypyrene in urine (marker)
- Football players (non-smoking) on SBR rubber field
  - urine samples during 3 days
  - 2 hours of playing on day 2
  - effect of massage oil



Nitrosamines $R_2N\text{-}N=O$

<u>Air measurements 1 field during use:</u>

- Dust particles with PAH and heavy metals
- Volatile aromatic hydrocarbons (“AH”)
- Volatile nitrosamines





⇨ *Uptake hazardous compounds via respiration?*

Nitrosamines - conclusion

Results air measurements 1 field during use:

- Amount PAH + heavy metals increases during use;

  levels lower than health threshold
- No volatile aromatic hydrocarbons found
- Level of nitrosamine (NDEA) *higher* than health threshold

3 times a week – 2 hr football training:

Maximum Exceptable Risk level exceeded after 8 years

⇒ *Extended measurements on NDEA*

Brief summary

Extended and thorough research on environmental and health risks of SBR rubber in The Netherlands

Reports expected end of November

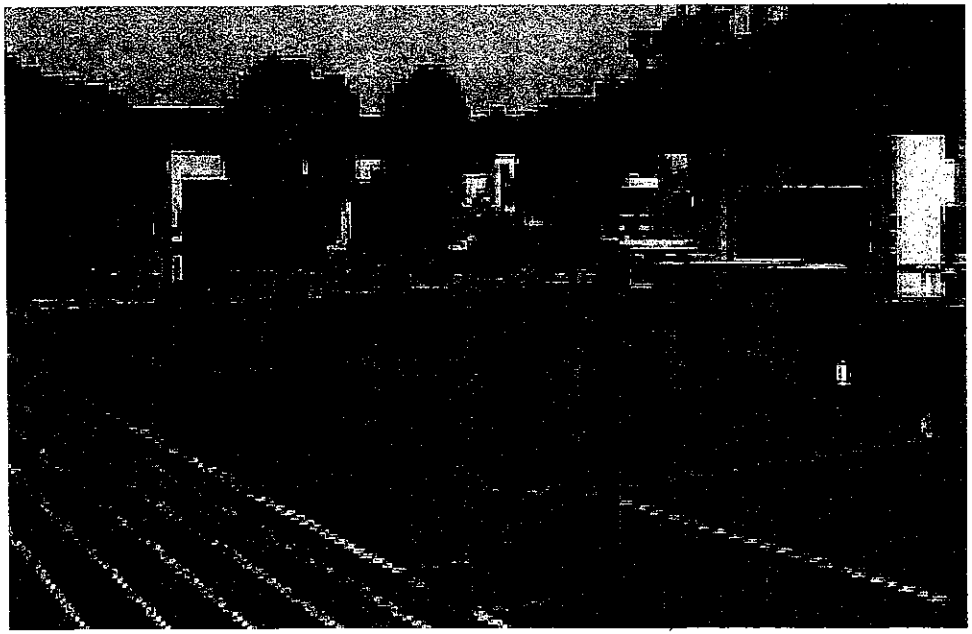
Instituut voor Sportaccommodaties

Thank you!

Assessing the Health and Environmental Impact from the Use of End-of-Life Tire Rubber Crumb as Artificial Turf in Sports Arenas

D.A. Birkholz,
Director of Research & Development, ALS Laboratory Group

Assessing the Health and Environmental Impact from the Use of End-of-Life Tire Rubber Crumb as Artificial Turf in Sports Arenas



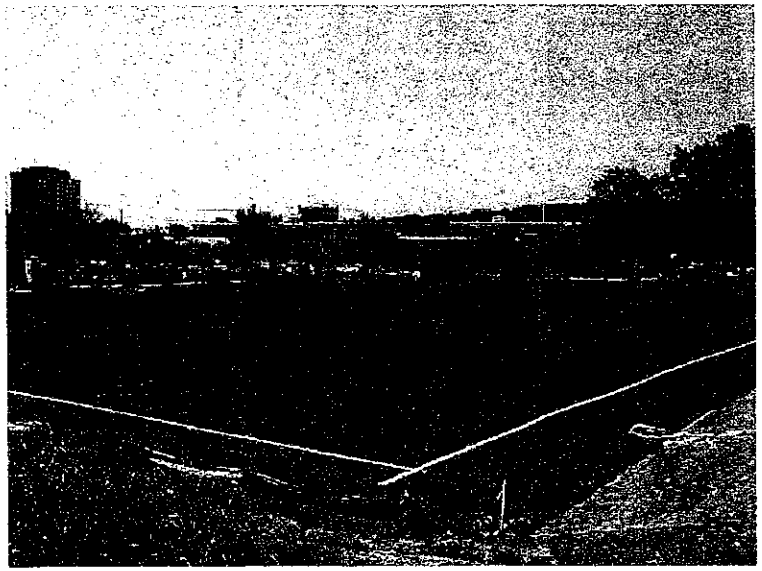
D.A. Birkholz

Director, Research and Development

ALS Laboratory Group

Edmonton, Alberta

Benefit of Artificial Turf

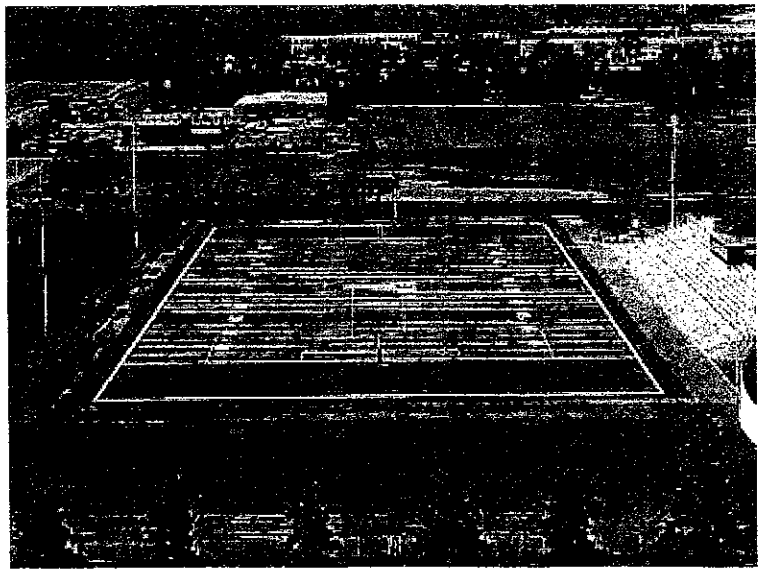


The artificial turf installed at Gunston is filled with rubber granules that ***prevent compaction and dangerous playing field conditions. It is a safer field that is easier on player knees and ankle joints.***

ASA Board member Mac Brown noted, "***This stuff plays like a great grass field, but does not die from overuse.***"

The synthetic surface allows ***unlimited play with low maintenance and predictable, grass-like performance***. The field has an underground field drainage systems that keeps the field playable in almost all weather conditions.

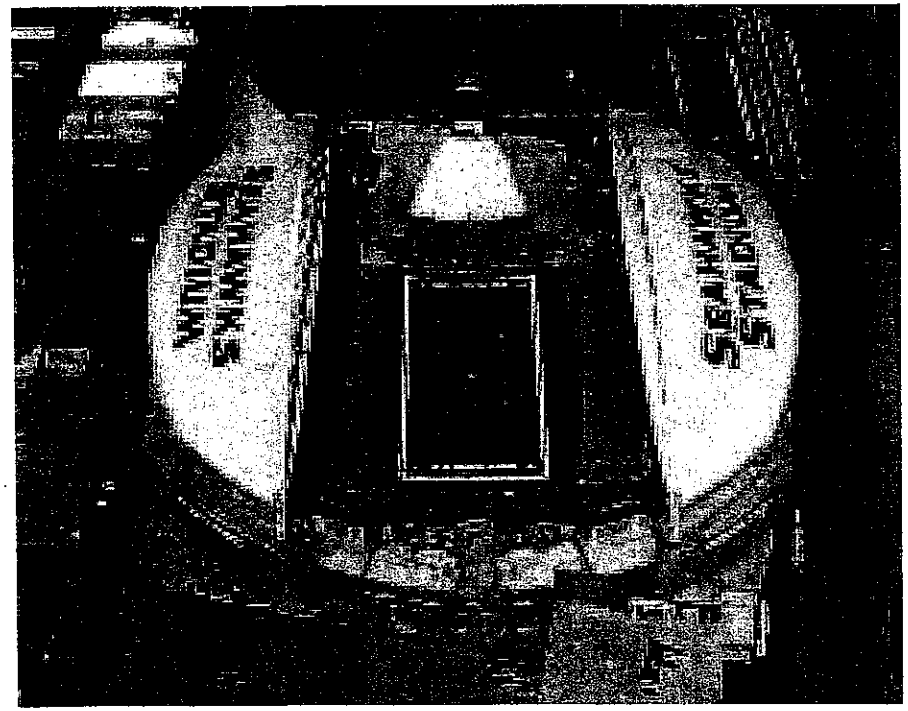
Benefits of Artificial Turf



The Artificial Turf Field is ***ideal for football, field hockey and soccer games and practices***

University of Alberta Faculty of Physical Education and Recreation

Benefit



Artificial turf requires no mowing, watering, fertilizing, or re-seeding. Regular maintenance involves brushing and occasional vacuuming using leased, rented or loaned equipment.

The typical sand-based soccer/football field can use between 2.5 million and 3.5 million gallons of water per year in the Pacific Northwest. Coupled with reduced labor costs related to maintenance, equipment and eliminated costs for supplies such as fertilizers, herbicides, and pesticides, several of our clients ***have seen a reduction in maintenance costs of as much as $30,000 to $60,000 per field, per year.***

Tire Crumb - Benefit

As for the tire crumb product, several potential advantages exist in its use as a playground surface amendment. Although most discarded tires are *placed into landfills to degrade slowly, economic use of tire crumb diverts old tires from landfills and piles where they present serious hazards. Stockpiled tires in landfills can contribute to fires that are difficult to extinguish, releasing combustion products (e.g., benzene, other volatile organic hydrocarbons, and dioxins) into the air. The hollow structure of a tire creates a breeding space for human disease vectors.* Advantages are that the crumb product is lightweight and cost-effective according to school district users. The manufacturer claims that the product has a superior degree of cushioning against falls, the main purpose of its use below play structures. Direct application is simple and cheap, much like that of sand: Simply shovel it into place.

Concerns raised over turf use in indoor facilities

- Exposure to ***carcinogenic*** PAHs, amines and N-nitrosamines –skin contact and ingestion
- Odour
- ***Breathing in toxic chemicals*** including fine rubber material
- ***Leaching of toxic chemicals*** with concomitant release to environment
- ***Abrasion of surfaces with use and concomitant release of particulates*** and toxic chemicals
- Increase incidence of methycillin resistant ***Staphylococcus aureus***
- Exposure to toxins produced by fungus, alga, and mould
- Foot blisters
- ***Latex allergy and asthma***
- Fire hazards

Concerns raised

A study of particulate air pollutants in Denver, Colorado, found ***black respirable particulates*** that were identified as ***airborne tire fragments***

suggest that these respirable "tire dust" particles ***may contribute to the pathogenesis of lung diseases related to air pollution***. Whether respirable particles are created during regular use of the tire crumb product requires further investigation, given that a high amount of energy is required to create smaller crumb rubber particles. Reports of haze while children played on the applied product may or may not be related.

Mitigating studies – Tire crumb in playgrounds

Anderson et al, ***2006*** – Environ. Health Perspectives

Group of physicians including Dr. Tee Guidotti

Reviewed scientific evidence and literature

Concluded that ***rubber crumb covering for play areas presents a very low risk for both children and environment***

Mitigating Studies

- ***Norwegian Institute for Water Research, 2005***
- Based upon study of the concentrations and leaching potential of hazardous chemicals used in artifical turf pitches
- Greatest environmental risk linked to the leaching of chemicals through surface water run-off in connection with precipitation
- Assessment shows there is a risk of environmental effects in both the water phase and sediment
- Zinc, alkylphenols and octylphenol *predicted* to exceed the limits for environmental effects
- The total annual amounts of hazardous substances leaching from a normal sports ground are fairly low which means that any environmental effects are expected to be local only
- Leachate generated by shaking 1 kg of material (fiber or rubber granulate) in 10 litres of water for 24 h.
- PNEC taken from EU's risk assessment documents, *no actual measure of toxicity*
- PAHs and phthalates found in leachate but not considered problematic

Mitigating Studies

- ***Norwegian Institute of Public Health and the Radium Hospital, January 2006***
- An assessment of the ***health risks for football players playing in sports halls with artificial turf pitches***
- Nine exposure scenarios were used: adults, juniors, older children and children
- ***Exposure routes assessed: inhalation exposure, skin exposure and oral exposure***
- Chemicals assessed include: VOCs (234 chemicals measured, 29 identified), PCBs, PAHs, phthalates, alkylphenols. ***Used highest analysis values in regards to recycled rubber granulate.***
- Adults ⌑ 20 years
- Juniors 16 – 19 years
- Older children 12 – 15 years
- Children 7 – 11 years

Mitigating Studies

Conclusions: *Norweigian study*

The use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults

Higher values of VOC were measured than are normally found in homes. It was concluded that the values which were measured for total VOC do not constitute any elevated health risk *but knowledge of this area is inadequate.*

As regards allergies, it is concluded that exposure to the low concentrations which were measured does not constitute any elevated risk with respect to the development of contact allergies.

The possibility that the use of car tires could cause exposure to latex allergens and thus lead to the development of airway allergies cannot be entirely eliminated

Studies have been carried out which indicate a link between exposure to phthalates and the development of asthma/allergies. At the present time, it is not possible to carry out a risk assessment in this area because of a lack of available knowledge.

Mitigating studies

Norwegian study

Training in sports halls does not cause any increased risk of leukemia as a result of benzene exposure or any elevated risk as a result of exposure to PAHs

On the basis of the exposures which have been calculated in connection with the use of indoor halls with artificial turf in which recycled rubber granulate is used, ***there is no evidence to indicate that the use of such halls causes an elevated health risk***.

Reservation with respect to the development of asthma/airway allergens as no information is available on the occurrence of latex allergens in hall air.

Mitigating Studies

Norwegian Building Research Institute, 2004

Study covers a total of ***four types of rubber granulate and two types of artificial turf fibre.***

The rubber granulates and artificial turf fibres were analysed with regard to the total content of arsenic, cadmium, copper, chromium, mercury, nickel, zinc, PCB, PAH, phthalates, and phenols

Leachate tests and degassing tests were also carried out.

The results are compared with Norwegian and foreign limits for soil and water

The aim of this project was to give a satisfactory fingerprint of potentially hazardous substances for soil, air, water and humans linked to the use of rubber granulate in artificial turf systems.

Mitigating Studies

Norwegian Building Research Institute, 2004

- Leachate was 10L/kg at 10 RPM for 24 h
- For the degassing test, 2 g of rubber granulate was heated to 70°C for 30 minutes before gas mixture was analysed

- ***Findings***

- Artificial turf fibers contain Cu, Zn, phthalates, 4-t-octylphenol and iso-nonylphenol. Zn and Cu levels comply with normative values for sensitive land use
- Leachate contained Zn and exceeded WQ guidelines but levels lower than Canadian DW guidelines.

Mitigating studies

Norwegian Building Research Institute

Rubber granulates contain Pb, Cd, Cu, Hg, Zn, PAHs, phthalates, and alkylphenols

Pb, Cd, Cu, and Hg below normative values for most sensitive land use

Zn and PAH in the recycled rubber granulates exceed values for the most sensitive land use

Dibutylphthalate and diisononlyphthalate exceed PNEC for terrestrial life taken from the EU program for risk assessment

Isononlphenol is above Canadian Environ. Quality guidelines for cultivated land

Leachate conc. anthracene, fluoranthene, pyrene, and nonlyphenols exceed Can. Environ. Quality guidelines for freshwater

An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the degree to which the conc. Of Zn, anthracene, fluoranthene, pyrene, phthalates, and nonylphenols in the leachate are actually harmful to people and the environment.

Mitigating studies

Norwegian Building Research Institute

Recycled rubber granulates ***give off significant number of alkylated benzenes in gaseous form. Trichloromethane and cis-1,2-dichloroethene were also found***

It is recommended that measurements be taken of air quality above pitches be taken to determine whether the air quality is satisfactory.

Mitigating Studies

Norwegian Institute for Air Pollution, 2005

Measured concentrations of ***airborne dust and gas phase compounds in indoor air in indoor artificial turf pitches***

Measurements taken in a hall with recently laid rubber granulate (styrene butadiene rubber, SBR) which had been in use for one year.

Mitigating studies

Ostfoldhallen has airborne dust concentrations that one would expect in an indoor environment for both PM10 and PM2.5

Manglerudhallen and Valhall have ***elevated levels of PM 2.5 and are close to the national recommended norm of 20 ug/m^3***

Airborne dusts in Manglerudhallen and Valhall ***contain large quantities of rubber from the granulate,*** whilst in Ostfoldhallen the proportion of rubber from the granulate is considerably less

In all three halls the proportion of organic material is considerable

The ***airborne dust contains PAHs, phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines***

Mitigating studies

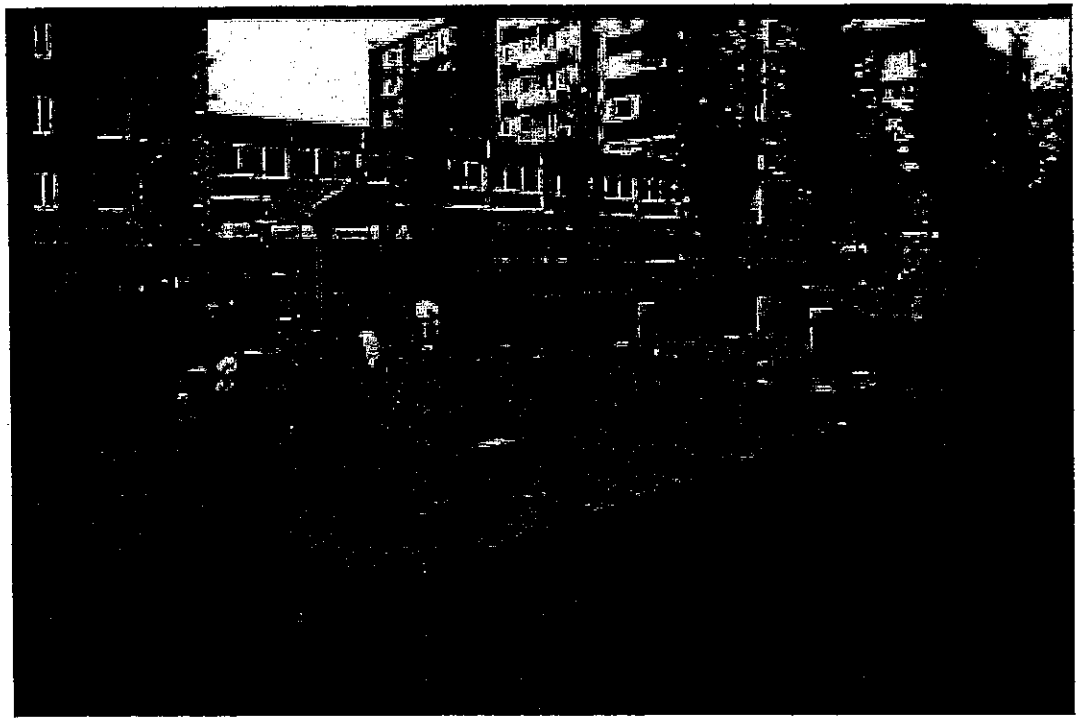
- Total VOC levels ***without ventilation in Manglerudhallen could reach very high levels***
- Component spectrum has a ***clear signature from rubber granulate and contains components which are associated with adverse effects on health***
- TVOC in Valhall is high.
- Measurements taken show that TVOC concentrations in Manglerudhallen and Valhall are higher than in Ostfoldhallen. This means that ***there are alternative rubber granulates which give lower TVOC levels than SBR rubber.***

Problem with Studies

- Reliance on chemical analysis
- Comparison with guidelines (which vary from country to country)
- Use risk assessment which public (competitors e.g. European Seed Association) may or may not buy into depending on agenda
- Open ended statements

Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds

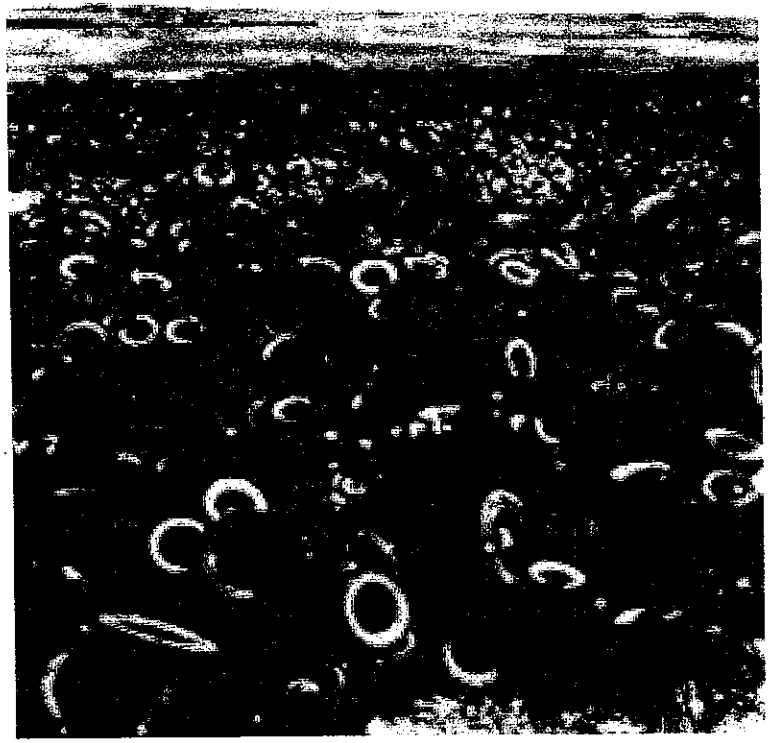




Birkholz et al (2003).
J Air & Waste Mgmt Assoc

Also presented at SETAC

Tire Recycling

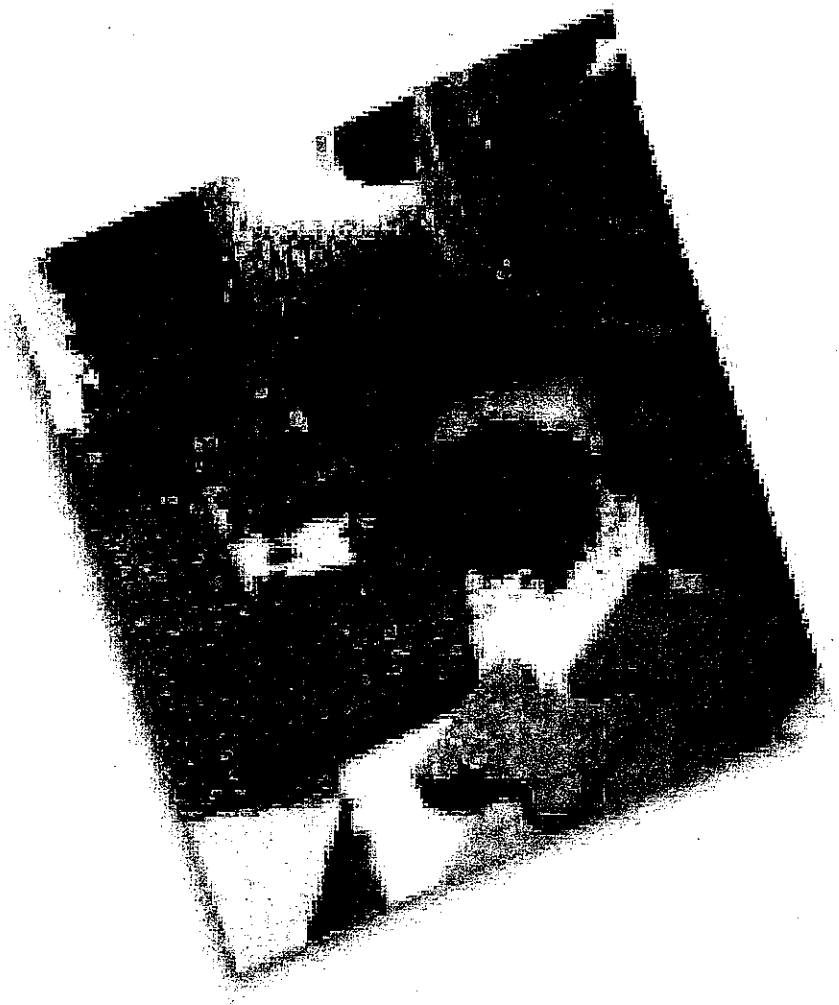


Approximately 2 million tires are generated in Alberta annually

In order to recycle 100% of spent tires, new uses will have to be found

Recycling is important to avoid situations such as the Hagarville, Ontario fire in 1990 in which a stockpile of 13 million scrap tires had burned uncontrolled

What is Tire Crumb and What Are We Proposing to Use it for?



- "Tire crumb" is crushed rubber obtained from spent vehicle tires
- Proposed use in playgrounds as a substitute for sand
- Has advantages over sand in that injuries to children such as scrapes and bruises are minimized
- Excellent way to deal with waste material, i.e. recycle used tires.

A Case Study of Tire Crumb Use on Playgrounds: Risk Analysis and Communication When Major Clinical Knowledge Gaps Exist

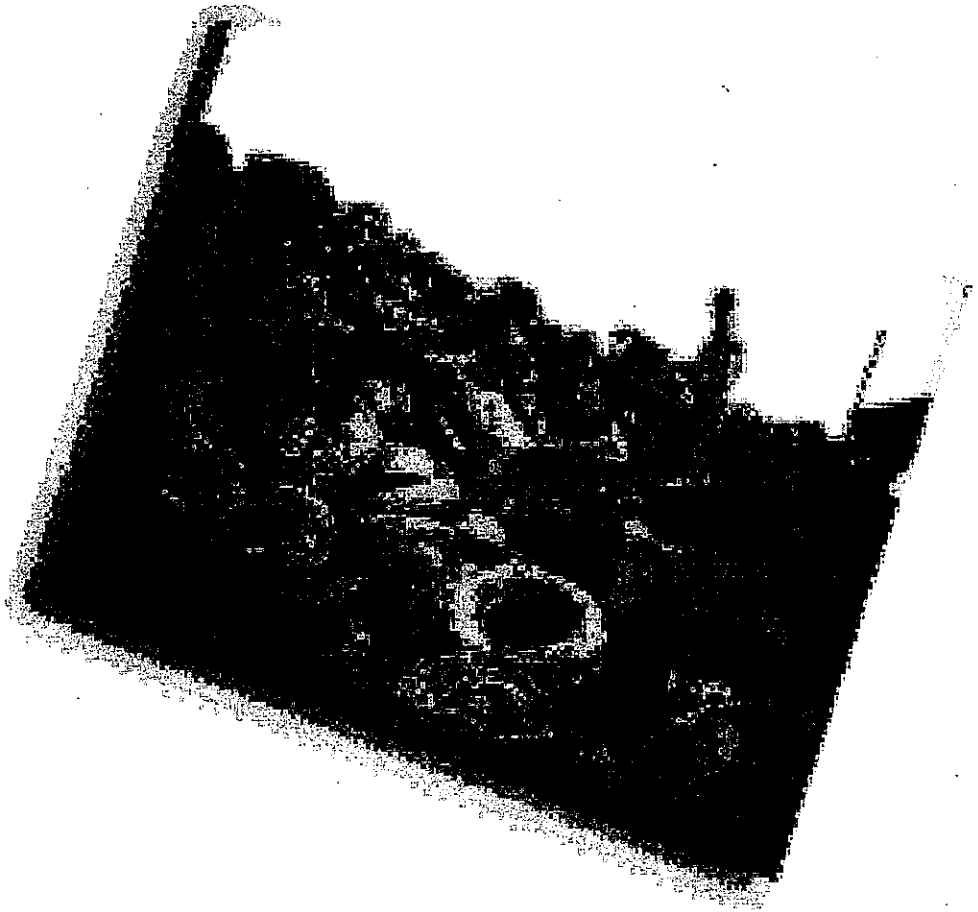
The stated concern relates to use of a loose, crumbled product made from used tires. ***Children playing on tire crumb could potentially be exposed by ingestion of the product directly, by ingestion of surface water runoff through the product, by inhalation of dust, or by skin contact with the material or surface water runoff.***

Concerns Over the Use of "Tire Crumb" in Playgrounds



- Human health concerns as a result of exposure of tire crumb to small children and potential exposure to toxic chemicals
- Environmental concerns as a result of potentially toxic playground runoff (rain, snowmelt) entering our storm sewers and being released to the aquatic environment

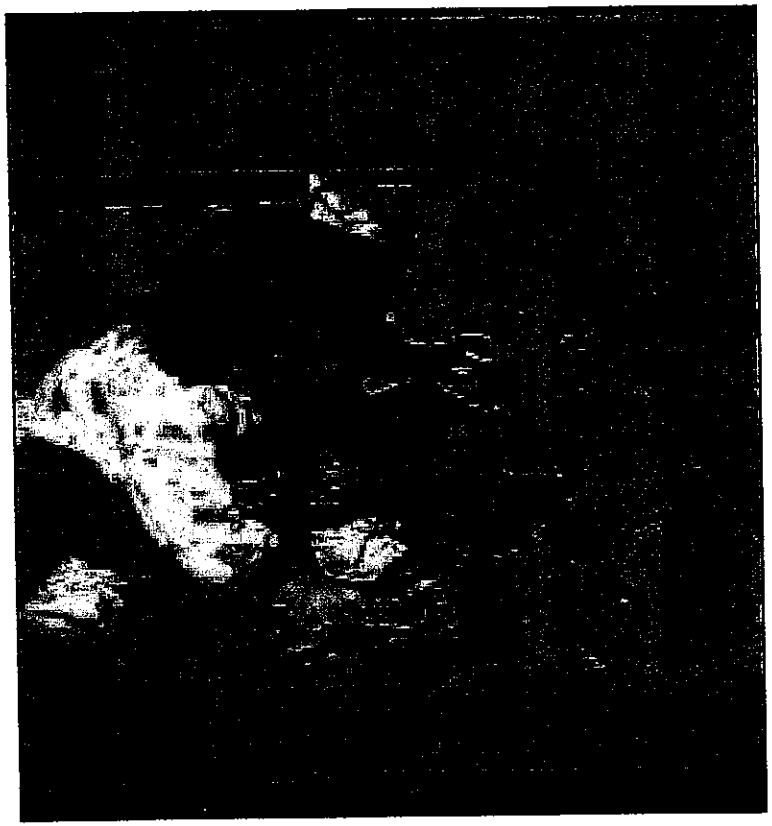
Approaches for Testing the Validity of Human Health Concerns



Exposure Assessment

Genotoxicity testing

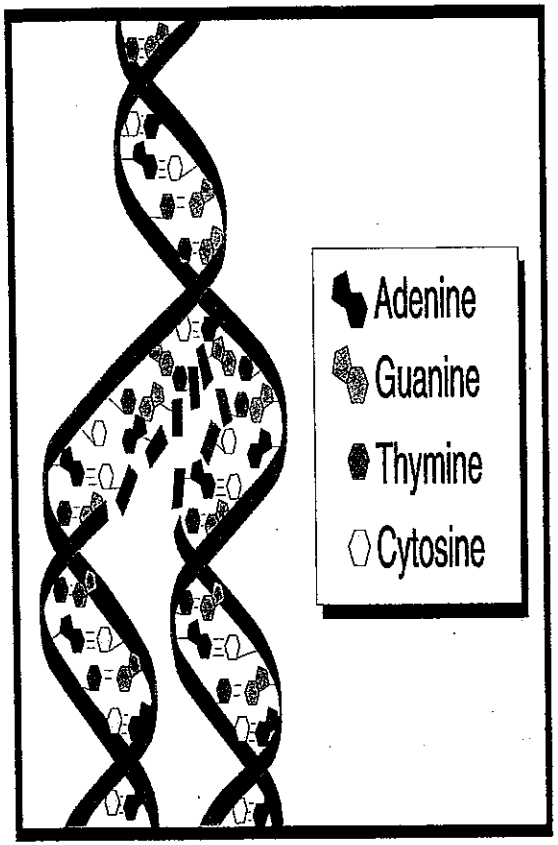
Methods: Exposure Assessment



Salient Features

- Risk of a toxic response to children is dependent upon exposure to chemicals which may be present in "tire crumb"
- This exposure may occur dermally (skin contact), or orally (via ingestion) and finally through inhalation of volatile constituents
- Each one of these routes of exposure was assessed in order to determine risk associated with exposure

Methods: Genotoxicity Testing



To determine whether ingestion of small amount of "tire crumb", by small children, poses a risk with respect to exposure of chemicals which may bioaccumulate and potentially cause cancer

Exhausative extraction (Soxhlet, 16-18h) of 200 g of "tire crumb" with dichloromethane

Genotoxicity testing performed on the resulting extracts using: *Salmonella typhimurium* mutagenicity fluctuation assay (TA98, TA100, TA1535, TA1537) , SOS chromotest and Mutatox

Tests conducted with and without S9 (liver homogenate)

Extracts tested for acute lethality using Microtox to determine dilution series.

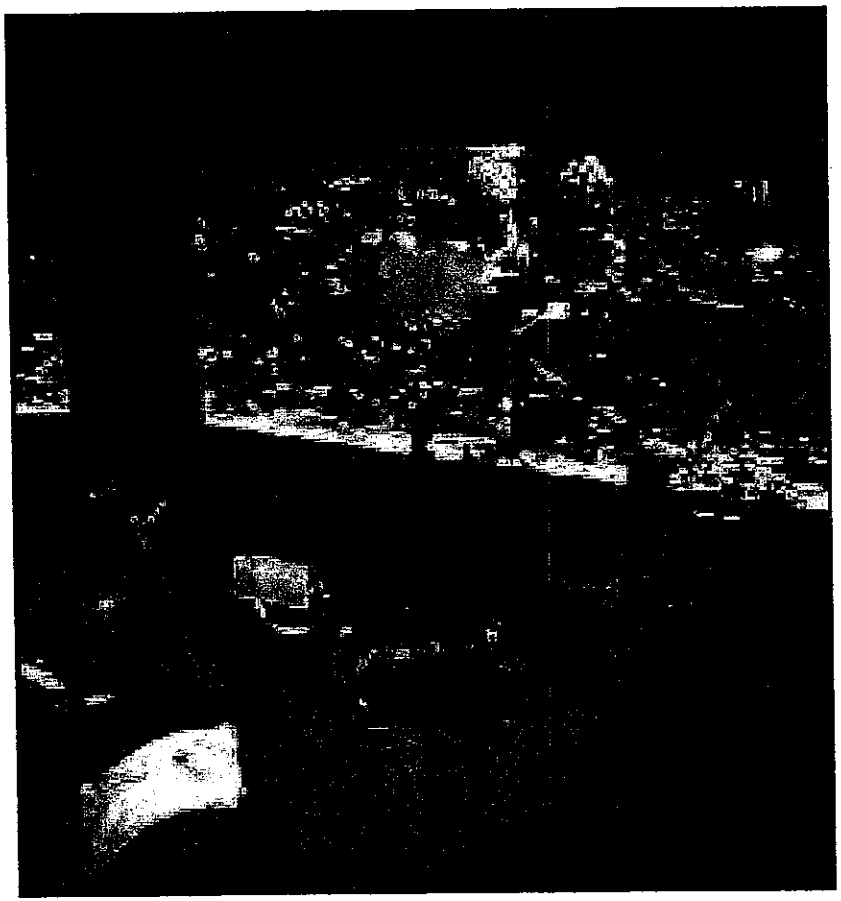
Exchanged into DMSO: final concentrations tested were 0.24 - 2.2 mg/mL

Approaches for Testing the Validity of Environmental Concerns



- **Generate a water leachate**
- **Test with a battery of aquatic tests representative of the major trophic levels in the aquatic receiving environment**
- **If toxic, determine persistence of toxic response, i.e. generate PEEP-index**

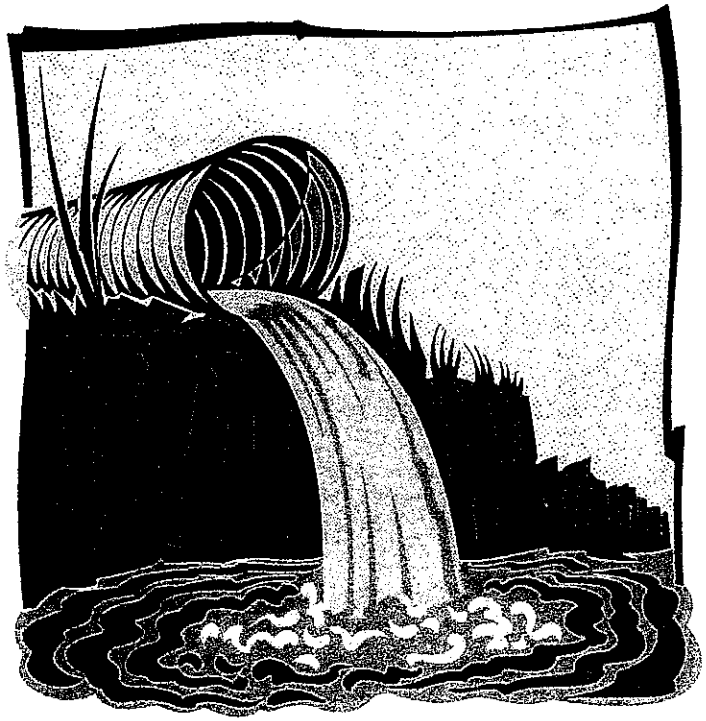
Methods



Aquatic Protection

- **Generate leachate by extracting 250 g of sample with 1L of laboratory water.**
- **Filter leachate and test using: luminescent bacteria, invertebrates, fish and algae**

Determination if toxicity is persistent



If initial testing reveals a toxic response using aquatic organisms

Generate leachate by extracting 250 g of sample with 1L of laboratory water

Filter sample

Add sewage seed, nutrients and aerate filtrate for 5-days

Retest for toxicity using luminescent bacteria, invertebrates, fish and algae

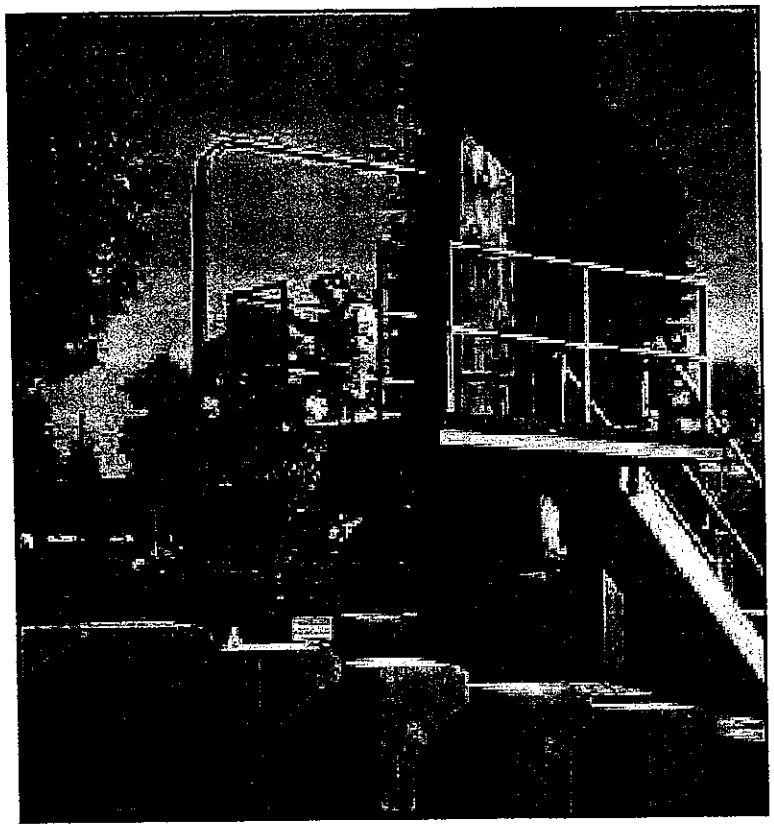
Calculate PEEP-index

PEEP-index

$$PEEP\ \ index = \log\left[1 + n\left(\frac{\sum_{i=1}^{n} T_{BB} + T_{AB}}{N}\right)\right]$$

n = number of tests producing a toxic response
N = total number of tests performed (=8)
TBB = toxicity before biodegradation in TU
TAB = toxicity after biodegradation in TU

Results



EXPOSURE ASSESSMENT

- "Tire crumb" does not contain chemicals with high vapour pressures, exposure via inhalation deemed low risk
- Dermal exposure deemed low risk because carrier solvent is needed to extract toxic chemicals from tire crumb and to penetrate protective skin layers
- Oral ingestion deemed low risk because ingestion not likely, furthermore, question of how effective stomach acids and enzymes are at extracting toxic chemicals from tire crumb and transporting them into the blood stream

Genotoxicity Testing

Sample	Ames Fluctuation Assay				SOS Test	Mutatox
	TA 98	TA 100	TA 1535	TA 1537		
Without Liver activation						
Tire #1	NT	NT	NT	NT	NT	NT
Tire #2	NT	NT	NT	NT	NT	NT
Tire #3	NT	NT	NT	NT	NT	NT
With Liver activation						
Tire #1	NT	MT	MT	MT	NT	NT
Tire #2	MT	NT	NT	NT	NT	NT
Tire #3	MT	MT	NT	MT	NT	NT

Results Initial Aquatic Testing

Test	Toxic Units (100/LC50 or EC50)		
	Tire Recycling #2	AB Envir R Products #1	Midwest Tire #3
Microtox	8.9	15.4	7.3
Daphnia magna	14.7	22.6	13.5
Fathead minnow	10	12.2	6.4
Alga	22.3	22	17
SUM	55.9	72.2	44.2

After Biodegradation

Test	Tire Recycling #2	AB Envir R Products #1	Midwest Tire #3
Microtox	4	10.5	5.7
Daphnia magna	1.4	6.8	1.8
Fathead minnow	<1	<1	<1
Algae	1.5	1.3	1.0
PEEP-index	1.75	1.90	1.68

Field Test: Crumb deployed in late fall, sampled in December

Test	Endpoint	AB Env. R Products #1	Crumb deployed in School
Microtox	TU	14.9	11.7
Daphnia magna	TU	16.0	8.0
Fathead minnow	TU	43.5	22.6
Algae	TU	1042	412
Cumulative toxicity	TU	1120	454
PEEP-index			3.2

Conclusions Concerning Environmental Protection

Bioassay of leachates obtained from four "tire crumb" samples revealed that all samples were toxic to all four species tested (luminescent bacteria, invertebrates, fish and green algae).

However, it was determined that the toxicity was transient, or short-term

Innoculation of "tire crumb" leachates in the laboratory with nutrients and sewage seed, followed by continuous aeration for 5-days, resulted in significant (73 - 86%) reduction in toxicity

Furthermore, bioassay of leachate samples obtained from bulk "tire crumb" before and after deployment in a school ground, revealed a 59% reduction in toxicity following short-term deployment (3 months).

These findings suggest that chemicals leaching from "tire crumb" are quickly degraded by natural processes to non-toxic forms.

In all instances except one, the PEEP-index was determined to be less than 3 which is considered to be acceptable by Environment Canada (Costan et al., 1993).

In the case of the schoolyard, the PEEP-index is marginally greater than 3 (I.e. 3.2), however, with aging this value should quickly drop to below 3.

Conclusions Concerning Human Health

An exposure assessment, performed to address the potential effects upon children playing in facilities where "tire crumb" is deployed, concluded that there was no adverse risk associated with this activity

Genotoxicity testing of "tire crumb" samples following solvent extraction concluded that no DNA-damaging or chromosome-damaging chemicals were present. This finding suggests that ingestion of small amounts of "tire crumb" by small children will not result in an unacceptable risk of contracting cancer. This finding supports the exposure assessment conclusions, particularly as it relates to oral ingestion of small amounts of "tire crumb"

Overall Conclusion



Since the impact on human health and the receiving environment is considered minimal, the benefit associated with injury control in playgrounds suggests that this use of recycled tires should be promoted and encouraged

Possible Closure

Oral exposure – use gastrointestinal leachate models to estimate bioavailability of chemicals taken up by digestive tract

Test using Ames mutagenicity assay and SOS-chromotest

Possibly CHEST and GJIC assays

Possible Closure

Dermal Exposure

Cyclodextrin extraction model

Ames mutagenicity test

SOS chromotest

ELISA – inhibition latex antigen test

Possible Closure

Environmental issues

Leachate (4:1 instead of 10:1)

PEEP index using variety of products and both acute and chronic toxicity tests

Possible Closure

Bacteria and toxins associated with fungus, molds, yeasts etc

Take swabs – culture and determine presence including *Staphylococcus aureus*

Possible closure

- Inhalation toxicity
- Collect PM 2.5 and PM 10
- Collect vapours (tenax, silica gel)
- Test using Ames mutagenicity, SOS-Chromosomal aberration, ELISA – inhibition latex antigen test and chemical analyses

Conclusion

- Numerous studies conducted to assess the human health and environmental impact associated with exposure to artificial turf
- Many studies based on chemical analysis and risk assessment
- Some studies done using toxicity assessments
- Despite conclusions that product is safe there is still skepticism
- It is clear that risk assessment is not readily acceptable to the public even when performed by government agencies
- Toxicological evaluations using toxicity endpoints may be more acceptable and less contentious.

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Rubber – Its Implications to Environmental Health – A Survey

Bryan Willoughby
Independent Consultant in Polymer Chemistry

Rubber – its implications to Environmental Health – a survey

Bryan Willoughby
Independent Consultant in Polymer Chemistry

The UK Sports and Play Construction Association (SAPCA) has convened a Working Group to investigate environmental and health concerns over the use of crumb rubber in artificial sports surfaces, and this paper covers one recent input to this Group. This input is an evaluation current findings in the light of our understanding of the nature and behaviour of rubber.

Rubber is a term applied to class of materials. Rubber is not a single chemical type, and a variety of different rubbers are encountered in everyday life. For example, the rubbers in granulate for artificial sports surfaces are found amongst the commodity hydrocarbon rubbers, e.g.: natural, SBR and EPDM. Quite possibly the different types may not be readily distinguishable from one another – but, even to the untrained observer, they will probably be immediately recognisable as rubber. Resilience and large-strain elasticity usually make for instant recognition.

The unique characteristics of a rubber arise from a unique molecular structure. This paper will consider the nature of rubber, and pay due attention to its molecular make-up from the perspectives of:

- the ingredients from which it is created
- the species it has the potential to release

and make the point that the two are not necessarily the same.

This paper will explain how this unique structure is the result of a chemical process (vulcanisation) and how the chemistry can consume and create species. It will explain how this molecular structure provides a particularly favourable matrix for the retention of some organic species – even to the extent that chemicals can be taken up into the rubber from its surroundings. By giving provenance to the various species encountered in studies of releases from rubber, it will provide a basis for understanding the release patterns observed.

A wealth of data has been published on the health and environmental risks from rubber. This paper will consider these findings in relation to specific concerns over:

- polycyclic aromatic hydrocarbons (PAHs)
- benzene
- phthlates
- alkylphenols
- heavy metals

in respect of exposures by releases to air or to water, or in skin contact scenarios.

In examining these findings, it will prove important to make the distinction between species which are the ingredients or by-products of manufacture, and those which result from uptake in service. In this context, virgin and used rubbers can present different release profiles. Thus the rubber type is not the only distinguishing variable, its history is also a factor. Whilst the latter can introduce an element of variability into a granulate, there are huge benefits to be gained by responsible reuse of scrap-tyre rubber.

Benzene, the PAHs and zinc compounds are all encountered in virgin tyre rubber, whilst zinc is also a common component of many other rubbers. Additionally, all are widespread in the environment from other sources. The phthalates and alkylphenols are not tyre ingredients, but are common environmental pollutants which can be absorbed into tyres in service.

That species of concern are amongst those preferentially retained by rubber is an important factor in the limitation of exposure risks. Furthermore, any risks to health from tyre or other rubbers must be put into context of the risks from daily life. In this context, no additional risks to health are apparent from the research seen to date.

Environmental risks are somewhat different, and it is important to recognise that tyre rubber should not serve as accumulator for environmental toxins (endocrine disruptors) which are then capable of localised release from granulate in sports-surface applications. No doubt this point will need to be addressed in any environmental standards for granulate from reused rubber.

In any environmental assessment, the required testing should only address realistic release scenarios, as there are a wide range of species which can remain firmly entrapped within the rubber under normal contact situations. Thermodynamic compatibility is a critical factor here, and those molecules of more limited affinity to rubber may face a form of molecular expulsion. This is another consequence of the unique molecular structure of rubber - in effect species of limited affinity can be "squeezed out" of the rubber and create a surface "bloom".

The common hydrocarbon rubbers are inherently hydrophobic, but the blooming of water-soluble species presents a mechanism for aqueous leaching. Zinc salts have a potential to bloom in rubber, and water of low pH can effect their subsequent removal from the rubber surface. This results in the possibility of an adverse localised environmental impact. No doubt, leachable zinc levels should figure in any environmental standards for rubber granulate.

Of course, a comprehensive risk assessment should also take account of the likely benefits. Few products can attack the scrap tyre mountain as effectively as these rubber granulates. On this basis, the environmental impact may be positive, whilst the risks to health appear negligible.

This assessment is now under review by the Working Group of SAPCA. A full report, with recommendations, will be issued in due course.

Dr Bryan Willoughby

Bryan Willoughby holds qualifications in polymer chemistry (PhD, BSc, CChem, FRSC), in materials science (FIMMM) and in occupational hygiene [MFOH(S)]. He was employed at Rapra (the UK-based Rubber and Plastics Consultancy) for thirty years, and set up his own independent consultancy in 2002.

During 1973-75, Bryan was involved in monitoring PAHs in workplace atmospheres in UK tyre companies, and proposed the method for workplace fume surveillance

subsequently adopted by the BRMA (1978) and UK HSE (1988). Since that time he has monitored workplace air and emissions at rubber companies in the UK, mainland Europe and in the USA. He has researched ingredient-emission relationships for rubber, from both technical and environmental perspectives, and published widely on the findings obtained.

Bryan is a member of the Standards for Artificial Turf Working Group of the Sports and Play Construction Association (SAPCA). SAPCA is working with the British Standards Institute (BSI) to help to prepare a new European (CEN) Standard for artificial sports surfaces.

Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Office of Environmental Health Hazard Assessment

Contractor's Report to the Board

Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Produced under contract by:

OEHHA
Office of Environmental Health Hazard Assessment

January 2007



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Additional Resources: The CIWMB suggests that in order to make an informed decision as to whether rubberized products for your playground and track are best for your needs, you should review the ASTM standard F1292, "Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment," and the Handbook for Public Playground Safety, U.S. Consumer Product Safety Commission, Pub. No. 325, and ask your playground/track contractor and/or manufacturer about any safety concerns you may have.

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Executive Summary

In response to the California Integrated Waste Management Board's (CIWMB) need to better understand the potential health risks to children using outdoor playground and track surfaces constructed from recycled waste tires, the Office of Environmental Health Hazard Assessment (OEHHA) conducted the following studies.

- The playground surfaces were evaluated for the release of chemicals that could cause toxicity in children following ingestion or dermal contact. Three routes of child exposure to chemicals in the rubber were considered: 1) ingestion of loose rubber tire shreds (acute exposure), 2) ingestion via hand-to-surface contact followed by hand-to-mouth contact (chronic exposure), and 3) skin sensitization via dermal contact (acute exposure).
- Playground surfaces constructed from recycled tires were tested for their ability to attenuate fall-related impacts.
- The potential of these rubberized surfaces to impact the local environment, including the local ecology, was also addressed through a discussion of the published literature.

Evaluation of toxicity due to ingestion of tire shreds based on the existing literature

OEHHA found 46 studies in the scientific literature that measured the release of chemicals by recycled tires in laboratory settings and in field studies where recycled tires were used in civil engineering applications: 49 chemicals were identified. Using the highest published levels of chemicals released by recycled tires, the likelihood for noncancer health effects was calculated for a one-time ingestion of ten grams of tire shreds by a typical three-year-old child; only exposure to zinc exceeded its health-based screening value (i.e., value promulgated by a regulatory agency such as OEHHA or U.S. EPA). Overall, we consider it unlikely that a one-time ingestion of tire shreds would produce adverse health effects. Seven of the chemicals leaching from tire shreds in published studies were carcinogens, yielding a 1.2×10^{-7} (1.2 in ten million) increased cancer risk for the one-time ingestion described above. This risk is well below the *di minimis* level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

Evaluation of toxicity due to ingestion of tire shreds based on gastric digestion simulation

OEHHA conducted a gastric digestion experiment in which 22 chemicals were found to be released by tire shreds incubated for 21 hours at 37^{o}C in a solution mimicking the gastric environment. OEHHA then compared the levels of released chemicals to their health-based screening values, assuming a young child ingested ten grams of tire shreds; all exposures were at or below the screening values suggesting a low risk of noncancer acute health effects. Five of the chemicals released by tire shreds in the gastric digestion experiment were carcinogens. If the released chemicals were ingested as a onetime event and averaged over a lifetime, the cancer risk would be 3.7×10^{-8} (3.7 in one hundred million). This risk is considerably below the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). The assumption that the risk from a onetime exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk.

Evaluation of toxicity due to chronic hand-to-surface-to-mouth activity

OEHHA performed wipe sampling of in-use playground surfaces containing recycled tire rubber; one metal (zinc) and four PAHs were measured at levels that were at least three times background. Assuming ingestion of the above five chemicals via chronic hand-to-mouth contact, exposures were below the corresponding chronic screening values, suggesting a low risk of

adverse noncancer health effects. From among the five chemicals identified by wipe sampling, the PAH chrysene is a carcinogen. Assuming playground use from 1 through 12 years of age, an increased cancer risk of 2.9×10^{-6} (2.9 in one million) was calculated due to the chronic ingestion of chrysene. This risk is slightly higher than the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). Calculation of the 2.9×10^{-6} (2.9 in one million) value does not account for many uncertainties, some of which would decrease the risk while others would increase the risk.

Testing for skin sensitization by playground surfaces made of recycled tires

Since children commonly contact these rubberized surfaces with their hands and other body parts, and since natural rubber contains the proven skin sensitizer latex, OEHHA contracted a laboratory to perform skin sensitization testing of tire-derived surfacing. Skin sensitization testing in the guinea pig was performed by Product Safety Laboratories (Dayton, NJ) with tire-derived playground surfacing as well as with the synthetic rubber EPDM; no sensitization was observed, suggesting that these surfaces would not cause skin sensitization in children, nor would they be expected to elicit skin reactions in children already sensitized to latex.

Evaluating the potential for damage to the local environment and ecology

Following a fire in a playground surface made of chipped tires at the Yulupa Elementary School in Sonoma County, soil samples from under the playground contained levels of metals, VOCs, PAHs, dioxins and furans that were at or below background, suggesting a low risk to the local ecology. Also following the Yulupa fire, the air above the burn site was judged by U.S. EPA to pose no health risks to clean-up workers, and the soil/rubber mixture removed from the site was judged not to be hazardous waste, and could therefore be deposited in a designated class III waste facility.

Groundwater in contact with tire shreds contained elevated levels of many chemicals; however, those levels rapidly approached background a few feet outside of the tire trench. Additional published studies indicate that concentrated leachate produced in the laboratory from tire shreds, crumb rubber or whole tires was toxic in 19/31 studies to a variety of organisms including bacteria, algae, aquatic invertebrates, fish, frogs and plants; however, it is unlikely that the use of shredded tires in outdoor applications such as playground surfaces would result in the leaching during rain events of high enough concentrations of chemicals to cause such effects. Further, shredded tires used in applications above the ground water table, as is the case for playground surfaces, produced no toxicity in sentinel species.

Evaluation of potential injury from falls on playground surfaces made of recycled tires

Using an accelerometer to test impact attenuation by California playground surfaces made of recycled tires, OEHHA staff visited 32 rubberized playground surfaces, to determine if the state mandated (CCR sections 65700-65750) standard for head impact (Head Impact Criterion or HIC) of ≤ 1000 was being met. Only 31 percent of rubberized playground surfaces passed the HIC standard. This is compared to 100 percent for surfaces made of wood chips, although only five surfaces of wood chips were tested. As the fall heights of playground structures increased, the underlying rubberized playground surface was more likely to fail the HIC standard; however, even at fall heights of 9-12 feet, some rubberized surfaces passed the standard. HIC values were not affected by the age of the rubberized surface, either during the first 2-3 months following installation or during the first two years. HIC values of rubberized surfaces increased with increasing surface temperature; in one playground the HIC value measured at dawn increased almost 20 percent when measured again in the afternoon during the heat of the day. These data point out the importance of testing the impact attenuation of rubberized playground surfaces to ensure that they meet the safety standards already in place.

Unfortunately, our survey found a 69 percent failure rate for rubberized California playground surfaces using attenuation standards. Theoretically, failure and potential injuries could be prevented with better installation practices by contractors who had placed rubberized material too thin. Further, if the purchaser of the product would have sought certification of impact attenuation standards at the completion of the project, each playground's HIC value should have been assured. This represents a missed opportunity for prevention of playground fall injuries, which are estimated to be in the thousands and which include serious trauma such as brain injury.

Chapter 1: Introduction

Waste tires are being used increasingly as a primary component of children's playground surfaces and running tracks. In addition to the benefits of recycling, playground surfaces made from recycled tires have the potential to reduce child injury due to falls in the playground. CIWMB provides grant funds to schools and city recreation departments to construct outdoor playgrounds and tracks using recycled waste tires. To be thorough and diligent, and to assure no inadvertent adverse health consequences, CIWMB asked OEHHA to evaluate outdoor playground and track surfaces made of recycled tires for potential toxicity from chemical exposure and for injury from falls.

Recycled tires in playground surfaces take one of three forms:

1. As uncompressed tire shreds or crumb comprising a rakeable surface,
2. As rubber tire shreds that are poured-in-place along with a binder, hardening into a permanent surface,
3. As tiles molded in the factory from tire shreds and binder, which are then transported to the playground and locked or glued into place, forming a permanent surface.

Track applications use the method described in #2 above.

Studying the toxicology of recycled tires used in playground surfaces

The first part of this study addresses the toxicologic safety of rubber playground and track surfaces made of recycled tires. We examined whether such surfaces release toxicants capable of adversely affecting either children's health or the health of the local ecology. These issues are addressed in three ways:

1. Through a review of the literature covering what is known to be released by recycled tires in laboratory studies and in civil engineering projects that utilized tire shreds (e.g., roadways, parking lots, leachate fields).
2. By conducting studies to identify chemicals released by tire shreds in a laboratory setting and at actual rubber surfaces in use at selected playgrounds and a track within California.
3. By conducting a skin sensitization study of pieces of recycled tire rubber used in playground surfacing.

Once we identified the chemical substances to which a child could be exposed, we estimated exposure potential and compared those values to toxicologic reference values. This approach enabled us to quantify the risks to children's health. We took a similar approach in evaluating potential environmental risks from playground recycled tire leachate.

Studying impact attenuation and the prevention of fall injury by playground surfaces made of recycled tires

The second part of this study evaluates whether playground surfaces made of recycled tires are an effective means for reducing serious head injury due to falls. The US CDC (2005) estimates that it cost 1.2 billion dollars to treat playground-related injuries in the United States in 1995. If 10 percent of these injuries occurred in California, then approximately 120 million dollars were spent in this state. Since approximately 80 percent of these injuries resulted from falls (Tinsworth and McDonald, 2001), then reducing the injury rate from falls by only 10 percent has the potential to save almost 10 million dollars in California. An accompanying reduction in injury severity would save even more.

While preliminary laboratory data suggest that crumb rubber should be effective at reducing the incidence of injury to children that fall, the three types of rubber surfaces have never been intercompared for injury reduction, and only sparse data exist regarding the efficacy of rubber surfaces relative to more traditional impact-absorbing surfaces such as sand or wood chips. While standards for head impact attenuation by playground surfaces have been written into California law (CCR sections 65700-65750), the compliance rate has not been systematically monitored.

Thus, measurement of the compliance rate for playground surfaces made of recycled tire rubber was an important part of this study. In effect, we have measured parameters of impact attenuation by in use playground surfaces to determine whether these surfaces, as they are currently being installed in California, can be expected to protect children from serious head injury due to falls. This approach was chosen in consultation with members of the Injury Surveillance and Epidemiology Section of the California Department of Health Services, and the Department of Epidemiology in the UCLA School of Public Health. Those discussions failed to identify a set of injury data collected from playgrounds before and after installation of a rubberized surface, or any information on insurance savings that could be directly linked to decreased playground injuries. Thus, we found it necessary to generate our own set of data covering the impact attenuating properties of California playground surfaces, from which estimates of fall injury risk could be made.

Chapter 2: Survey of CIWMB playground grantees 2001–2003: playground surface types and locations

Background: Municipalities and school districts receiving CIWMB grants for installation of playground surfaces made of recycled tires were surveyed by telephone. The CIWMB allocated 90 playground surface grants in the 2000-2001 cycle and 59 grants in the 2001-2002 cycle. Contact persons were asked to provide information on the type of surface installed (pour-in-place, tiles or rakeable shreds/crumb), the composition of the surface and the name of the manufacturer/installer. Approximately one third of the grantees who were contacted provided this information. Below are the data on surface type and composition.

Nomenclature: The synthetic rubber called styrene-butadiene rubber is a major component of tires. Thus, the abbreviation SBR is often used as a designation for the shredded tire component of these surfaces. For pour-in-place surfaces, the SBR is mixed with a binder and poured at the playground site, where it hardens into a uniform surface. At this point, granules of synthetic rubber called ethylene propylene diene monomer (EPDM) are often mixed with a binder and poured into the playground to serve as a top layer. When this process is performed at a factory using molds, tiles of SBR with top layers of EPDM result. These tiles are put in the playground and locked in place, also forming a uniform surface. Both pour-in-place surfaces and surfaces of tiles can be constructed using SBR only. Lastly, shredded SBR can be used much like wood chips or gravel by simply transporting it to the playground site where it is raked into place.

Playground materials survey results

- **Pour-in-place SBR only:** no grantees installed surfaces of this material
- **Pour-in-place SBR with a pour-in-place top layer of EPDM:** 44 playground surfaces in Antioch, Bear Mountain, Belvedere, Cathedral City, Commerce, Conejo, Culver City, Downey, Duarte, El Cerrito, Eureka, Fair Oaks, Greater Vallejo Recreation District, Imperial, Kern County, King City, Lodi, Long Beach, Modesto, Monterey, Morongo Valley Community Service District, Napa, Pacheco, Pacifica Community Charter School (L.A. Unified School District), Paramount, Pico Rivera, Poway, Reef Sunset Unified, San Clemente, San Diego, San Francisco, San Luis Obispo, Santa Barbara, Saugas, Silverado-Modjeska, Sunrise, Union City, Wilsona School District
- **SBR tiles:** 2 playground surfaces in Gridley and Smith River
- **SBR tiles with top layer of EPDM:** 2 playgrounds in Long Beach and Bell
- **Rakeable rubber shreds:** 3 playgrounds in Horicon Elementary School District, Morongo Valley Community Service District and Salinas

Comment: Since the great majority of grantees (44/51) installed a pour-in-place surface consisting of a base layer of recycled SBR covered by an EPDM top layer, OEHHA focused its testing on both EPDM and SBR playground materials. These products were used to analyze the chemicals released by in-use playground surfaces and for conducting the skin sensitization test.

Chapter 3: Substances released by recycled tires: values from the published literature

Introduction

Table 1 lists the published studies that identified metals, compounds and particulates released by tires in laboratory and field settings. In some cases, whole tires were used, but more often tire shreds, chips or crumb was tested. The studies are approximately evenly distributed between field and laboratory studies. Field studies involved the use of tire pieces in road beds, road embankments, leachate fields, a parking lot, and as a component of turf. In addition, an application with whole tires in water was that of reef construction. No study was located identifying substances released by recycled tires in playground surfaces, although a single study tested for ecotoxicity by the water-soluble extracts from playground tire crumb (Birkholz et al., 2003). Therefore, until our gastric digestion and wipe sampling studies, the data shown here were the only information available for making predictions about the behavior of tire pieces in playground surfaces. Using these surrogate data to assess risks from rubberized playground and track surfaces introduces a variety of uncertainties due to the following:

1. Waste tire processing for playground and track surfaces includes a step to remove the metal belts and metal beads, and the rubber end product is generally washed, while the shredded tires used in these published studies still contained the metallic components, and the end product was not necessarily washed; therefore, the shredded tires used in these published studies represent a potentially greater source of leaching chemicals compared to the tire shreds and crumb rubber used in playground surfaces,

2. Most playground and track surfaces made of the recycled tire rubber also use a chemical binder such as polyurethane to hold the rubber pieces in place, while the shredded tires used in these published studies did not include a binder; therefore, chemicals leaching from the binder cannot be identified from these published studies,

3. Playground and track surfaces are continually exposed to changing climatic conditions including sunlight, precipitation, and variations in temperature, as well as to volatile chemicals in the ambient atmosphere,

4. The laboratory studies collected from the literature generally consisted of day, week, or month-long incubations of tire shreds in aqueous solutions in closed tanks or other reaction vessels; these laboratory conditions do not replicate the predicted routes of child exposure to recycled tire rubber in playground surfaces, such as through hand-to-surface-to-mouth contact or ingestion of tire shreds.

Table 1. Substances released by whole tires or tire chips/shreds in laboratory and field studies

Authors	*Type of study*	*VOCs*	*sVOCs*	*Metals*	*Other*
Al-Tabbaa and Aravinthan, 1998	Lab			Cu, Ni	
Anthony et al., 1995	Tire shred leachate in lab	Nitro compounds, hydrophilic compounds	Morpholino-thio-benzothiazole	Iron, manganese, nickel, zinc	
Anthony and Latawiec, 1993	Whole tire leachates in lab	An olefinic hydrocarbon, an alkoxy ether/alcohol, series of nitro-aliphatic ethers	Morpholino-thio-benzothiazole		
BAS Inc., 1993	MSDS for crumb rubber				Fine particles
Boniak et al., 2001	Tire crumb in field test			Zn	
Chien et al., 2003	Tire shredding factory-particulates in air		Amines, aniline, quinoline, amides, benzothiazole all in particulates		Respirable particulates
Edil et al., 2003	Tire chip leachate in field	Methyl isobutyl ketone			
Exponent, 2003	Tire shred leachate in field	Acetone, 1,1-dichloroethane, cis-1,2-dichloroethene, chloroethane, benzene, trichloroethene, toluene	Aniline, N-Nitrosodimethylamine, N-Nitrosodiphenylamine	Manganese, iron	
Florida Community College, 1999	Leachate from crumb rubber in the field and soil measurements	Toluene		Fe, Zn, Ba, Na, Cr, Pb, Cu, Sb	
Florida Dept. of Envir. Protect., 1999	Lab study conducted by the Virginia DOT			Cd, Cr, Pb, Al, Cu, Fe, Ni, Zn	

Authors	Type of study	VOCs	sVOCs	Metals	Other
Florida Dept. of Envir. Protect., 1999	Field study conducted in Idaho			Zn	
Fukuzaki et al., 1986	Field				5-24 ng/m^3 tire dust
Gaultieri et al., 2005	Lab			Zn	
Gunter et al., undated	Tire chip leachate in lab	Acetone, benzene, trichloroethylene, methyl ethyl ketone, methyl isobutyl ketone		Iron, lead, manganese	
Hartwell et al., 1998	Tire shred leachate in lab	Naphthalene, 2 Methyl naphthalene	Morpholinothio-benzothiazole, bis(2-ethylhexyl)phthalate	Al, Ba, Cd, Cr, Co, Cu, Mn, Ni, Zn, Fe	
Hildemann et al., 1991	Field + lab				Fine particulate organic C (105 µg/m^2/day)
Horner, 1996	Tire chip leachate in lab and soil near tire dump			Cadmium, zinc, lead	
Humphrey, 1999	Tire chip leachate in field	None detected	None detected	Barium, iron, manganese, zinc	Chloride, sulfate
Humphrey and Katz, 2000	Tire shred leachate in field	1,1-dichlorethane, 4-methyl-2-pentanone (MIBK)	2-(4-morpholinyl)-benzothiazole	Iron, manganese	
Humphrey and Katz, 2001	Tire shred leachate in field	1,1-dichloroethane, 4-methyl-2-pentanone (MIBK), acetone, benzene, cis-1,2-dichloroethene	Aniline, m+p cresol	Iron, manganese, zinc	

Authors	Type of study	VOCs	sVOCs	Metals	Other
Johnson et al., 2002	Tire chip leachate in lab			Zinc	
Kim et al., 1990	Suspended particulate matter in urban air				Tire tread particles
Kumata et al., 1996	Street dust, river sediment, air		2-(4-morpholinyl)benzothiazole		
Kumata et al., 2002	Highway runoff, river sediment		2-(4-morpholinyl)-benzothiazole, N-cyclohexyl-2-benzothiazolamine		
Liu et al., 1998	Tire shred leachate in field			Iron, manganese	Latex allergens
Miguel et al., 1996	Air samples and guardrail swipes near freeway				Particulates with latex allergens
Miller and Chadik, 1993	Tire shred leachate in field and laboratory	Methyl isobutyl ketone, 1,3,5-trimethylbenzene, benzene	aniline	Arsenic, zinc	
Minn. DOT, 1995	Tire chip leachate in lab	Isophorone, 2,6-dinitrotoluene		Mercury, zinc	
Minn. Pollution Control Agency, 1990	Tire chip leachate in lab	Total petroleum hydrocarbons, PAHs		Aluminum, barium, cadmium, chromium, iron, selenium, zinc, lead	

Authors	Type of study	VOCs	sVOCs	Metals	Other
Nelson et al., 1994	Whole tire and tire plug leachates in lab			Zinc copper, cadmium lead	
Ontario Ministry of Environment and Energy, 1994	Lab		Benzothiazole, 4-(phenylamino)-phenol, 2-(4-morpholinyl)benzothiazole, 24 other organic compounds at lower levels	Zn	
O'Shaughnessy and Garga, 2000	Lab		Benzothiazole, 2(3H)-benzothiazolone, (1,1-diethylethyl)-2-methoxyphenol, 4-(2-benzothiazolythio)-morpholine	Al, Fe, Mn, Zn	
Park et al., 2003	Tire shred leachate in lab			Zinc, barium and lead in precipitates	
Pierce and Blackwell, 2003	Lab	VOCs absorbed by ground tire rubber added to slurry cutoff wall backfill material			
Radian Corp., 1989	Tire chip leachate in lab	Phenol		Barium, chromium, lead, mercury, selenium	
Reddy and Quinn, 1997	Field + lab		Benzothiazole, 2-hydroxybenzothiazole, 2-(4-morpholinyl)-benzothiazole		
Rogge et al., 1993	Tire dust generated in lab	Alkanes, PAHs	alkanoic acids, natural resins, benzothiazole		

Authors	Type of study	VOCs	sVOCs	Metals	Other
Schauer et al., 2002	Field	`			Fine particulate organic C (1 µg /m^3) [total part.=2µg]
Scrap Tire Management Council, 1991	Tire chip leachate in lab	Methyl ethyl ketone, toluene	phenol	Barium, chromium, lead, mercury	Carbon disulfide
Sengupta and Miller, 1999	Tire shred leachate in lab			Iron, aluminum, zinc, copper	Chloride
Shieh, 2001	Tire chip leachate in lab	Methyl ethyl ketone, toluene	Phenol	Arsenic, lead	Carbon disulfide
Spies et al., 1987	SF bay sediment		Benzthiazole, 2-(4-morpholinyl)-benzthiazole		
Stephensen et al., 2003	Lab	PAHs, aromatic nitrogen compounds			
Tatlisoz et al., 1996	Field and lab	Benzene, toluene	Phenol	As, Ba, Cd, Cr, Pb, Fe, Mn, Se, Hg, Zn	
Williams et al., 1995	Air near freeway				Rubber particles with latex allergens
Yoon et al., 2005	Tire shred leachate in the field			As, Ba, Cd, Cr, Se	

VOC = volatile organic compound; sVOC = semi-volatile organic compound

Substances released by tires

Tables 2 through 5 show the concentrations of substances released by recycled tires (or "in use" tires in the case of airborne particulates) for the studies listed in Table 1. The substances released comprise four groups consisting of 15 metals (Table 2), 20 volatile organic compounds (VOCs, Table 3), 14 semi-volatile organic compounds (sVOCs, Table 4), and particulates in air resulting from tire wear (Table 5). Where possible, the data are reported as amount of chemical released per gram of tire. This facilitated the use of these data to predict how much of each chemical would be released were a child to intentionally ingest a specific amount of tire shreds.

Metals

From among the 15 metals listed in Table 2, zinc (21 instances) and iron (sixteen instances) were detected most frequently and at the highest levels. Iron is a component of the steel belts and beads, while zinc oxide is used as an activator in the vulcanization process (CIWMB, 1996). Manganese was the next most frequently detected (ten instances). Like iron, it probably originated from the steel belts and beads. Today, the production of crumb rubber from tires typically includes a step to remove 99 percent of the steel belting and bead material. This would be expected to greatly reduce the release of iron and manganese from the recycled tire material. Barium was the next most commonly detected metal (nine instances), possibly as a result of its use to catalyze the synthesis of polybutadiene rubber (Halasa et al., 2003).

Lead was also identified in eight instances, possibly due to its former use as an activator of the vulcanization process, in the form of lead oxide (CIWMB, 1996). Chromium detection in seven instances may have resulted from its use in steel production. If this is the case, removal of the steel wire from recycled tires should also markedly reduce the release of this metal. Unfortunately, none of the studies determined whether the chromium was in the +6 or +3 oxidation state, since the former ion is highly carcinogenic (by inhalation) while the latter is not. The remaining nine metals (cadmium, copper, aluminum, antimony, mercury, nickel, arsenic, selenium, cobalt) were detected in five or fewer instances.

While the presence of metals at levels above background is noteworthy, the toxicologic significance depends upon the concentrations and magnitude of exposure. As shown in Table 2, both zinc and iron were detected in tire chip leachate at levels indicating that milligram amounts of these metals were released per gram of tire. These studies were conducted in the laboratory under controlled conditions. Similar laboratory studies indicate that microgram amounts of manganese, aluminum, barium and copper were released per gram of tire, while only nanogram amounts of lead, cadmium, chromium, nickel, arsenic, selenium and cobalt were released (Table 2).

To assess the toxicologic significance of these findings, these levels will first be used to estimate child exposure by the oral route. Exposures will then be compared to corresponding oral reference toxicity values, such as a public health goal (PHG), reference concentration (RfC), minimal risk level (MRL), or reference exposure level (REL). These values have been developed by various authoritative bodies including OEHHA, U.S. EPA, the Centers for Disease Control (CDC), and the Agency for Toxic Substances and Disease Registry (ATSDR). The calculations will determine whether exposures are likely to cause adverse health effects.

VOCs

Tire shreds released lower concentrations of volatile organic compounds (VOCs) than metals (Table 3). A total of 20 compounds were identified, including three classes of compounds (polycyclic aromatic hydrocarbons, aromatic nitrogen-containing, total petroleum hydrocarbons). Other than the unidentified ether compound whose level was estimated in the laboratory study by Anthony and Latawiec (1993), the highest values were for the solvent methyl isobutyl ketone (1,151 ng released per gram of tire; Gunter et al., undated) and for naphthalene (1,100 ng released per gram of tire; Hartwell et al., 1998). The presence of methyl isobutyl ketone may be the result of its use in the production of rubber antioxidants (U.S. EPA, 2003b), while naphthalene may originate from carbon black.

Seven compounds or groups of compounds were released in ng amounts per gram of tire: acetone, toluene, benzene, total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, methyl ethyl ketone and 2-methyl naphthalene. All these compounds except for the last may result from the use of petroleum oils (the source of carbon black) and coal tar fractions in tire production, which serve as softeners and extenders (Sullivan et al., 1992). These findings were from studies performed in the laboratory, where the volatile organic compounds were released into aqueous solutions.

A clue towards how these volatile compounds might behave when tire shreds are used in playground surfaces, and the compounds are released directly into the air, may be provided by the study of Chang et al. (1999). In that study of rubberized athletic tracks, the emission of volatile organic compounds decreased with time, so that after about two years the levels at breathing heights were near background. Unfortunately, since recycled tire rubber was most likely not used in the construction of these tracks, it is problematic to use these data to draw firm conclusions about the release of VOCs from playground surfaces made of recycled tires. Chapter 8 presents wipe sampling data from a running track containing recycled tires as well as a discussion of the safety benefits of such a surface.

sVOCs

A total of 14 sVOCs are listed in Table 4. This includes five different benzothiazoles, three of which were released at µg amounts per gram of tire. These benzothiazole contaminants have been proposed as environmental markers for tire-derived material (Kumata et al., 2002). Benzothiazoles are used in tire production to accelerate the vulcanization process (Kumata et al., 2002), as antioxidants (Spies et al., 1987), and to help bond the metal wire and metal belts to the tire rubber (CIWMB, 1996). Aniline, phenol, 4-(phenylamino)-phenol, phenoxazine, and 2(3H)-benzothiazolone were released in ng amounts per gram of tire. Aniline is added to tires to inhibit rubber degradation (CIWMB, 1996).

Detection of phenol (and cresol) may be due to the use of petroleum oils and/or coal tar fractions as softeners and extenders in tire production. In addition, treatment of the steel cords and fabrics comprising the belts with phenol/formaldehyde improves their adhesion to the rubber (Sullivan et al., 1992). Lastly, two nitrosoamines (diphenyl and dimethyl) were detected in the same study; this could be the result of their use to inhibit both the vulcanization process during tire production, and the decomposition of rubber in the finished product (CIWMB, 1996).

Particulates

Particles of tire-derived rubber have been measured in the air in a number of studies (Table 5). Three studies measured from 1-7 $\mu g/m^3$ in ambient air (Kim et al., 1990; Miguel et al., 1996; Schauer et al., 2002). This demonstrates that any measurements of rubber particulates above a rubber playground surface must take into account the ambient, background level. Two of the studies in Table 5 (Williams et al, 1995; Miguel et al., 1996) identified latex as a component of the airborne particulate matter. Such airborne particles containing latex allergens have been suggested as potential inducers of both latex sensitization and asthma (Miguel et al., 1996; Williams et al., 1995).

Table 2. Concentrations of metals leaching from tire shreds used in various civil engineering applications in the field or leaching in lab studies

Metal	Study Type	Concentration
Aluminum (Al)	Lab leachate study (Minn Poll Cntrl Agency, 1990)	2,000 ng released (per g tire)
	Lab leachate study (Hartwell et al., 1998)	1200 ng released (per g of tire)
	Lab study (Florida Dept. Environ. Protection, 1999)	420 ng released (per g of tire)
	Lab leachate study (Sengupta and Miller, 1999)	790 ppb in leachate
	Lab leachate study (O'Shaughnessy and Garga, 2000)	550 ppb in leachate
Antimony	Field leachate study (FCC at Jacksonville, 1999)	489 ppb in soil
Arsenic (As)	Lab leachate studies (Miller and Chadik, 1993)	130 ng released (per g tire)
	Field leachate study (Yoon et al., 2005)	19 ppb in leachate
Barium (Ba)	Lab leachate study (Minn Poll Cntrl Agency, 1990)	1,000 ng released (per g tire)
	Lab leachate study (Scrap Tire Man Cncl, 1991)	590 ppb in leachate
	Lab leachate studies (Tatlisoz et al., 1996)	100 to 1000 ng released (per g tire)
	Lab leachate study (Hartwell et al., 1998)	1700 ng released (per g of tire)
	Field leachate study (Humphrey, 1999)	21 ppb in leachate
	Field leachate study (FCC at Jacksonville, 1999)	1,230 ppb in surface water
	Field leachate study (FCC at Jacksonville, 1999)	10,000 ppb in soil
	Lab leachate study (Park et al., 2003)	340 ng released (per g of tire)
	Field leachate study (Yoon et al., 2005)	113 ppb in leachate
Cadmium (Cd)	Lab leachate study (Minn Poll Cntr Agency, 1990)	270 ng released (per g of tire)
	Lab leachate study (Hartwell et al., 1998)	270 ng released (per g of tire)

Metal	Study Type	Concentration
	Lab study (Florida Dept. Environ. Protection, 1999)	4 ng released (per g of tire)
	Field leachate study (Yoon et al., 2005)	1.1 ppb in leachate
Chromium (Cr) with oxidation state (Cr^{+3} or Cr^{+6}) not determined	Lab leachate study (Minn Poll Cntrl Agency, 1990)	500 ng released (per g tire)
	Lab leachate study (Scrap Tire Man Cncl, 1991)	48 ppb in leachate
	Lab leachate studies (Tatlisoz et al., 1996)	8 to 500 ng released (per g of tire)
	Lab leachate study (Hartwell et al., 1998)	100 ng released (per g of tire)
	Field leachate study (FCC at Jacksonville, 1999)	2 ppb in surface water
	Field leachate study (FCC at Jacksonville, 1999)	4 ppb in ground water
	Lab study (Florida Dept. Environ. Protection, 1999)	8 ng released (per g of tire)
	Field leachate study (Yoon et al., 2005)	55 ppb in leachate
Cobalt (Co)	Lab leachate study (Hartwell et al., 1998)	100 ng released (per g of tire)
Copper (Cu)	Lab leachate study (Al-Tabbaa and Aravinthan, 1998)	360 to 4880 ng released (per g of tire)
	Lab leachate study (Hartwell et al., 1998)	320 ng released (per g of tire)
	Field leaching study (FCC at Jacksonville, 1999)	2,300 ppb in leachate
	Lab study (Florida Dept. Environ. Protection, 1999)	235 ng released (per g of tire)
	Lab leachate study (Sengupta and Miller, 1999)	2,400 ppb in leachate
Iron (Fe)	Lab leachate study (Gunter et al., undated)	13,000 ng released (per g of tire)
	Lab leachate study (Minn. Poll. Cntr. Agency, 1990)	1,100,000 ng released (per g of tire)
	Lab leachate study (Anthony et al., 1995)	26,000 ng released (per g of tire)

Metal	Study Type	Concentration
	Lab leachate studies (Tatlisoz et al., 1996)	1,150 to 1,100,000 ng released (per g tire)
	Field leachate study (Liu et al., 1998)	55,000 ppb in leachate
	Lab leachate study (Hartwell et al., 1998)	27,000 ng released (per g of tire)
	Lab study (Florida Dept. Environ. Protection, 1999)	341,000 ng released (per g of tire)
	Field leachate study (Humphrey et al., 1999)	30,000 ppb in leachate
	Field leachate study (FCC at Jacksonville, 1999)	1,500 ppb in ground water
	Field leachate study (FCC at Jacksonville, 1999)	210 ppb in surface water
	Field leachate study (FCC at Jacksonville, 1999)	960,000 ppb in soil
	Field leachate study (Humphrey 1999)	22,000 ppb in leachate
	Lab leachate study (Sengupta and Miller, 1999)	18,000 ppb in leachate
	Lab leachate study (O'Shaughnessy and Garga, 2000)	700 ppb in leachate
	Field leachate study (Humphrey et al., 2001)	33,000 ppb in leachate
	Field leachate study (Exponent, 2003)	80,000 ppb in leachate
Lead (Pb)	Lab leachate study (Gunter et al., undated)	12 ng released (per g of tire)
	Lab leachate study (Minn. Poll. Cntr. Agency, 1990	920 ng released (per g of tire)
	Lab leachate study (Scrap Tire Man. Cncl., 1991)	30 ppb in leachate
	Lab leachate studies (Tatlisoz et al., 1996)	3 to 920 ng released (per g tire)
	Field leachate study (FCC at Jacksonville, 1999)	6 ppb in surface water
	Lab study (Florida Dept. Environ. Protection, 1999)	56 ng released (per g tire)
	Field leachate study (FCC at Jacksonville, 1999)	13,300 ppb in soil

Metal	Study Type	Concentration
	Lab leachate study (Park et al., 2003)	120 ng released (per g of tire)
Manganese (Mn)	Lab leachate study (Gunter et al, undated)	1,040 ng released (per g tire)
	Lab leachate study (Anthony et al., 1995)	5800 ng released (per g tire)
	Lab leachate studies (Tatlisoz et al., 1996)	1,500 ng released (per g of tire)
	Field leachate study (Liu et al., 1998)	3,000 ppb in leachate
	Lab leachate study (Hartwell et al., 1998)	5800 ng released (per g of tire)
	Field leachate study (Humphrey, 1999)	2,500 ppb in leachate
	Lab leachate study (O'Shaughnessy and Garga, 2000)	180 ppb in leachate
	Field leachate study (Humphrey and Katz, 2000)	22,000 ppb in leachate
	Field leachate study (Humphrey and Katz, 2001)	1,300 ppb in leachate
	Field leachate study (Exponent, 2003)	910 ppb in leachate
Mercury (Hg)	Lab leachate study (Scrap Tire Man Cncl, 1991)	0.4 ppb in leachate
	Lab leachate study (Minn Dept Trans, 1995)	0.4 ppb in leachate
	Lab leachate studies (Tatlisoz et al., 1996)	0.07 ng released (per g tire)
Nickel (Ni)	Lab leachate study (Anthony et al., 1995)	80 ng released (per g of tire)
	Lab leachate study (Hartwell et al., 1998)	120 ng released (per g of tire)
	Lab leachate study (Al-Tabbaa and Aravinthan, 1998)	5-12 µg released (per g of tire)
	Lab study (Florida Dept. Environ. Protection, 1999)	113 ng released (per g of tire)
Selenium (Se) (elemental)	Lab leachate study (Minn Poll Cntrl Agency, 1990)	440 ng released (per g tire)
	Lab leachate studies (Tatlisoz et al., 1996)	50 to 440 ng released (per g tire)

Metal	Study Type	Concentration
	Field leachate study (Yoon et al., 2005)	23 ppb in leachate
Zinc (Zn)	Lab leachate study (Minn. Poll Cntrl Agency, 1990)	50,000 ng released (per g tire)
	Lab leachate study (Scrap Tire Man. Councl., 1991)	500 ppb in leachate
	Lab leachate study (Miller and Chadik, 1993)	3,200 ng released (per g of tire)
	Lab leachate study (Nelson et al., 1994)	4,200 ng released (per g tire)
	Lab leachate study (Ontario Ministry of Environment and Energy, 1994)	1,000 ng released (per g of tire)
	Lab leachate study (Minn. Dept. Trans., 1995)	2,950 ppb in leachate
	Lab leachate study (Horner, 1996)	2,320,000 ng released (per g tire)
	Lab leachate studies (Tatlisoz et al., 1996)	1,130 to 50,000 ng released (per g tire)
	Lab leachate study (Hartwell et al., 1998)	68,000 ng released (per g of tire)
	Field leachate study (FCC at Jacksonville, 1999)	45,000 ppb in soil
	Field leachate study (Humphrey, 1999)	140 ppb in leachate
	Field leachate study (FCC at Jacksonville, 1999)	103 ppb in surface water
	Field study (Florida Dept. Environ. Protection, 1999)	618 ppb in leachate
	Lab study (Florida Dept. Environ. Protection, 1999)	30,000 ng released (per g of tire)
	Field leachate study (Humphrey and Katz, 2000)	26 ppb in leachate
	Lab leachate study (O'Shaughnessy and Garga, 2000)	590 ppb in leachate
	Field leaching study (Boniak et al., 2001)	310 ppb in soil
	Lab leachate study (Johnson et al., 2002)	2,950 ppb in leachate

Metal	Study Type	Concentration
	Lab leachate study (Park et al., 2003)	1100 ng released (per g of tire)
	Lab leachate study (Birkholz et al., 2003)	68,000 ng released (per g of tire)
	Lab leachate study (Gualtieri et al., 2005)	890,000 ng released (per g tire rubber)

Table 3. Concentrations of Volatile Organic Compounds (VOCs) released from tire shreds in various field applications and laboratory studies, and in ambient air samples

Compound	Study Type	Concentration
1,1-dichloroethane	Field leachate study (Humphrey and Katz, 2000)	Trace (<5 ppb) in leachate
2,6-dinitrotoluene	Lab leaching study (Minn Dept Trans, 1995)	45 ppb in leachate
2-Methyl naphthalene	Lab leaching study (Hartwell et al., 1998)	540 ng released (per g of tire)
1,3,5-trimethylbenzene	Field leaching study (Miller and Chadik, 1993)	4 ppb in leachate
Acetone	Lab leachate study (Gunter et al., undated)	115 ng released (per g of tire)
	Leachate in field (Humphrey and Katz, 2001)	28 ppb in leachate
	Leachate in field (Exponent, 2003)	27 ppb in leachate
Benzene	Lab leachate study (Gunter et al., undated)	0.9 ng released (per g of tire)
	Leaching study in lab (Miller and Chadik, 1993)	218 ng released (per g of tire)
	Field leachate study (Humphrey and Katz, 2001)	4 ppb in leachate
	Field leachate study (Exponent, 2003)	1.35 ppb in leachate
Chloroethane	Field leaching study (Exponent, 2003)	2 ppb in leachate
Cis-1,2-dichloroethene	Field leachate study (Humphrey and Katz, 2001)	24 ppb in leachate
Isophorone	Lab leaching study (Minn Dept Trans, 1995)	2 ppb in leachate

Compound	Study Type	Concentration
Methyl ethyl ketone	Lab leachate study (Gunter et al., undated)	17 ng released (per g of tire)
	Lab leachate study (Scrap Tire Manag Concl, 1991)	21 ppb in leachate
Methyl isobutyl ketone	Lab leachate study (Gunter et al., undated)	1151 ng released (per g of tire)
	Field leachate study (Miller and Chadik, 1993)	3 ppb in leachate
	Field leachate study (Humphrey and Katz, 2000)	Trace (<5 ppb) in leachate
	Field leachate study (Humphrey and Katz, 2001)	58 ppb in leachate
	Field leachate study (Edil et al., 2003)	69 ppb in leachate
Naphthalene	Lab leaching study (Hartwell et al., 1998)	1,100 ng released (per g of tire)
A nitro-aliphatic ether compound	Lab leaching study (Anthony and Latawiec, 1993)	5000 to 25000 ppb in leachate
n-pentatriacontane	Air sampling study (Schauer et al., 2002)	3 ng/m^3
n-tetratriacontane	Air sampling study (Schauer et al., 2002)	3 ng/m^3
Polycyclic aromatic hydrocarbons (PAHs)	Lab leaching study (Minn Poll Cntr Agency, 1990)	140 ng released (per g of tire)
Toluene	Lab leaching study (Scrap Tire Man Cncl, 1991)	190 ppb in leachate
	Lab leaching studies (Tatlisoz et al., 1996)	34 to 280 ng released (per g of tire)
	Field leaching study (FCC at Jacksonville, 1999)	63 ppb in soil
	Field leaching study (Exponent, 2003)	2.6 ppb in leachate
Total petroleum hydrocarbons	Lab leaching study (Minn Poll Cntr Agency, 1990)	140 ng released (per g of tire)
	Lab leaching study (Stephensen et al., 2003)	Up to 450 ng/g fish bile fluid
Trichloroethene	Field leaching study (Exponent, 2003)	0.8 ppb in leachate

Compound	Study Type	Concentration
Trichloroethylene	Lab leachate study (Gunter et al., undated)	0.8 ng released (per g of tire)
	Field leachate study (Humphrey and Katz, 2001)	6 ppb in leachate
	Field leachate study (Exponent, 2003)	2 ppb in leachate
	Field leachate study (Exponent, 2003)	16 ppb in leachate

Table 4. Concentrations of Semi-Volatile Organic Compounds (sVOCs) released from tire shreds in various field applications and laboratory studies, and in some ambient environmental samples

Compound	Study Type	Concentration
(1,1-diethylethyl)-2-methoxyphenol	Lab leachate study (O'Shaughnessy and Garga, 2000)	330 ppb in leachate
2(3H)-benzothiazolone	Lab leachate (Ontario Ministry of Environment and Energy, 1994)	170 ng released (per g of tire)
	Lab leachate study (O'Shaughnessy and Garga, 2000)	640 ppb in leachate
2-hydroxybenzothiazole	Lab leachate study (Reddy and Quinn, 1997)	36,000 ng released (per g crumb rubber)
	Urban runoff (Reddy and Quinn, 1997)	7.0 ppb in urban runoff
2-(4-morpholinyl)benzothiazole	S.F. bay sediment (Spies et al., 1987)	360 ppb in sediment
	Lab leachate (Ontario Ministry of Environment and Energy, 1994)	260 ng released (per g of tire)
	Background air sample (Kumata et al., 1996)	5.9 pg/m^3
	Lab leachate study (Reddy and Quinn, 1997)	2,000 ng released (per g crumb rubber)
	Urban runoff (Reddy and Quinn, 1997)	0.28 ppb in runoff
	Lab leachate study (Hartwell et al., 1998)	Not quantifiable
	Lab leachate study (O'Shaughnessy and Garga, 2000)	340 ppb in leachate
	River sediment (Kumata et al., 2002)	9 ppb in sediment
	Highway runoff (Kumata et al., 2002)	0.417 ppb in runoff
4-(phenylamino)-phenol	Lab leachate (Ontario Ministry of Environment and Energy, 1994)	340 ng released (per g of tire)
aniline	Lab leachate study (Miller and Chadik, 1993)	742 ng released (per g tire)
	Lab leachate (Ontario Ministry of Environment and Energy,	129 ng released (per g tire)

Compound	Study Type	Concentration
	1994)	
	Field leachate study (Humphrey and Katz, 2001)	71 ppb in leachate
	Field leachate study (Exponent, 2003)	100 ppb in leachate
benzothiazole	Lab leachate (Ontario Ministry of Environment and Energy, 1994)	430 ng released (per g of tire)
	Urban runoff (Reddy and Quinn, 1997)	1.3 ppb in urban runoff
	Lab leachate study (Reddy and Quinn, 1997)	100,000 ng released (per g crumb rubber)
	Lab leachate study (O'Shaughnessy and Garga, 2000)	900 ppb in leachate
Bis(2-ethylhexyl)phthalate	Lab leachate study (Hartwell et al., 1998)	Not quantifiable
m + p cresol	Field leachate study (Humphrey and Katz, 2001)	39 ppb in leachate
N-cyclohexyl-2-benzothiazolamine	Highway runoff (Kumata et al., 2002)	0.508 ppb in runoff
	River sediment (Kumata et al., 2002)	17 ppb in sediment
N-nitrosodimethylamine	Field leachate study (Exponent, 2003)	7 ppb in leachate
N-nitrosodiphenylamine	Field leachate study (Exponent, 2003)	7 ppb in leachate
phenol	Lab leachate study (Scrap Tire Man Concl, 1991)	50 ppb in leachate
	Lab leachate study (Tatlisoz et al., 1996)	10 ng released (per g of tire)
phenoxazine	Lab leachate (Ontario Ministry of Environment and Energy, 1994)	220 ng released (per g of tire)

Table 5. Concentrations of particulates in the air resulting from tire wear

Substance	Study Type	Concentration
Rubber particulates (<10 microns) containing latex	Air sampling and guardrail swipes near freeway (Miguel et al., 1996)	1 µg/m^3
Rubber particles (59%<10 microns) with latex	Air sampling near freeway (Williams et al., 1995)	3800-6900 particles/m^3
Rubber particulates	Air sampling in urban area (Kim et al., 1990)	Up to 7 µg/m^3
Fine particulate organic carbon due to tire wear	Emissions into air in urban area (Hildemann et al., 1991)	105 µg /m^2 of urban surface area/day
Fine particulate organic carbon from tires	Air sampling (Schauer et al., 2002)	1 µg/m^3
Airborne dust from tire tread	Air sampling near busy urban road (Fukuzaki et al., 1986)	24 ng/m^3

Chapter 4: Toxicity reference values for substances released by recycled tires

To determine if an environmental contaminant poses a threat to human health, its environmental concentration is used to estimate human exposure, which is then compared to reference toxicity values. Such reference values (i.e., RfD = reference dose, MRL = minimal risk level, PHG = public health goal, REL = reference exposure level) are often derived from data determined experimentally in studies with laboratory animals. Alternatively, human epidemiologic data can be used. This section lists the reference toxicity values for most of the substances identified in the previous section. The tables are arranged according to type of toxicant (metal, VOC, sVOC, particulate) and are for the oral route of exposure. Reference values were collected for acute (single), subchronic (up to 90 days) and chronic (one year or more) exposures. When available, OEHHA values were used. Information was also included regarding carcinogenicity and whether children represent a sensitive subgroup relative to the adult population.

Table 6: Metals: Oral route: Toxicity Values

Aluminum (noncarcinogenic, the data do not suggest an increased susceptibility of infants or children; OEHHA, 2001a; ATSDR, 1999a)
Acute: not acutely toxic in healthy adults based on widespread exposure via food, water and antacid tablets (OEHHA, 2001a)
Subchronic: minimal risk level (MRL) = 2.0 mg/kg-d based on a NOAEL of 62 mg/kg-day in mice fed for 6 weeks and exhibiting decreased activity (uncertainty factors of 3 for interspecies and 10 for intraspecies variability; ATSDR, 1999a)
Chronic: a public health goal (PHG) for aluminum in drinking water was developed using a chronic oral screening value of 0.018 mg/kg-d derived from a human study in which volunteers fed the metal for 20 days exhibited a significant increase in serum aluminum (NOAEL/LOAEL = 125 mg/d, UF = 10 for intrahuman variability and 10 for subchronic to chronic extrapolation; OEHHA, 2001a)
Antimony (no data were located on carcinogenicity by the oral route or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: An LOAEL of 0.43 mg/kg-day was based on minor clinical signs and a slight decrease in longevity in a chronic rat study, yielding a chronic screening level of 1.4 µg/kg-day (UFs of 3 for LOAEL to NOAEL extrapolation, and 100 for intra- and interspecies extrapolation) (OEHHA, 1997c)
Arsenic (considered a group A human carcinogen; IRIS, 1998a) (no evidence that the young are more sensitive than adults)
Acute: an acute Minimal Risk Level (MRL) of 5 µg/kg-d was developed based on a 2-3 week exposure in humans which produced nausea, vomiting, diarrhea, occult blood in feces and duodenal juice (UF = 10 for LOAEL to NOAEL extrapolation; ATSDR, 2000a)
Subchronic: no screening level identified
Chronic: a $1x10^{-6}$ excess risk of lung and bladder cancer was calculated for a chronic oral intake by humans of 1.1×10^{-4} µg/kg-d (OEHHA, 2004a)
Barium (Dog and rat pharmacokinetic studies (Taylor et al., 1962; Cuddihy and Griffith, 1974) suggest that gastrointestinal absorption of barium may be higher in young animals than in older animals; IRIS, 1999) (not carcinogenic; OEHHA, 2003b)

Acute: LD_{50} in weanling and adult rats of 220 and 132 mg/kg, respectively (OEHHA, 2003b); fatal dose of barium carbonate suggested to be about 800 mg (OEHHA, 2003b)
Subchronic: NOAEL of 0.21 mg/kg-day in adult humans exposed for four weeks (OEHHA, 2003b)
Chronic: 0.07 mg/kg-day in adult humans based on the absence of cardiovascular effects (NOAEL = 0.21 mg/kg-day) and an uncertainty factor (human variability) of 3 (OEHHA, 2003b)
Cadmium (considered a potential human carcinogen by the oral route; OEHHA, 1999a) (following ingestion, absorption was higher in young rats and guinea pigs compared to adults, suggesting that young humans may also absorb more ingested cadmium than adults; ATSDR, 1999b)
Acute: a single dose of 25 mg/kg was lethal in a human suicide (ATSDR, 1999b); a single dose LD_{50} of 29 mg/kg was measured in 2 week old rats (ATSDR, 1999b)
Subchronic: no screening level identified
Chronic: a Reference Exposure Level (REL) of 0.5 µg/kg-day was calculated based on proteinuria in an exposed human population (UFs = 10 for intraspecies variation; OEHHA, 2000a); an RfD of 0.5 µg/kg-day for cadmium intake in water was calculated based on the same critical study and UF listed above for the REL (IRIS, 1994a); Minimal Risk Level (MRL) = 0.21 µg/kg-day based on kidney effects in an exposed human population (UF = 10 for intraspecies variability; ATSDR, 1999b); a dose of 2.6 ng/kg-day yielded a *de minimis* excess lifetime cancer risk of $1x10^{-6}$ (OEHHA, 1999a)
Chromium (hexavalent) (no data to indicate children more susceptible; listed as a carcinogen by inhalation, OEHHA, 2004b)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: RfD = 3 µg/kg-day in rats based on the absence of toxicity at the highest dose tested (2.5 mg/kg-d) (uncertainty factors of 10 each for intraspecies and interspecies variability and 3 for subchronic to chronic extrapolation; IRIS, 1998b); the RDA for total chromium for a 1-3 year old child is 11 µg/day (USDA, 2006)
Cobalt (no data were located on carcinogenicity by the oral route or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: an MRL of 10 µg/kg-day was developed based on a 25 day study in which exposed humans exhibited polycythemia (UFs of 10 for LOAEL to NOAEL extrapolation and 10 for intrahuman variability) (ATSDR, 2004b)

Chronic: no screening level identified
Copper (infants and children may be more susceptible; OEHHA, 1997a) [Carcinogenicity classification -- D; not classified basis -- There are no human data, inadequate animal data from assays of copper compounds, and equivocal mutagenicity data (IRIS, 1991a)
Acute: 5.3 mg (76 µg/kg) ingested by human adults caused gastrointestinal distress, headaches and dizziness (OEHHA, 1997a)
Subchronic: in adults a NOAEL of 0.0538 mg/kg-day (over two weeks) for gastrointestinal effects was divided by an UF = 3 (for human variability) to give an MRL (minimal risk level) of 0.02 mg/kg-day (ATSDR, 2002)
Chronic the RDA (recommended daily allowance) is 13 µg /kg-day (ATSDR, 2002) for an adult and 23 µg /kg-day for a 1-3 year old child weighing 15 kg (USDA, 2006).
Iron
Acute: 0.5 grams can be lethal if ingested by a child (Goyer, 1996; Spivey and Rader, 1988); acute ingestion of 20 mg/kg by adults was associated with gastrointestinal irritation (Institute of Medicine, 2002).
Subchronic: LOAEL = 70 mg/day (1 mg/kg/day in 70 kg adult) for 4 weeks of ingestion by adults resulting in GI effects, UL = LOAEL/1.5 (UF) = 45 mg/day (Institute of Medicine, 2002)
Chronic: Upper intake level = 40 mg/day for ingestion by infants and small children (Institute of Medicine, 2002); the RDA for a 1-3 year old child is 7 mg/day (USDA, 2006).
Lead (children may be most sensitive group, possibly due to greater absorption; OEHHA, 1997b) [B2; probable human carcinogen (IRIS, 1993a); determined to be carcinogenic by the oral route (OEHHA, 2004b)]
Acute: colic would be expected in a child following ingestion of approximately 80 µg /kg bodyweight (approximately 60 µg /dL blood level; ATSDR, 1999c) and dividing by UFs of 10 for intrahuman variability and 3 for LOAEL to NOAEL extrapolation gives an acute screening level = 2.7 µg /kg
Subchronic: no screening level identified
Chronic: intake of 29 µg/day by children associated with decreased IQ and other neurological effects, then, applying an UF = 3 results in a screening value of 10 µg/day or 0.67 µg /kg-day for a 15 kg child (OEHHA, 1997b); NSRL = 15 µg/day, MADL = 0.5 µg/day (OEHHA, 2004b); a dose of 0.18 µg/kg-day yielded an excess lifetime cancer risk of $1x10^{-6}$ (OEHHA, 1997b)

Manganese (neonates may absorb and retain more manganese than adults)
Acute: acute LD_{50} in rats = 200-300 mg/kg/day (ATSDR, 2000b)
Subchronic: no screening level identified
Chronic: RfD = 3 mg/day for non-food sources of manganese in adults (IRIS, 1996a); the RDA for a 1-3 year old child is 1.2 mg/day (USDA, 2006)
Mercury (inorganic) (not on Proposition 65 list as chemical known to the state to cause cancer; OEHHA, 2004b; listed as a Group C possible human carcinogen by the IRIS, 1995b) (suckling rats absorbed inorganic mercury from ingested food at a 30 to 40-fold higher rate than adults; ATSDR, 1999d)
Acute: Ingestion of 0.5 g can be lethal in humans, while LD_{50}s in rats ranged from 30 to 77 mg/kg (OEHHA, 1999b)
Subchronic: a subchronic screening value of 1.6 µg/kg-d was based on decreased weight gain and increased kidney weights in rats (UFs = 10 for intrahuman variability and 10 for interspecies extrapolation; OEHHA, 1999b)
Chronic: a screening value of 0.16 µg/kg-d was calculated based on decreased weight gain and increased kidney weights in rats (UFs = 10 for intrahuman variability, 10 for interspecies extrapolation, 10 for subchronic to chronic extrapolation; OEHHA, 1999b)
Molybdenum (no data located on carcinogenicity or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: an RfD of 5 µg/kg-day was developed based on increased serum uric acid levels in a chronically exposed human population (a UF of 3 was applied for intrahuman variability and 10 for LOAEL to NOAEL extrapolation; IRIS, 1993c)
Nickel (water soluble) (not a known oral carcinogen) (no data were located indicating that the young are more susceptible than adults)
Acute: adult humans became sick (nausea, abdominal cramps, diarrhea, vomiting) after ingesting water contaminated with nickel at dose levels ranging from 7 to 36 mg nickel/kg (OEHHA, 2001b) and dividing by UFs of 10 for intrahuman variability and 3 for LOAEL to NOAEL extrapolation gives an acute screening level = 233 µg/kg
Subchronic: no screening level identified

Chronic: a chronic screening level of 1.12 µg/kg-d was calculated based on increased pup mortality in rat reproductive toxicity studies (UFs = 10 for intrahuman variability, 10 for interspecies extrapolation, 10 for potential carcinogenicity of soluble nickel by the oral route; OEHHA, 2001b); an RfD of 20 µg/kg-d was calculated based on decreased body and organ weights in rats fed nickel (UFs = 10 for intrahuman variability, 10 for interspecies extrapolation, 3 for inadequacies in the reproductive toxicity studies; IRIS, 1996b)
Selenium (designated a class D carcinogen: not classifiable as to carcinogenicity in humans; IRIS, 1993b) (no data to indicate that children are more sensitive than adults; ATSDR, 2003a)
Acute: no screening level identified
Subchronic: use chronic REL
Chronic: a chronic oral reference exposure level (REL) of 0.005 mg/kg-day was developed based on a human epidemiological study of lifetime exposures (3-fold UF for intrahuman variability; OEHHA, 2003a); the recommended daily allowance is 1.07 to 1.53 µg/kg-day for children (IRIS, 1993b)
Vanadium (no data were located on carcinogenicity by the oral route or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: An intermediate MRL of 3 µg/kg-day was developed based on a 3 month study in the rat producing hemorrhagic foci in the renal system (UFs of 10 for interspecies and 10 for intrahuman variability) (ATSDR, 1992c)
Chronic: an RfD of 9 µg/kg-day was developed based on decreased hair cystine in chronically exposed rats (an UF of 10 was applied for interspecies extrapolation and 10 for intrahuman variability; IRIS, 1996c).
Zinc (no evidence to suggest children more sensitive than adults)
Acute: LOAEL approx. 2-8 mg/kg based on gastrointestinal distress in adults after single-dose ingestion (ATSDR, 2003b)
Subchronic: subchronic MRL = 0.3 mg/kg-day based on decreased erythrocyte SOD activity, hematocrit and serum ferritin in human females (composite UF = 3; ATSDR, 2003b)
Chronic: RfD = 0.3 mg/kg-day based on same subchronic study cited above (IRIS, 1992); Recommended Dietary Allowance of 3 mg/day and a Tolerable Upper Intake Level of 7 mg/day in 1-3 year olds (The National Academies, 2001)

Table 7: VOCs: Oral route: Toxicity Values

1,1-Dichloroethane (carcinogenic based on rodent studies, no evidence of enhanced sensitivity of infants or children; OEHHA, 2003c; ATSDR, 1990)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: lifetime oral consumption of 0.171 µg/kg-d yielded an excess individual cancer risk of 10^{-6} (OEHHA, 2003c); no significant risk level (NSRL) = 100 µg/day (yields an excess individual cancer risk of 10^{-5} for a 70 year exposure; OEHHA, 2004b)
1,2-Dichloroethene (no carcinogenicity studies were located, ATSDR, 1996; IRIS, 1995a; no evidence of increased sensitivity of infants or children, ATSDR, 1996)
Acute: minimal risk level (MRL) = 1.0 mg/kg-d based on decreased hematocrit and erythrocytes in female rats treated by single-dose oral gavage (NOAEL = 97 mg/kg-day, UFs of 10 for intraspecies and 10 for interspecies variability, ATSDR, 1996)
Subchronic: minimal risk levels (MRL) = 0.3 mg/kg-day based on decreased hematocrit in male rats dosed by gavage for 90 days with the cis isomer (NOAEL = 32 mg/kg-day, UFs 10 for intraspecies and 10 for interspecies variability, ATSDR, 1996); MRL = 0.2 mg/kg-day based on increased serum alkaline phosphatase and increased relative liver weight in male mice fed the trans isomer via the drinking water for 90 days (NOAEL = 17 mg/kg-day, UFs of 10 for intraspecies and 10 for interspecies variability, ATSDR, 1996)
Chronic: no screening level identified
Acetone (minimal evidence that young or pregnant rats more sensitive than nonpregnant adults; ATSDR, 1994) (data inadequate for assessment of human carcinogenic potential; IRIS, 2003c)
Acute: no screening level identified
Subchronic: Minimal Risk Level (MRL) = 2 mg/kg-day based on a 13 week study in rats identifying mild macrocytic anemia (UFs of 10 for intraspecies and 10 for interspecies extrapolation; ATSDR 1994)
Chronic: RfD = 0.9 mg/kg-day based on same subchronic rat drinking water study as above producing nephropathy (NOAEL = 900 mg/kg-day, UF = 10 for intraspecies, $10^{1/2}$ for interspecies, $10^{1/2}$ for subchronic to chronic extrapolation, 10 for data base deficiencies; IRIS, 2003c)
Benzene (classified as a human carcinogen; IRIS, 2000; OEHHA, 2001c; no data to indicate that infants or children are more susceptible than adults to the carcinogenic effects)

Acute: a single oral dose of 125 mg/kg is estimated to be lethal in humans (OEHHA, 2001c); as little as 50 mg/kg has caused death in humans (ATSDR, 2004)
Subchronic: no screening level identified
Chronic: a noncancer screening value of 9 µg/kg-day was based on hematological effects in workers exposed for up to 21 years (UF = 10 for intrahuman variability; OEHHA, 2001c); a *de minimis* excess individual cancer risk of 10^{-6} was associated with a lifetime exposure of 0.01 µg/kg-d (OEHHA, 2001c); a No Significant Risk Level (NSRL) of 7 µg/day for a cancer risk of 10^{-5} (equivalent to 0.01 µg/kg-d at a cancer risk level of 10^{-6}; OEHHA, 2004b); MADL = 0.34 µg/kg-day (OEHHA, 2004b)
Benzo[b]fluoranthene (classified as a group B2 probable human carcinogen by IRIS, 1994d)
Acute: no data located
Subchronic: no data located
Chronic: a No Significant Risk Level (NSRL) of 0.096 µg/day (equivalent to 0.16 ng/kg-d at the 10-6 cancer risk level; OEHHA, 2004b)
Chrysene (classified as a group B2 probable human carcinogen by IRIS, 1994e)
Acute: no data located
Subchronic: no data located
Chronic: a No Significant Risk Level (NSRL) of 0.36 µg/day (equivalent to 0.58 ng/kg-d at the 10^{-6} cancer risk level; OEHHA, 2004b)
Fluoranthene (classified as a group D carcinogen [not classifiable as to human carcinogenicity] by IRIS, 1990b)
Acute: no data located
Subchronic: see chronic study below
Chronic: an oral RfD of 40 µg/kg-d was developed based on a 13 week subchronic study in which mice developed nephropathy, increased liver weights, hematological changes and clinical signs (UFs of 10 for intraspecies extrapolation, 10 for interspecies extrapolation, and 30 for both subchronic to chronic extrapolation and the absence of reproductive/developmental data and data from a second animal species; IRIS, 1990b)
Methyl ethyl ketone (data judged inadequate for determination of carcinogenicity in humans; IRIS, 2003a) (no data on whether the young are more susceptible)
Acute: mild renal tubular necrosis in rats after a single oral dose of 1080 mg (ATSDR, 1992a)
Subchronic: no screening level identified

Chronic: RfD of 0.6 mg/kg-day based on decreased rat pup weight in a repro study, UF = 1000 (10 for interspecies, 10 for intraspecies, 10 for deficiencies in data base) (IRIS, 2003a)
Methyl Isobutyl Ketone (listed as food additive by FDA)
Acute: no screening level identified
Subchronic: NOAEL = 250 mg/kg-day based on a variety of mild effects at 1000 mg/kg-day in rats gavaged for 13 weeks (IRIS, 2003b); applying UF = 100 gives a subchronic screening level = 10 mg/kg-day
Chronic: using above subchronic study and applying another UF = 10 for subchronic to chronic extrapolation gives chronic screening level = 1 mg/kg-day (IRIS thought data insufficient for derivation of a chronic RfD)
Phenanthrene (classified as a group D carcinogen [not classifiable as to human carcinogenicity] by IRIS, 1990c)
Acute: no data located
Subchronic: no data located
Chronic: no data located
Pyrene (classified as a group D carcinogen [not classifiable as to human carcinogenicity] by IRIS, 1991b)
Acute: no data located
Subchronic: see chronic study below
Chronic: an oral RfD of 30 µg/kg-d was developed based on a 13 week subchronic study in which mice developed kidney effects (UFs of 10 for interspecies extrapolation, 10 for intraspecies extrapolation, 10 for subchronic to chronic extrapolation, and 3 for the absence of developmental/reproductive data and data from a second animal speicies; IRIS, 1991b)
Styrene (no evidence for increased sensitivity of the young; listed as a group 2B possible human carcinogen by IARC [1994] with inadequate evidence in humans and limited evidence in animals
Acute: no screening level identified
Subchronic: Minimal Risk Level (MRL) = 0.2 mg/kg-day based on a 100 day study in rats identifying changes in hepatic enzymes (UFs of 10 for interspecies, 10 for intraspecies, and 10 for use of a LOAEL; ATSDR, 1992b)
Chronic: RfD = 2 mg/kg-day for effects in rbcs and livers of dogs (UF = 100 for intra and interspecies variability, they also included 10 for subchronic to chronic extrapolation which I have dropped since the study ran for 560 days; IRIS, 1990a)
Toluene (carcinogenicity judged not classifiable [Group D] due to absence of human data and inadequate animal data; IRIS, 1994b) (only minimal data indicating that neonatal humans may be more sensitive than adults)

Acute: Minimal Risk Level (MRL) = 0.8 mg/kg-day based on neurological changes (altered visual information processing) in rats following single-dose oral gavage (UFs of 10 for human variability, 10 for interspecies extrapolation, and 3 for use of a minimally adverse LOAEL; ATSDR, 2000c)
Subchronic: Minimal Risk Level (MRL) = 0.02 mg/kg-day based on a 28 day drinking water study in mice identifying increased brain norepinephrine and dopamine (UFs of 10 for human variability, 10 for interspecies extrapolation, and 3 for use of a minimally adverse LOAEL; ATSDR, 2000c)
Chronic: a chronic screening value of .022 mg/kg-day was identified from a subchronic mouse drinking water study producing immunological toxicity (UFs of 10 for interspecies, 10 for intraspecies, and 10 for subchronic to chronic extrapolation; OEHHA, 1999c); an RfD = 0.2 mg/kg-day was based on a subchronic rat gavage study which detected changes in liver and kidney weights (UF = 1000 for intraspecies and interspecies extrapolation, subchronic to chronic extrapolation, and limited developmental and reproductive toxicity data; IRIS, 1994b); maximum allowable dose level (MADL) = 7.0 mg/day (OEHHA, 2004b)
Trichloroethylene (IARC considers the evidence for carcinogenicity to be sufficient in animals and limited in humans; OEHHA, 1999d) (no data were located showing that the young are more sensitive than adults)
Acute: single-dose oral LD_{50}s were 2400 mg/kg-d in mice and 7200 mg/kg-d in rats (ATSDR, 1997b)
Subchronic: no screening level identified
Chronic: a chronic screening level of 0.5 mg/kg-day was based on kidney nephropathy in rats (UFs of 10 for interspecies and 10 for intrahuman variability; OEHHA, 1999d); an excess individual cancer risk of 10^{-6} was associated with a lifetime exposure of 0.077 µg/kg-d (OEHHA, 1999d)

Table 8: sVOCs: Oral route: Toxicity Values

1H-isoindole-1,3(2H)-dione (a.k.a. captan) (no data were located on the carcinogenicity of 1H-isoindole-1,3(2H)-dione or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: an RfD of 130 µg/kg-d was developed based on decreased bodyweight in the rat (an UF of 10 was applied for interspecies and 10 for intrahuman extrapolation; IRIS, 1989)
Aniline (classified as a B2 probable human carcinogen by IRIS, 1994c)
Acute: Methemoglobinema is the principle mechanism of acute aniline toxicity in man (Hazardous Substances Data Bank, 2004); a dose-dependent increase in methemoglobin resulted from single oral doses of aniline of 25-65 mg/person (Jenkins et al., 1972; IARC, 1982) with a NOEL at 15 mg (approximately 0.21 mg/kg); applying an UF of 10 for intrahuman variability yields an acute screening level of 0.021 mg/kg-day.
Subchronic: no screening level identified
Chronic: an excess cancer risk of 10^{-6} was calculated for a daily exposure of 0.175 µg/kg-d based on a two year feeding study in rats (IRIS, 1994c)
Benzothiazole (no data located on carcinogenicity or susceptibility of children) (used as a flavoring in foods at up to 0.5 ppm, listed as a GRAS substance [“generally recognized as safe”]; NTP, 2004)
Acute: Oral LD_{50}s: rat = 380-479 mg/kg, mouse = 900 mg/kg (NTP, 2004)
Subchronic: no screening level identified
Chronic: no screening level identified
Cyclohexanone (no data were located on the carcinogenicity of cyclohexanone or whether children represent a sensitive subpopulation)
Acute: no screening level identified
Subchronic: no screening level identified
Chronic: an RfD of 5.0 mg/kg-d was developed based on decreased bodyweight gain in the rat (an UF of 10 was applied for interspecies and 10 for intrahuman extrapolation; IRIS, 1987)

Phenol (data considered insufficient to determine if children are more sensitive than adults; ATSDR, 1998) (data considered inadequate for carcinogenicity assessment in humans; IRIS, 2002)
Acute: no screening level identified
Subchronic: The chronic RfD of 0.3 mg/kg-d (see below) could be applied to subchronic exposures, since it is based on a developmental study with an exposure duration of 10 days
Chronic: an RfD of 0.3 mg/kg-d was developed based on decreased maternal weight gain in a rat developmental study (UFs = 10 for interspecies variability, 10 for intrahuman variability, and 3 for immunological and hematological effects noted in a 28 day mouse drinking water study; IRIS, 2002)

Chapter 5: Evaluation of Toxicity Due to Ingestion of Tire Shreds Based on the Existing Literature of Tire Leachate Studies

Table 9 lists 27 chemicals and the highest amount of each that leached per gram of tire, as found in the published literature, along with leaching conditions. Measurements were made in laboratory settings under a variety of different conditions. Aqueous solutions containing various salts and/or buffers were used, with the pH ranging from 2.1 to 12.1 across the studies, or not controlled. Perhaps even more problematic was the variable leaching times, ranging from 17 hours to six months. These studies also utilized different starting material: whole tires, tire shreds, chips and crumb.

The different brands of tires used in the different studies almost certainly contributed to the variable levels of chemicals released (Tables 2-4), since tire components, as well as the tire manufacturing process itself, vary across the industry. Keeping these uncertainties in mind, the highest leaching value for each chemical was chosen for calculating the dose. In this respect, the calculations represent worst-case scenarios. Using the laboratory leaching values in this way assumes that the same amounts of these chemicals would leach following ingestion of tire-derived shreds or crumb by a child. All such leaching chemicals were also assumed to be 100 percent bioavailable, representing another worst-case assumption.

The doses calculated in Table 9 are based on a one-time (acute) ingestion of 10 grams of tire shreds or crumb rubber by a 15 kg child. The value of 10 grams has been recommended for acute risk assessment for children who ingest large amounts of soil on 1-2 days out of the year (U.S. EPA, 2002; OEHHA, 2000c). This is not a typical behavior pattern observed in most children, but rather a poorly characterized behavior seen in a subset of young children (U.S. EPA, 2002). It seems reasonable to assume that a child ingesting 10 grams of soil in a single episode would also be capable of ingesting 10 grams of crumb rubber. A bodyweight of 15 kg is the 50^{th} percentile value for both male and female children that are three years old (U.S. EPA, 2002).

As discussed earlier in this report, toxicity reference values from authoritative bodies were collected for acute, subchronic and chronic oral exposures to the substances released by tires. The acronyms for these reference values, together with their meanings and issuing bodies, are listed at the end of Table 9. These can be used as screening levels and compared to the estimated dose a child might ingest, to predict whether adverse noncancer health effects would occur. If the estimated dose were less than the screening level, then acute health effects would not be expected. Toxicity reference values for use as screening levels have not been developed for every chemical listed in Table 9; therefore, in some cases screening levels were calculated where adequate toxicity data were located in the published literature (toxicity data cited by chemical in Tables 6-8).

Since the exposure scenario being considered here is an acute, single-dose exposure, acute health effects are expected, and acute screening levels are most appropriate for use in risk calculations. However, Table 9 shows that an acute screening level was usually not available. In such cases, a subchronic screening level was used, and if this was also unavailable, a chronic screening level was used. The following reasoning was applied in these latter two cases; if the estimated dose was lower than the subchronic or chronic

screening level, then acute health effects were considered unlikely. When available, OEHHA values were used as screening levels. Conclusions reached from this comparison of screening level with estimated dose are listed in Table 9 for each chemical.

The dose levels of ingested chemicals presented in Table 9 are due to ingestion of tire shreds. For comparison, Table 10 shows the average daily intakes resulting from the presence of these chemicals in food, water and air. In many cases these average daily intakes are rough estimates. Nonetheless, it is useful to compare the tire-derived levels to the average daily intakes. Average daily intakes were located for 17 of the chemicals listed in Table 9. For 12, the average daily intakes equal or exceed the tire-derived exposures. In many cases the exposure due to ingestion of tire shreds is much lower than the average daily intake. Only for arsenic, iron, lead, nickel and zinc does the tire-derived exposure exceed the average daily intake. This indicates that particular care should be taken when comparing the tire-derived exposures to these chemicals to their corresponding health-based screening levels.

Table 9. Comparison of ingested dose to health-based screening level for an acute ingestion of tire-derived crumb/shreds by a child based on published studies of tire leachate: noncancer health effects.

Chemical	***Highest amount released per g of tire and leaching conditions[1]***	**Dose[2]**	***Screening level[3]***
Metals			
Aluminum	2.0 µg released per g of tire for slices of tire incubated in an aqueous solution at pH 3.5, 20-40°C for 24 h with agitation	1.3 µg/kg	Not acutely toxic in humans based on widespread presence in antacids, water and food; a 20 day human study was used to develop a chronic screening level of 18 µg/kg-d (OEHHA, 2001a)
Conclusion	*No acute screening level was identified. However, the estimated dose is 14-fold lower than the chronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Arsenic	0.13 µg released per g of tire for shredded tires incubated in an aqueous solution whose pH ranged from 2.1 to 5.5 over 38 days	0.087 µg/kg	Acute MRL = 5 µg/kg-day (ATSDR, 2000a)
Conclusion	*The estimated dose is over 50-fold lower than the acute MRL, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Barium	1.7 µg released per g of tire shreds shaken for seven days in an aqueous solutions of 0-25 percent salinity	1.13 µg/kg	Subchronic screening level = 21 µg/kg-day (OEHHA, 2003b in Table 6)
Conclusion	*No acute screening level was identified. However, the estimated dose is 19-fold lower than the subchronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Cadmium	0.27 µg released per g of tire (leaching conditions as for Al)	0.18 µg/kg	Chronic REL in adults = 0.5 µg/kg-day (OEHHA, 1999a)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 2.8-fold lower than the chronic REL, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Cobalt	0.1 µg released per g of tire (leaching conditions as for barium)	0.07 µg/kg	Intermediate MRL = 10 µg/kg-day (ATSDR, 2004b)
Conclusion	*The estimated dose is 143-fold lower than the intermediate MRL, suggesting a low risk of adverse effects from a one-time ingestion.*		

Chemical	***Highest amount released per g of tire and leaching conditions[1]***	**Dose[2]**	***Screening level[3]***
Copper	4.88 µg released per g of tire for shredded tires shaken for 17 h in an aqueous solution, pH = 4.9	3.25 µg/kg	The recommended daily allowance (RDA) for a 1-3 year old child is 23 µg/kg-day (USDA, 2006)
Conclusion	*Since the estimated dose is below the recommended daily allowance, adverse health effects are not expected.*		
Chromium	0.5 µg (fractions as trivalent and hexavalent not determined) released per g of tire (leaching conditions as for Al)	0.33 µg/kg	Chronic RfD (hexavalent) = 3.0 µg/kg-day (IRIS, 1998b)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 9-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Iron	1.1 mg released per g of tire (leaching conditions as for Al)	0.73 mg/kg	Upper intake level = 2.7 mg/kg-day for a 15 kg child (Institute of Medicine, 2002)
Conclusion	*The estimated dose is 3.7-fold lower than the upper intake level, suggesting a low risk of adverse health effects from a one-time exposure*		
Lead	0.92 µg released per g of tire (leaching conditions as for Al)	0.61 µg/kg	Acute screening level = 2.7 µg/kg (ATSDR, 1999c in Table 6); chronic screening level = 0.67 µg/kg-day (OEHHA, 1997b in Table 6)
Conclusion	*The estimated dose is 4.4-fold lower than the acute screening level in children. It is also below the chronic screening level. This suggests a low risk of adverse health effects from a one-time ingestion.*		
Manganese	5.8 µg released per g of tire for tire shreds shaken for 7 days in an aqueous solution at pH 6-7 and 25 parts per thousand salinity	3.9 µg/kg	Chronic RfD for nonfood sources of Mn in adults = 43 µg/kg-day (IRIS, 1996a in Table 6)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 11-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time ingestion.*		

Chemical	***Highest amount released per g of tire and leaching conditions[1]***	**Dose[2]**	***Screening level[3]***
Mercury	0.07 ng released per g of tire for ground tires shaken in aqueous solutions ranging in pH from 2.9 to 4.9 and for times ranging from 18 to 24 hours	0.05 ng/kg	Subchronic screening value of 1.6 µg/kg-day (OEHHA, 1999b)
Conclusion	*No acute screening level was identified. However, the estimated dose is 32,000-fold lower than the subchronic screening level, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Nickel	12 µg released per g of tire (leaching conditions as for Cu)	8.0 µg/kg	Acute screening level = 233 µg/kg (OEHHA, 2001b in Table 6)
Conclusion	*The estimated dose is 29-fold below the acute screening level, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Selenium (elemental)	0.44 µg released per g of tire (leaching conditions as for Al)	0.29µg/kg	Chronic REL = 5 µg/kg-day (OEHHA, 2003a)
Conclusion	*The estimated dose is 17-fold below the chronic REL, suggesting a low risk of adverse health effects.*		
Zinc	2.32 mg released per g of tire chips shaken for 67 h in an aqueous solution at pH 2.5	1.55 mg/kg	Subchronic MRL = 0.3 mg/kg-day (ATSDR, 2003b)
Conclusion	*The estimated dose is 5.1-fold higher than the subchronic MRL, so adverse health effects are possible, but unlikely from an acute ingestion of tire shreds*		
Volatile Organic Compounds			
Acetone	0.115 µg released per g of tire chips incubated in water for at least 6 months prior to sampling	0.077 µg/kg	Subchronic MRL = 2.0 mg/kg-day (ATSDR, 1994)
Conclusion	*No acute screening level was identified. However, the estimated dose is over 25,000-fold lower than the subchronic MRL, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Benzene	0.218 µg released per g of shredded tires incubated for 38 days in an aqueous solution, where the pH varied from 2.1 to 4.7	0.145 µg/kg	MADL = 0.34 µg/kg-day (OEHHA, 2004b)

Chemical	***Highest amount released per g of tire and leaching conditions[1]***	**Dose[2]**	***Screening level[3]***
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 2.3-fold lower than the chronic MADL, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Methyl ethyl ketone	0.017 µg released per g of tire chips (leaching conditions as for Acetone	0.011µg/kg	Chronic RfD = 0.6 mg/kg-day (IRIS, 2003a)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is over 50,000-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time exposure.*		
Methyl isobutyl ketone	1.15 µg released per g of tire chips (leaching conditions as for Acetone)	0.77 µg/kg	Subchronic screening level = 10 mg/kg-day (IRIS, 2003b in Table 6)
Conclusion	*No acute screening level was identified. However, the estimated dose is more than 10,000-fold lower than the subchronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Toluene	0.28 µg released per g of tire shreds (leaching conditions as for benzene)	0.187 µg/kg	Acute MRL = 0.8 mg/kg (ATSDR, 2000c)
Conclusion	*The estimated dose is over 4,000-fold lower than the acute MRL, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Naphthalene	1.1 µg released per g of tire shreds (leaching conditions as for barium)	0.73 µg/kg	Acute oral MRL = 600 µg/kg-day (ATSDR, 2005)
Conclusion	*The estimated dose is over 800-fold lower than the acute MRL, suggesting a low risk of health effects from a one-time ingestion.*		
2-Methyl naphthalene	0.54 µg released per g of tire shreds (leaching conditions as for barium)	0.36 µg/kg	Chronic oral MRL = 40 µg/kg-day (ATSDR, 2005)
Conclusion	*The estimated dose is 111-fold lower than the chronic MRL, suggesting a low risk of health effects from a one-time ingestion.*		
Trichloro-ethylene	0.8 ng released per g of tire chips (leaching conditions as for acetone)	0.53 ng/kg	Chronic screening level = 0.5 mg/kg-day (OEHHA, 1999d)

Chemical	***Highest amount released per g of tire and leaching conditions[1]***	**Dose[2]**	***Screening level[3]***
Conclusion	*No acute or subchronic screening levels were identified. The estimated dose is 900,000-fold lower than the chronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion*		
Semi-volatile Organic Compounds			
aniline	0.74 µg released per g of tire shreds incubated for 38 days in an aqueous solution, pH 12.0-12.1	0.5 µg/kg	Acute screening level = 0.021 mg/kg-day (Jenkins et al., 1972 and IARC, 1982 in Table 6)
Conclusion	*The estimated dose is 42-fold lower than the acute screening level, suggesting a low risk of adverse health effects from a one-time oral ingestion.*		
Benzothiazole	100 µg released per g of tire crumb shaken in water at 25°C for 5 days	67 µg/kg	On GRAS list; oral LD_{50} in rats = 380-479 mg/kg (NTP, 2004)
Conclusion	*Inadequate screening level data.*		
2(3H)-Benzothiazolone	0.17 µg released per g of whole tire submerged in water for 2 weeks with aeration	0.11 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
2-Hydroxy-benzothiazole	36 µg released per g of tire crumb (leaching conditions as for Benzothiazole)	24 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
2-(4-Morpholin-yl)benzothiazole	2.0 µg released per g of tire crumb (leaching conditions as for Benzothiazole)	1.33 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
Phenol	0.01 µg released per g of ground tire incubated in aqueous solutions ranging in pH from 2.9 to 4.9 and for times ranging from 18 to 24 hours		0.0

Chemical	*Highest amount released per g of tire and leaching conditions*[1]	Dose[2]	*Screening level*[3]	
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is over 42,000-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time ingestion.*			
Phenoxazine	0.22 µg released per g of whole tire (leaching conditions as for 2(3H)-Benzothiazolone)			0.
Conclusion	*Inadequate screening level data.*			
4-(Phenyl-amino)-phenol	0.34 µg released per g of whole tire (leaching conditions as for 2(3H)-Benzothiazolone)			0.
Conclusion	*Inadequate screening level data.*			

[1] See Table 2 for references.

[2]The dose is the amount of chemical assumed to leach from 10 grams of tire crumb/shreds following ingestion by a 15 kg child.

[3] See Tables 6, 7 and 8 for references associated with the screening levels covering metals, volatile organic compounds and semi-volatile organic compounds, respectively.

MRL = minimal risk level (ATSDR)

NSRL = no significant risk level (OEHHA)

REL = reference exposure level (OEHHA)

RfD = reference dose (U.S. EPA)

MADL = maximum allowable dose level (OEHHA)

GRAS = generally recognized as safe (FDA)

RDA = recommended daily allowance (NAS/NRC)

UL = upper intake level (Institute of Medicine)

Table 10. Average daily intakes of chemicals released by tires[1]

Chemical	Source	Ave. daily intake in µg/kg	Reference
Metals			
Aluminum	Total diet	13-270	OEHHA, 2001d
Antimony	Food and water	0.061	OEHHA, 1997c
Arsenic	Food and water	0.013	OEHHA, 2004a
Barium	Food and water	9-24	ATSDR, 2005b
Cadmium	Food and water	0.08-1.17	OEHHA, 1999a
Chromium (total)	Total diet	1.0	ATSDR, 2000d
Cobalt	Food	0.07-0.53	ATSDR, 2004b
Copper	Total diet	39	OEHHA, 1997a
Iron	All sources	120-230	HSDB, 2006a
Lead	Total diet	0.23	ATSDR, 2005c
Manganese	Food	100	HSDB, 2006b
Mercury (inorganic)	Food	0.06	OEHHA, 1999b
Nickel	Total diet	2.2	OEHHA, 2001b
Selenium	Total diet	1.5	ATSDR, 2003a
Vanadium	Total diet	A few tenths of µg	ATSDR, 1992c
Zinc	All sources	67-213	ATSDR, 2005d
Organics			
1H-isoindole-1,3(2H)dione (a.k.a. captan)	All sources	0.007-0.014	HSDB, 2006c
Benzene	Air	0.1	OEHHA, 2001c
Chrysene	Total diet	0.007	HSDB, 2006d
Fluoranthene	Air	0.00006	HSDB, 2006e
Naphthalene	All sources	0.27	HSDB, 2006f
Phenanthrene	Air and water	0.0007-0.0054	HSDB, 2006g
Pyrene	All sources	0.00001	HSDB, 2006h
Toluene	Air	0.27	HSDB, 2006i
Trichloroethylene	Air and water	186-757	ATSDR, 1997b
Total Polycyclic Aromatic Hydrocarbons	Food	0.023-0.23	ATSDR, 1995

[1] Intakes were normalized to bodyweights of 70 kg for adult data and 15 kg for data from 2 year old children

Comparison of ingested dose to screening levels: noncancer effects

Comparison performed using the data from Table 9:

µg chemical released/gram tire shreds **x** 10 grams tire shreds ingested/15 kg child =

µg chemical ingested **x** 10/15 kg child → does dose exceed screening value?

Zn

Addressing acute health effects, only the estimated dose of leachable zinc (1.55 mg/kg) exceeded its associated screening level: in this case 5.1-fold above a subchronic MRL of 0.3 mg/kg-day based on decreased erythrocyte SOD activity, hematocrit and serum ferritin in human females dosed daily for 10 weeks. These effects were probably due to zinc-induced changes in the copper and iron balance, causing the above-mentioned hematological effects to develop towards the end of the study (IRIS, 1992). Thus, zinc supplementation acted as an inducer of copper and iron deficiency.

Since nutritional deficiencies and their related health effects develop over extended periods of time, these effects are unlikely to occur in response to an acute ingestion of zinc. In addition, zinc is an essential element with a Recommended Dietary Allowance of 3 mg/day and a Tolerable Upper Intake Level of 7 mg/day for a 3-year-old child (National Academies, 2001). These considerations make it unlikely that an acute, oral ingestion of 1.55 mg/kg of zinc by a child would result in adverse health effects, other than the gastrointestinal distress observed in adults ingesting 2-8 mg/kg acutely (Table 6).

An additional area of uncertainty in the zinc risk calculations relates to the range of zinc leaching values listed in Table 2. The highest value (2.3 mg leached per gram of tire) was selected for use in the risk calculation described in Table 9. However, this value is from 2.6- to 2,300-fold higher than other zinc measurements listed in Table 2, and 18-fold higher than the value measured in the gastric digestion simulation experiment shown below in Table 16. Thus, using most zinc leaching values other than the maximum value in Table 9 would result in an estimated dose that was below the subchronic screening level for zinc. This underscores the importance of accurate leaching data.

Other chemicals

Six of the chemicals listed in Table 9 could not be evaluated due to the absence of screening levels. In addition, 11 of the VOCs and sVOCs identified in Tables 3 and 4 as leaching from tires could not be evaluated due to the absence of information on the amount of tire rubber that was used to produce each leachate. Therefore, the acute risks from these chemicals remain uncharacterized. Other than for naphthalene and 2-methyl naphthalene, the data on polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons could not be evaluated since leaching data were not presented for individual compounds (Table 3).

It has become common practice to perform calculations to determine whether health effects are expected from exposures to complex mixtures of toxicants. The leachate from tires represents such a complex mixture. One methodology (CIWMB, 2004) is to calculate a Hazard Quotient for each individual toxicant by dividing the dose by the

associated health-based screening level, and then add all values together to give a Hazard Index (Table 11). A Hazard Index less than one suggests that health effects are unlikely, while an Index greater than one suggests that health effects are more likely. This approach is most meaningful when applied to chemicals that cause similar effects on the same target organ. Such is not the case here. It should also be noted that for most chemicals listed in Table 9 an acute screening level was not available, so that subchronic or chronic values were used instead. This undoubtedly led to higher individual Hazard Quotients than would have been calculated if acute screening values were available. On the other hand, for some chemicals there were no screening level data, so that a Hazard Quotient could not be calculated.

Nonetheless, the Hazard Index approach was used as a first tier screening procedure to estimate whether cumulative impacts would be expected from all the chemicals released by tire shreds. The Hazard Index based on all chemicals except zinc is 1.8, while that including zinc is 6.9. As discussed above, since zinc-induced copper or iron deficiencies develop over a period of weeks in which zinc is ingested daily, we believe it unlikely that zinc released from a one-time ingestion of tire shreds would cause health effects other than gastrointestinal distress. Since the Hazard Index for all chemicals other than zinc is close to one, this first tier screening suggests that this complex mixture of chemicals does not represent a serious health hazard.

Table 11. Hazard Quotients and Hazard Index for an Acute Ingestion of Chemicals Identified in Published Studies of Tire Leachate

Chemical	Dose[1]/screening value[1]	Hazard quotient[2]
Metals		
aluminum	1.3/18	0.072
arsenic	0.087/5	0.017
barium	1.13/21	0.054
cadmium	0.18/0.5	0.360
cobalt	0.07/10	0.007
copper	3.25/23 (RDA)	Not calculated
chromium (hexavalent)	0.33/3	0.110
iron	730/2700	0.27
lead	0.61/2.7	0.226
manganese	3.9/43	0.091
mercury	0.00005/1.6	0.00003
nickel	8/233	0.034
selenium (elemental)	0.29/5	0.058
zinc	1550/300	5.167

Chemical	Dose[1]/screening value[1]	Hazard quotient[2]
Volatile Organic Compounds		
acetone	0.077/2000	0.00004
benzene	0.145/0.34	0.426
methyl ethyl ketone	0.011/600	0.00002
methyl isobutyl ketone	0.77/10,000	0.00008
toluene	0.187/800	0.0002
naphthalene	0.73/600	0.001
2-methyl naphthalene	0.36/40	0.009
trichloroethylene	0.00053/500	1.1×10^{-6}
Semi-volatile Organic Compounds		
aniline	0.5/21	0.024
phenol	0.007/300	0.00002
HAZARD INDEX (-) ZINC		**1.8**
HAZARD INDEX (+) ZINC		**6.9**

[1]from Table 9, both in µg/kg [2]calculated from second column of this table

In summary, serious noncancer health effects are not expected following a one-time ingestion of tire-derived shreds or crumb by a child. Gastrointestinal distress might occur as has been observed in adults ingesting high amounts of zinc (Table 6); however, the variable levels of zinc that leached from tire-derived material (Table 2 and the gastric digestion simulation experiment shown in Table 16) suggest that the amount leaching from ingested rubber would be significantly lower than that used in the calculation in Table 9, so that acute effects would not be expected. Chronic effects are also not expected due to the single-dose nature of the exposure (chronic health effects are examined more closely in a Chapter 7 dealing with chronic exposures via hand-to-mouth activity). Should a child ingest ten grams of tire shreds on more than one occassion, the methodology followed here would yield a proportional increase in ingested dose that could exceed some of the acute screening values listed in Table 9. Whether a child ingests ten grams of tire shreds often enough for such exposures to qualify as subchronic or chronic is unknown.

Estimating the increased cancer risk

From among the chemicals listed in Table 9, seven (arsenic, cadmium, lead, benzene, trichloroethylene, aniline, naphthalene) are currently listed as oral carcinogens by the State of California (OEHHA, 2005). In general, data are lacking as to whether a one-time ingestion of most carcinogens is sufficient to cause cancer. Nonetheless, Table 10 calculates the increased cancer risk to a three year old assuming that a one-time ingestion of these seven chemicals is sufficient, however, the true risk may be greater or less than the calculated risk. The calculations were performed according to draft methodology recommended by the U.S. EPA (2003c). Following this methodology, the dose from

Table 9 was averaged over a 70-year lifetime, multiplied by the Cancer Slope Factor, and multiplied by a factor of three to cover the increased sensitivity of a three-year-old child to some carcinogens:

> ingested dose/(70)(365) **x** oral cancer slope factor **x** (3) = increased cancer risk in a three-year-old

The increased cancer risk from exposure to each of seven chemicals (arsenic, cadmium, lead, benzene, trichloroethylene, aniline, naphthalene) is low, while the total increased risk is 1.2×10^{-7}. This is 3-fold higher than the increased cancer risk of 3.7×10^{-8} based on a "gastric digestion" experiment carried out by OEHHA (see Table 17). Thus, ingestion of tire-derived shreds by a three-year-old child is associated with a low cancer risk. The same U.S. EPA draft methodology that recommends the use of a safety factor of three for calculating the cancer risk to children between the ages of 2 and 15, also recommends the use of a safety factor of ten for children below the age of two (U.S. EPA, 2003c). Thus, multiplying the above total increased risk by 3.3 yields an increased risk of 3.6×10^{-7}.

Therefore, should a child below the age of two ingest ten grams of shredded tire rubber, the cancer risk would still be below the *di minimis* risk level of 1×10^{-6}, generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). As for the noncancer health effects discussed above, calculating the increased cancer risk assumes a one-time ingestion of ten grams of tire shreds. Should this behavior be repeated in the same child, the risk would increase proportionately. However, lacking data as to whether ingestion of ten grams of tire shreds is a behavior that is repeated in some children, we have not calculated the increased cancer risk for other than a one-time ingestion.

Table 12. Increased cancer risk in a 3 year old following a one-time ingestion of 10 grams of shredded tires based on published tire leachate studies

Carcinogen	Dose ingested by a 3 year old in mg/kg[(1)]	Ingested dose averaged over 70 x 365 days in mg/kg-d	Oral Cancer Slope Factor in $(mg/kg\text{-}d)^{-1}$ [(2)]	Increased cancer risk in a 3 year old [(3)]
Arsenic	8.7×10^{-5}	3.4×10^{-9}	9.45	9.6×10^{-8}
Cadmium	1.8×10^{-4}	7.0×10^{-9}	0.38	8.0×10^{-9}
Lead	6.1×10^{-4}	2.3×10^{-8}	0.0085	6.1×10^{-10}
Benzene	1.45×10^{-4}	5.7×10^{-9}	0.1	1.7×10^{-9}
Trichloroethylene	5.3×10^{-7}	2.1×10^{-11}	0.013	8.2×10^{-13}
Aniline	5.0×10^{-4}	2.0×10^{-8}	0.0057	3.4×10^{-10}
Naphthalene	7.3×10^{-4}	2.9×10^{-8}	0.12	1.0×10^{-8}

Calculated thus: ingested dose/(70)(365) **x** oral cancer slope factor **x** (3) = increased cancer risk in a three-year-old

(1) From Table 9.

(2) From the OEHHA Toxicity Criteria Database, available at www.oehha.ca.gov

[3] Calculated by multiplying the Cancer Slope Factor in column four by the averaged dose in column three, and then multiplying by a factor of three for the increased sensitivity of 3 year old children to carcinogens released by tires (U.S. EPA, 2003c).

Chronic ingestion of excess zinc is not considered to be carcinogenic by the ATSDR (2003b), while IRIS (1992) classifies zinc into Group D: not classifiable as to human carcinogenicity.

Chapter 6: Evaluation of Toxicity Due to Ingestion of Tire Shreds Based on OEHHA Gastric Digestion Simulation Study

Measuring the chemicals released from tire-derived shreds

To estimate the kinds and amounts of chemicals that could potentially be extracted in a child's gastrointestinal tract, we performed the following gastric digestion simulation experiment. Three samples of shredded tire rubber were obtained from three recyclers; two located in California and one in Ohio. Forty grams of shredded tire rubber were added to each of three glass flasks. A fourth control flask received no rubber. Then 200 mls of a solution were added to simulate the environment of the human stomach. The chart below lists the components of this gastric digestion solution along with references. A citric acid-sodium citrate buffer was added to help maintain a constant pH.

Table 13. Composition of "Gastric Digestion" Solution (Guyton and Hall, 2000; Semple et al., 2001)

Compound	*Concentration*
Citric acid (buffer)	20.0 mM
Sodium citrate (buffer)	0.5 mM
Potassium chloride	15.0 mM
Sodium chloride	3.0 mM
Pepsin	1.0 mg/ml
All in distilled water with pH = 2.3	

Following addition of shredded tires and solution, each flask was sealed with parafilm, placed in a temperature-controlled rotary shaker, and gently shaken at 37^{o}C for 21 hours. Each solution was then filtered through Whatman filter paper into a glass sample jar. Samples were immediately refrigerated, followed by transport to the analyzing laboratory (Sequoia Analytical, Morgan Hill, CA). Metals were analyzed by EPA Method 6020 and sVOCs (including sixteen PAHs) by EPA Method 8270C.

Table 14 lists the metals and sVOCs that were identified in the extract. The tire leachates contained 13 metals and 9 sVOCs that were present at lower levels or not at all in the control. No PAHs were detected. The control sample contained two sVOCs that were not detected in any tire samples. Unfortunately, these measurements give no information on bioavailability, which was assumed to be 100 percent for all chemicals.

All 13 metals were higher in the three rubber samples than in the control. Three sVOCs were also present in all three rubber samples but not in the control: benzothiazole, 2(3H)-benzothiazolone and aniline. Comparing the results of the digestion experiment to the studies gathered from the literature and listed in Tables 2-4, our digestion experiment

identified three metals and five sVOCs not previously identified as leaching from tire rubber: antimony, molybdenum, vanadium, cyclohexanamine N-cyclohexyl, cyclohexanone, formamide,N-cyclohexyl, 1H-isoindole-1,3(2H)dione and o-cyanobenzoic acid. In addition, two other metals and three other sVOCs leached at higher levels in the digestion experiment compared to the literature values: barium, copper, aniline, 2(3H)-benzothiazolone and phenol. Importantly, the amount of zinc released per gram of rubber was 18-fold lower in the digestion experiment compared to the highest value found in the literature and used in Table 9. Thus, our value for leaching zinc as well as the majority of zinc values gathered from the literature (Table 2), suggest that the value used in Table 9 overestimates the dose.

Table 14. Chemicals leaching from three shredded tire samples in "gastric digestion" experiment (all units are µg/l, ND = below reporting limit)[1]

Chemical	Reporting limit	Tire sample "G"	Tire sample "S"	Tire sample "O"	Control
Metals					
Antimony	0.50	110	42	1.7	ND
Arsenic	1.0	6.1	5.4	4.7	ND
Barium	1.0	130	110	870	4.2
Cadmium	0.25	2.2	2.8	1.1	0.44
Chromium (total)	2.0	41	57	35	16
Cobalt	0.50	45	50	33	ND
Copper	0.5-50	1500	960	1600	8.3
Lead	0.50	140	120	48	4.6
Molybdenum	1.0	11	18	8.5	ND
Nickel	1.0	27	27	22	1.1
Selenium	1.0	18	10	7.1	3.0
Vanadium	1.0	9.0	9.5	5.8	3.3
Zinc	5.0-500	17000	26000	13000	16
Organics					
o-cyanobenzoic acid	36-190	990	ND	910	ND
Cyclohexanamine, N-cyclohexyl-	190	190	410	ND	ND
Benzothiazole	36-190	320	450	390	ND
2(3H)-Benzothi-azolone	36-190	640	450	480	ND

Chemical	Reporting limit	Tire sample "G"	Tire sample "S"	Tire sample "O"	Control
1H-isoindole-1,3 (2H)-dione	190	ND	490	ND	ND
Cyclohexanone	36	ND	ND	48	ND
Formamide, N-Cyclohexyl-	36	ND	ND	110	ND
Benzaldehyde, 3-Hydroxyl-4-methoxy-	19	ND	ND	ND	25
Hexanedioic acid, bis(2-ethylhexyl)	19	ND	ND	ND	28
Aniline	190-360	2800	3000	6700	ND
Phenol	19-360	190	ND	ND	ND

[1] Data reported in Appendix A in Work Order MOC0103. Ranges of reporting limits for some chemicals indicate that different reporting limits were associated with different samples.

COMPARISON OF CHEMICAL EXPOSURE DUE TO INGESTION OF TIRE SHREDS TO SCREENING LEVELS: NONCANCER EFFECTS

Comparison performed using the data from Table 14:

µg chemical released/gram tire shreds **x** 10 grams tire shreds ingested/15 kg child =

µg chemical ingested **x** 10/15 kg child → does dose exceed screening value?

Exposure doses were calculated for chemicals that were detected in at least one rubber sample at a level that was either: 1) at least three times the control, or, if the control was a nondetect, at a level that was 2) at least three times one-half the reporting limit for that chemical. Multiplying the reporting limit by a factor of three has been recommended for setting the minimum level of quantitation (US EPA, 2004). In order to represent a worst case scenario, the highest value from among the three rubber samples was used in Table 16 for calculating exposure doses.

Chemicals released were assumed to be 100 percent bioavailable. It was also assumed that a 15 kg child might acutely ingest 10 grams of shredded rubber at one time, similar to the upper limit of soil ingestion recommended for estimating acute exposures in children (US EPA, 2002; OEHHA, 2000c). This kind of soil ingestion is not a typical behavior pattern observed in most children, but rather a poorly characterized behavior seen in a subset of young children (US EPA, 2002).

Estimated doses were calculated for each contaminant and compared to the corresponding screening value cited in Tables 6-8. Table 16 shows this comparison for noncancer health effects. As discussed in the previous section, acute screening levels were often lacking, so subchronic or chronic screening levels were used instead. The reasoning was that if the estimated dose was lower than the subchronic or chronic screening level, then acute health effects were unlikely. When available, OEHHA screening values were used.

The dose levels of ingested chemicals presented in Table 16 are due to ingestion of tire shreds. For comparison, Table 10 shows the average daily intakes resulting from the presence of these chemicals in food, water and air. In many cases these average daily intakes are rough estimates. Nonetheless, it is useful to compare the tire-derived levels to the average daily intakes. Average daily intakes were located for thirteen of the chemicals listed in Table 16. For nine, the average daily intake equals or exceeds the tire-derived exposure. In many cases the exposure due to ingestion of tire shreds is much lower than the average daily intake. Only for antimony, arsenic, lead and captan does the tire-derived exposure exceed the average daily intake. This indicates that particular care should be taken when comparing the tire-derived exposures to these chemicals to their corresponding health-based screening levels.

From among the 20 chemicals listed in Table 16, 15 yielded ingested dose levels that fell at or below the corresponding screening level. The remaining five chemicals had no associated screening levels, so that the risk of health effects could not be estimated. Thus, our measurements of chemicals that leach from tire rubber, under conditions approximating those in a child's stomach, suggest that acute health effects would not occur following ingestion of ten grams of shredded rubber by a 15 kg child. Should a child ingest ten grams of tire shreds on more than one occassion, the methodology followed here would yield a proportional increase in ingested dose that could exceed some of the acute screening values listed in Table 9. Whether a child ingests ten grams of tire shreds often enough for such exposures to qualify as subchronic or chronic is unknown

As in Chapter 5, the Hazard Index approach was again used as a first tier screening procedure to estimate whether cumulative impacts would be expected from all the chemicals released by tire shreds in the gastric digestion study (Table 15). The Hazard Index based on all chemicals is 2.2. Since the Hazard Index is close to one, this first tier screening suggests that this complex mixture of chemicals does not represent a serious health hazard.

Table 15. Hazard Quotients and Hazard Index for an Acute Ingestion of Chemicals Identified in OEHHA Gastric Digestion Simulation Experiment

Chemical	Dose[1]/screening value[1]	Hazard quotient[2]
Metals		
antimony	0.37/1.4	0.26
arsenic	0.02/5	0.004
barium	2.9/21	0.138
cadmium	0.009/0.5	0.180
chromium (hexavalent)	0.19/3	0.063
cobalt	0.17/10	0.017
copper	5.3/23 (RDA)	Not calculated
lead	0.47/2.7	0.174
molybdenum	0.06/5	0.012

Chemical	Dose[1]/screening value[1]	Hazard quotient[2]
nickel	0.09/233	0.0004
selenium	0.06/5	0.012
vanadium	0.032/3	0.011
zinc	87/300	0.29
Semi-volatile organic compounds		
aniline	22.3/21	1.062
1H-isoindole-1,3(2H)-dione	1.6/130	0.012
HAZARD INDEX		**2.2**

[1]from Table 16, both in µg/kg [2]calculated from second column of this table

Table 16. Comparison of ingested dose to health-based screening level for an acute ingestion of tire-derived shreds based on "gastric digestion" study: noncancer health effects.

Chemical	***Highest amount released per g of tire (from among the three shredded tire samples subjected to "gastric digestion" in Table 14)***	**Dose[1]**	***Screening level***
Metals			
Antimony	0.55 µg	0.37 µg/kg	Chronic screening level = 1.4 µg/kg-day (OEHHA, 1997c)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 26% of the chronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Arsenic	0.031 µg	0.02 µg/kg	Acute MRL = 5 µg/kg-day (ATSDR, 2000a)
Conclusion	*The estimated dose is 250-fold lower than the acute MRL, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Barium	4.35 µg	2.9 µg/kg	Subchronic screening level = 21 µg/kg-day (OEHHA, 2003b in Table 6)
Conclusion	*No acute screening level was identified. However, the estimated dose is 7-fold lower than the subchronic screening level, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Cadmium	0.014 µg	0.009 µg/kg	Chronic REL in adults = 0.5 µg/kg-day (OEHHA, 1999a)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 56-fold lower than the chronic REL, suggesting a low risk of adverse health effects from a one-time ingestion.*		

Chemical	***Highest amount released per g of tire (from among the three shredded tire samples subjected to "gastric digestion" in Table 14)***	**Dose[1]**	***Screening level***
Chromium	0.285 µg (fractions of trivalent and hexavalent not determined)	0.19 µg/kg	Chronic RfD (hexavalent) = 3.0 µg/kg-day (IRIS, 1998b)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 16-fold lower than the chronic RfD, suggesting that health effects are unlikely from an acute ingestion.*		
Cobalt	0.25 µg	0.17 µg/kg	Intermediate MRL = 10 µg/kg-day (ATSDR, 2004b)
Conclusion	*No acute screening level was identified. However, the estimated dose is 59-fold lower than the intermediate MRL, suggesting a low risk of adverse health effects from a one-time ingestion.*		
Copper	8.0 µg	5.3 µg/kg	The recommended daily allowance (RDA) for a 1-3 year old is 23 µg/kg-day (USDA, 2006)
Conclusion	*Since the estimated dose is below the recommended daily allowance, adverse health effects are not expected.*		
Lead	0.7 µg	0.47 µg/kg	Acute screening level = 2.7 µg/kg (ATSDR, 1999c in Table 6); chronic screening level = 0.67 µg/kg-day (OEHHA, 1997b in Table 6)
Conclusion	*The estimated dose is 5.7-fold lower than the acute screening level in children. It is also below the chronic screening level. This suggests a low risk of adverse health effects from a one-time ingestion.*		
Molybdenum	0.09 µg	0.06 µg/kg	Chronic RfD = 5 µg/kg-day (IRIS, 1993c)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 83-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time ingestion.*		

Chemical	***Highest amount released per g of tire (from among the three shredded tire samples subjected to "gastric digestion" in Table 14)***	**Dose[1]**	***Screening level***
Nickel	0.135 µg	0.09 µg/kg	Acute screening level = 233 µg/kg (OEHHA, 2001b in Table 6)
Conclusion	*The estimated dose is more than 2,500-fold below the acute screening level, suggesting a low risk of adverse health effects from a one-time oral exposure.*		
Selenium	0.09 µg	0.06 µg/kg	Chronic REL = 5 µg/kg-day (OEHHA, 2003a)
Conclusion	*The estimated dose is 83-fold below the chronic REL, suggesting a low risk of adverse health effects.*		
Vanadium	0.048 µg	0.032 µg/kg	Intermediate MRL = 3.0 µg/kg-day (ATSDR, 1992c)
Conclusion	*The estimated dose is 94-fold lower than the intermediate MRL, suggesting a low risk of adverse health effects from a one-time oral ingestion.*		
Zinc	130 µg	87 µg /kg	Subchronic MRL = 300 µg/kg-day (ATSDR, 2003b)
Conclusion	*The estimated dose is 3.4-fold lower than the subchronic MRL, suggesting a low risk of adverse health effects..*		
Semi-volatile Organic Compounds			
Aniline	33.5 µg	22.3 µg/kg	Acute screening level = 21 µg/kg-day (IARC, 1982 and Jenkins et al., 1972 in Table 10)
Conclusion	*The estimated dose is almost identical to the acute screening level, suggesting a low risk of adverse health effects from a one-time oral ingestion.*		

Chemical	***Highest amount released per g of tire (from among the three shredded tire samples subjected to "gastric digestion" in Table 14)***	**Dose[1]**	***Screening level***
Benzothiazole	2.25 µg	1.5 µg/kg	On GRAS list; oral LD_{50} in rats = 380-479 mg/kg (NTP, 2004)
Conclusion	*Inadequate screening level data.*		
2(3H)-Benzothiazolone	3.2 µg	2.1 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
Cyclohexanamine,N-cyclohexyl-	2.1 µg	1.4 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
Formamide, N-cyclohexyl	0.55	0.37 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		
1H-isoindole-1,3(2H)-dione (a.k.a. captan)	2.45 µg	1.6 µg/kg	Chronic RfD = 130 µg/kg-day (IRIS, 1989)
Conclusion	*No acute or subchronic screening levels were identified. However, the estimated dose is 81-fold lower than the chronic RfD, suggesting a low risk of adverse health effects from a one-time ingestion.*		
o-Cyanobenzoic acid	4.95 µg	3.3 µg/kg	No data located
Conclusion	*Inadequate screening level data.*		

[1]The dose is the amount of chemical assumed to leach from 10 grams of tire crumb/shreds following ingestion by a 15 kg child, based on the results listed in the second column of the table.

MRL = minimal risk level (ATSDR)

NSRL = no significant risk level (OEHHA)

REL = reference exposure level (OEHHA)

RfD = reference dose (US EPA)

MADL = maximum allowable dose level (OEHHA)

GRAS = generally recognized as safe (FDA)

RDA = recommended daily allowance (NAS/NRC)

UL = upper intake level (Institute of Medicine)

ESTIMATING THE INCREASED CANCER RISK

From among the chemicals listed in Table 16, five (arsenic, cadmium, cobalt, lead, aniline) are currently listed as oral carcinogens by the State of California (OEHHA, 2005). However, data are lacking as to whether a one-time ingestion of these carcinogens is sufficient to cause cancer. Nonetheless, Table 17 calculates the increased cancer risk to a three year old assuming that a one-time ingestion is sufficient.

To do this, the dose from Table 16 was averaged over a 70 year lifetime, multiplied by the Cancer Slope Factor, and multiplied by a factor of three to cover the increased sensitivity of a three year old child to some carcinogens (US EPA, 2003c). These calculations could not be performed for cobalt, due to the absence of a Cancer Slope Factor. The increased cancer risk from exposure to each of four chemicals (arsenic, cadmium, lead, aniline) is low, while the total increased risk is 3.7×10^{-8}. This is 3-fold lower than the total increased cancer risk of 1.2×10^{-7} calculated above using published studies of chemicals that leached from tire shreds (see previous section).

The same US EPA draft methodology that recommends the use of a safety factor of three for calculating the cancer risk to children between the ages of two and fifteen, also recommends the use of a safety factor of ten for children below the age of two (US EPA, 2003c). Thus, multiplying the above total increased risk by 3.3 yields an increased risk of 1.2×10^{-7}. Therefore, should a child below the age of two ingest ten grams of shredded tire rubber, the increased cancer risk would still be below the *di minimis* risk level of 1×10^{-6}, generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

Table 17. Increased cancer risk in a 3 year old following a one-time ingestion of 10 grams of shredded tires based on OEHHA "gastric digestion" study

Carcinogen	Dose ingested by a 3 year old in mg/kg[(1)]	Ingested dose averaged over 70 x 365 days in mg/kg-d	Oral Cancer Slope Factor in $(mg/kg\text{-}d)^{-1}$ [(2)]	Increased cancer risk in a 3 year old [(3)]
Arsenic	2×10^{-5}	7.8×10^{-10}	9.45	2.2×10^{-8}
Cadmium	9×10^{-6}	3.5×10^{-10}	0.38	4.0×10^{-10}
Cobalt	1.7×10^{-4}	6.6×10^{-9}	Unavailable	-
Lead	4.7×10^{-4}	1.8×10^{-8}	0.0085	4.6×10^{-10}
Aniline	2.2×10^{-2}	8.6×10^{-7}	0.0057	1.5×10^{-8}

Calculated thus: ingested dose/(70)(365) **x** oral cancer slope factor **x** (3) = increased cancer risk in a three-year-old

(1) From Table 16.

(2) From the OEHHA Toxicity Criteria Database, available at www.oehha.ca.gov

(3) Calculated by multiplying the Cancer Slope Factor in column four by the averaged dose in column three, and then multiplying by a factor of three for the increased sensitivity of 3 year old children to carcinogens released by tire shreds (US EPA, 2003c).

Conclusions

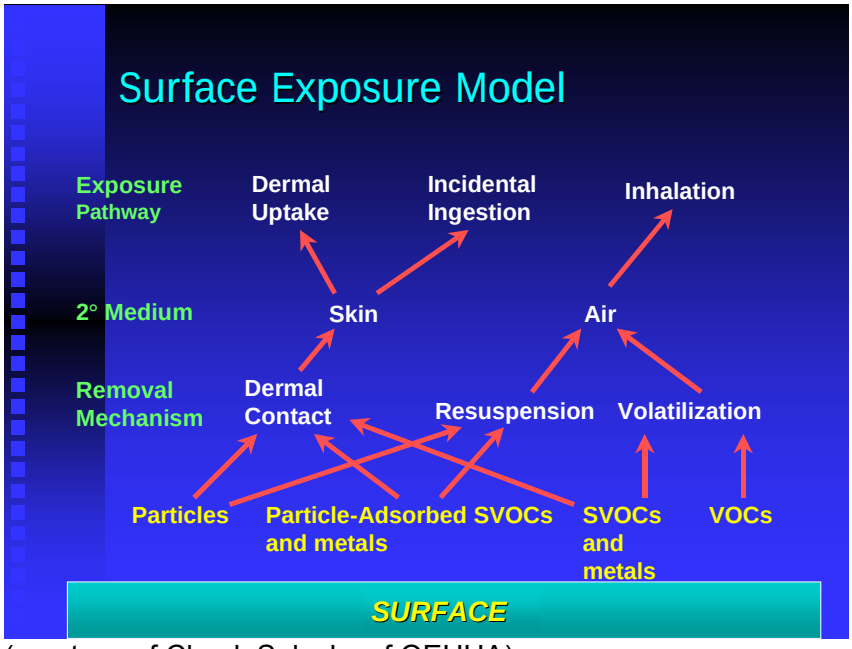
- Our gastric digestion experiment identified 22 chemicals released from tire shreds during a 21 hour incubation at 37^{o}C in a solution that mimicked the gastric environment; these data were used to estimate the amounts of chemicals released following ingestion of 10 grams of tire shreds by a 15 kg child.
- All calculated exposure doses were at or below the corresponding screening value, suggesting a low risk of adverse noncancer health effects.
- Five of the leaching chemicals are currently listed by the State of California (OEHHA, 2005b) as carcinogens by the oral route.
- The acute ingestion of 10 grams of tire rubber by a 15 kg three year old child is associated with a 3.7 x 10^{-8} increased risk of cancer, based on the experimental results reported here; this is below the *di minimis* risk level of 1 x 10^{-6}, generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

Chapter 7: Evaluation of Toxicity Due to Chronic Hand-To-Mouth Behavior Based on OEHHA Wipe Sampling of Playground Surfaces

Exposure model

Figure 1 shows our model for estimating child exposure to toxicants released by unitary playground surfaces made of recycled tires. As discussed earlier in this report, unitary surfaces are solid surfaces that cannot be put into the mouth and ingested, unlike tire shreds. This eliminates the route of intentional ingestion (not shown in Figure 1). Since the playgrounds that are the subjects of this report are outdoors, we considered that any VOCs and sVOCs volatilizing from the rubber surfaces or fine particles becoming resuspended would enter the atmosphere and quickly disperse, precluding the inhalation of significant amounts by children. Thus, we did not consider the inhalation route in estimating exposure, nor did we measure VOCs released by these rubberized surfaces. Dermal uptake was estimated to be much less than incidental ingestion (hand-to-mouth), for reasons discussed in detail below. This left the route of incidental ingestion (hand-to-mouth) as the relevant route of exposure. This route is discussed in detail below.

Figure 1. Exposure model for children using rubberized playground surfaces



(courtesy of Chuck Salocks of OEHHA).

Measuring the concentration of dislodgeable toxicants on the playground surface

To measure the chemicals that might be transferred to a child's hand through contact with a unitary playground surface made of recycled waste tires, the following wipe sampling study was performed by OEHHA. The protocol is modified from the US EPA (2003a) protocol used to wipe sample arsenic from CCA-treated wood. Polyester wipes (catalogue #TX1009) were purchased from ITW Texwipe (Upper Saddle River, New Jersey). These wipes are 9 inches by 9 inches and weigh approximately 8.3 grams. Prior to sampling, each wipe was put into a clean glass jar with 23 mls of distilled water (for metals or sVOCs) or isopropyl alcohol (for PAHs).

A cylindrical steel weight was kindly provided by Oakland Machine Works (Oakland, CA). It weighed 1.1 kg and had a surface at each end that was 8.26 cm in diameter. For each sample, the weight was wrapped in a clean disposable plastic bag and then wrapped with the wetted wipe. The weight was then dragged for twelve feet (366 cm) along a tape measure laid on the rubber or control surface. Dragging was then reversed without rotating the weight, and finally the dragging was done once more for a total of three passes along the same twelve foot path. The area wiped was 3021 cm^2. The wipe was then returned to its glass jar. Clean nitrile gloves were used for each sample. Playground surfaces were sampled in duplicate per analyte class (metals, mercury, sVOCs, PAHs). Single field control wipes were performed on nearby sections of cement sidewalk. Two pour-in-place playground surfaces with bottom layers of recycled tires and top layers of EPDM were wipe tested. A single playground surface consisting of tiles made of 100% recycled tire rubber held together with a binder was also wipe sampled.

Samples were transported to Sequoia Analytical (Morgan Hill, CA) for analysis. The following methods were followed: calcium, iron, potassium and magnesium by EPA 6010B; mercury by EPA 7471A; all other metals by EPA 6020; sVOCs by EPA 8270C; PAHs by GCMS-SIM. Table 18 shows the chemicals that were detected in the wipe samples. Ten metals and six PAHs were detected. Another twelve metals and nine PAHs were not detected in any sample. In addition, no sVOCs were detected in any wipe sample.

Table 18. Chemicals detected by wipe sampling three rubberized playground surfaces (A,B,C)[1]

Chemical	Reporting limit	A	A (field control)	B	B (field control)	C	C (field control)
aluminum	2.0	91	75	-	-	370	330
antimony	1.0	2.8	4.2	155	220	170	170
barium	5.0	ND	ND	6.5	19	ND	ND
calcium	12	425	240	ND	ND	405	1300
copper	5.0	ND	ND	ND	6.3	ND	ND
iron	5.0	180	170	ND	ND	685	670
magnesium	2.5	78	58	ND	ND	210	220
mercury	0.005	ND	ND	ND	0.012	ND	ND

Chemical	Reporting limit	A	A (field control)	B	B (field control)	C	C (field control)
potassium	100	85	ND	ND	ND	145	120
zinc	10	ND	ND	73	66	105	26
benzo(b)-fluoranthene	0.10	0.13	ND	ND	ND	ND	ND
chrysene	0.10	0.25	ND	ND	ND	ND	ND
fluoranthene	0.10	0.25	ND	0.14	ND	0.1	ND
naphthalene	0.10	0.10	ND	ND	0.11	0.12	0.11
phenanthrene	0.10	0.14	0.10	ND	ND	0.25	ND
pyrene	0.10	0.39	0.10	0.28	ND	0.36	0.11

[1] All values are in µg/wipe. Playground surface values are averages of two duplicate wipes. Field control values are from single wipes. Surfaces A and B were pour-in-place with a top layer of EPDM. Surface C consisted of tiles that were 100% recycled tire rubber. ND = not detected.

Surface A data reported in Appendix B in Work Orders MOF0403 (rubber wipe samples A, B, D, E, G, H, J, K; background wipe samples C, F, I, L) and MOI0327 (rubber wipe samples UC1, UC2; background wipe sample UC3).

Surface B data reported in Appendix B in Work Orders MOF0623 (rubber wipe samples A, B, D, E, G, H, J, K; background wipe samples C, F, I, L) and MOI0327 (rubber wipe samples EC1, EC2; background wipe sample EC3).

Surface C data reported in Appendix B in Work Order MOF0858 (rubber wipe samples A, B, D, E, G, H, J, K; background wipe samples C, F, I, L) and MOI0327 (rubber wipe samples GR1, GR2; background wipe sample GR3).

Results

Five chemicals in the above table were detected at levels that were at least three times the field control, or if the field control was a nondetect (ND), at least three times one-half the reporting limit. Multiplying the reporting limit by a factor of three has been recommended for setting the minimum level of quantitation (US EPA, 2004). One metal (zinc) and four PAHs (chrysene, fluoranthene, phenanthrene, pyrene) fell into these two categories. Therefore, the potential toxicity of these chemicals was evaluated.

The duplicate wipes of playground surface C gave an average zinc value of 105 µg/wipe, that was at least 3-fold higher than the field control wipe (26 µg/wipe). This surface was made of tiles composed of 100% shredded tire rubber held together with a binder. Zinc was not detected on pour-in-place surface A, and was only slightly above the field control for pour-in-place surface B. Both surfaces A and B had top layers of EPDM above a bottom layer of recycled tire rubber. A possible explanation for these findings is that the EPDM layer acted as a barrier to tire-derived zinc. This finding of zinc by wipe testing the tiles made of 100% recycled tire rubber is in good agreement with the results of the gastric digestion experiment. Digestion of shredded tire rubber identified zinc as the chemical released in the highest amount: 130 µg of zinc per gram of tire rubber (Table 14). Thus, it may not be surprising that zinc was identified by wipe sampling. As

discussed earlier, zinc oxide is used as an activator in the rubber vulcanization process (CIWMB, 1996).

From among the four PAHs that were evaluated, chrysene and fluoranthene were detected on playground surface A, phenanthrene on playground surface C, and pyrene on all three playground surfaces. These PAHs are all products of combustion, and are present in the exhaust from gasoline and diesel engines, as well as on barbecued foods. We were not able to determine whether the PAHs detected on the wipes originated from the rubber playground surface itself, or from automobile/truck exhaust fumes followed by atmospheric deposition onto the playground.

This toxicity evaluation uses the wipe values as surrogates for the amounts of chemicals a child would pick up on its hands after touching the playground surface. Therefore, since the wipe procedure sampled an area of playground surface equal to 3,021 cm^2, then the dislodgeable chemicals that can be transferred to a child's hands are estimated to be:

- Zinc = 105 µg/3021 cm^2 = 34.8 ng/cm^2
- Chrysene = 0.25 µg/3021 cm^2 = 0.0828 ng/cm^2
- Fluoranthene = 0.25 µg/3021 cm^2 = 0.0828 ng/cm^2
- Phenanthrene = 0.25 µg/3021 cm^2 = 0.0828 ng/cm^2
- Pyrene = 0.39 µg/3021 cm^2 = 0.129 ng/cm^2

Estimating the child's body surface area that contacts the playground surface and from which toxicants can be transferred to the mouth

Since unitary rubber playground surfaces are solid surfaces that cannot be picked up by a child and put into its mouth, hands touching the surface and then put into the mouth is considered the pertinent route by which dislodgeable residues could be ingested. Hand-to-mouth activity, a subset of the category often called nondietary or incidental ingestion, is an important route of child exposure to environmental contaminants (Hubal et al., 2000; Zartarian et al., 2000). The surface area of a three year old child's hands is approximately 400 cm^2 (50^{th} percentile value), comprising approximately six percent of the total body surface area (US EPA, 2002).

However, less than 100 percent of the hand's surface area would be expected to contact the rubber surface. A maximum value of 50 percent was estimated to be the fraction of the hand's surface area that is available to pick up a toxicant from a contaminated surface (Zartarian et al., 2000). However, using modeling techniques this same study found that less of a child's hand (5 to 30 percent corresponding to 10 to 60 cm^2) contacts the mouth per mouthing event. The US EPA (2001) recommends the use of 20 cm^2 per mouthing event, which falls within the range specified in the Zartarian et al. (2000) study. Therefore, this toxicity evaluation uses a value of 20 cm^2 as the area of the child's hand that transfers dislodgeable toxicants from a playground surface to the child's mouth.

Estimating the frequency of hand-to-playground surface contact

No data were found on the frequency of child hand-to-playground surface contact, and only limited data were located on the frequency of hand-to-floor contact. The data in Table 19 below show that the hand-to-floor data come primarily from children engaged in indoor activities. However, playground behavior encompasses outdoor activities. Unfortunately, there is poor agreement between the two studies that observed children

outdoors, with AuYeung et al. (2004a) reporting a hand-to-floor contact rate of 27/hour and Freeman et al. (2005) reporting a rate of 3/hr. Due to the dearth of data on hand-to-floor contact rates, the four values from the studies shown in the bottom three rows of Table 19 were averaged (40 + 21 + 3 + 27) to give 23 contacts per hour. The data from Freeman et al. (2001) were not included since only a single child was observed per age group. Therefore, this toxicity evaluation will use 23 hand-to-playground surface contacts per hour for a three year old.

Table 19. Hand-to-floor contact rates for children

Study	Age and number of children (n)	Child mobility and setting	Hand-to-floor contacts
Freeman et al. (2001)	6 year old female (n=1)	Walker, indoors	5/hr
	8 year old female (n=1)	Walker, indoors	1/hr
Beamer et al. (2004)	6 and 24 months (n=11)	Walkers, mostly indoors	Mean = 40/hr
Freeman et al. (2005)	7-53 months (n=68)	Infants + toddlers, indoors	Median = 21/hr
		Infants + toddlers, outdoors	Median = 3/hr
AuYeung et al. (2004a)	1-6 years (n=38)	Mostly outdoors	Median = 27

Estimating the frequency of hand-to-mouth activity

To estimate the frequency at which a child might transfer a dislodgeable toxicant from a rubber playground surface to its mouth, studies were located on the rate of hand-to-mouth activity. Such studies used direct observation or videotape analysis of children engaged in various activities, both indoors and outdoors. Table 20 shows the results of those studies.

Table 20. Frequency of hand-to-mouth activity in children

Study	Age and setting	Hourly hand-to-mouth contacts
US EPA, 2002	24-72 months, mostly indoors	Mean = 9
Tulve et al., 2002	10-60 months, indoors	Median = 11
AuYeung et al., 2004b	14-82 months, outdoors	Median = 8
Black et al., 2004	7-53 months, outdoors	Median = 5

The US EPA, in their Child-Specific Exposure Factors Handbook (US EPA, 2002), recommends the use of 9 contacts per hour for the frequency of hand-to-mouth activity in children age 24 to 72 months. This value is based mostly on data from children observed indoors. However, the playground is an outdoor environment, and children playing outdoors exhibited 2 to 3-fold less hand-to-mouth behavior than those playing indoors (AuYeung et al., 2004b; Black et al., 2004). Two recent studies in Table 20 provide

hand-to-mouth frequency data for children in outdoor environments: AuYeung et al (2004b) and Black et al. (2004). Using these two studies OEHHA calculates that 7 hand-to-mouth contacts per hour [(5 + 8) ÷ 2 = 7] represents the best available value for a three year old child playing outdoors. Therefore, we have used the value of 7 hand-to-mouth contacts per hour in the following calculations.

Estimating the efficiency of transfer of toxicants from the child's hand to the mouth

Measurements of transfer efficiency (a.k.a. saliva removal efficiency) have been made for the transfer of pesticides and soil from the hands of children to their mouths. Maximum transfer efficiencies of 50 percent and 16 percent were measured for pesticides and soil, respectively (Zartarian et al., 2000). The lower value for soil may be related to a lower propensity of a child to extensively suck dirty hands compared to hands bearing a relatively tasteless and invisible chemical. In a more recent study the transfer of riboflavin from the hand to the mouth was measured in college-age volunteers (Cohen Hubal et al., 2005). The highest rate of transfer for a single mouthing event was 34 percent; however, the measured values were highly variable and often much lower. US EPA (2001) uses a standard value of 50 percent for hand-to-mouth transfer efficiency. Therefore, considering these data, this toxicity evaluation uses the value of 50 percent for the efficiency by which dislodgeable toxicants might be transferred from a child's hand to its mouth, thereby becoming ingested.

Estimating dermal loading

The amount of toxicant accumulating on a child's hand as a result of touching a contaminated surface has been termed dermal loading, and is a prerequisite for estimating the amount of a toxicant that can be ingested through hand-to-surface-to-mouth activity. Dermal loading in this situation depends on how often the child touches the playground surface, how often it touches its mouth, the amount of a toxicant that is transferred from the surface to the hand at each contact, and the amount transferred to the mouth at each contact. Table 21 shows these parameters, all of which were discussed above.

Table 21. Factors considered in estimating dermal loading

Parameter	Variable measured	Value	Reference
Hand-to-surface	Frequency	23/hr	Beamer et al., 2004; Freeman et al. 2005; AuYeung et al. 2004a
Hand-to-mouth	Frequency	7/hr	AuYeung et al., 2004b; Black et al., 2004
Surface-to-hand	Amount of toxicant transferred	Wipe measurements in Table 15	This study
Hand-to-mouth	Transfer efficiency	50%	US EPA, 2001
Length of playground visit	time	2 hr (see below)	Gallup Organization (2003)

Assuming that 3 (23/7) hand-to-playground surface contacts occur between each hand-to-mouth contact, and 50 percent of the toxicant transfers from the hand to the mouth at each contact, then the amount of dermal loading per cm^2 occurring between each hand-to-mouth contact approaches 6 times the wipe value; i.e., where x is the amount of chemical detected by wipe sampling per cm^2, then dermal loading at each successive hand-to-mouth contact would be 3x, 4.5x, 5.25x, 5.625x, 5.8125x, etc. (this calculation also assumes that the efficiency of loading does not change with sequential playground surface contacts). Thus, a three year old is estimated to load each chemical on its hands to the following levels:

- Zinc = 34.8 ng/cm^2 X 6 = 209 ng/cm^2
- Chrysene = 0.0828 ng/cm^2 X 6 = 0.5 ng/cm^2
- Fluoranthene = 0.0828 ng/cm^2 X 6 = 0.5 ng/cm^2
- Phenanthrene = 0.0828 ng/cm^2 X 6 = 0.5 ng/cm^2
- Pyrene = 0.129 ng/cm^2 X 6 = 0.77 ng/cm^2

Estimating the time and frequency of playground use

Three studies were located that measured the time and/or frequency that children spent in the playground. Table 22 lists those studies and their findings.

Table 22. Time and/or frequency of playground use

Study	Age	Time and/or frequency of playground use
Bjorklid-Chu, 1977	1 to 15 years	"practically every day" for 56% of those surveyed
Air Resources Board, 1991	Under 12 years	An average of 49 minutes per day for those surveyed
Gallup Organization, 2003	3-12 years	1)Daily or several times a week for 29% of those surveyed. 2)At least 1-2 hours per visit for 52% of those surveyed.

Data on the frequency of playground use by American children are sparse. The study by Bjorklid-Chu (1977) was conducted in a modern housing development in Sweden. The other two studies were performed in the United States, with the Air Resources Board (1991) study being performed in California and the Gallup study being a national survey. While the frequency of playground use and time spent in the playground per visit are hard to know with precision given the above data, it is clear that a significant fraction of children visit a playground daily or multiple times per week, and a large fraction of those visits last on the order of one or more hours.

Thus, it seems justified to consider child exposure to potential playground surface contaminants as a chronic exposure scenario. More specifically, the data in the table suggest that a significant subset of users visits a playground daily, for at least two hours per visit. Therefore, these are the values we use in the subsequent calculations. US EPA

(2005) recently completed an exposure assessment for children contacting chromated copper arsenate(CCA)-treated wooden playsets, in which two hours/day was considered the mean time that children used these playsets, either in public playgrounds or at home.

Estimating exposure due to dermal absorption

Some chemicals that become deposited on human skin are able to enter the body by passing through the skin. This rate of dermal absorption varies greatly, depending upon the chemical and body part. While hands are the body parts which participate in hand-to-mouth transfer of environmental contaminants, dermal absorption can potentially occur at any place on the body. Considering children using the playground, we believe that hands are the body parts likely to come into repeated contact with the rubberized surface. The amount of dermal loading on the hands is discussed above. It is also estimated above that 50 percent of a toxicant picked up on a child's hands would transfer to the mouth every 8.6 minutes (7 times per hour).

Thus, for dermal absorption from the hands to make a significant contribution to the amount of a toxicant entering a child's body, its rate should not be much less than this 50 percent/8.6 minutes value. Table 23 below shows dermal absorption rates for 20 chemicals, covering a wide range of molecular weights and structures. For example, 0.02 percent of the applied dermal dose of zinc was absorbed in 8.6 minutes. All rates of dermal absorption were less than 1 percent/8.6 minutes except for 4,4'-methylene dianiline, which was 3.9 percent/8.6 minutes. Therefore, based on this survey of dermal absorption rates, we believe it unlikely that dermal absorption from the hands would contribute significantly to the amount of toxicant entering a child's body, due to the much higher rate of ingestion resulting from hand-to-mouth activity. Therefore, we will not calculate exposure via dermal absorption.

Table 23. Dermal absorption rates of 20 chemicals found in published studies[1]

Study	Species	Chemical	Dermal absorption[2]
Aoyama et al., 1986	human	tobramycin	0.21
Shah et al., 1987	rat	carbofuran	0.04
Agren, 1990	human	zinc	0.02
Agren et al., 1991	rat	zinc	0.02
Koizumi, 1991	rat	hexachlorobenzene	0.02
VanRooij et al., 1993	human	pyrene (a PAH)	0.57
Brunmark et al., 1995	human	4,4'-methylene dianiline	3.9
Moody et al., 1995	human	Benzo[a]pyrene	0.1
Timchalk et al., 1998	human	ortho-phenylphenol	0.74
Flarend et al., 2001	human	aluminum	<0.025
Qiao and Riviere, 2002	pig	pentachlorophenol	0.04
Meuling et al., 2004	human	chlorpyrifos	0.12
US EPA, 1992	pig	Caffeine	0.06

Study	Species	Chemical	Dermal absorption[2]
"	"	Benzoic acid	0.06
"	"	N,N-dimethyl-m-toluamide	0.02
"	"	Fluocinolone acetonide	0.01
"	"	Malathion	0.01
"	"	Parathion	0.04
"	"	Testosterone	0.01
"	"	Lindane	0.02
"	"	Progesterone	0.02

[1] All studies were performed *in vivo* except for the US EPA study which was performed *ex vivo*.

[2] Percent of applied dose entering the skin per 8.6 minutes.

Calculating exposure via hand-to-mouth activity

Using zinc as an example, the mass of ingested zinc was calculated as follows:

hand loaded zinc concentration ($\mu g/cm^2$) **X** hand surface area transferring zinc to mouth (cm^2/hand-to-mouth event) **X** total events (hand-to-mouth events/day) **X** hand-to-mouth transfer efficiency (dimensionless) =

0.209 $\mu g/cm^2$ **X** 20 cm^2/event **X** 14 events/day **X** 0.5 = 29.3 µg/day

For a 15 kg child the ingested zinc dose would be 1.95 µg/kg-day

Table 24. Estimated exposures from hand-to-mouth activity in a 15 kg three year old child at a playground where rubberized surfaces are present

Chemical	Exposures
Zinc	1.95 µg/kg-d
Chrysene	0.005 µg/kg-d
Fluoranthene	0.005 µg/kg-d
Phenanthrene	0.005 µg/kg-d
Pyrene	0.007 µg/kg-d

The dose levels of ingested chemicals presented in Table 24 are due to contact with tire-derived playground surfaces. For comparison, Table 10 shows the average daily intakes resulting from the presence of these chemicals in food, water and air. In many cases these average daily intakes are rough estimates. Nonetheless, it is useful to compare the tire-derived levels in Table 24 to the average daily intakes. Average daily intakes were located for all five chemicals listed in Table 24. For zinc, chrysene and phenanthrene the average daily intake equals or exceeds the tire-derived exposure. Only for fluoranthene and pyrene does the tire-derived exposure exceed the average daily intake. This indicates

that particular care should be taken when comparing the tire-derived exposures to these chemicals to their corresponding health-based screening levels.

Comparison of playground chemical exposure to screening levels: noncarcinogenic effects

Table 25 below shows a comparison of the zinc exposure value for children using playground surfaces to screening values for subchronic and chronic zinc ingestion, and to its recommended daily dietary allowance (RDA). Chronic screening values were also located for the two PAHs, fluoranthene and pyrene, so that comparisons could be made to the chronic exposure values.

Zinc

The subchronic and chronic zinc screening values are based on the same study by Yadrick et al. (1989) in which healthy adult females were given zinc to supplement their normal diets for a period of ten weeks. The lowest observed adverse effects level (LOAEL, 0.83 mg/kg-day) was based on decreased red blood cell superoxide dismutase, hematocrit and serum ferritin. There was no NOAEL. Application of an uncertainty factor of 3 (for use of a minimal LOAEL and intrahuman variability) to the LOAEL yielded a subchronic MRL (ATSDR, 2003b) and a chronic RfD (IRIS, 1992) of 0.3 mg/kg-day. Since the zinc exposure is less than the MRL and RfD, subchronic and chronic health effects are not expected. This conclusion is supported by the RDA for zinc, also shown in Table 25. The RDA was developed for children 1-3 years old. It is slightly lower than the MRL and RfD, reflecting the importance of zinc in the human diet. The RDA is 100-fold greater than the exposure due to contact with the playground surface, suggesting that adverse health effects would not occur.

Fluoranthene and pyrene

In the case of fluoranthene, the exposure value is 8,000-fold lower than the RfD, which is based on nephropathy, increased liver weights, hematological changes and clinical signs in mice (Table 7). The calculated exposure to pyrene is 4,286-fold lower than the RfD, based on kidney effects in mice (Table 7). Thus, adverse health effects are not expected due to exposure to fluoranthene and pyrene. The absence of screening values for chrysene and phenanthrene makes it difficult to draw conclusions about those exposures, although the large margins of safety for the structurally related PAHs fluoranthene and pyrene suggest that exposure to similar dose levels of chrysene and phenanthrene would also be without health effects.

Table 25. Playground-associated chemical exposures and associated noncancer screening values

Chemical	Calculated ingested dose[1]	Noncancer screening value
Zinc	1.95 µg/kg-day	Intermediate MRL = 300 µg/kg-day (ATSDR, 2003b)
"	"	Chronic RfD = 300 µg/kg-day (IRIS, 1992)
"	"	RDA* = 200 µg/kg-day (The National Academies, 2001)

Chemical	Calculated ingested dose[1]	Noncancer screening value
Chrysene	0.005 µg/kg-day	None located
Fluoranthene	0.005 µg/kg-day	Chronic RfD = 40 µg/kg-d (IRIS, 1990b)
Phenanthrene	0.005 µg/kg-day	None located
Pyrene	0.007 µg/kg-day	Chronic RfD = 30 µg/kg-day (IRIS, 1991b)

[1] From Table 24

[*] Normalized for a 15 kg child

MRL = minimal risk level; RfD = reference dose; RDA = recommended dietary allowance

Risk characterization for noncancer effects

Uncertainties that would increase exposure

- Eating in the playground would tend to increase the transfer of toxicants from the surface of the hands to the food and into the mouth (Cohen Hubal et al., 2000; Black et al., 2004).
- Going barefoot in the playground would increase non-dietary ingestion in those children that exhibit toes-to-mouth activity (Freeman et al., 2001).
- Toxicants loaded onto the hands would be subject to hand-to-mouth transfer after the child had left the playground, unless its hands were washed.
- Objects that contact the playground surface and then are put into the child's mouth would increase non-dietary ingestion.

Uncertainties that would decrease exposure

- The transfer efficiency from a surface to the hand decreased with increasing number of hand-to-surface contacts (Cohen Hubal et al, 2005), and the loading of Cr, Cu and As onto children's hands did not increase with time (Hamula et al., 2006), both suggesting a saturation for loading.
- Hand-to-mouth events are often clustered, with few or no intervening hand-to-floor events (Ross, 2005). This suggests that hands become "fully loaded" for only a fraction of the total hand-to-mouth contacts.
- Some toxicants may be transferred from the child's hand to surfaces other than the child's mouth, such as playground equipment or clothes. This would decrease the amount transferred into the mouth.
- The duration of mouthing at each hand-to-mouth contact may decrease with increasing child age, leading to less toxicant transfer from the hands to the mouth (Cohen Hubal et al., 2000); however, at least one study suggests that mouthing times do not decrease between 1-3 months and 5 years of age (Dept. of Trade and Industry (UK), 2002).

- A bioavailability of 100 percent has been assumed for each chemical. It is likely that the true values are less, but this assumption represents a public health upper bound in the absence of empirical data.
- For the two hours per day a child is estimated to spend in the playground, it would be on the rubber surface for only a fraction of the total time.

Zinc

In the Table 25 above, both the subchronic MRL and chronic RfD of 0.3 mg/kg-day for zinc were based on the same study by Yadrick et al. (1989), showing decreased red cell superoxide dismutase (SOD) activity (a copper-requiring enzyme), hematocrit and serum ferritin in human females dosed daily for 10 weeks. These effects were probably due to zinc-induced changes in the copper and iron balance, causing the above-mentioned hematological effects to develop towards the end of the study (IRIS, 1992). Thus, zinc supplementation acted as an inducer of copper and iron deficiency.

Similar hematological changes have been observed in subchronic studies performed in the rat, mouse, rabbit, cow and ferret, in which the animals' diets were supplemented with zinc either via the food or water (ATSDR, 2003b). Also, another subchronic study in humans identified a LOAEL based on reduced red cell SOD (Fischer et al., 1984). Lastly, a chronic study of zinc supplementation in the elderly identified a LOAEL based on reduced red blood cells (Hale et al., 1988). Thus, in a range of mammalian species, excess zinc caused hematological changes consistent with iron and copper deficiency, as might result from a competition between zinc and these cations. Therefore, these findings support the use of the MRL/RfD of 300 µg/kg-day for evaluating whether zinc-induced health effects would occur in children contacting rubberized playground surfaces.

Chronic ingestion of excess zinc is not considered to be carcinogenic by the ATSDR (2003b), while IRIS (1992) classifies zinc into Group D: not classifiable as to human carcinogenicity. Therefore, the zinc subchronic MRL and chronic RfD are the appropriate reference values for evaluating chronic oral exposures.

Fluoranthene

The chronic RfD for fluoranthene is based on a 13 week study in mice gavaged daily with 0, 125, 250 or 500 mg/kg-d (IRIS, 1990b). At the two highest dose levels the animals exhibited a variety of adverse effects including increased serum alanine transaminase, kidney and liver pathology, increased clinical signs and hematological changes. Therefore, the NOAEL was 125 mg/kg-d. The following uncertainty factors were selected by IRIS: 10 for interspecies extrapolation, 10 for intraspecies variability and 30 for both subchronic to chronic extrapolation and a lack of reproductive/developmental data. Applying these uncertainty factors to the NOAEL yielded a chronic RfD of 40 µg/kg-d.

Carcinogenicity studies of fluoranthene (mostly via the dermal route) have also been performed in mice. Most have been negative with regard to tumor induction (IRIS, 1990b). However, these data were judged inadequate for determining the carcinogenicity. In addition, most studies in both mammalian cells and bacteria found that fluoranthene was not mutagenic (IRIS, 1990b). Thus, the RfD for fluoranthene shown in the table is the appropriate screening value for evaluating its long-term health effects.

Pyrene

The chronic RfD for pyrene is based on a 13 week study in mice gavaged daily with 0, 75, 125 or 250 mg/kg-d (IRIS, 1991b). At the two highest dose levels the animals exhibited mild kidney lesions and reduced kidney weights. Therefore, the NOAEL was 75 mg/kg-d. The following uncertainty factors were chosen by IRIS: 10 for interspecies extrapolation, 10 for intraspecies variability, 10 for subchronic to chronic extrapolation, and 3 for both the lack of data from other species and the lack of reproductive/developmental data. Applying the uncertainty factors to the NOAEL yielded a chronic RfD of 30 µg/kg-d.

Pyrene did not induce tumors in mouse studies (intraperitoneal injection and dermal routes), however, the data were considered inadequate for judging this chemical's carcinogenicity (IRIS, 1991b). Most studies in mammalian cells and bacteria indicated that pyrene was not mutagenic (IRIS, 1991b). Thus, the RfD for pyrene shown in the table is the appropriate screening value for evaluating its long-term health effects.

Estimating the increased cancer risk

From among the five chemicals identified by wipe sampling rubber playground surfaces, chrysene is currently listed as an oral carcinogen by the State of California (OEHHA, 2005). US EPA (2003c) draft methodology was followed to quantify the increased cancer risk to a child using these surfaces.

As discussed above in the section entitled "Estimating the frequency of playground use", survey data support the assumption that a significant percentage of children use playgrounds daily, although the data do not provide information as to how many years a child can be expected to use playgrounds. Thus, in order to calculate the cancer risk, estimates must be made as to when a child starts and stops using playgrounds. We believe it is reasonable to assume children start to use playgrounds with impact-attenuating surfaces at the time they begin to walk.

Prior to the walking stage, it is unlikely that a crawling child could access the equipment found in playgrounds such as rockers, slides, swings and climbers. It is well established that most children begin walking between the ages of 12 and 18 months (Bayley, 1936; Cratty, 1979; Bottos et al., 1989; Adolph et al., 1998). Therefore, we will consider 12 months as the age at which some children begin using these playgrounds. However, it should be kept in mind that should a child in the crawling stage have access to one of these surfaces, its exposure could be much higher due to a much higher hand-to-playground surface contact rate in crawlers compared to walkers.

The age at which most children stop using playgrounds is not well defined. We have not located any data addressing this question. Therefore, we will use the age of twelve years, which corresponds to the age when most children enter junior high school, where the playgrounds of elementary school are replaced by basketball courts, tennis courts, etc. This age range of 1 to 12 years is similar to the range of 1 to 13 years recently used as one of the target populations in an exposure assessment for children using playsets and decks made of CCA-treated wood (US EPA, 2005).

In the section above entitled "Estimating the frequency of playground use", it was concluded that a significant fraction of children use playgrounds daily. However, this is different from saying that a child uses a playground every day of the year. Obviously, on many days the weather could prevent playground use. Also, a child would not be expected to use the playground when sick. Recently, it was estimated that children

between the ages of one and six use public playgrounds an average of 185 days out of the year (US EPA, 2005). Therefore, this value has been applied to children between the ages of one and twelve in the cancer risk calculations presented below.

Table 26 below shows the values used to estimate the increased cancer risk to a child resulting from eleven years of hand-to-mouth activity in playgrounds with rubberized surfaces. The calculations follow the US EPA (2003c) draft methodology for assessing the cancer risk from exposures in childhood. The total increased risk of 2.9×10^{-6} is above the benchmark value of 1×10^{-6}, usually considered the maximum acceptable value for increased cancer risk.

Table 26. Estimated increased cancer risk from exposure to chrysene via hand-to-mouth activity in a child (ages 1-12) frequenting a playground with a rubberized surface

Age	Dose[1] in mg/kg-d	Cancer Slope Factor[2] in $(mg/kg\text{-}d)^{-1}$	Duration of use normalized to 70 yr lifetime[3]	Days of playground use per year[4]	Safety Factor[5]	Increased cancer risk[6]
1-2 years	5×10^{-6}	2.0	1 yr/70 yrs	185 days/ 365 days	10	0.7×10^{-6}
2-12 years	5×10^{-6}	2.0	10 yrs/70 yrs	185 days/ 365 days	3	2.2×10^{-6}
Total increased cancer risk[7]						2.9×10^{-6}

[1]From Table 24.

[2]Available at www.oehha.ca.gov/prop65/law/pdf_zip/6pahnsrl62104.pdf

[3]Estimated durations of playground use normalized to 70 year lifetime.

[4]Days in the year that included "public playset time" (US EPA, 2005).

[5]Safety factor for the increased sensitivity of a 0-2 year old (SF = 10) or 2-15 year old (SF = 3) child to some carcinogens (US EPA, 2003c).

[6]Calculated by multiplying columns 2, 3, 4, 5 and 6 according to US EPA (2003c) draft methodology.

[7]Calculated by adding the two individual increased cancer risks for the two age groups (US EPA, 2003c).

Discussion of the increased cancer risk

Uncertainties that would increase exposure

- Were a child in the crawling stage to use these surfaces, its exposure from hand-to floor-to-mouth activity would be greater than that of a child of walking age.
- Use of the rubberized playground surfaces may continue past the age of 12.
- Eating in the playground would tend to increase the transfer of toxicants from the surface of the hands to the food and into the mouth (Cohen Hubal et al., 2000; Black et al., 2004).
- Going barefoot in the playground would increase non-dietary ingestion in those children that exhibit toes-to-mouth activity (Freeman et al., 2001).
- Toxicants loaded onto the hands would be subject to hand-to-mouth transfer after the child had left the playground, unless its hands were washed.
- Objects that contact the playground surface and then are put into the child's mouth would increase non-dietary ingestion.

Uncertainties that would decrease exposure

- The data on hand-to-floor contact rates presented in Table 19 above suggest that this rate decreases as the child grows older. While this toxicity evaluation uses a rate of 23 hand-to-floor contacts per 2 hours for a three year old child, it is likely that this rate is substantially less for at least the age range six through twelve. This would lead to a substantially decreased transfer of toxicants from the playground surface to the child's mouth during the second half of the proposed exposure period.

- Almost no data were located on the hand-to-mouth contact rates for adults, or for children older than six. Common experience tells us that this rate decreases as the child grows older, as discussed above for the hand-to-floor contact rate. Consequently, the transfer of toxicants from the playground surface to the mouth is most likely substantially less during the second half of the proposed exposure period, from ages six to twelve.

- The transfer efficiency from a surface to the hand decreased with increasing number of hand-to-surface contacts (Cohen Hubal et al, 2005), and the loading of Cr, Cu and As onto children's hands did not increase with time (Hamula et al., 2006), both suggesting a saturation for loading.

- Hand-to-mouth events are often clustered, with few or no intervening hand-to-floor events (Ross, 2005). This suggests that hands become "fully loaded" for only a fraction of the total hand-to-mouth contacts.

- Some toxicants may be transferred from the child's hand to surfaces other than the child's mouth, such as playground equipment or clothes. This would decrease the amount transferred into the mouth.

- The duration of mouthing at each hand-to-mouth contact may decrease with increasing child age, leading to less toxicant transfer from the hands to the mouth (Cohen Hubal et al., 2000); however, at least one study suggests that mouthing times do not decrease between 1-3 months and 5 years of age (Dept. of Trade and Industry (UK), 2002).

- A bioavailability of 100 percent has been assumed for each chemical. It is likely that the true values are less, but this assumption represents a public health upper bound in the absence of empirical data.

- For the two hours per day a child is estimated to spend in the playground, it would be on the rubber surface for only a fraction of the total time.

As enumerated above, there are many uncertainties associated with the exposure calculations. Some tend to increase the dose and therefore risk levels, while others decrease it. Another area of uncertainty to be considered is whether the chrysene measured on the surface of playground A originated from the rubber surface or resulted from atmospheric deposition. Referring to Table 18, two of three playground surfaces yielded chrysene values that were indistinguishable from field control wipes (all below the reporting limit).

These results, coupled with the finding that playground surface A yielded a wipe value for chrysene that was only 2.5 times the reporting limit (Table 18), indicate that more wipe tests should be performed on additional rubberized surfaces to determine if these surfaces consistently yield elevated levels of dislodgeable chrysene relative to field

controls. Seen in this light, the data collected from these playground surfaces suggest that if chrysene is elevated on these surfaces, regardless of its origin, the magnitude of the increase over background is small, and may occur only in a minority of playgrounds. In this regard, the wipes of the rubberized surfaces were always much dirtier than the control wipes performed on adjacent sidewalks, suggesting that the rubberized surfaces trap dirt more efficiently than concrete. If they also trap PAHs more efficiently, this might explain the increased PAH levels on wipes of the rubber surfaces.

The Cancer Slope Factor for chrysene shown in Table 26 was developed from intraperitoneal injection studies in neonatal mice, using an oral equivalent potency approach (OEHHA, 2004c). This approach first calculates the ratio of the potency of benzo[a]pyrene determined in the adult mouse by the oral route to that determined in the neonatal mouse by the intraperitoneal injection route. Then this ratio is applied to the neonatal intraperitoneal injection potency of chrysene, yielding the adult oral potency for chrysene used here.

Thus, it should be kept in mind that the Cancer Slope Factor for chrysene used here has its basis in intraperitoneal injection studies with neonatal mice. Those studies were performed with chrysene dissolved in DMSO, due to its very low solubility in water. Thus, its absorption from the intraperitoneal space in the carcinogenicity studies may differ from its absorption following ingestion due to hand-to-mouth activity in children (where DMSO is not used as a vehicle). These factors must be considered sources of uncertainty in applying the adult oral Cancer Slope Factor for chrysene to exposures in the playground.

Considering the uncertainty associated with both the exposure value and the Cancer Slope Factor for chrysene, the 2.9×10^{-6}-fold increased cancer risk calculated here could be either higher or lower than the true value. In addition, this relatively small increased cancer risk should be weighed against the beneficial impact-mitigating properties of rubberized surfaces, discussed elsewhere in this report.

Conclusions

- Wipe sampling of tire-derived playground surfaces was performed to measure the amounts of dislodgeable chemicals subject to ingestion through child hand-to-surface-to-mouth activity.
- Ten metals and six PAHs were identified, with five at levels that were at least 3-fold above background: zinc, chrysene, fluoranthene, phenanthrene and pyrene.
- Chronic exposure assessment was performed for the five chemicals using published values for child hand surface area, hand-to-floor contact rate, hand-to-mouth contact rate, saliva removal efficiency, and frequency of playground use; this exposure assessment was associated with large degrees of uncertainty, some of which could increase exposure and some decrease exposure.
- The exposure values were then compared to the corresponding chronic health-based screening values; all exposures were below the corresponding screening levels, suggesting a low risk of adverse noncancer health effects.
- Chrysene was the only chemical from among the five listed above that was identified as a carcinogen by the State of California (OEHHA, 2005b).

- Assuming playground use from ages one through twelve, a total increased cancer risk of 2.9×10^{-6} was calculated due to the chronic ingestion of chrysene via hand-to-surface-to-mouth activity on rubberized playground surfaces. This risk is slightly higher than the benchmark of 1×10^{-6}, generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).
- The calculation of cancer risk due to chrysene was associated with additional areas of uncertainty, regarding both the years of playground use during childhood, and whether the low levels of PAHs (including chrysene) on playground surfaces originate from the rubber surface itself or from atmospheric deposition.

Chapter 8: A First-Step Evaluation of High School Running Tracks Containing Recycled Tire Rubber: Wipe Testing and Customer Satisfaction Survey

Introduction and Methods

In addition to playgrounds, the CIWMB also provides funds for the installation of running tracks made of recycled tires. One method of track construction follows that used for playground surfaces; a bottom layer primarily (80%) of recycled tire shreds is poured together with a chemical binder. After the bottom layer hardens, a top layer of synthetic rubber particles called EPDM is poured together with more binder. To determine if such tracks release chemicals following dermal contact, one such track at a northern California high school (funded by the CIWMB) was wipe sampled according to the methodology described above for sampling playground surfaces. Wipe sampling was performed twice, on two separate days. The field control wipes were performed on a concrete apron surrounding the track. Wipes were analyzed for metals, sVOCs and PAHs.

To obtain a first impression of how these rubberized track surfaces are performing, a customer satisfaction survey was taken among the track coaches at high schools awarded CIWMB grants. From among some twenty high schools contacted, six track or cross country coaches were kind enough to discuss their thoughts on track performance, with special attention paid to injury rates and athletic performance.

Wipe testing results and discussion

Table 27 shows the results of wipe sampling a high school track made of recycled tires. Metals from wipes of the track surface were below the values of the field control wipes. No sVOCs were detected. Five PAHs were detected at higher levels on the track compared to the field control (chrysene, fluoranthene, naphthalene, phenanthrene, pyrene). Pyrene was detected at the highest levels, with good agreement between the two sampling days (4.5 and 3.1 µg/wipe); however, the background field control wipes for pyrene varied almost 7-fold over the two sampling days. The PAH fluorene was detected on the field control wipe but not on the track wipes.

Table 27. Chemicals detected on a track surface made of recycled tires.

Date	Chemical	Reporting limit[1]	Track wipe[1,2]	Field control wipe[1,3]
6/27/05	Phenanthrene	0.82	1.7	ND
6/27/05	Pyrene	0.82	4.5	1.8
9/6/05	Chrysene	0.10	0.27	ND
9/6/05	Fluoranthene	0.10	0.43	0.11
9/6/05	Fluorene	0.10	ND	0.22

Date	Chemical	Reporting limit[1]	Track wipe[1,2]	Field control wipe[1,3]
9/6/05	Naphthalene	0.10	0.12	0.10
9/6/05	Phenanthrene	0.10	1.0	0.15
9/6/05	Pyrene	0.10	3.1	0.26

[1] All values in µg/wipe.

[2] Each value is an average of two wipe samples.

[3] Each value represents a single wipe sample.

Data reported in Appendix B in Work Order MOF0960 (track wipe samples A, B, D, E, G, H, J, K; background wipe samples C, F, I, L) and Work Order MOI0327 (track wipe samples SM1, SM2; background wipe sample SM3).

In the preceding section, toxicity evaluations were performed for chemicals that were at least 3-fold higher in playground surface wipes compared to field control wipes (with one-half the reporting limit used for nondetects). Four PAHs from the above Table 27 fall into this category: chrysene, fluoranthene, phenanthrene and pyrene; however, it should be noted that while pyrene from track wipes exceeded the control wipe by almost 12-fold on 9/6/05, the margin was only 2.5-fold on 6/27/05. The reasons for this variability are unknown. On both days the samples were collected early in the morning when the skies were overcast with the typical morning fog. One possible explanation is that the PAHs detected on the track and cement apron resulted from atmospheric deposition, rather than from the material comprising the surfaces. Numerous studies have shown that the soil concentrations of various PAHs are increased in the vicinity of busy roads.

A comparison of exposure to health-based screening values was not performed for the high school students using this track surface, since their exposure to these chemicals was considered minimal for the following reasons: 1) hand-to-surface activity followed by hand-to-mouth activity was not considered an important route of exposure for these teenagers, 2) unlike the use of playgrounds by children, the use of this high school track by teenagers was considered a seasonal rather than daily activity.

Customer satisfaction survey

The six high school track and cross country coaches that comprise this survey were uniformly complimentary in the their opinions of the new rubberized track surfaces compared to the old surfaces of cinders, dirt, or crushed stone. Most coaches felt their athletes suffered fewer injuries on the rubberized surfaces, with improved athletic performance. In addition, the coaches saw increased student participation on track teams, most likely due to the attractiveness and comfort of the rubberized surfaces. Community use of the tracks also increased. Lastly, some coaches mentioned the superior performance of the rubberized surfaces in foul weather compared to traditional track materials, leading to more training days per school year.

Table 28. Track Coach Satisfaction Survey

Track #1
Date Installed: unknown

Previous Surface: dirt
Injury Effects: unknown
Athletic Performance: more students have joined the track team-in the opinion of the coach, this is in large part due to the attractiveness of the new rubberized track
Track #2
Date Installed: in 2005
Previous Surface: clay and dirt
Injury Effects: fewer injuries in general compared to old track, fewer shin splints in particular
Athletic Performance: better athletic performance, including faster times; they can now train in foul weather; greater community use of the track
Track #3
Date Installed: October, 2003
Previous Surface: dirt and "granite fines"
Injury Effects: reduced shin splints especially in female distance runners
Athletic Performance: more students have joined the track team-in the opinion of the coach, this is in large part due to the attractiveness of the new rubberized track; the athletes can train harder and more often; there is increased usage of the track by people living in the neighborhood
Track #4
Date Installed: 2003
Previous Surface: crushed brick
Injury Effects: fewer injuries in general, fewer shin splints in particular
Athletic Performance: greatly improved times in the highly technical events, such as high hurdles
Track #5
Date Installed: 2004
Previous Surface: cinder, granite and sand
Injury Effects: dramatic decrease in shin splints and "runner's knee"
Athletic Performance: the softer rubberized surface allows the cross country team to train on the track, with more interval training-as a result, times for the distance events have decreased
Track #6
Date Installed: 2005
Previous Surface: unknown
Injury Effects: unknown but coach expects fewer injuries
Athletic Performance: unknown but coach expects more students will participate on the track team

Chapter 9: Skin Sensitization Testing of Rubberized Playground Surfacing

Introduction

Tires contain varying amounts of natural rubber, in addition to the more prevalent synthetic rubber called styrene-butadiene. Natural rubber contains latex, which can form allergenic proteins leading to hypersensitization in susceptible individuals. Sensitized individuals become extremely sensitive to subsequent contact with material carrying latex allergens. These latex complexes have caused mild to severe allergic responses from dermal contact and through inhalation. This purpose of this study was to determine the potential of the recycled tire product in playground surfaces to cause skin sensitization in a laboratory animal model.

No data were located on either the latex allergen content of tires, or skin sensitization by vulcanized tire rubber in dermally exposed humans or laboratory animals. More importantly for this contract, data are also lacking for playground surfaces made from recycled tires. Such surfaces could potentially cause contact skin sensitization via latex allergens, or other unidentified allergens. Therefore, to quantitatively assess the skin sensitization endpoint, a laboratory study was performed in which guinea pigs were dermally exposed to pieces of playground surfaces made from recycled tires. The guinea pig has served as an effective animal model for identifying human contact skin sensitizers (Robinson et al., 1989), including latex (Sugiura et al., 2002).

As mentioned above, the major type of rubber in tires is the synthetic polymer styrene-butadiene. Manufacturers often refer to a playground surface made of tire pieces as SBR (styrene-butadiene rubber). Most schools and towns in California that install playground surfaces of SBR choose to add a top layer of virgin, synthetic rubber called EPDM, which contains no latex allergens. The EPDM layer is installed over the SBR layer, either in the factory (tiles) or directly in the playground itself (pour-in-place), and provides an attractive, weather-resistant surface. A survey of CIWMB grantees (see above) showed that 86 percent of responders installed a pour-in-place SBR base layer covered by a pour-in-place EPDM top layer. A few installed rakeable crumb rubber (SBR only), tiles of SBR only, or tiles of SBR constructed with an EPDM top layer. Therefore, we performed skin sensitization testing using tiles of SBR, EPDM, and loose crumb rubber (SBR).

Materials and Methods

Delayed skin sensitization testing was carried out by a modified Buehler method for solid materials according to testing guidelines (US EPA, 1998) and in accordance with Good Laboratory Practices at Product Safety Laboratories (Dayton, NJ). Guinea pigs were the test animals. The test samples were SBR tiles (Unity Surfacing, Hickesville, NY), EPDM tiles (All About Play, Sacramento, CA) and loose SBR crumb (West Coast Rubber Recycling, Gilroy, CA). All SBR was from recycled tires.

Skin sensitization testing consisted of three 6 hr induction exposures, each exposure separated by one week from the preceding exposure. All test samples were applied to the animals' skin. Then, after an additional two weeks, the animals were challenged with the test sample for 6 hrs and examined after 24 and 48 hours for signs of erythema (skin reddening). The negative control substance was high density polyethylene sheeting (TOLAS Health Care, Feasterville, PA), often used in medical packaging for its very low

incidence of allergic reaction. The positive control substance was alpha-Hexylcinnamaldehyde (HCA), a standard skin sensitizer. Additional controls included exposing animals to high density polyethylene for the induction exposure only, followed by challenge exposure to SBR or EPDM. The nine treatment groups are shown below:

Group	Induction	Challenge	# of animals
1	HD polyethylene	HD polyethylene	10
2	HD polyethylene	SBR crumb	10
3	SBR crumb	SBR crumb	10
4	HD polyethylene	SBR tile	10
5	SBR tile	SBR tile	10
6	HD polyethylene	EPDM tile	10
7	EPDM tile	EPDM tile	10
8	HCA[1]	HCA	10
9	none	HCA	5

[1] alpha-Hexylcinnamaldehyde (positive control)

Initially, the animals in the positive control group (#8) failed to exhibit skin sensitization reactions following the challenge exposure. No animals in any other group showed sensitization reactions either. Therefore, all animals were re-challenged seven days after the first challenge, in exactly the same manner with the same samples. The results of this re-challenge are shown below in the Results section.

The scoring system for characterizing skin reactions was as follows:

0	no reaction
0.5	very faint erythema, usually non-confluent[1]
1	faint erythema, usually confluent
2	moderate erythema
3	severe erythema with or without reaction

[1] not considered a positive reaction

Results

A single animal in group #4 was euthanized for humane reasons on the second day of the test. There was no reason to believe that the morbidity observed in this animal was treatment related. All other animals displayed normal clinical signs, food consumption and weight gain for the duration of the test. No animal showed a positive skin reaction (skin score 1, 2 or 3) following any of the three induction doses. However, no positive reactions were observed after the challenge dose, including the positive control group. This made it necessary to re-challenge the animals seven days later. The need to re-challenge is common with this protocol (Buehler, 1994).

The skin reaction results from the re-challenge exposure are shown below. Fifty percent of the animals (5/10) in the positive control group (#8) showed positive skin reactions (skin score of 1, 2 or 3) at 24 hours after re-challenge, indicating that skin sensitization had occurred. These positive skin reactions persisted to 48 hrs after re-challenge in four of the five animals. Persistent skin reactions are hallmarks of skin sensitization (Buehler, 1994). No other treatment group contained any animal with a positive response. Thus,

the SBR tiles, SBR crumb and EPDM tiles were considered not to be contact skin sensitizers.

Numbers of animals showing positive skin reactions (skin score of 1, 2 or 3) following re-challenge[1]

Group	24 hrs after re-challenge	48 hrs after re-challenge
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	5/10	4/10
9	0	0

[1] Data reported in Appendix C.

Discussion

Tires contain some natural rubber, and natural rubber contains latex allergens. Following dermal contact, latex allergens can induce skin sensitization in susceptible individuals. It is also possible that tire rubber contains allergens other than latex. Children using playgrounds with surfaces made of recycled tires can be exposed to substances on those surfaces through dermal contact. Hands would probably be the most common points of contact, while children playing without shoes or socks would have multiple contacts through their feet. Thus, it is prudent to determine whether such dermal exposures lead to skin sensitization.

The protocol used here to test for skin sensitization is a standard protocol for identifying contact sensitizers (US EPA, 1998). The test animal of choice is the guinea pig. Of the 85 animals used in the current study, one animal became sick early on and was euthanized. All other animals remained healthy throughout the testing period, as demonstrated by their normal clinical signs and weight gain. The only animals showing sensitization were those in the positive control group that had been exposed to an induction and re-challenge dose of the skin sensitizer alpha-Hexylcinnamaldehyde.

Five of ten animals in this group exhibited positive skin reactions at 24 hours after re-challenge, with four of ten also exhibiting positive skin reactions at 48 hours. No animals in any other group displayed positive skin reactions. Thus, the validity of this test to detect skin sensitization was demonstrated, and no playground surface sample caused sensitization. The SBR tile and SBR crumb samples contained some natural rubber, and therefore they also contained some latex allergens. However, the allergens may have become denatured during the vulcanization process, thereby losing the ability to cause skin sensitization. EPDM does not contain latex allergens. Nonetheless, it was tested and did not elicit skin sensitization.

These results suggest that recycled tires (SBR) used in playground surfaces do not cause skin sensitization in children. In addition, skin sensitization was not induced by EPDM, the material that is often used as a top layer to cover a bottom layer of SBR.

In performing risk assessment for potential skin sensitizers in humans, it has been recommended that human skin testing should follow testing in the guinea pig (Robinson et al., 1989). Nonetheless, negative results in the guinea pig, as found in our tests of SBR and EPDM, have been accurate predictors of negative results in humans (Robinson et al., 1989). Thus, these test results stand as evidence that playground surfaces made of recycled tires do not constitute a skin sensitization risk to children.

Conclusions

- Skin sensitization testing was performed with the guinea pig as test animal.
- Three materials used in rubberized playground surfaces were tested: 1) loose crumb rubber made from recycled tires, 2) tiles molded from tire shreds mixed with a binder, 3) tiles molded from particles of the synthetic rubber EPDM mixed with a binder.
- None of the components of rubberized playground surfaces caused any skin sensitization, while the positive control substance (alpha-Hexylcinnamaldehyde) produced positive reactions in 40-50 percent of the animals.
- These data suggest that playground surfaces made of recycled tires do not constitute a skin sensitization risk to children.

Chapter 10: Ecotoxicity of recycled tires including Yulupa Elementary School tire chips fire

Introduction

This section addresses the potential of recycled tires as a source of soil or groundwater contamination, and if so, whether the contamination is sufficiently high to constitute a hazard to the ecology. In addition, the results of toxicity testing in sentinel organisms are presented as an indication of the potential of recycled tires to adversely impact the animals and plants that compose many local ecologies.

Soil Contamination

Five studies contained measurements of metals and chemicals in soil either containing or within a few feet of recycled tire applications (Table 29). These applications were in a playground surface (CIWMB, 2004), in roadbed construction (Minnesota Pollution Control Agency, 1990), as cover for school parking lots and roadways (FCCJNC, 1999), as a rootzone amendment for the cultivation of turf grass (Boniak et al., 2001) and in a septic tank field (Amoozengar and Robarge, undated). A study by Newman et al. (1997) added ground tires to the potting medium used to grow hot-house flowers, while in a laboratory study by Smolders and Degryse (2002), fine tire debris was mixed with soil, allowed to weather, and filtered with water to measure the leaching of zinc.

Neither the playground study nor the roadbed study detected significant increases in metals or chemicals in the soil near the recycled tires (compared to background). For the turf grass application, the maximum increase in soil zinc was to 31 ppm: a level within the range of most agricultural soils in southern Illinois (Boniak et al., 2001). Soil zinc also increased in the laboratory study by Smolders and Degryse (2002), while both zinc and copper increased in the potting medium used to grow geraniums in a hot-house (Newman et al., 1997).

The parking lot study (FCCJNC, 1999) measured increases that correlated with the presence of recycled tire chips as cover for road surfaces: however, only the increase in iron appears to be significant based on the data presented in the report. As discussed previously in this report, the iron most likely originates from the steel belts and beads used in tire construction. At least 99 percent of this steel material is removed when tires are processed into crumb rubber for use in playground construction. Lastly, while the soil within 5 cm of rubber/gravel trenches of a septic field contained elevated levels of Zn, Se, Cr and Ni, the levels of the first three fell to background between 5 and 20 cm (Amoozegar and Robarge, undated).

None of the soil levels of metals or toluene measured in these studies exceeded either the U.S. EPA Region 9 Preliminary Remedial Goals for soil (U.S. EPA, 2003d), the screening values for soil-bound chemicals recently proposed by OEHHA (2005b), or the California Regional Water Quality Control Board Environmental Screening Levels (2003). Therefore, this limited data suggests that recycled tires do not leach sufficient chemicals into the surrounding soil so as to present a risk to human health.

Ecological toxicity

With regard to ecological toxicity, the screening levels set by the California Regional Water Quality Control Board (2003) also address risks to the flora and fauna. None of the levels reported in Table 29 exceed those screening levels; thus, risks to the health of the non-human organisms are not expected by those criteria. However, another set of Preliminary Remediation Goals for Ecological Endpoints (Efroymson et al., 1997) include soil values for zinc (8.5 ppm) and selenium (210 ppb) that are exceeded by the corresponding values in the table. In the case of selenium, the screening value is based on toxicity in the White-footed mouse, while the screening value for zinc is based on toxicity in the American woodcock.

Thus, ecological effects from contaminated soil cannot be ruled out based on these Preliminary Remediation Goals, although the selenium level in the soil was only marginally higher than the PRG and the zinc levels were close to the normal background levels. It should be added that these PRGs (Efroymson et al., 1997) assume widespread soil contamination and unlimited access of the wildlife to the contaminated soil. Since the soil values in the table reflect measurements made no more than a few feet away from the tire rubber, it is quite possible that any detected contamination did not extend more than a few feet. In the case of the only playground for which soil data exist (CIWMB, 2004 in Table 29) this was the case, since only background levels of metals and chemicals were present where the soil was sampled at 1.5 feet below the rubber chip layer.

Table 29. Soil analysis in the vicinity of recycled tires used in road/parking lot construction, a playground surface, or as a soil amendment.

Citation	Methods	Findings
Amoozegar and Robarge, undated	Chipped tires mixed with gravel and used to fill trenches of a septic system	Soil within 5 cm of trenches was at least 3-fold above background for Zn, Se, Cr (total) and Ni; levels of all but Ni fell to background between 5 and 20 cm of trenches
Boniak et al., 2001	Crumb rubber mixed with soil for use as a rootzone mix at 20, 30 or 40% rubber/g soil; grass was planted and soil analyzed approximately one year later	Soil zinc content increased 7- to 16-fold to 31 ppm (but still within range of most soil in southern Illinois), soil phosphorous and potassium increased up to 2-fold
CIWMB, 2004	3-24 inches of tire chips used as playground surface for 5 years; soil sampled 1.5 feet below tire layer	Metals, VOCs, PAHs, dioxins and furans all at or below background levels
FCCJNC, 1999	Ground rubber used to cover dirt parking areas and internal roadways of a community college; soil sampled from directly beneath tire layer over 2.5 years	Toluene 63 ppb, antimony 500 ppb, copper 2.3 ppm, iron 960 ppm, lead 13 ppm, zinc 45 ppm, barium 10 ppm, selenium 253 ppb, all elevated compared to pre-installation baselines (largest increase was for iron, at least 50-fold); all levels of contamination were below state soil cleanup goals
Minnesota Pollution Control Agency, 1990	Shredded tires used in roadbed construction; soil sampled 3 feet from tire layers and 4 feet below the surface	Fifteen metals measured; 5 were elevated (about 2-fold) relative to background levels, however, the differences were not significant
Newman et al., 1997	Ground tire rubber mixed with peat and/or vermiculite for use as a medium for growing hot-house geraniums (2 months duration)	Medium containing rubber had zinc and copper levels that were 40- and 11-fold greater than controls.
Smolders and Degryse, 2002	Fine rubber tire debris mixed with soil and allowed to weather outside for eleven months	Leachates from soil/rubber mixtures analyzed for Zn: the Zn content of leachate from truck tire rubber/soil was not different from controls, while the Zn content of leachate from car tire rubber/soil was three-fold higher than control

A Case Study of Possible Soil Contamination: Evaluation of the Construction Completion Report for the Yulupa Elementary School Tire Chip Fire, Sonoma County, June 2004 (CIWMB, 2004)

Summary

- A playground surface made of recycled tire chips burned at the Yulupa School. A clean-up followed.
- Environmental measurements were made by the US EPA and by DTSC of CAL EPA.
- The US EPA report showed:
    5. The soil/rubber material removed from the site was not hazardous waste and could be disposed of in a Class III landfill.
    6. The air above the burn site posed no health risks to clean-up workers.
    7. The soil below the burned layer posed no significant risks to human health.
- The DTSC report showed**:**
    1. The soil remaining after the clean-up contained only background levels of chemicals, suggesting the tire chips had not released chemicals into the soil.
    2. A human health risk assessment confirmed that the background levels of chemicals in the soil remaining after the clean-up were not expected to produce health effects in persons using the school site.

Introduction

The Yulupa School fire occurred in August, 2003, in a playground surface composed of metal-free rubber chips derived from recycled tire side-walls. The chips had been in place for over five years. The chip layer varied from 3-24 inches deep. Under the chip layer was a bed of fill material of undetermined depth. Approximately 50 percent of the chip surface burned in the fire, which lasted about 15 minutes. The subsequent activities were aimed at removing all rubber material and a layer of soil under the rubber, followed by testing whether the remaining soil contained tire chip-derived toxicants that posed a health hazard to persons attending the school.

US EPA Assessment Sampling Report

A contractor was hired by US EPA to assess the following:

1. Whether the soil below the burned chip layer had become contaminated with rubber-derived chemicals.
2. Whether the soil removed from the site should be classified as hazardous waste.
3. Whether the air sampled during one day of clean-up activities was contaminated with any rubber-derived chemicals or dust.

OEHHA Evaluation: While some soil samples from beneath the combusted tire chip layer contained levels of metals and/or chemicals that were above reporting limits, since

only a single background sample was analyzed, it was not possible to determine whether any substance detected below the tire chip layer was significantly higher than background. Accurate determination of background was particularly important in this instance, given that the entire playground was built on top of fill material brought in from another location. None of the reported levels approached the US EPA Region 9 Preliminary Remediation Goals for Soil or the OEHHA (2005b) Human-Exposure-Based Screening Numbers to Aid Estimation of Cleanup Costs for Contaminated Soil. Thus, human health effects were not expected.

A variety of procedures were used to demonstrate that the soil removed from the burn area was not hazardous waste. Thus, the soil could be disposed of in a class III landfill.

Two of four air samples taken from around the perimeter of the playground during the clean-up were slightly above the detection limit for zinc. It was concluded that no significant personal health risks were posed to clean-up workers by any of the monitored chemicals (zinc, dust, benzene, polycyclic aromatic hydrocarbons, total hydrocarbons, carbon monoxide or explosive atmospheres).

DTSC Confirmation Sampling Plan and Report

After the tire chips had been removed along with a layer of fill extending 1.5 feet below the chip layer, the remaining soil was sampled for analysis of metals, VOCs, PAHs, dioxins and furans. Four background samples from nonimpacted areas at the school were analyzed for metals only. In addition, three soil samples were taken from points adjacent to the playground downwind of the fire. These "adjacent" samples were from under a six inch layer of wood chips.

OEHHA Evaluation: No VOCs were detected in any samples. A variety of PAHs were detected in samples from under the playground and adjacent/downwind of the playground fire. Although background PAH levels at nonimpacted locations were not determined, historical background levels measured in urban US soil (ATSDR, 1995) were actually higher than the levels measured in the Yulupa school samples. Similarly, levels of dioxins and furans in soil samples from under the burned chip layer were five-fold lower than the mean background levels in US rural soil and in California agricultural soil (Australian Government, 2004). These results suggest that neither the burned nor unburned tire chips released measurable amounts of these chemicals into the soil that remained after the clean-up (i.e., in soil at 1.5 feet below the chip layer).

Levels of five metals detected at one of three adjacent sites downwind of the playground were considered above background; however, the following suggest that these levels were not tire-derived:

1. The two other samples at adjacent/downwind sites were not above background for these metals.

2. No samples from under the chip layer were above background for these metals.

The soil measurements made by DTSC suggest that neither burned nor unburned tire chips in the Yulupa playground released chemicals into the soil that remained following the clean-up. Nonetheless, a human health risk assessment was performed based on the measured levels of both carcinogens and noncarcinogens. For carcinogens, the risk was determined to be less than 10^{-6}, and for noncarcinogens the hazard index was less than 1. Thus, health effects were not expected for persons using the school site following the clean-up.

Groundwater contamination

Although groundwater is a part of most local ecologies, its contamination usually represents only a human health risk in so far as it serves as a source of drinking water. However, groundwater can also be used for crop irrigation and as a drinking water source for livestock. Groundwater can also enter surface water systems such as lakes and streams. Thus, groundwater contamination has the potential to affect surface flora and fauna.

Five studies were located which analyzed groundwater for tire-derived metals and compounds (Table 30). For the studies by the Minnesota Pollution Control Agency (1990), Humphrey and Katz (2001) and Exponent (2003), the tire shreds were located below the water table; thus, the shreds were in constant hydraulic communication with the local groundwater. In the cases of storm runoff from crumb rubber-covered areas of a parking lot (FCCJNC, 1999) or storm seepage through a road embankment made of sand and tire shreds (Yoon et al., 2005), the rainwater entered the local groundwater followed by sampling of the groundwater.

Iron was noteworthy as the only substance identified in four of the studies as exceeding the US EPA National Drinking Water Standard (2005a); for iron the standard was a Secondary National Drinking Water Standard. Exceeding a Secondary Drinking Water Standard is associated with cosmetic or aesthetic effects. In the study by the Minnesota Pollution Control Agency (1990) the iron standard was exceeded by 1000-fold. As discussed earlier in this report, the source of iron in these studies was most likely the steel belts and beads used in tire construction. Since current methods for processing tires into crumb rubber for use in playgrounds includes a step that removes 99% of the steel material, the iron levels leaching from rubberized playgrounds should be at least 100-fold lower than those cited above.

Manganese exceeded its Secondary National Drinking Water Standard in two of the studies (maximum 26-fold higher). Like iron, it probably also originated from the steel belts and beads in the tires. Cadmium, chromium, aluminum and lead exceeded their National Primary Drinking Water Standards in the single study by the Minnesota Pollution Control Agency (1990). All other levels of compounds or metals either fell below their National Drinking Water Standard or had no standard established for them.

It should be noted that in the study by Humphrey and Katz (2001), almost all high values from within the tire trench fell to background at three meters downgradient from the trench. Similarly, Exponent (2003) reported that the iron concentration was only elevated in the area close to the tire shreds, and that leached iron was quickly diluted or precipitated within 2-10 feet of the tire trench. Iron was specifically discussed since it was believed to be responsible for the toxicity of the groundwater from the tire trench towards *Ceriodaphnia dubia*. Thus, these limited data suggest that the tire-derived contaminants in groundwater do not migrate very far from their source.

Table 30. Groundwater analysis in the vicinity of recycled tires used in road and parking lot construction, and in underground test trenches.

Citation	Methods	Findings
Exponent, 2003	Groundwater collected from shredded tire trench located in saturated soil below the water table; water samples taken from inside trench and at a well 2 feet downgradient from the trench	Concentrations above background, all in ppb: chloroethane 2; 1,1-dichloroethane 2; cis-1,2-dichloroethene 16; benzene 1.6; trichloroethene 0.8; toluene 2.6; N-Nitrosodimethylamine 7; N-Nitrosodiphenylamine 7; aniline 100; bis(2-ethylhexyl)phthalate 5; acetone 11; iron 80,000; manganese 570; zinc 90; barium 30
FCCJNC, 1999	Ground rubber used to cover dirt parking areas and internal roadways of a community college; groundwater sampled from wells within a few meters of rubber-covered areas; wells were “in hydraulic communication with the aquifer”	Concentrations above background, all in ppb: total xylenes 1.4; iron 1,500; chromium 4
Humphrey and Katz, 2001	Groundwater collected from shredded tire trench located in saturated soil below the water table; water samples taken from inside trench and at a well 3 meters downgradient from the trench	Concentrations inside trench and above background, all in ppb: 1,1-dichloroethane 6; 4-methyl-2-pentanone 58; acetone 28; benzene 4; chloroethane 4; cis-1,2-dichloroethene 24; aniline 71; phenol 33; m+p cresol 39; iron 33,000; manganese 1,300; zinc 26; almost all values were at background in the groundwater sampled 3 meters downgradient from the tire trench
Minnesota Pollution Control Agency, 1990	Road bed construction with tire shreds over a wetland area; groundwater sampled from wells within a few feet of road bed	Concentrations above background, all in ppb: aluminum 180,000; barium 2000; cadmium 32; chromium (total) 350; iron 300,000; lead 230; zinc 870
Yoon et al., 2005	Tires shreds used in constructing a road embankment; groundwater sampled from a well adjacent to and downgradient of the embankment	Metal concentrations above background, all in ppb: arsenic 19; barium 113; cadmium 1.1; chromium (total) 55; selenium 23

Toxicity tests in sentinel organisms

Table 31 shows results of toxicity tests with sentinel organisms used as a means of identifying potential ecological toxicants. In almost all cases, whole tires, tire shreds or crumb rubber was used to produce concentrated leachates in the laboratory. The organisms used to test these concentrated leachates included single-celled bacteria (*Vibrio fisheri*) and algae (*S. capricornutum, R. subcapitata*), the aquatic invertebrates *Daphnia* and shrimp, three species of fish (rainbow trout, fathead minnows and sheepshead minnows), the frog species *X. laevis* and lettuce. In addition, four studies measured the effects of recycled crumb rubber on the growth of turf grass, while one study followed the growth of hot-house geraniums, all prompted by its use as a soil amendment.

The study by Birkholz et al. (2003) utilized crumb rubber manufactured specifically for use in playground surfaces. All other studies utilized either whole tires or tires processed into chips, shreds, plugs or powder.

Toxicity, often measured as lethality, was observed for all aquatic organisms (bacteria, algae, *Daphnia*, shrimp, minnows, trout, frog) exposed to recycled tires, although some individual studies were negative. Fathead minnows appeared to be less sensitive than rainbow trout, since 2/6 studies with the former detected toxicity compared to 3/3 studies with the latter. Three studies out of eight involving terrestrial plants documented adverse effects: decreased germination in turfgrass (Boniak et al., 2001), decreased growth rates for bermudagrass (Owings and Bush, 2001) and decreased growth rates and flower count in geraniums (Newman et al., 1997).

With regard to identifying the responsible toxicant(s), in *Daphnia* metals were thought to be responsible: zinc in the studies by Nelson et al. (1994) and Gaultieri et al. (2005) and iron precipitates forming on the feeding apparatus in the study by Exponent (2003). The lethality in rainbow trout was consistent with a nonvolatile (Day et al., 1993) and nonmetallic (Ontario Ministry of Environment and Energy, 1994) toxicant.

While these studies (mostly laboratory) show that recycled tire rubber has the potential to cause adverse effects in non-human organisms, whether this would occur in the environment surrounding rubberized playground surfaces would depend on the dilution, dispersion and precipitation of the relatively low levels of chemicals released by these surfaces. The chemicals released by tires could also be transformed through interactions with reactive chemicals already in the environment.

All but one of the studies with aquatic sentinel organisms discussed here utilized tire leachates produced in the laboratory. Chemicals in such leachates may be at lower or higher concentrations than would be achieved in the area surrounding rubberized playground surfaces. For the single study of tire leachate produced in the field (Exponent, 2003), only tire shreds below the water table released sufficient iron to cause toxicity, and then only within 2-10 feet of the tire trench. The tire trench above the water table did not release toxic levels of iron. This latter situation more closely represents what would be expected in the environment surrounding rubberized playground surfaces, where the surfaces are not in constant hydraulic communication with groundwater.

Table 31. Toxicologic responses of sentinel organisms to recycled tire rubber and its leachate.

Citation	Methods	Findings
Bacteria		
Birkholz et al., 2003	Playground crumb rubber used to produce leachate in lab; toxicity measured in luminescent bacteria *Vibrio fisheri*	Toxicity observed-less for crumb rubber aged by use in playground for 3 months
Algae		
Basel Convention, 1999	Powdered tire rubber shaken in water for 24 h; growth of *S. capricornutum* measured	No effects at highest dose tested
Gualtieri et al., 2005	Finely ground tire rubber shaken in water at pH 3 for 24 h; growth of *R. subcapitata* measured	Growth inhibited over the 72 h of incubation
Minnesota DOT, 1995	Chipped tires and chipped wood used to produce leachate in lab; survival and reproduction measured in green algae (*S. capricornutum*)	Tire and wood leachates were equitoxic at lowest dose level tested
Daphnia (aquatic invertebrate)		
Basel Convention, 1999	Powdered tire rubber shaken in water for 24 h; testing for changes in mobility of *Daphnia magnia*	No effects at highest dose level tested
Birkholz et al., 2003	Playground crumb rubber used to produce leachate in lab; lethality measured in *Daphnia magna* (exposure time not specified)	Lethality observed-less for crumb rubber aged by use in playground for 3 months
Day et al., 1993	Whole tires immersed in water in tanks for increasing times	No lethality observed
Exponent, 2003	Leachate from tire trench below and above water table; survival and reproduction measured in *Ceriodaphnia dubia*	Lower survival and less reproduction compared to controls for below water table application only-believed due to iron precipitates forming on feeding apparatus
Gualtieri et al., 2005	Finely ground tire rubber shaken in water at pH 3 for 24 h; toxicity to *D. magna* measured	Immobility/mortality was observed after 24 and 48 h of incubation

Citation	Methods	Findings
Minnesota DOT, 1995	Chipped tires and chipped wood used to produce leachate in lab; survival and reproduction measured in *Ceriodaphnia dubia*	Tire chip leachate was 5- to 8-fold more toxic than wood chip leachate
Nelson et al., 1994	Tire plugs immersed in lake water in lab for 31 days; 24 h LC_{50} determined in *Ceriodaphnia dubia*	Lethality observed; believed due to Zn
Ontario Ministry of Environment and Energy, 1994	Whole tire immersed in water in tank for up to 2 weeks; water tested with Daphnia magna and Ceriodaphnia dubia in 48 hour incubations	No lethality observed
Wik and Dave, 2005	Finely ground tire rubber incubated in water for 72 h prior to addition of Daphnia magna for another 24 h	Variable toxicity in tire samples possibly due to nonpolar organic compounds
Daggerblade Grass Shrimp (aquatic invertebrate)		
Hartwell et al., 1998	Shredded tires used to produce leachate in lab at salinities of 5-25 percent; survival and growth measured over 96 hrs in grass shrimp *Palaemonetes pugio*	Lethality and growth inhibition both observed in response to tire leachate
Minnows		
Basel Convention, 1999	Powdered tire rubber shaken in water for 24 h; mortality of *Brachydanio rerio* measured	No mortality observed at highest dose level tested
Birkholz et al., 2003	Playground crumb rubber used to produce leachate in lab; lethality measured in the fathead minnow *P. promelas* (exposure time not specified)	Lethality observed-less for crumb rubber aged by use in playground for 3 months
Day et al., 1993	Whole tires immersed in water in tanks for increasing times; lethality measured in the fathead minnow	No lethality observed
Exponent, 2003	Leachate from tire trench below and above water table; seven day survival and reproduction measured in fathead minnow *P. promelas*	No effects observed

Citation	Methods	Findings
Hartwell et al., 1998	Shredded tires used to produce leachate in lab at salinities of 5-25 percent; survival and growth measured over 96 hrs in larval sheepshead minnows *Cyprinodon variegatus*	Lethality and growth inhibition both observed in response to tire leachate
Minnesota DOT, 1995	Chipped tires and chipped wood used to produce leachate in lab; survival and reproduction measured in fathead minnow (*P. promelas*)	For survival and growth the leachate from tires was 2 to 3-fold more toxic than the leachate from wood
Ontario Ministry of Environment and Energy, 1994	Whole tire immersed in water in tank for up to 2 weeks; water tested with fathead minnow *P. promelas* in 4 day exposures	No lethality observed
Trout		
Day et al., 1993	Whole tires immersed in water in tanks for increasing times; lethality measured in rainbow trout	Lethality observed-lethality was stable for 2-3 days if tires removed, then slowly decreased over 32 days (believed due to break down of nonvolatile toxicants)
Ontario Ministry of Environment and Energy, 1994	Whole tire immersed in water in tank for up to 2 weeks; lethality measured in rainbow trout fry for exposures of up to 4 days	Lethality observed after 24 hours of exposure; toxicity completely removed by pretreating water with activated carbon
Stephensen et al., 2003	Whole tires immersed in water in tanks with rainbow trout; liver and bile examined from the fish	Tire-exposed fish exhibited the following: increased liver weight, increased hepatic CYP1A1, glutathione, glutathione reductase, glutathione S-transferase and glucose-6-phosphate dehydrogenase; bile contained hydroxylated PAHs and aromatic nitrogen compounds

Citation	Methods	Findings
X. laevis (frog) embryos		
Gaultieri et al., 2005	Finely ground tire rubber shaken in water at pH 3 for 24 h; toxicity measured with *X. laevis* (frog) embryos incubated in Petri dishes	Lethality and malformations produced in the frog embryos during the 120 h incubation
Plants		
Boniak et al., 2001	Crumb rubber mixed with soil for use as a rootzone mix in the cultivation of turf grass (tall fescue and Kentucky bluegrass)	Smallest size of crumb rubber caused a dose-dependent decrease in germination rate and decrease in turf quality
Groenevelt and Grunthal, 1998	Crumb rubber mixed with soil used to grow turf grass	The Zn content of the turf grass approximately doubled, to over 80 mg/kg; no accompanying toxicity
Lisi et al., 2004	Crumb rubber installed as a drainage layer 30 cm beneath the root zone of a golf course putting green	No detrimental effects observed on turf grass quality, color or density
Minnesota DOT, 1995	Chipped tires and chipped wood used to produce leachate in lab; survival and growth of lettuce (*Lactuca sativa*) from seed measured	No effects observed on survival or growth
Minnesota Pollution Control Agency, 1990	Shredded tires used in roadbed construction	No differences observed in the diversity of plant species growing in the tire and control areas
Newman et al., 1997	Ground tire rubber mixed with peat and/or vermiculite for use as a medium for growing hot-house geraniums (2 months duration)	Plant growth and flower count were lower for plants grown in medium containing ground rubber, possibly due to released zinc and copper, both of which were elevated in the plant tissue

Citation	Methods	Findings
Owings and Bush, 2001	Growth of bermudagrass in containers of sand, peat moss and various concentrations of crumb rubber	Growth rates decreased, possibly due to released zinc and manganese
Tompkins et al., 1997	Crumb rubber as a soil amendment for the growth of turf grass	No effects observed on emergence rates; slightly better color was observed in the presence of the crumb rubber

Conclusions

- Only a limited number of soil samples from locations adjacent to recycled tire shreds have been analyzed; while a number of metals were above background in some studies, most increases were small.
- In the single case where soil samples from under a playground surface made of recycled tires were analyzed, the metals, VOCs, PAHs, dioxins and furans were at or below background levels, suggesting no risk to the local ecology.
- Measurements of chemicals released from recycled tires into groundwater are also scarce.
- Groundwater in contact with tire shreds contained elevated levels of many chemicals; however, those levels rapidly approached background a few feet outside of the tire trench.
- Recycled tires released chemicals that were toxic to a variety of sentinel organisms including bacteria, algae, aquatic invertebrates, fish, frogs and plants; importantly, almost all of these studies in animals, bacteria and algae utilized concentrated leachate produced in the laboratory.
- Considering all the data, it seems doubtful that recycled tire rubber in outdoor applications such as playground surfaces releases high enough levels of chemicals to cause toxicity to animals and plants living in the vicinity.

Chapter 11: Evaluating the Risk of Serious Head Injury Due to Falls on California Playground Surfaces Made of Recycled Tires

Abstract

Recycled tires continue to be used in the construction of rubberized playground surfaces in California. To function as an effective means of reducing the incidence of serious head injury when children fall in the playground, these surfaces should meet standards for impact attenuation, as cited in the California Code of Regulations (sections 65700-65750). This study was conducted to determine whether rubberized surfaces are meeting the standards for impact attenuation, and whether those properties change as the surfaces age. Data have been gathered from 32 rubberized playground surfaces and 5 surfaces made of wood chips/engineered wood fiber.

An accelerometer was used to measure maximal deceleration rates (G_{max}) and Head Impact Criterion (HIC) values for the surface below each play structure (131 tested) within the playgrounds, which were then compared to the American Society for Testing and Materials (ASTM) F1292 standard for impact attenuation by playground surfaces. Approximately 33 percent of the play structures on rubberized surfaces failed to meet the HIC standard, compared to no failures on wood chips. Approximately 69 percent of the rubberized playground surfaces contained at least one failing structure. Failing structures over rubberized surfaces included swings, climbers, slides, upper body rings and elevated platforms.

As the heights of the play structures in rubberized playgrounds increased, so did the likelihood that the surface below would fail to meet the HIC standard, although some of the highest structures had underlying surfaces that met the standard. There appeared to be little or no difference in impact attenuation by surfaces less than one year old compared to surfaces that were between one and two years old. In addition, HIC values in two pour-in-place surfaces were stable for at least the first two to three months following installation. Lastly, HIC values of pour-in-place surfaces increased with increasing surface temperature. These results demonstrate the importance of testing rubberized playground surfaces following installation, to verify that the surfaces meet the standards for impact attenuation.

Introduction

Nationwide, up to 80 percent of serious playground injuries are the results of falls to the surface (Tinsworth and McDonald, 2001). Most were injuries to the upper limbs (Altman et al., 1996; Chalmers et al., 1996), although this varied with age; for children younger than five years old the head or face was injured most frequently, while for children 5-14 years old injuries to the hand or arm predominated (Tinsworth and McDonald, 2001).

Epidemiologic studies performed with data from hospitals and daycare centers demonstrated that as the height of playground equipment increased, the injury rate from falls also increased (Briss et al., 1995; Chalmers et al., 1996; Mott et al., 1997; Macarthur et al., 2000). Less clear, however, is the influence of playground surface type on

frequency and kind of injury. In some instances impact-absorbing surfaces such as wood chips, sand, rubber tile/mats and rubber shreds were effective at reducing injuries from falls compared to hard surfaces such as asphalt, cement, turf and dirt (Chalmers et al., 1996; Mott et al., 1997; Mowat et al., 1998; Norton et al., 2004b), while other studies found little or no benefit (Sosin et al., 1993; Briss et al., 1995; Waltzman et al., 1999).

There are too few data to draw reliable conclusions on impact attenuation and injury reduction by rubber playground surfaces compared to other surfaces,. An epidemiologic study by Mott et al. (1997) found that playgrounds with "rubber surfaces" (rubber surface type not specified) performed better than those consisting of bark or concrete. However, as discussed above, other epidemiologic studies have failed to detect any significant differences among surfaces.

Turning to laboratory studies where impact attenuation was measured with mechanical devices under controlled conditions, in two studies rubber chips outperformed sand, wood chips and gravel (Mack et al., 2000; CPSC, undated), while in a third study wood chips outperformed rubber mats (Lewis et al., 1993). Clearly, data collected from playgrounds being used by children are needed in order to determine whether the different types of rubber surfacing (crumb, shreds, pour-in-place, molded tiles) lower the injury rate compared to other impact-absorbing surfaces.

Therefore, discussions were held with members of the Injury Surveillance and Epidemiology Section of the California Department of Health Services and the Department of Epidemiology in the UCLA School of Public Health, in an effort to locate injury data collected from playgrounds both before and after installation of rubberized surfaces. No such data were located, including no information on insurance savings directly attributable to decreased playground injuries. Thus, OEHHA decided to collect impact attenuation data from California playground surfaces made of recycled tires, from which to estimate the risk of serious head injury from falls.

That lowering the number of playground injuries would produce a large reduction in health care-related costs is demonstrated by the estimate that playground-related injuries in the United States cost 1.2 billion dollars to treat in 1995 (U.S. Centers for Disease Control, 2005). If ten percent of these occurred in California, then approximately 120 million dollars were spent in this state. Since approximately 80 percent of these injuries resulted from falls (Tinsworth and McDonald, 2001), then reducing the injury rate from falls by only ten percent has the potential to save almost 10 million dollars in California (higher savings in 2006 dollars). An accompanying reduction in injury severity would save even more.

It may also be particularly important to compare injury rates for specific types of injuries, such as head concussions and long-bone fractures of the arm. Some studies suggest that impact attenuation properties vary between surfaces, such that head injury might be optimally prevented by one surface, while long-bone injury might be optimally prevented by another (Briss et al., 1995; Rabinovitch and Chiu, 1998; Petridou et al., 2002; Norton et al., 2004a; Norton et al., 2004b). This was in fact demonstrated in a laboratory study that used a test dummy to simulate the short-distance falls that children experience when falling out of bed (Bertocci et al., 2003). While similar "g" forces for head impact were measured on playground foam compared to padded carpet, the foam produced significantly less axial tension to the femur. Similar data are needed for the different types of rubberized playground surfaces.

More than 40 million waste tires are generated each year in California (CIWMB, 2006). Increasingly, these used tires are being recycled into rubberized playground surfaces. Such surfaces can be made thick enough to provide significant impact attenuation when children fall from play structures in the playground, thereby reducing the chance of serious head injury (U.S. CPSC, 1997). This is accomplished by deformation and/or displacement of the surface in the local area of the impact, thereby absorbing some of the energy of impact. While the standards for impact attenuation by playground surfaces are cited in the California Code of Regulations (sections 65700-65750), these standards have never been enforced.

Thus, it is currently unknown whether the standards are being met, either by the relatively new playground safety surfaces made of recycled tires, or by more traditional surfaces also in use in California including sand, wood chips and pea gravel. The primary objective of this study was to determine whether California playground surfaces made of recycled tires are in compliance with the California standards for impact attenuation. In addition, since these surfaces are exposed to the environment, we studied whether their impact attenuating properties are influenced by temperature and whether they change over time.

Materials and Methods

We tested playgrounds of municipalities and school districts awarded grants by the CIWMB for the installation of playground surfaces made of recycled tires. These were located in San Francisco and surrounding regions. In a number of instances, grantees had additional playgrounds with rubberized surfaces made of recycled tires that were not funded by the CIWMB. Permission was obtained to test both the CIWMB-funded and non-funded surfaces. There were no obvious differences in the types or sizes of playground structures contained in these two groups. One private childcare facility with a rubberized playground surface made of recycled tires was included in the study.

A total of 32 rubberized playground surfaces were tested for impact attenuation. Twenty-six were pour-in-place surfaces consisting of a bottom layer of shredded tires and a top layer of the synthetic rubber called ethylene propylene diene monomer (EPDM). Pour-in-place surfaces are made by mixing shredded tire rubber with polyurethane binder on site, and pouring the mixture into the playground to harden into a unitary surface. The top layer of EPDM is then added using a similar process. Four playground surfaces were constructed out of tiles made of shredded tires. Such tiles are pre-molded by the manufacturer and transported to the playground site, where they are attached to each other by glue or other method to form a unitary surface. Two surfaces were tested that consisted of loose-fill shredded tires. This material is raked into place, and requires periodic maintenance that includes removal of foreign objects and evening of the surface. Five playgrounds were tested that had surfaces made of wood chips/engineered wood fiber. These surfaces are also raked into place, and require regular maintenance similar to that required by the loose-fill rubber surfaces. Table 32 lists some of the advantages and disadvantages of these safety surfaces, including sand.

Table 32. Advantages and disadvantages of different playground safety surfaces (adapted with modification from Huber, 2001)

Pour-in-place or tiles made of shredded tires
Advantages: low maintenance and easy to clean; consistent shock absorbency; does not harbor foreign objects; does not readily support microbial growth; not subject to displacement during children's play; accessible to the disabled; good footing; unattractive to dogs and cats as a place

to defecate; cannot be swallowed by children
Disadvantages: high installation cost; shock absorbency may decrease somewhat over a time frame of years; can become uncomfortably hot on warm days; flammable
Loose-fill shredded tires
Advantages: low installation cost; drains well; depth easily increased to increase shock absorbency; does not readily support microbial growth; less attractive to dogs and cats as a place to defecate; less subject to compaction over time
Disadvantages: requires regular maintenance; gets dirty over time; harbors/hides foreign objects; subject to displacement during children's play; can be thrown by children; flammable; less accessible to the disabled; can be swallowed by children; difficult footing; smaller particles prone to being tracked indoors by children
Wood chips/engineered wood fiber
Advantages: low installation cost; drains well; depth easily increased to increase shock absorbency; stays relatively cool on hot days
Disadvantages: requires regular maintenance; combines with dirt over time; harbors/hides foreign objects; subject to displacement during children's play; can be thrown by children; supports microbial growth; used by cats and dogs as a place to defecate; flammable; can become compacted over time; less accessible to the disabled; can be swallowed by children
Sand
Advantages: low installation cost; drains well; depth easily increased to increase shock absorbency; nonflammable; does not readily support microbial growth
Disadvantages: requires regular maintenance; combines with dirt over time; harbors/hides foreign objects; subject to displacement during children's play; can be thrown by children; used by cats and dogs as a place to defecate; can become compacted over time; not accessible to the disabled; can be swallowed by children; difficult footing; looses shock absorbency when water saturated
Pea Gravel
Advantages: low installation cost; drains well; depth easily increased to increase shock absorbency; nonflammable; does not readily support microbial growth
Disadvantages: requires regular maintenance; combines with dirt over time; harbors/hides foreign objects; subject to displacement during children's play; can be thrown by children; used by cates and dogs as a place to defecate; can become compacted over time; not accessible to the disabled; can be swallowed by children; difficult footing; can be inserted by the child into its body openings such as ears and nose

Measurement of surface impact attenuation (HIC, G_{max}) was performed with a Triax2000 triaxial accelerometer (Playground Clearing House, Trenton, New Jersey) according to the American Society for Testing and Materials (ASTM, 2004) standard number F1292: Standard Specification for Impact Attenuation of Surfacing Materials Within the Use Zone of Playground Equipment. HIC and G_{max} data can be used to predict whether serious head injury would result from a fall onto a surface. According to this standard, the surface below each play structure is tested at its fall height at three locations within its use zone. Fall heights and use zones were according to ASTM standard F1487 and United States Consumer Products Safety Commission publication No. 325: Handbook for Public Playground Safety.

The Triax2000 utilizes a ten pound headform (Figure 2). For reference comparison and quality control purposes, the accelerometer in the headform was routinely tested by performing drops onto a rubber reference pad supplied by the manufacturer. Those HIC and G_{max} values were always within 2% of the reference pad values specified for our accelerometer, as required by the ASTM F1292 standard (ASTM, 2004).

All testing was conducted on days when it had not rained, and on dry surfaces (other than surface dampness that might be due to fog or morning dew). Prior to testing, loose-fill surfaces were compacted with a hand tamper as described in ASTM F1292. Temperatures of both the surface and ambient air were recorded.

Results

Figure 3 shows the results of drops at 368 locations around 121 playground structures standing on rubberized surfaces. For a drop location to meet the ASTM F1292 standard, the G_{max} value must be less than or equal to 200, and the HIC value must be less than or equal to 1000. A number of drops failed the HIC standard, while a smaller number failed the G_{max} standard. Every drop that passed the HIC standard also passed the G_{max} standard. In contrast, many drops that passed the G_{max} standard failed to pass the HIC standard. Thus, the HIC=1000 standard is a more sensitive test of impact attenuation by these rubber surfaces, and in subsequent graphs only the HIC value was plotted for each drop location.

Figure 4 contains the HIC data from Figure 3 plotted as a function of playground structure fall height. Data from five playgrounds with surfaces made of wood chips/engineered wood fiber are included. Both sets of data show increasing HIC with increasing fall height, although the increase appears to be greater for the drops on rubber. As stated in the Methods section, each structure was tested at three drop locations within the use zone. Many of the drops on rubber surfaces exceeded the HIC=1000 standard, leading to a playground structure compliance rate of 67 percent (Table 33), and an overall playground surface California regulatory compliance rate of 31 percent. There were no failures out of ten structures tested on surfaces made of wood chips.

While the data in Figure 4 show a generally greater likelihood of rubberized surfaces to fail the HIC=1000 standard at higher fall heights, a number of drops at heights up to almost twelve feet yielded values that met the standard. This demonstrates that rubber surfaces in the use zones of quite tall playground structures can be constructed to meet the standard.

The data from Figure 4 have been plotted in Figure 5 so as to show how the playground structure compliance rate decreased as the fall height increased. Only a single structure failed the HIC standard at < six feet. However, above six feet the compliance rate fell continuously up to nine feet. At structure drop heights greater than nine feet, the small number of structures makes it difficult to know the true compliance rate.

The structures failing the HIC standard are shown in Table 34, where they have been categorized according to structure type. No specific type of play structure stood out as being responsible for the failure rate observed here.

To determine whether rubberized playground surfaces failed the HIC standard at only a single location or at multiple locations, the number of failing structures per playground were plotted in Figure 6. While the largest group (ten playgrounds) contained only a single failing structure, three surfaces each contained three failing structures and two

surfaces each contained four failing structures. Clearly, some rubberized playgrounds did not comply with the HIC standard over much of their surface.

Some municipalities were able to supply the installation dates for their particular playground surfaces. Figure 7 uses these data to calculate surface age, and compare those ages to the corresponding HIC compliance rate. The small numbers of surfaces greater than two years old make those data unreliable. Comparing surfaces in their first year following installation to those in their second year, the compliance rates were not significantly different according to a 2-tailed Fisher's Exact Test, suggesting that the surfaces experienced little or no change in impact attenuation over their first two years of life. However, since other explanations are possible, we followed impact attenuation over time at the same locations in the same playgrounds.

Figures 8 and 9 show surface HIC values as a function of time, over the first two to three months of surface life. The playground represented in Figure 8 was first measured two days after installation of the top EPDM layer, while the playground in Figure 9 was first measured at four days after installation. Both surfaces were pour-in-place with bottom layers of recycled tire rubber and tops layers of EPDM. Normally, these two layers are poured on consecutive days. Thus, these data give an indication of how quickly the surfaces hardened, and to what extent the hardness changed over the first few months of surface life. Because surface hardness is affected by temperature, the air temperatures measured in the shade are presented, showing that the HIC data were collected over a relatively narrow temperature range. The data show little or no change in hardness over the first two to three months, indicating that these surfaces provide stable impact attenuation soon after they are poured, and for months thereafter. Taken together, the data in Figures 7-9 are consistent with stable impact attenuation by these surfaces for at least the first two years of surface life.

Two surfaces composed of loose-fill shredded tire rubber were also tested. One had play structures that were less than two feet high, yielding HIC values of 129 or less (data not shown). The second playground had structures up to eight feet tall. The HIC testing data for this playground are shown in Figure 10. The values fluctuated over a wide range. For example, the three testing locations for the swing set ranged from a low of 558 to a high of 2821. Also, comparing the platform values to the rings values, both tested at a fall height of 6.5 feet, the platform values were approximately three fold higher than those of the rings. Since this surface consisted of loose-fill shredded tire rubber, each drop location was inspected to determine thickness of the rubber layer. It was immediately obvious that the locations with high HIC values were spots where most of the rubber shreds had been kicked away, leaving only a relatively thin layer behind. Thus, variability in surface thickness was responsible for the variability in HIC values. We believe it likely that for pour-in-place surfaces, variability in surface thickness is also the primary cause of the variability in HIC values, as exemplified by the data in Figure 4.

As mentioned briefly above, the temperature of the pour-in-place surface had a small but reproducible effect on its HIC value. The data in Figures 11 and 12 show HIC values for three drop locations as a function of surface temperature. These data were collected in a single playground, beginning early in the morning when the temperature was cool until the last measurements were made during the heat of the day (Figure 11), or starting in the hottest part of the afternoon with measurements lasting until just after sundown (Figure 12). At all three locations, the HIC values increased with increasing temperature. The largest increases were at location #1 in Figure 11, where the HIC values increased approximately 20 percent as the surface temperature rose from 52 to 114 degrees

Fahrenheit. Counterintuitively, the surface became harder as it warmed and softer as it cooled.

To substantiate the findings regarding suface temperature, two series of drops were performed at location #1 over a range of fall heights, one at a surface temperature of 49 degrees Fahrenheit and one at 108 degrees. Figure 13 shows that the higher temperature was associated with higher HIC values at every drop height, and that the temperature effect increased with increasing fall height. Thus, the surface was consistently harder at the higher temperature. This temperature experiment was repeated at a second playground (playground II, Figure 14), over a lower range of HIC values (approximately 200 to 500) compared to playground I in Figure 13 (approximately 400 to 2000). As for playground I, every fall height in playground II gave higher HIC values when measured at the higher temperature. The smaller temperature effect in playground II may have been due to the smaller temperature difference: 36 degrees F for playground II compared to 59 degrees F for playground I. These results demonstrate the importance of controlling the temperature of these surfaces for obtaining consistent HIC values. In addition, these data indicate that testing pour-in-place surfaces for compliance with the ASTM standards is best done on warmer days rather than cooler days, to help ensure that the surface is compliant throughout the entire year.

Discussion

Extent and nature of injuries

A total of 1,299 Californians (presumably children) were admitted to California hospitals in 2003 due to fall-related playground injuries (California Department of Health Services, 2006). The USCPSC estimates that for each playground injury requiring hospitalization, there are at least 22 emergency room "treat and release" playground injuries (USCPSC, 2006). Therefore, there were an estimated 1,299 X 22 = 28,578 fall-related playground injuries in California in 2003 serious enough to require an emergency room visit. Thus, injury due to falls in the playground represents a significant public health problem. Furthermore, since fall-related injuries comprise about 80 percent of all playground injuries (Tinsworth and McDonald, 2001), impact-attenuating surfaces represent an effective means for reducing the playground injury rate. (Chalmers et al., 1996; Mott et al., 1997; Mowat et al., 1998).

However, care must be taken to ensure that such safety surfacing is thick enough and installed correctly to provide sufficient impact attenuation (U.S. CPSC, 1997). Various standards have been promulgated to help achieve this goal. California is one of the few states with regulatory playground surface safety standards. The Code of Regulations, sections 65700 through 65750 specify compliance with the U.S. CPSC Handbook for Public Playground Safety (Publication Number 325, 1997) and ASTM standard F1487-98 (ASTM, 1998), both of which cite ASTM standard F1292. It is F1292 (ASTM, 2004) that specifies the actual physical measures of impact attenuation ($G_{max} \leq 200$ and HIC $\leq$ 1000) and the methodology for their measurement. Prior to our work, none of the playground surfaces comprising this study had been tested after installation to determine compliance with these regulatory standards.

Development of the regulatory standard

G_{max} is the maximum deceleration produced by contact between the falling Triax2000 headform and the surface. HIC is derived by transforming the deceleration versus time data and integrating under the curve (ASTM, 2004). Both values have a history of use by

those concerned with predicting head injury, including the automotive and airline crash test communities (Bandak et al., 1996; Nahum and Melvin, 2002) and the sports helmet industry (Camacho et al., 2001; Duma et al., 2005). However, significant uncertainty is associated with the use of these measures to predict serious head injury. This uncertainty is due to many factors, including the limited dataset used to define the relationship of G_{max} and HIC to serious head injury, and a general paucity of child head injury data. Evidence indicating that as children develop, their skulls become harder (Goldsmith and Plunkett, 2004) and their brains become more viscous (Thibault and Margulies, 1998) illustrates the difficulties raised by this gap in child head injury data. Nonetheless, ASTM standard F1292 states that a playground surface must have a G_{max} value ≤ 200 and an HIC value ≤ 1000.

An HIC value of 1000 is associated with a risk of critical head injury from a head-first fall of from 5 percent (ASTM, 2004) to 16 percent (Prasad and Mertz, 1985). The threshold for fatal head injury has been estimated as low as HIC = 840 to as high as HIC = 1475 (Cory et al., 2001). To give an idea of how high the HIC = 1000 value is, the mean HIC value for an impact to the football helmet of an NFL player that resulted in a concussion was 400, while the blows of an Olympic boxer produced HIC values below 100 (Viano et al., 2005). ASTM F1292 states that playgrounds with surfaces not meeting the standard should be closed until the surface is brought into compliance.

G_{max} vs. HIC

Since values for G_{max} and HIC were collected for every test drop performed with the accelerometer, it was a simple matter to plot these data to study the relationship between these two parameters. Figure 3 shows that for the rubber surfaces made of recycled tires, the HIC values tended to increase faster than the G_{max} values. As a result, the HIC = 1000 standard was often exceeded while the corresponding G_{max} value remained in compliance at ≤ 200. In fact, in no instance either on rubber or any other material did the surface pass the HIC standard pass but fail the G_{max} standard. Thus, it may well be a general finding that the HIC = 1000 standard is a more sensitive test of playground surface impact attenuation than the $G_{max} = 200$ standard.

Compliance as a function of fall height

Plotting the HIC data from Figure 2 as a function of fall height (Figure 4), there is a clear trend towards a greater HIC failure rate as the fall height increases. These data also illustrate a generally large degree of variability in the HIC values associated with any given fall height. For example, at a fall height of slightly less than eight feet, the HIC values range from less than 500 up to almost 2000. While a number of explanations are possible for these HIC failures and variability, we believe the simplest one is that of a failure to install a surface of sufficient thickness. This was shown to be the case for the loose-fill surface in Figure 10, where a rubber layer of varying thickness yielded a number of high HIC values.

This hypothesis is also supported by the finding that surfaces under some quite high play structures easily passed the HIC standard. For example, one structure just over nine feet tall yielded two drops with HIC values around 500 (Figure 4). Two structures over eleven feet tall also had surfaces that were in compliance at some or all drop locations. From these observations, we conclude that rubberized surfaces under high playground structures can be constructed to meet the HIC standard. The determining factor in surface thickness may only be cost, not technological infeasibility or absence of a performance standard.

In comparison to rubberized surfaces, surfaces of wood chips yielded HIC values that were always in compliance with the standard, and the HIC values at any given fall height appeared to vary less than those for the rubber surfaces (Figure 4). These results could be explained if wood chips were routinely installed at relatively great depth providing a high degree of impact attenuation. The approximately 10-fold lower cost of installing wood chips compared to pour-in-place rubber provides a possible reason for why municipalities might have the resources to install a surface of great depth out of wood chips but not of pour-in-place rubber.

Number and location of failures

Approximately 33 percent of all playground structures over rubber surfaces failed the HIC standard (Table 33). ASTM standard F1292 states that if a single drop location within the use zone of a single structure fails the standard, then the playground fails and should be closed until the problem is corrected. Since most playgrounds contained multiple structures, the overall failure rate of rubberized surfaces was considerably higher, at 69 percent (Table 33).

To get a better sense of whether failing surfaces were failing at only one or many locations within the playground, the numbers of failing structures per playground were plotted (Figure 6). The data show that many surfaces failed due to a single structure. Thus, correcting these inadequacies might be a cost-effective approach towards bringing these surfaces into compliance. However, other surfaces failed at multiple structures, suggesting that most if not all of the rubberized surfaces in those playgrounds were noncompliant. If, as discussed earlier, this is due to the surfaces being of insufficient thickness, a completely new and thicker surface may be required to bring these playgrounds into compliance. Alternatively, the playground structures could be lowered.

Compliance as a function of surface age

Pour-in-place surfaces made of recycled tires require considerably less day-to-day maintenance than traditional surfaces such as wood chips or sand. In addition, the unitary rubber surfaces are expected to be long lasting, with advertised useful lifetimes of 5-10 years or more. These desirable characteristics are important considerations when deciding whether to pay the relatively high cost of installing a pour-in-place surface. If the useful lifetime of these surfaces is on the order of 10 years or greater, it is important to determine if their impact attenuating properties change as a function of surface age.

For example, a surface that hardens over time in response to environmental factors could be in compliance with F1292 during the first few years following installation, but not in subsequent years. We have addressed this question by comparing the playground structure failure rate to surface age (Figure 7). Because the use of recycled tires in playground surfaces is a relatively recent development, most of the surfaces we tested were less than two years old.

Nonetheless, the failure rates were not significantly different between the first and second years post-installation, suggesting that surface hardness had not changed over this period. However, other explanations are possible. Therefore, to better address the effects of surface age, we also measured surface hardness at the same locations within the same playgrounds over the first two to three months of surface life. There was little or no change in HIC values at three locations in each of two playgrounds (Figures 8 and 9), suggesting that once these pour-in-place surfaces harden, they provide stable impact attenuation.

Discussion of the head injury standard

As mentioned above, there is much uncertainty associated with the estimate that an HIC = 1000 yields a less than 5 percent risk of critical head injury (ASTM, 2004). Much of this uncertainty stems from the small data set that was used to construct the head injury risk curve (King, 2000; Melvin and Lighthall, 2002). Since only a small subset of these data were from children, application of the HIC standard to predict child head injury is even more problematic (Goldsmith, 1981; Goldsmith and Plunkett, 2004). Thus, a surface with an HIC value that is significantly lower than 1000 may be highly desirable to provide a greater level of protection against critical head injury. In addition, a lower HIC might help protect against minor head/brain injury, which actually comprises 60-80 percent of all head injury, with unknown health consequences over the long term (Fearnside and Simpson, 1997).

An HIC value below 250 has been recommended to reduce the chance of such relatively minor brain injury (Pellman et al., 2003). Looking at the data in Figure 4, it is hard to escape the conclusion that the surfaces of wood chips currently in use in California playgrounds provide a greater margin of safety than those of pour-in-place rubber. This need not be the case, since those same data show that pour-in-place surfaces can be constructed to provide as great a margin of safety as the surfaces of wood chips.

While the HIC was developed to predict serious head injury, a recently published study by Sherker et al. (2005) indicates that reducing the HIC value of a given surface also helps reduce the risk of arm fracture. This is welcome news since arm fracture is a more common playground-related fall injury than head injury (Tinsworth and McDonald, 2001). However, the high coefficient of friction associated with pour-in-place rubber surfaces may increase the likelihood of long bone fractures relative to smoother surfaces or surfaces of loose-fill material. Further studies are needed to address these issues.

In summary, our study indicates that California surfaces made of recycled tires commonly fail to meet the HIC standard for impact attenuation specified in state regulations. It is likely that these failures resulted from installation of surfaces that were not sufficiently thick, given the heights of the play structures in the playgrounds. It seems that a relatively simple way to prevent this would be for future purchasers to require that the installer test the surface after installation, to verify that all structures in the playground had surfaces below that met the HIC standard. Given the temperature dependence of the HIC measurements, it would probably be public health protective to make the measurements on a day when the ambient temperature was near the maximum expected for that location. That testing after installation is rarely done is suggested by our finding that none of the surfaces comprising this study had been tested prior to our work.

Conclusions

- The head impact criterion (HIC) standard = 1000 was a more sensitive measure of impact attenuation by rubberized playground surfaces than the G_{max} standard = 200.

- As the fall height of playground structures increased, the underlying rubberized playground surface was more likely to fail the HIC standard; however, even at fall heights of 9-12 feet, some rubberized surfaces passed the standard.

- Only 31 percent of rubberized playground surfaces (32 tested) passed the HIC standard below every play structure, compared to 100 percent for surfaces made of wood chips (5 tested).

- The large proportion (69 percent) of new rubberized playground surfaces in California not meeting impact attenuation standards represents a missed opportunity for prevention of playground fall injuries, which are estimated to be in the thousands and which include serious trauma such as brain injury.

- Some rubberized surfaces failed the HIC standard at multiple locations, indicating a widespread deficiency in impact attenuation for those surfaces.

- HIC values were not influenced by surface age, either during the first 2-3 months following installation or during the first 2 years.

- HIC values of rubberized surfaces increased with increasing surface temperature; in one playground the HIC value measured at dawn increased almost 20 percent when measured again in the afternoon during the heat of the day.

- These data point out the importance of testing the impact attenuation of rubberized playground surfaces following installation, to ensure that they meet the standards.

- Given the uncertainty associated with the HIC$\leq$1000 standard, as well as the seriousness of the endpoint (critical head injury), customers should consider installing rubberized surfaces that provide as low an HIC value as possible.

Table 33. HIC standard compliance rates (HIC ≤ 1000) for playground surfaces: rubber vs wood.[1]

	No. tested	percent passing HIC standard
Structures over rubber surfaces	121	67
Structures over wood surfaces	10	100
Entire rubber playground surface	32	31
Entire wood playground surface	5	100

[1]Rubber surfaces were made of recycled tires and wood surfaces were made of wood chips/engineered wood fiber.

Table 34. Types of playground structures failing the HIC standard[1]

	No. of failing structures/No. tested
Standard swings	12/22
Tot swings	8/18
Slides	4/13
Climbers	8/16
Upper body rings	6/11
Platforms	5/29

[1] A total of 121 structures were tested (these six types and other types not shown), with these 43 having at least one HIC value greater than 1000.



Figure 2: Triax2000 triaxial accelerometer.

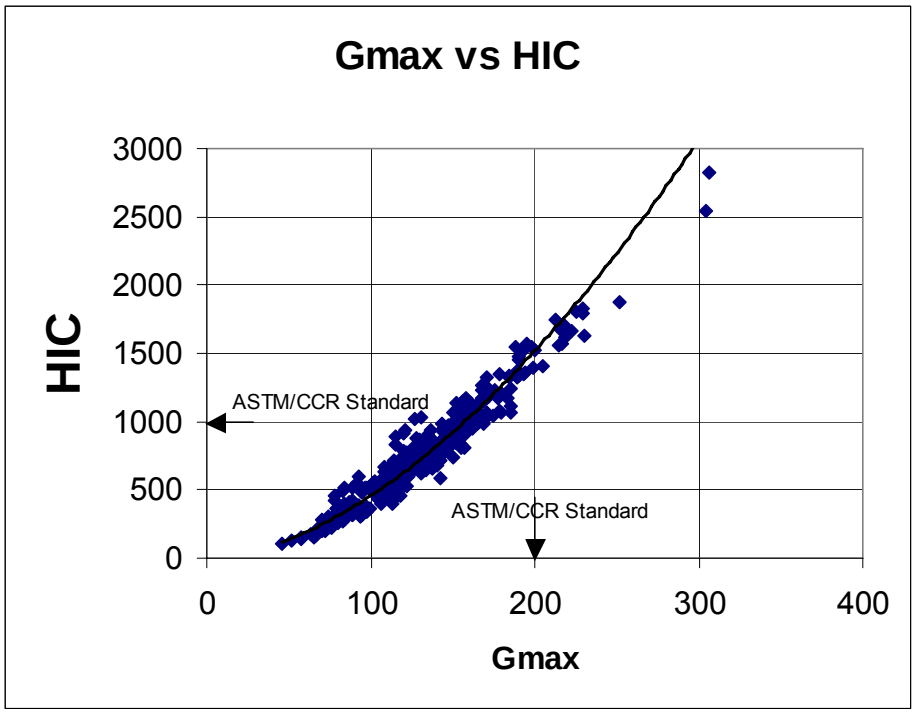


Figure 3: HIC as a function of G_{max}.

Data points represent 368 individual drop locations in 32 rubberized playground surfaces (26 pour-in-place, 4 tiles, 2 shredded rubber). The trend line was fitted by regression analysis according to a power function. ASTM/CCR standards: $G_{max} \leq 200$ and HIC $\leq$ 1000.

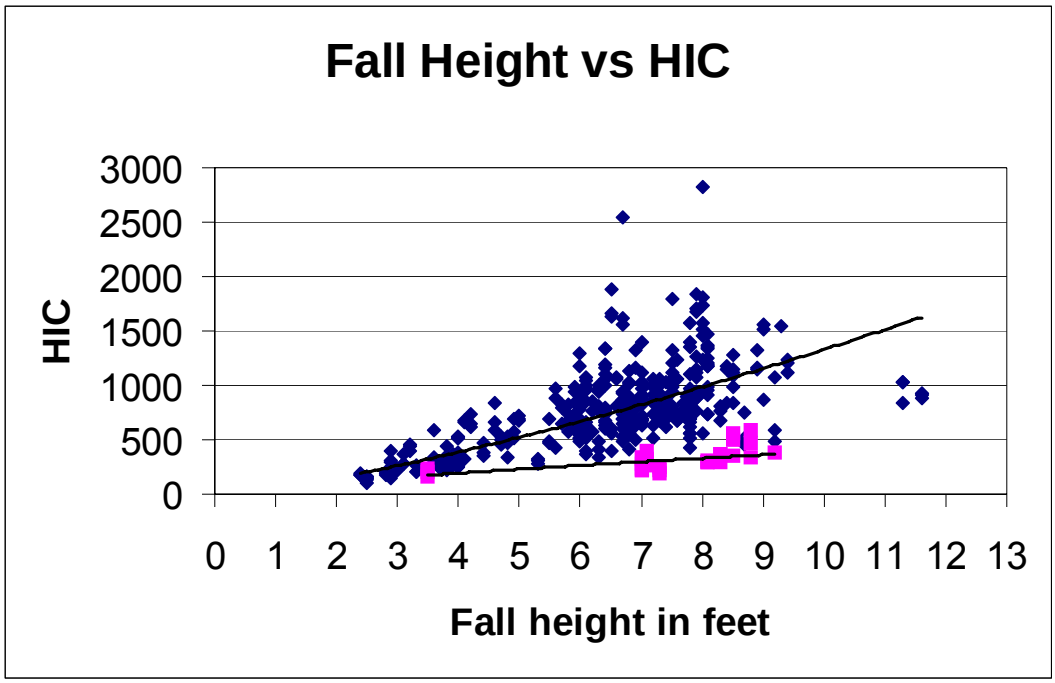


Figure 4: HIC as a function of playground structure fall height.

Data points represent individual drop locations in 32 rubberized playgrounds (diamonds) and 5 playgrounds with surfaces of wood chips/engineered wood fiber (squares). Trend lines were fitted by regression analysis according to power functions.

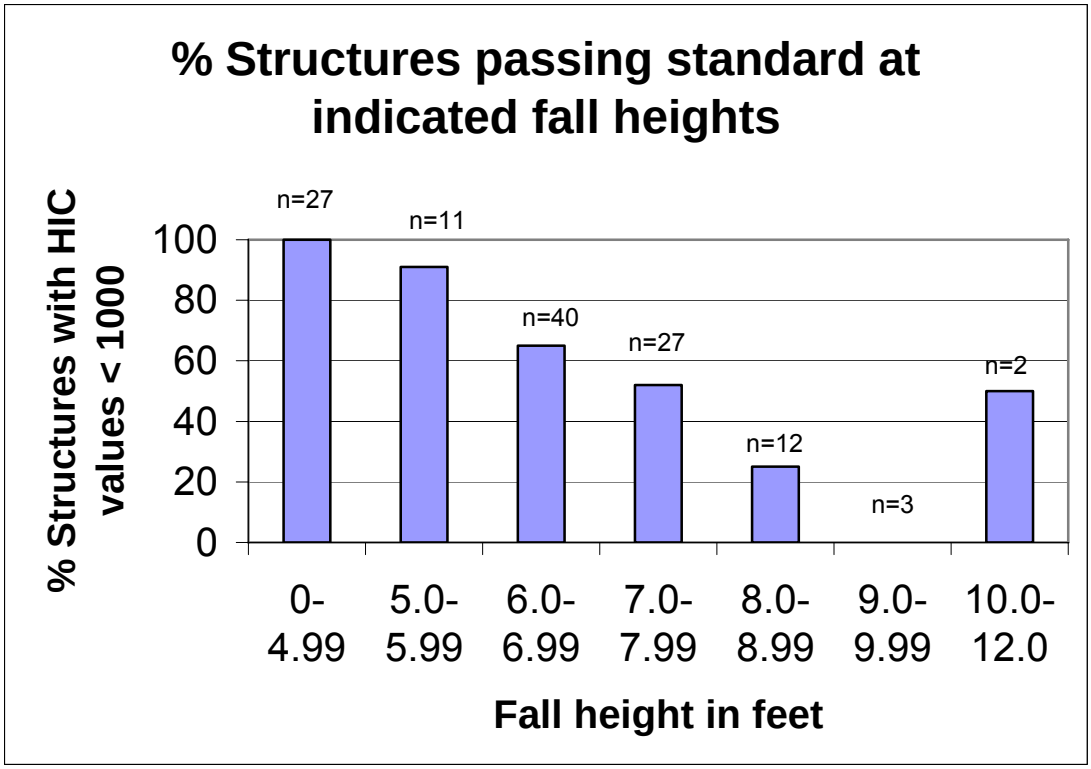


Figure 5: Percentages of playground structures on rubberized surfaces passing the HIC standard at increasing fall height.

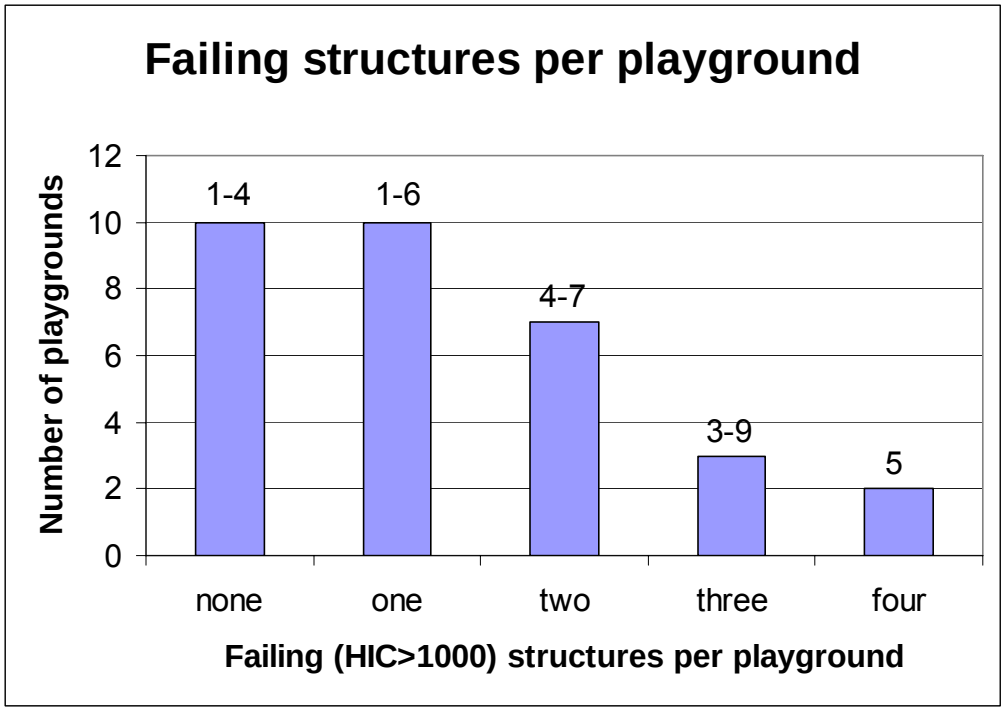


Figure 6: Numbers of failing structures (HIC > 1000) per rubberized playground surface.

A total of 131 structures in 32 playgrounds were tested. Ranges at the top of each bar indicate the numbers of structures per playground.

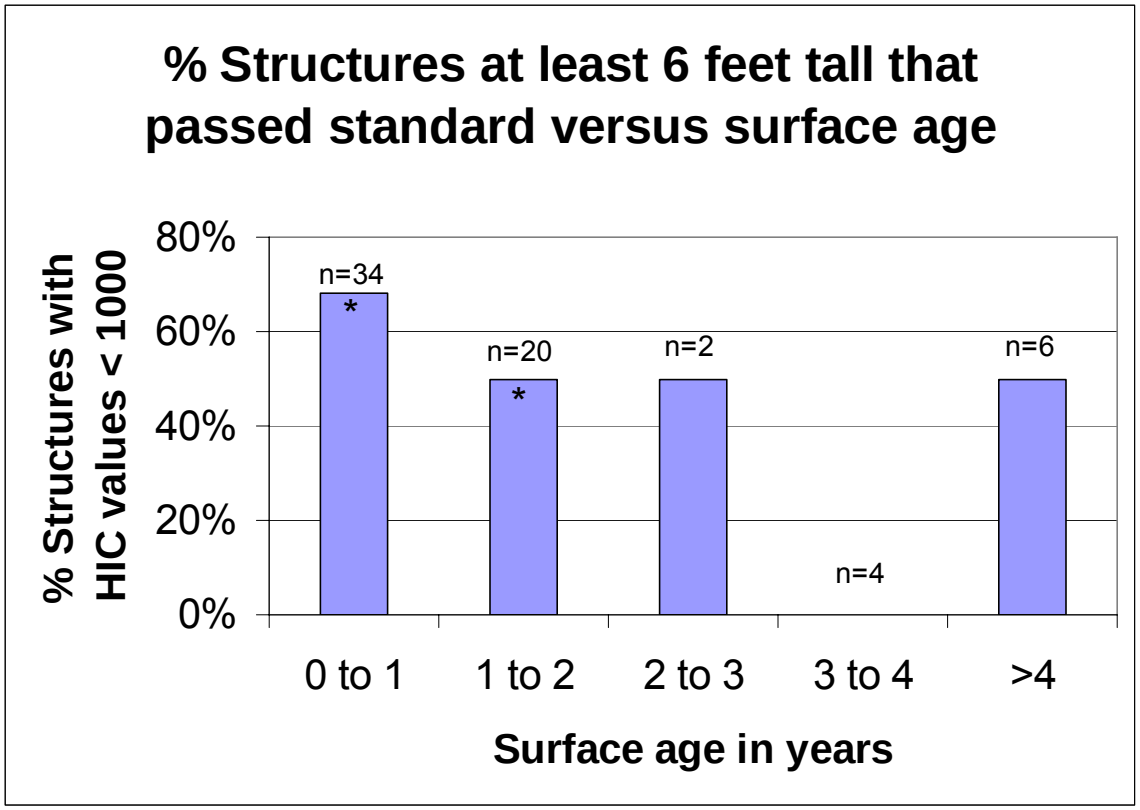


Figure 7: Percentages of playground structures with fall heights ≥ 6 feet yielding HIC values ≤ 1000 as a function of rubberized surface age.

Data from pour-in-place and tiled surfaces were included. Each n represents the total number of structures tested at the indicated surface age. Asterisks (*) indicate no significant difference between the two bars in a 2-tailed Fisher's Exact Test.

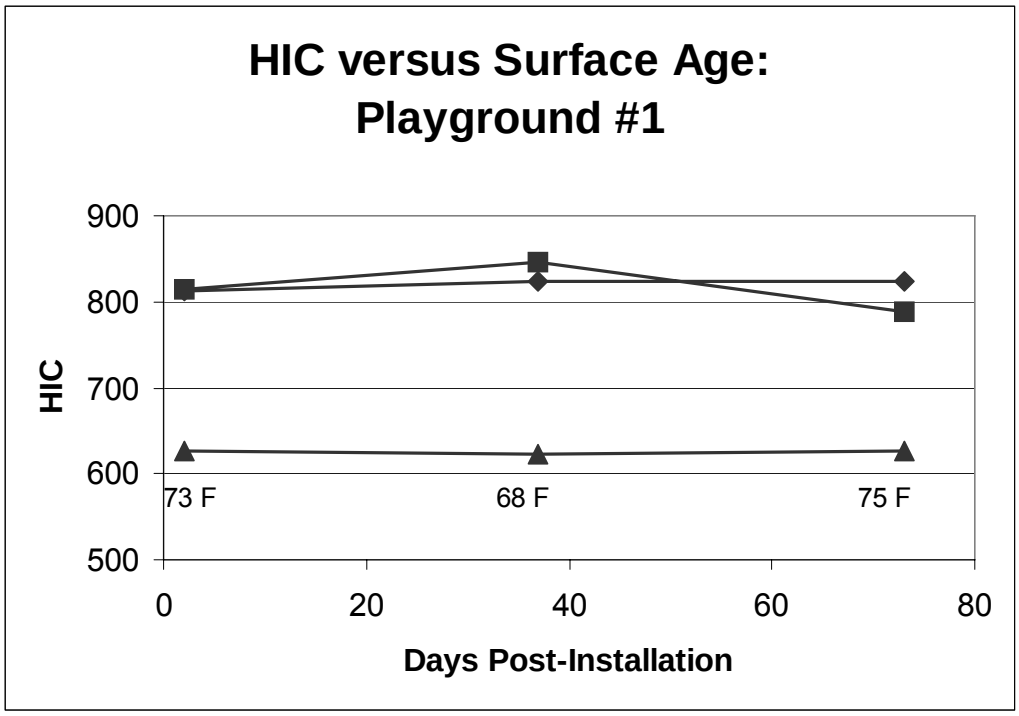


Figure 8. HIC as a function of surface age during the first two to three months following installation.

This pour-in-place playground surface consisted of a bottom layer of recycled tire rubber and a top layer of EPDM. At two days after the top layer was poured, HIC measurements were made at three locations (squares, triangles or diamonds) on the surface from a drop height of seven feet. Measurements were repeated on the indicated days at the same locations. The temperature of the air in the shade was recorded on each day as indicated on the graph.

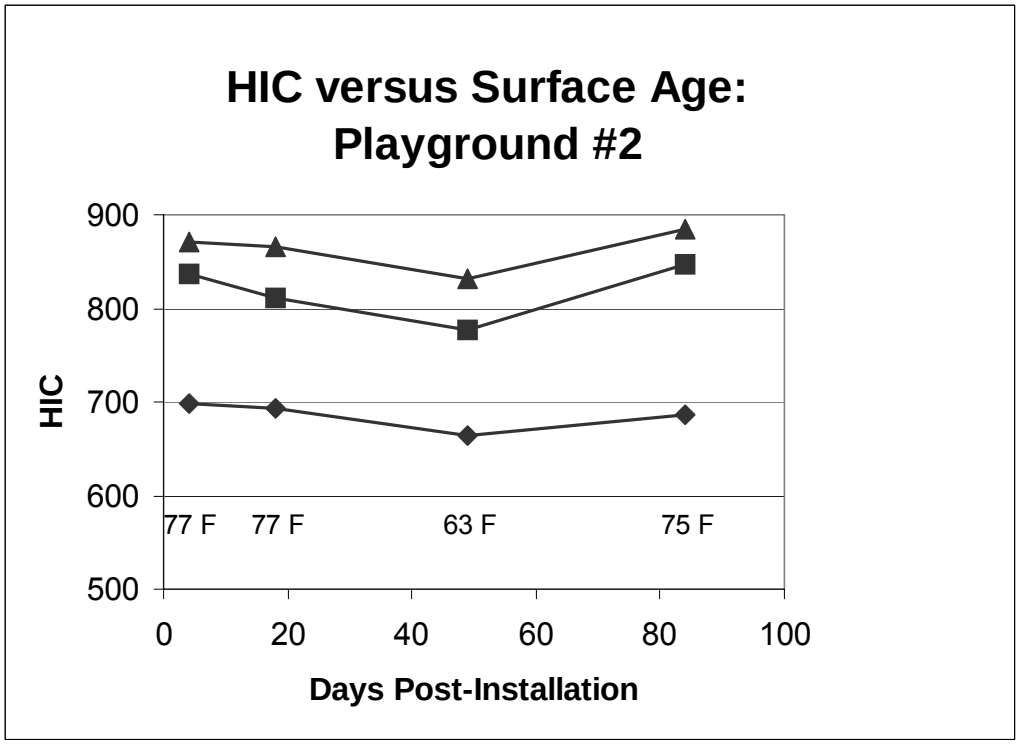


Figure 9: Same as for Figure 8, except that for this playground the first measurement day was at four days after installation of the top layer.

Three different locations on the playground were followed, represented by the squares, triangles or diamonds.

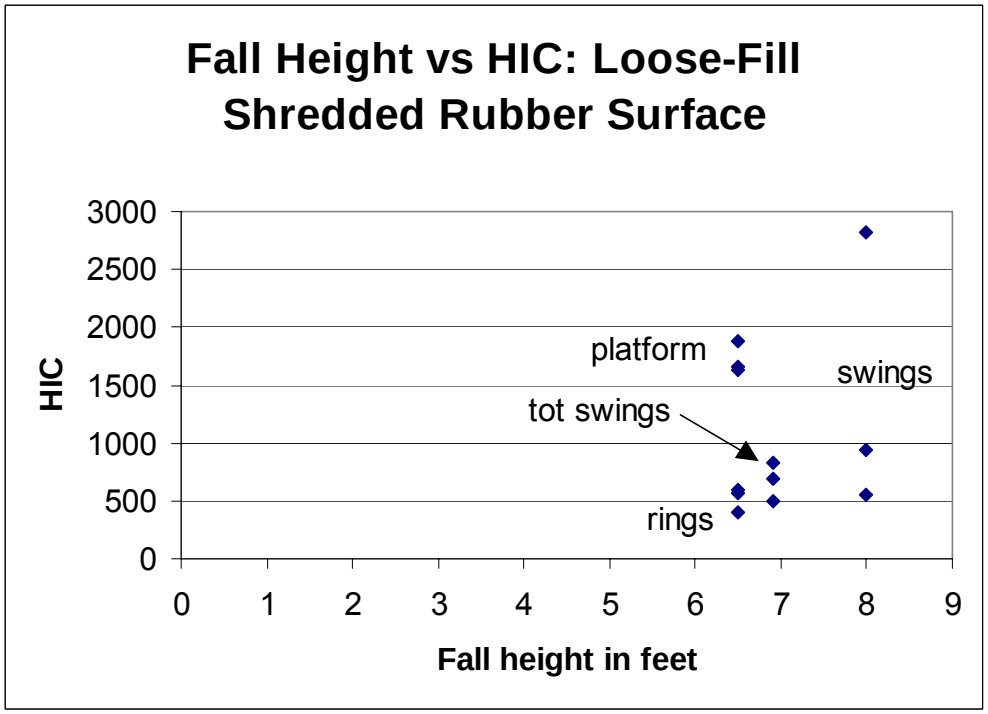


Figure 10: HIC values for four playground structures on a loose-fill surface of shredded tire rubber.

Each datum point represents the HIC value for one of three drop locations around each playground structure.

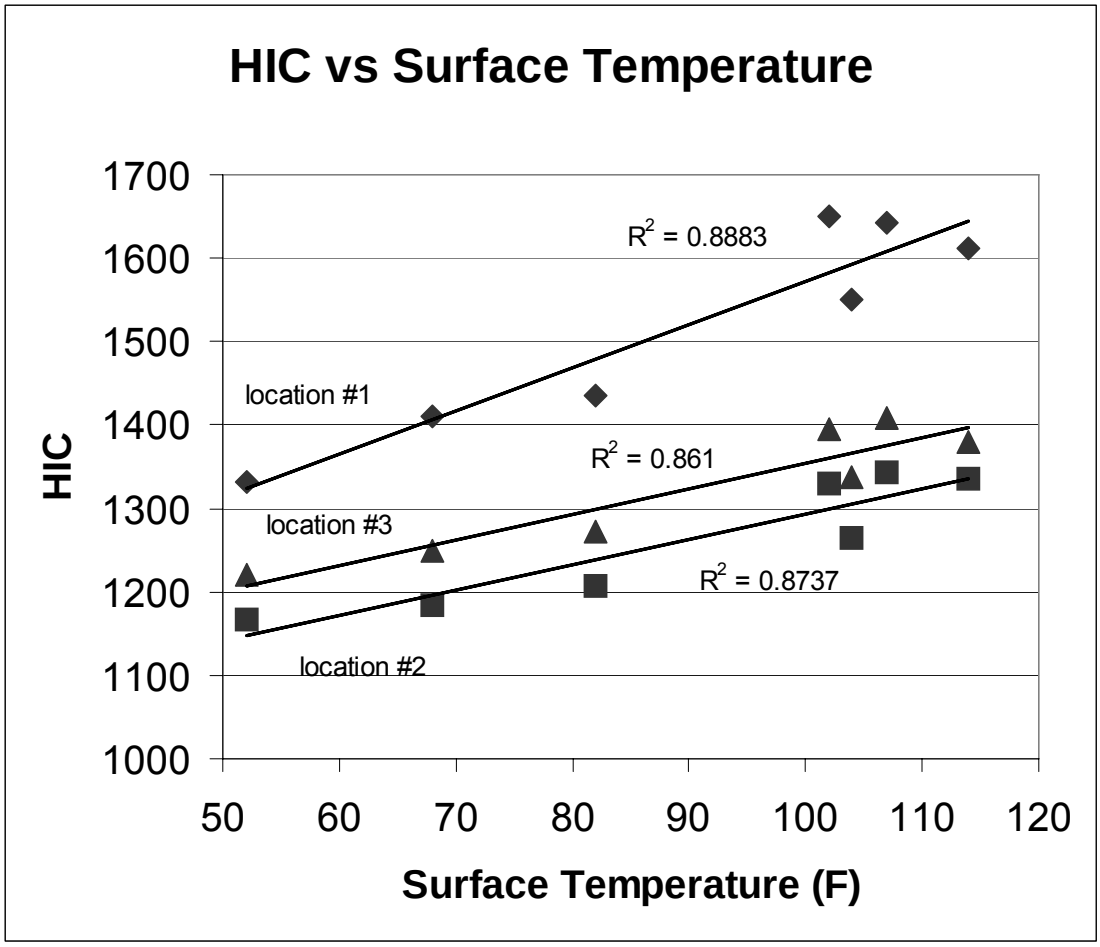


Figure 11: Temperature dependence of HIC measurements on a pour-in-place surface: cold to hot.

HIC measurements were made at three locations in a single playground. The drop height was seven feet. Measurements began at 8:00 am in the coolest part of the day, and finished at 2:00 pm during the heat of the day. Curves were fit by linear regression and correlation coefficients are also shown.

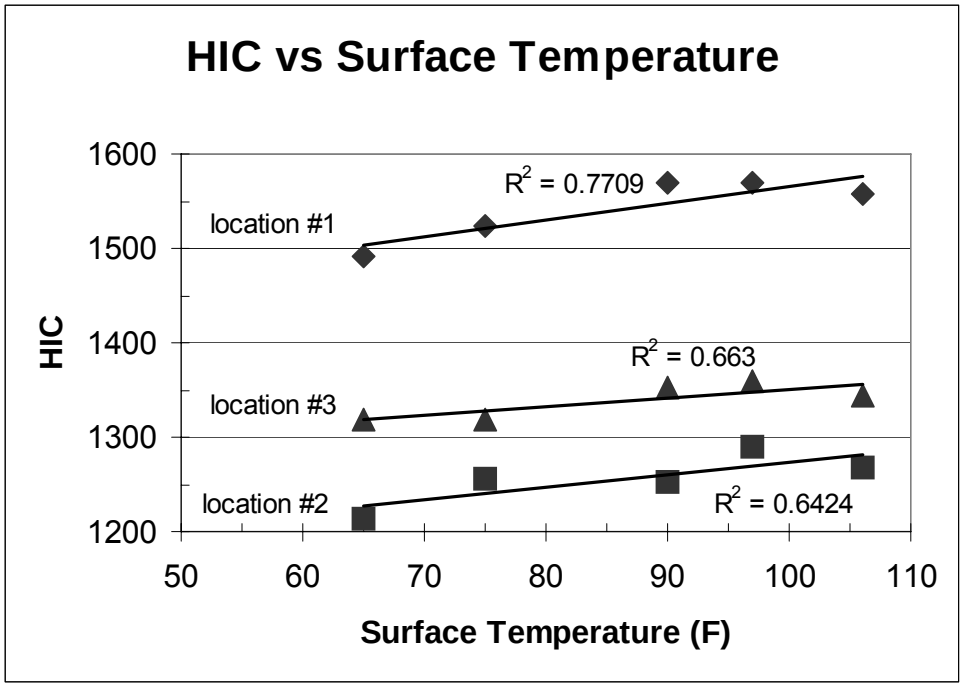


Figure 12: Temperature dependence of HIC measurements on a pour-in-place surface: hot to cold.

Same playground and protocol as for Figure 11 except that measurements began at 3:00 pm during the heat of the day and ended at sundown at 7:20 pm. Curves were fit by linear regression and correlation coefficients are also shown.

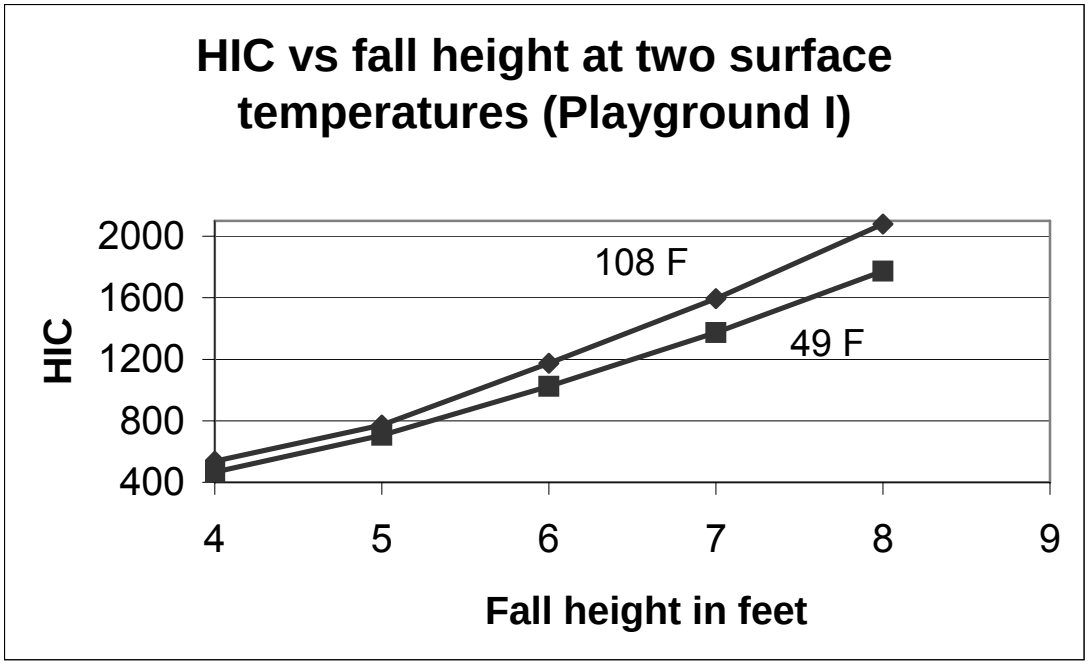


Figure 13: HIC as a function of fall height measured at two different surface temperatures: Playground I.

Drops were performed at the same location #1 shown in Figures 11 and 12. The drops at 108 degrees Fahrenheit were performed during the heat of the day at 2:00 pm, while the drops at 49 degrees Fahrenheit were performed shortly after sunrise at 7:45 am.

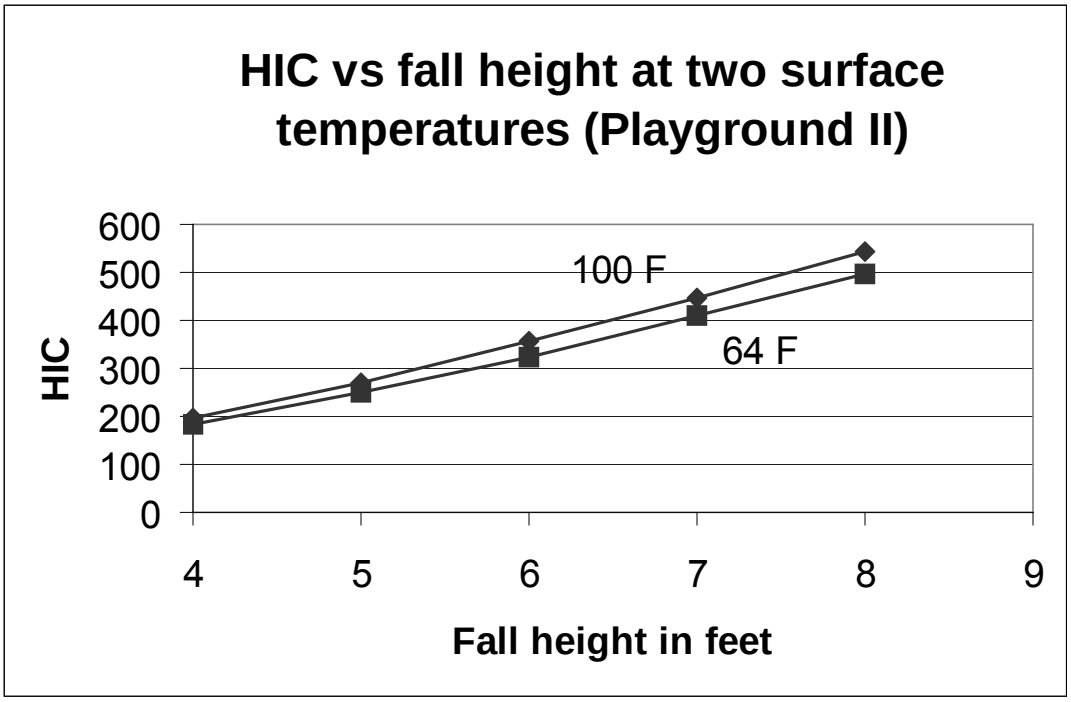


Figure 14: HIC as a function of fall height measured at two different surface temperatures: Playground II.

Drops were performed at the same location on two different days, with the surface temperature varying by 36 degrees F between.

Abbreviations

ASTM	American Society for Testing and Materials International
ATSDR	Agency for Toxic Substances and Disease Registry
C	Centigrade
CCA	Chromated Copper Arsenate
CDC	Centers for Disease Control
cm^2	square centimeters
CIWMB	California Integrated Waste Management Board
DOT	Department of Transportation
DTSC	Department of Toxic Substances Control
EPDM	ethylene propylene diene monomer
F	Fahrenheit
FCCJNC	Florida Community College at Jacksonville Nassau Center
FDA	Food and Drug Administration
g	grams
GCMS-SIM	Gas chromatography mass spec selective ion monitoring
G_{max}	maximum acceleration during impact
GRAS	Generally recognized as safe
HCA	alpha-Hexylcinnamaldehyde
HD	high density
HIC	Head impact criterion
hr	hour
IARC	International Agency for Research on Cancer
IRIS	Integrated Risk Information System
kg	kilogram (approximately 2.2 pounds)
kg-d	kilograms per day
l	liter
LD_{50}	Lethal dose 50 percent
LOAEL	Lowest observed adverse effect level
m^2	square meters
m^3	cubic meters
MADL	Maximum Allowable Dose Level
mg	milligram

ml	milliliter
mM	millimolar
MRL	Minimal Risk Level
n	number
NAS	National Academy of Sciences
ND	not detected
ng	nanogram (10^{-9} grams)
NOAEL	No observed adverse effect level
NRC	National Research Council
NSRL	No Significant Risk Level
NTP	National Toxicology Program
OEHHA	Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration
PAH	polycyclic aromatic hydrocarbon
PEL	Permissible Exposure Limit
pg	picogram (10^{-12} grams)
PHG	Public Health Goal
ppb	parts per billion
ppm	parts per million
PRG	Preliminary Remediation Goal
RDA	Recommended Daily Allowance
REL	Reference Exposure Level
RfC	Reference concentration
RfD	Reference dose
SBR	styrene butadiene rubber
SF	safety factor
SOD	superoxide dismutase
sVOC	semi-volatile organic compound
UF	uncertainty factor
µg	microgram (10^{-6} grams)
ul	microliter (10^{-6} liters)
U.S. CPSC	United States Consumer Products Safety Commission
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compound

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

An investigation of the effects of waste tires and tire rubber on soil, water, and air under various conditions or combinations of conditions

University of California, Lawrence Livermore National Laboratory and the U.S. Department of Energy

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Attachment A Scope of Work
Attachment B Initial Keyword List
Attachment C Revised Keyword List
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1.0 Introduction

This report outlines through available literature the conditions which waste tires, waste tire facilities, and waste tire projects would create adverse effects on the environment. Analysis was performed under the work-for-others contract LL-4406, signed by The Executive Director of the California Integrated Waste Management Board on June 9, 1994 and by the Department of Energy Contracting Officer on June 10, 1994. The scope of work, Attachment A, calls for an investigation of the effects of waste tires and tire rubber on soil, water, and air under various conditions or combinations of conditions. There are 4 tasks associated with this contract.

1.1 Work Scope

As performed, Tasks 1 and 2 included a literature search to investigate the effects on the environment of wastes tires as they relate to:

- acidity
- alkalinity
- ultra violet radiation
- high and low temperatures
- particle size (whole, shredded, chips, crumb, granulate)
- moisture
- contact time
- tire composition
- reaction kinetics associated with chemicals present in the environment
- rates of diffusion
- environmental partitioning of components or byproducts of components
- leaching potential
- and other environmental effects.

In addition, Task 3 was to draw conclusions from, discuss validity of, and identify gaps in compiled research. Also determined were the conditions under which tires are likely to be considered toxic, hazardous, or create adverse effects on the environment, the necessary mitigation measures to minimize or prevent these effects, and mitigation

measures for siting waste tire processing or manufacturing facilities in compliance with CEQA.

This report encompasses:

- the methodology used by DOE to develop information herein,
- the actual work performed leading to the creation of this report, and
- problems encountered during report development, and solutions used to solve those problems.

A list of references is found in the attachments, conclusions are drawn and discussed related to task 3, and recommendations for field and lab work are also addressed.

1.2 Methodology

A literature search was performed related to task 1 and task 2 simultaneously. To initiate the literature search, abstracts of waste tire literary articles were selected based on a prepared list of key words. The abstracts selected were read and the literature was selected from the abstracts that seemed most pertinent or had the most promise in providing the information needed to develop the report. Literature was photocopied or borrowed, as appropriate. Articles, papers, and texts were grouped together into categories of composition, tire manufacturing, thermal processing, and miscellaneous topics. Those that fit more than one category were grouped together as multiple topics. The literature reading was assigned to personnel based on knowledge, experience, and interest. During assigned reading, topics related to the scope of work were analyzed, excerpted, recorded and compiled. Discussions among staff were performed and concluded, report sections were outlined and organized, and the report was written.

1.3 Work Performed

On August 10, 1994, a list of words corresponding to tire issues was prepared and submitted to the Lawrence Livermore National Laboratory (LLNL) library to initiate the literature search. The list consisted of 4 key words (tires, waste tires, rubber, and styrene-

butadiene rubber) and 27 words associated directly to the scope of work in the contract. Attachment B is a copy of the word list submitted to the library.

On August 11, 1994, the library staff initiated the literature search using the word list. The number of articles from the initial search exceeded 5 million records. The list was scaled down to 3 key words (tires, waste tires, styrene-butadiene rubber) and 10 words to be associated with the key words. Attachment C is a copy of the scaled down word list submitted to the library. Using the scaled down list, the number of records was reduced to approximately 5,000. Further cuts were made by selecting titles that were English only and selecting articles that were no more than 10 years old. The total number of records came to 531.

General information concerning the 531 records were retrieved from the library and the information was formatted to show the author, journal, title, abstract, keywords, and other information that appear pertinent to the subject of interest.

On August 22, 1994 the information (e.g., abstracts, titles, keywords) from the 531 records was reviewed by LLNL and the records that appeared pertinent to the subject of interest were selected. In some instances, several abstracts (or records) covered the same information or topic. When abstracts contained similar information, the abstract that was the most detailed was selected. The remaining abstracts were set aside for future use if the need for additional information should arise. The review narrowed the selection down from 531 records to 75 records.

On August 24, 1994, the list of 75 records was submitted to the LLNL library to obtain the articles. Attachment D is a list of the records submitted to the library. The key words in Attachment C are highlighted in bold text. The list of remaining records was filed and is to be used at a later date if information from the selected abstracts is insufficient. This list is available upon request. Some of the articles from the library could not be obtained and additional articles were added based on reviews. New items that were identified during the review process of the articles were added to the list. These items were cited in the reference section of existing articles. The final bibliography in Attachment E shows those documents that were reviewed. In the review, pertinent information was recorded, analyzed and later compiled to be used in this report.

1.4 Organization of Subsequent Sections of this Report

This report is organized into sections and subsections that discuss all phases of tires as they may adversely effect the environment. Background information is discussed in these various sections as well as many of the details pertinent to effects caused by tires in the environment. The following sections discuss: (1) tire processing and manufacturing, (2) environmental and health effects based on composition and the vulcanization process, (3) recycling, reuse and disposal of waste tires, (4) environmental and health effects based on tire reuse and disposal, (5) CEQA evaluation factors, and (6) recommendations for future work.

2.0 Processing and Manufacturing of Tires

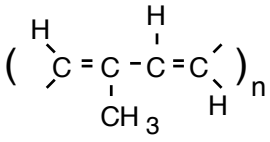
Processing and manufacturing of tires are discussed here because formulations and chemical compounds used to make tires may give insight into environmental effects of waste tires. This discussion is broken down into rubber manufacturing, tire manufacturing, and materials required to manufacture tires. The focus of much of the literature reviewed is related to tire performance, durability, and ease in manufacture.[1, 2, 3, 4, 5, 6] Some articles discussed additives and chemistry that related to the effects of the environment on the tire.[7, 8, 9, 1] A couple articles discussed composition as it relates to the value of old tires [10, 11] and fire retardation additives.[12] Others articles relating to waste tire processing, environmental effects, and physical and chemical parameters, are to be discussed in subsequent sections of this report.

2.1 Rubber Manufacturing

The rubbers used in tire manufacturing are all thermal set polymers. These polymers have various additives that serve a variety of functions. The basic units of the polymer(s) used in tires are natural rubber (NR), synthetic polyisoprene (IR), polybutadiene (BR), and presently the most commonly used styrene butadiene (SBR). The monomer units are shown in Figure 1. Note that natural rubber contains approximately 5000 monomer units[13] (330,500 grams per mole) and that tire rubber composed of the monomers of

butadiene and styrene have uniformly distributed linkages were 75 mole percent are butadiene and 25 mole percent are styrene.

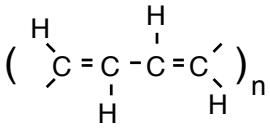
Figure 1. Monomers, Units Used in Tire Rubber



Isoprene

Molecular Weight per unit
66.104 grams per mole

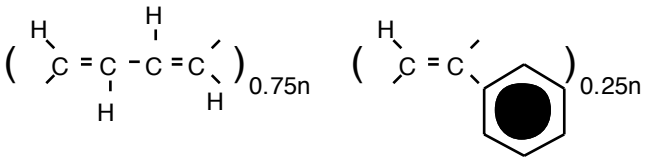
Carbon 90.85 mole %
Hydrogen 9.15 mole %



Butadiene

Molecular Weight per unit
52.076 grams per mole

Carbon 92.26 mole %
Hydrogen 7.74 mole %



Styrene-Butadiene

Molecular Weight per unit
64.59 grams per mole

Carbon 92.72 mole %
Hydrogen 7.29 mole %

2.1.1 Overview of Monomer Production

During the manufacturing process of synthetic rubbers, it is difficult to determine exact chain substitutions. In Figure 1, bonds are shown in place of hydrogen atoms at the end of the monomer unit. In almost all cases the saturated bond of one of the monomers become unsaturated during condensation (or polymerization). There are about 5 primary processes that manufacture monomers of butadiene in the United States.[13] The Haudry process (one of the more common processes) catalytically dehydrogenates butane and butylenes from light end refinery fractions. There is one primary process that is used to manufacture styrene. Styrene is manufactured from alkylated ethylene with benzene to form ethylbenzene and subsequent dehydrogenation to styrene. Catalysts for dehydrogenation are aluminum chloride, solid phosphoric acid, and silica-alumina.

There is no indication of how much residual catalyst may be found in the monomer. Aluminum chloride is fairly reactive when finely divided and should not pose environmental harm. Silica-alumina is fairly expensive, environmentally benign and should be recovered well. Phosphoric acid, if found in appreciable amounts, may cause harm to phosphate sensitive organisms but no papers were informative on the subject.

2.1.2 Overview of Added Material During Rubber Production

There are several additives that go into the monomers and/or polymerized rubbers. Activators are zinc oxide, stearic acid, litharge, magnesium oxide, amines, and amine soaps. These are added for the vulcanization process that occurs later. Primary activators for tire rubbers are zinc oxide, stearic acid, and amine soaps. These compounds reduce the time to vulcanize rubber from several hours to a few minutes. They also allow the vulcanization process to use less sulfur and still maintain a uniform vulcanite. These compounds are said to activate sulfur to form the sulfur bridge necessary for good vulcanization of the rubber.

Age resistors or antioxidants are also added to the rubber to provide for longer life without degradation. These materials protect the tire from oxygen and ozone. They are derivatives of p-phenylenediamine (PPD). These compounds stop chain destruction of the rubber by combining with the free radicals formed as intermediates during degradation of the tire rubber.

Softeners and extenders are also added. These are used to increase the workability of the rubber during preliminary processing before vulcanization. They consist of mostly petroleum oils and coal tar fractions. Peptizers or catalytic plasticizers, generally thiophenols, other thiol compounds, and disulfides can be used as well to reduce the viscosity of the rubber during preliminary processing. These compounds are usually recovered in solvent extraction processes but can be found in proprietary rubber compositions.

The major pigment in tires is carbon black. For white walls, titanium dioxide is used. Carbon black is also called a filler. In many cases, filler is known to reduce tensile strength. But for tire rubber the appeal of the black color, the resistance to staining by

other additives such as antioxidants, and its ability to improve tire rubber tensile strength and abrasion resistance, make it the ideal filler. Carbon black is by mass the largest amount of additive in tire rubber.

Carbon black is defined by adsorption properties and particle size much like carbon used to adsorb organics from water and air. Typical parameters include nitrogen sorption surface area measurements (typically 150 square meters per gram), adsorption of dibutyl phthalate (typically greater than 120 ml per 100 grams), and particle diameter (typically 40 to 80 μm). There are other additives that increase tensile strength and abrasion resistance. Second to carbon is silica but carbon black is always added with it.

2.1.3 Overview of Rubber Processing

The specific formulations of tires can be quite complex as indicated by the patents and the records of invention examined.[14, 2, 15, 4, 16, 17, 18] Formulations of SBR are categorized in terms of polymerization process (either solution or emulsion). Styrene content and oil extensions make up from 0 to 50 mole percent of the rubber. Vinyl may also be in SBR at up to 80 mole percent.

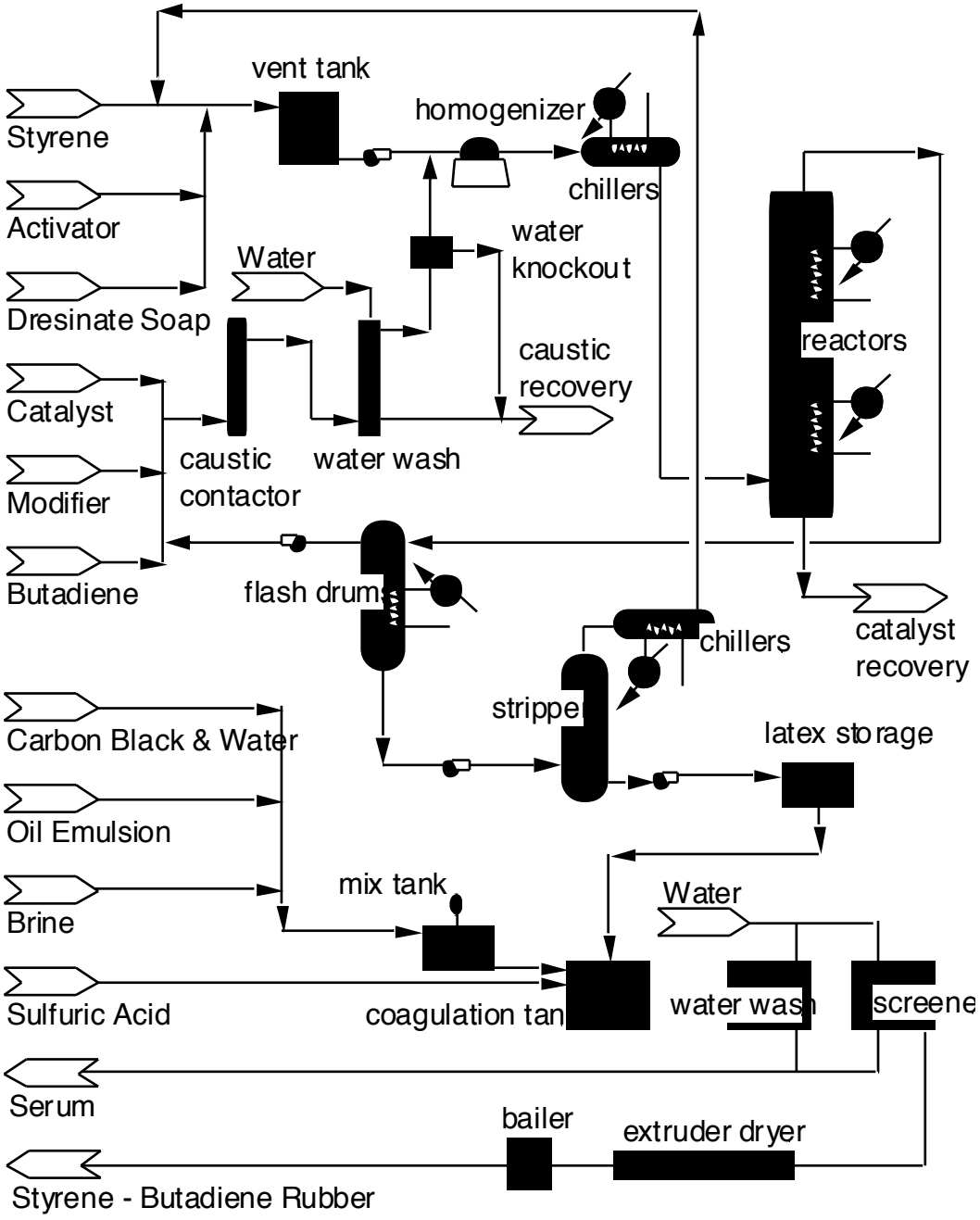
There are two general processes referred to as an emulsion process and solution process.[19] Table 1 gives one of many recipes for the emulsion process. The reaction begins with the initiation of mercaptyl free radical. This is formed by oxidizing the mercaptan with peroxide. The mercaptyl free radical then attaches itself to a monomer (either styrene or butadiene). The free radical continues to grow by attacking monomers. The active radical is terminated by attacking another free radical (bimolecular coupling) or by disproportionation (hydrogen free radical transfer). The molecular weight can usually be controlled by mercaptan type or concentration. The solution process is a more complex process involving alkyllithium based catalysis. The complexity arises from the widely varying reactivity ratios. It is difficult to get consistent molecular weights and degrees of branching.

Table 1. Emulsion Process for SBR Manufacturing

Component	weight %
Ferrous sulfate heptahydrate	0.01
p-Methane hydroperoxide	0.02
Sodium formaldehyde sulfoxylate	0.02
tert-Dodecyl mercaptan	0.05
Tetrasodiumdiaminetetraacetatate	0.10
Trisodium phosphate decahydrate	0.15
Rosin acid soap	1.31
Styrene	8.45
Aromatic oil	10.93
Butadiene	20.69
Water	58.27

A flow chart in Figure 2 depicts the process of manufacturing styrene-butadiene rubber by use of the monomers in the emulsion process. After the rubber is manufactured it is bailed and can be stored for years.

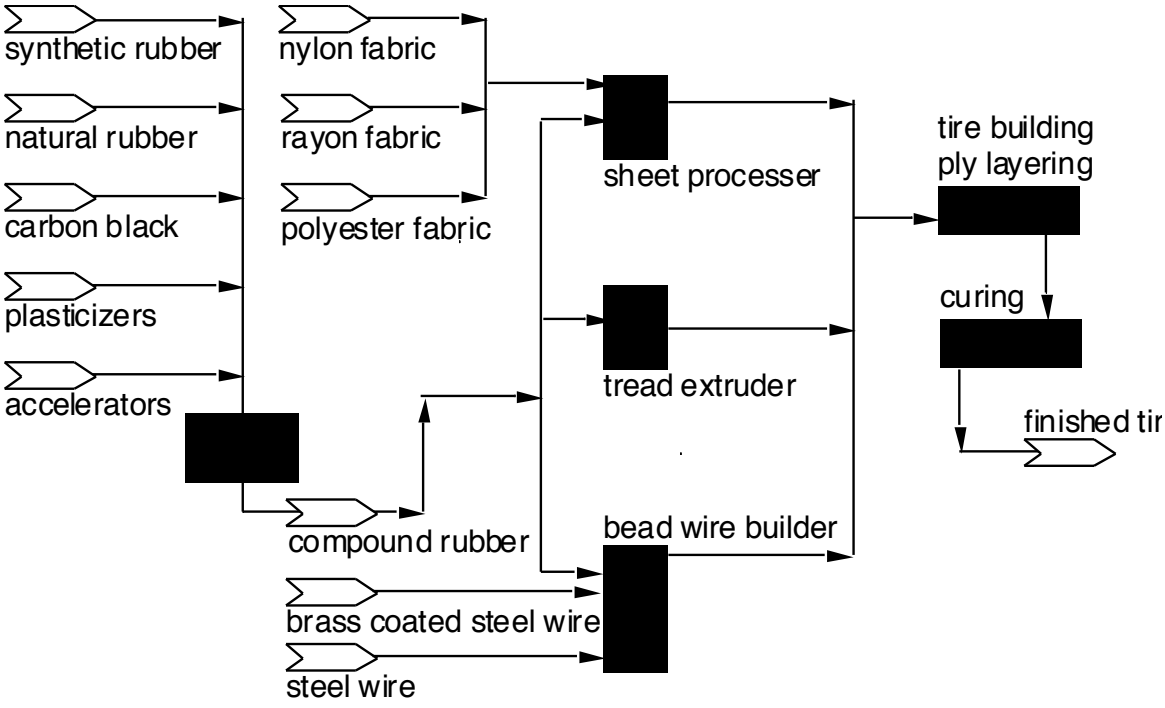
Figure 2. Styrene Butadiene Rubber Manufacturing Process



2.2 Tire Manufacturing

The tire manufacturing process includes the manufacture of rubber and placing additives in the rubber. It also includes the coating of fabrics for the radial belts and bias plies and integrating them into the rubber. Rayon, nylon, and now more commonly polyester in addition to building wire bead stock, make up the structural components of tires. The fabric with rubber, the bead stock with rubber, and the rubber tread is combined on a drum by layering (the tread is put on last). There can be as many as 40 layers of fabric and steal bead wire on a truck tire. Once the layers are put on, the tire stock is put into a mold over an inflatable steam heated tube. The tube is inflated and the mold is closed. The tire is heated and cured and the excess rubber extrudes out of weep holes in the mold. Curing times and temperatures vary widely between manufacturers and tire compositions. Typical curing times are around 20 minutes with temperatures around 160°F. The curing is were the vulcanization takes place. Figure 3 flow charts the process as a brief summary.

Figure 3. Flow Chart Summarizing Tire Manufacturing Process



2.2.1 The Vulcanization or Curing Process

The main applications of elastomers require that the polymer chains be cross-linked after being formed into a desired shape (like a tire). After cross-linking of the polymer chains, which is called curing or vulcanization, the article is elastic. It deforms under stress but returns to the shape it had when vulcanization occurred if the stress is removed. The most common method of cross-linking elastomeric polymers is through the use of sulfur. The sulfur forms a bridge between large chains of polymer, linking them together in a fixed pattern.

Tire rubber manufacture requires a variety of operations that produce and require heat, e.g., mixing, extruding, calendering, molding, etc. during which cross-linking of the polymer to an appreciable extent cannot be tolerated. The need to prevent premature cross-linking has been met by the development of delayed-action accelerators. These materials are not accelerators initially but undergo chemical reactions during processing to produce the active accelerator species in a delayed manner. The main accelerators in use exhibit some degree of delayed action. If more delay is required, a vulcanization retarder can be incorporated.

A large portion of the vulcanization accelerators produced in the United States are comprised of derivatives of 2mercaptobenzothiazole (MBT). There is a large variety of crosslinked polymers. They range from polymers having a high degree of unsaturation to those with very low levels or no unsaturation. This variety in polymers and the wide variety of vulcanite physical-property and processing requirements has resulted in the industrial use of a large number of different accelerators and curing agents.

Although a good deal of effort has been directed at understanding the chemical mechanism of sulfur cross-linking, the exact steps are in contention. The main uncertainty is whether the steps are ionic or free radical in nature. The evidence indicates that the following general steps occur:

- The accelerators which are generally organic sulfur anion or radical, attacks S_8 to form a polysulfide adduct.
- The adduct becomes attached to the polymer chain through sulfur as a pendant polysulfide and is capped by the accelerator.

- The cross-link forms through these pendant polysulfide groups by one of several possible mechanisms.
- The average number of sulfur atoms in the cross-link decreases as the vulcanization process continues (this decline is probably a continuation of attack on the polysulfide groups by the accelerator).

2.2.2 Cord and Fabrics, Structural Importance and Chemical Make

A tire must safely support a specified load under dynamic conditions with a minimum of power loss, overcome minor obstacles, and provide a reasonable endurance life. In addition, a tire should provide a long wear life, a smooth and quiet ride with good cornering, adequate skid resistance, and traction under various road conditions. A tire is also expected to have a pleasing appearance to complement the vehicle.

The cord and fabric of a tire provide for the tires continued structural integrity, increased wear resistance, and road grip. The rubber alone would not provide durability under conditions for which a tire is used. Excessive stress due to carrying large amounts of weight at high speeds in various weather conditions requires tires to be structurally sound. The layers of fabric made from rayon, nylon, and polyester, provide wear resistance and structural integrity. One of the most important factors in maintaining this integrity and wear resistance is the adhesion of the fabrics to the rubber. This is done by placing a steel wire bead around the circumference of both side walls of the tire. This bead is then used to tie on the fabric layers during tire building. Steel and brass coated steel may be used in addition to rayon, nylon, and polyester to form the plies. Steel is drawn and twisted in the same fashion as the fabric (yarn). The configurations of fabric and steel vary with manufacturer and make of tire.

The fabric layers or plies of reinforcing material are firmly adhered to the rubber and remain effective after the article has been subjected to repeated and varying strains in use. Thus, the tire's durability and its ability to perform under increasingly severe operating conditions is directly linked to the adhesion of the ply material to its adjacent rubber surface.

A technique for obtaining good adhesion between fabric plies and tire rubber is the dry adhesive system in which the bonding agents are mixed directly into the rubber compound. Bonding agents used in the dry adhesive system are as follows: 2.5 parts resorcinol (dihydric phenol) and 1.6 parts HEXA, 2.0 parts Bonding Agent R-6 (a resorcinol donor) and 1.0 part Bonding Agent M-3 (a methylene donor), 2.5 parts hexamethoxymethyl melamine, and 3.0 parts of the condensation product of resorcinol and formaldehyde that is deficient in formaldehyde.

Good adhesion between rubber and metal is of considerable importance in tires. The composite may include more than one compound discussed below. It is preferable to use more than one compound with different ligand groups if the metal is an alloy. Thus, if the metal is a brass-coated steel tire cord, there may be present three different compounds in each of which there is a different ligand group, particularly compounds in which the ligand groups are benzotriazole, mercaptobenzothiazole and 1,2,3-trihydroxybenzene. The compounds are used in proportions depending on the composition of the brass coating and steel. A typical mixture of compounds would be such as to provide molar 30-60 molar percent, benzotriazole ligand groups, 30-60 molar percent, mercaptobenzothiazole, and 5-30 molar percent of 1,2,3-trihydroxybenzene ligand groups totaling 100%. Other compounds used to form ligands are:

- 6(hexa-2,4-dienoylamino)-2-mercaptobenzothiazole;
- 6(undec-10-enoylamino)-2 mercaptobenzothiazole;
- 6(2,4-bis(allylamino)-s-triazin-6-ylamino)-2-mercaptobenzothiazole; and
- 6(2,4-bis(diallylamino)-s-triazine-6-ylamino)-2 mercaptobenzothiazole.

2.2.3 Descriptions of Tire Rubber Recipes

Table 2 gives a series of formulations used in tire manufacturing.[5, 4, 3] These are examples which may provide insight into the wide variety of rubber compositions used in the tire industry. It is believed that mercaptans and other additives are not included in these formulations because they are included in the rubber formulations themselves and are not itemized in Table 2. Brand and proprietary names are also called out. It is assumed that HA-oil is an aromatic oil extender, "polymer" varies. The numbers or "codes" in the carbon black descriptors in Table 2 are manufacturers' or distributors'

codes. These may be related to adsorption properties, particle size, and specific surface area as discussed earlier. Santoflex 13[20] was found to be an antiozonant (formulation unknown), and Santocure MOR is actually 2-benzothiazoyl-N-morpholinosulfide.[21] Sundex 790 may be a copolymer it was not found in our literature search but, it has a high concentration. DTPD and IPPD as well as antioxidant 6C are p-phenylenediamine derivatives. MBTS and MBS are mercaptobenzene derivatives. TMTM is tetramethylthiuram monosulfide another accelerator compound. The values in the Table 2 are mass percentages but the most common units used in the tire industry are parts per hundred of thermal set polymer (phr).

Table 2. Typical Tire Compositions[§]

Compound Name Formula 1	Mass %	Compound Name Formula 2	Mass %	Compound Name Formula 3	Mass %	Compound Name Formula 4	Mass %
Polymer	18.28%	styrene butadiene	88.89%	styrene butadiene	46.78%	natural rubber	44.70%
						butadiene rubber	11.18%
N-299 Carbon Black	10.97%			carbon black	45.59%	N-375 Carbon Black	30.73%
				aromatic oil	1.74%	HA-oil	4.47%
zinc oxide	0.55%	zinc oxide	2.67%	zinc oxide	1.40%	zinc oxide	2.79%
stearic acid	0.37%	stearic acid	1.78%	stearic acid	0.94%	stearic acid/ org. zinc salts	1.40%
Santoflex 13	0.18%	Antioxidant 6C	2.67%	Antioxidant 6C	1.40%	IPPD	0.84%
Sundex 790	69.01%					DTPD	0.84%
Santocure MOR	0.23%	wax	0.44%	wax	0.23%	antiozone wax	1.12%
MBTS	0.05%	Accelerator CZ	1.33%	Accelerator CZ	0.75%	MBS	0.34%
sulfur	0.37%	sulfur	2.22%	sulfur	1.17%	TMTM	0.07%

§ Formula 1 and Formula 2 represent two different test formula to test tire properties, Formula 3 is a passenger tire recipe and Formula 4 is a truck tire recap. Steel and fabrics generally compose less than 5% of the final tire mass.

2.3 Materials Required for Tire Production

Materials required for tire production were discussed in the preceding sections related to the production of tire rubber and the manufacture of tires. This section discusses the materials used in rubber and tire production in summary and provides some additional details related to their usage. The discussion includes descriptions of all materials and

compounds used to manufacture tires to the extent possible. This section may be used to reference materials that may partition themselves in the environment.

2.3.1 Dry Pigments

Dry pigments other than those added to rubber as vulcanizing agents or vulcanizing aids are loosely classified either as reinforcing agents or fillers. The former improve the properties of the vulcanites and the latter serve primarily as diluents. There is no general agreement among rubber technologists as to what reinforcement is, how it can be measured, or precisely where the dividing line is that distinguishes the reinforcing materials from the fillers. Many records of invention and patent disclosures discuss these materials and show a wide range of physical and chemical properties of the rubber and the tire. One statement can be made and that is most carbon black additives increase abrasion resistance and tensile strength. Reinforcement increases with a decrease in particle size. There is more disagreement with respect to the non carbon black fillers, but it is generally conceded that some reinforcement results from the use of fine-particle zinc oxides, fine precipitated calcium carbonates, calcium silicates, amorphous hydrated silicon dioxide, pure silicon dioxides, fine clays, and fine-particle magnesium carbonate.

2.3.2 Softeners and Extenders

Softeners include a wide variety of oils, tars, resins, pitches, and synthetic organic materials and are used for a number of reasons, some of them having little or no relation to softness of either the raw, uncured stock or the vulcanite. Some of these reasons are to decrease the viscosity and thereby improve the workability of the compound, to reduce mixing temperatures and power consumption, to increase tack and stickiness, to aid in the dispersion of fillers, to reduce mill and calendar shrinkage, to provide lubrication so as to aid extrusion and molding, and to modify the physical properties of the vulcanized compound. A few of these reasons are exact opposites, so it is important to be able to pick the type of softener that gives the desired effect.

Extenders are materials possessing plastic or rubber-like properties and can be used to replace a portion of the rubber, usually with a processing advantage. Both softeners and

extenders can be used simply as diluents. Thus the distinction between a softener or extender and a diluent is somewhat arbitrary. Certain materials may be used as both softeners and extenders on one hand and as extenders and diluents on the other. Extenders may be of similar makeup as the softeners described above. Scrap tire rubber can also be considered an extender.

2.3.3 Plasticizers

Chemical plasticizers like 2,2'-dibenzamidodiphenyl disulfide and activated dithiobisbenzanilide are used in very low concentrations and their effect is chemical rather than physical. The chemical plasticizers or peptizers are generally used to lower the viscosity of the uncured compound. They function in the thermomechanical and thermooxidative breakdown of rubbers as oxidation catalysts at high temperatures but as radical acceptors at low temperatures. They have little effect on vulcanite properties. The addition of certain compounding ingredients to the batch like clay, carbon black, and sulfur, stops their plasticizing action. These compounds are not used in the tire rubber but can be used in the adhesion materials and the chord for the bias plies and radial plies.

2.3.4 Activators

Activators are metal oxides and stearic acid. These materials are added to "activate" the accelerators. Presently stearic acid and zinc oxide are used exclusively. Zinc oxide does provide some reinforcement like pigments but the primary purpose of this material is to allow accelerators to act fast in vulcanizing rubber. The mechanism of how this activation occurs was not discovered in the literature. Other metals were used in the past, especially lead oxide.

2.3.5 Accelerators and Retarders

When elemental sulfur is used as the vulcanizing agent, certain auxiliary materials must also be added to obtain desirable properties. The most important of these materials is the organic accelerator. The accelerator has a profound influence on the nature of the sulfur

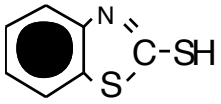
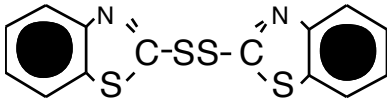
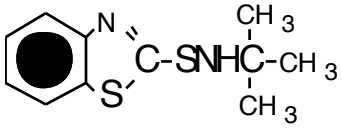
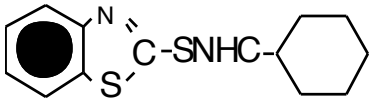
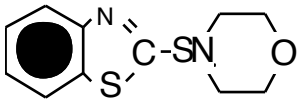
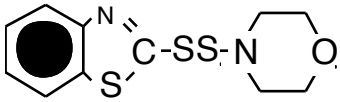
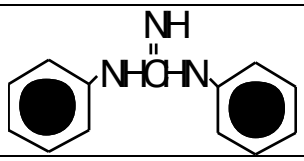
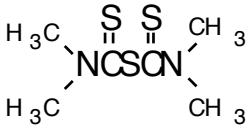
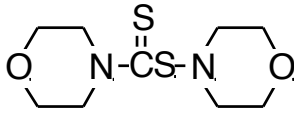
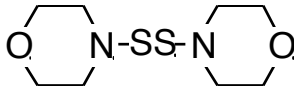
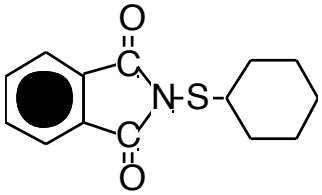
cross-link, which largely determines the thermal stability, flex-cracking, and aging resistance of the vulcanite. Because of the use of organic accelerators, scorch of rubber compounds play an important part in the preparation, storage, and further processing.

Accelerators are frequently used in combination in order to produce a faster cure than can be obtained by either material separately. The most common combinations consist of an acidic accelerator like mercaptobenzothiazole (MBT) or one that becomes acidic during vulcanization like benzothiazyl disulfide (MBTS), combined with a basic type like diphenylguanidine (DPG) or thiuram disulfide.

Occasionally retarders are used to lengthen the scorch time and to slow the cure rate of excessively fast accelerator combinations. Retarders are chemicals that prevent the premature vulcanization of rubber compounds during mixing, calendering, and other processing steps. In the absence of the processing safety provided by retarders, scorched stocks, and consequently, waste results either during the processing steps or during the storage of the fully compounded green stocks. Retarders are often called antiscorching agents, scorch inhibitors, cure retarders, or prevulcanization inhibitors. Retarders having a sulfonamide group are called prevulcanization inhibitors, whereas such conventional retarders as salicylic acid, benzoic acid, phthalic anhydride, and N-nitrosodiphenylamine (NDPA) are simply called retarders.

The main compounds used in rubber curing accelerating and retarding appear in Table 3.[22] Table 3 gives names, chemical formula, and uses. Acute oral LD_{50} ranges from 375 mg/kg for guanidine to greater than 16,000 mg/kg for MTB. These compounds contain sulfur and nitrogen with, in general, high degrees of saturation. These compounds become part of the rubber's structure and are generally not recovered.

Table 3. Accelerators, Curing Agents, Vulcanizers, and Retarding Agents

Compound	Structure	Uses
2-mercaptobenzothiazole (MBT)		primary accelerator for natural rubber
bis(2,2-benzothiazolyl) disulfide (MBTS)		primary accelerator for natural rubber (scorch safety)
N-tert-2-benzothiazolesulfenamide (TBBS)		delayed action accelerator for natural rubber
N-cyclohexyl-2-benzothiazolesulfenamide (CBS)		delayed action accelerator for natural rubber
2-(4-morpholinylthio) benzothiazole (MTB)		delayed action accelerator for natural and styrene butadiene rubber
2-(4-morpholinyldithio) benzothiazole		accelerator and sulfur donor for natural and synthetic rubbers
1,3-diphenylguanidine		secondary accelerator used with thiozoles, sulfeneamides, and thiurams
Tetramethylthiuram monosulfide (TMTM)		booster for thiozole acceleration
N-oxydiethylenethiocarbamyl-N'-oxydiethylenesulfenamide		primary accelerator for natural and synthetic rubber (scorch safety)
4,4'-dithiobismorpholine		vulcanizing agent for natural and synthetic rubber (excellent heat aging)
N-(cyclohexylthio)phthalimide (CTP)		retarder for synthetic rubber used with sulfenamides

§ Trade names are numerous, manufacturers are Akron Chemical, American Cyanamid, BF Goodrich, Monsanto, Mobay, Ouchi Shinko, Pennwalt, Uniroyal, Sanshin, Sumitomo, Vanderbilt, and Vulnax

2.3.6 Protectants

Natural rubber is different from SBR and other synthetic rubbers of the diene types in its need for protection. Latex as taken from the rubber tree contains natural antioxidants, proteins, and complex phenols, which protect it from deterioration during the coagulation and drying steps. These natural protectants are destroyed during vulcanization and thus synthetic protectant must be added to ensure an adequate service life of cured natural-rubber products. On the other hand, synthetic rubber of the diene type is quite unstable when freshly prepared and requires synthetic protectants both during the flocculation and drying of the polymers and sometimes after vulcanization. Protectants are called stabilizers prior to the vulcanization process and are called antioxidants or antiozonants after vulcanization.

Antioxidants are substances that retard oxidation by atmospheric oxygen at moderate temperatures (autoxidation). Autoxidation is a free radical chain reaction and, therefore, can be inhibited at the initiation and propagation steps. Antioxidants are used in the manufacture of all tire rubber. Autoxidation often has a long kinetic pathway. Therefore, agents that interrupt the propagation step markedly reduce the oxidation rate.

Many different commercial antioxidants have been developed for specific applications:

- Amines;
- Phenols;
- Metal salts of dithioacids; and
- Bound antioxidants.

The amine-type antioxidants (N-phenyl-N'-isopropyl-p-phenylenediamine, or CD and N-phenyl-β-naphthylamine, or PBN) usually are the most effective in rubber and are used in the largest volume. They can be classified further as ketone-amine condensation products, diaryldiamines, diarylamines, and ketone-diarylamine condensation products. Both solid and liquid products are marketed. Most are discoloring and staining and are used in applications where this property can be ignored.

Phenolic antioxidants are less discoloring than amines. They are used in applications where staining is undesirable. Because of this, these compounds are of increasing

commercial importance. Most of the newer commercial antioxidants are of this type, such as alkylated hydroquinones (e.g., 2,2,4-trimethyl-1,2-dihydroquinoline, or TMQ). In high temperature applications, polynuclear phenols generally are preferred over monophenols because of their lower sublimation rates.

Most phenolic antioxidants are readily prepared by alkylating either hydroquinones, phenols, or cresols. All aromatic amine antioxidants or antiozonants are made from aniline or substituted anilines. Diphenylamine and p-phenylenediamine likewise are derived from aniline and are the basic raw materials for other products.

Metal salts of dithioacids act as hydroperoxide decomposers and propagation inhibitors, and are used in conjunction with other antioxidants, particularly phenols for rubber, petroleum products, and plastics.

Recently, antioxidants have been developed that are copolymerized into the elastomer chain. These are called bound antioxidants. The main advantage of such a system is low antioxidant extractability in applications where the elastomer is in contact with solvents capable of extracting conventional antioxidants.

Atmospheric ozone (O_3) is, by far, the most damaging factor on rubbers. The failure of rubber tires in service is often the direct result of O_3 attack. Fatigue and mechanical failure is initiated by the surface cracks produced by O_3 oxidation.[9] Atmospheric ozone degrades polydiene rubbers by reacting directly with polymer main chain unsaturation.[23] Research on ozone induced crack growth established that the rate of ozone absorption for a typical diene polymer is linear and directly proportional to the ozone concentration, and that unstressed rubber still reacts with ozone to form oxidized surface films even though it does not show the characteristic cracking patterns.[23]

Today rubber vulcanites are protected through the use of chemical antiozonants. These protectants possess several common features:

- all effective materials react competitively and directly with ozone;
- they must migrate to the surface of the rubber to be effective;
- their presence decreases the rate of cut growth; and

- some materials such as the N,N'-dialky-p-phenylenediamines and the N-alkyl-N'-aryl-p-phenylenediamines also affect the polymer by raising the apparent critical stress.[23]

Two broad groups of additives are used commercially to inhibit ozonolysis of unsaturated elastomers. One group includes relatively unreactive, film-forming waxes. The other comprises certain reagents that react rapidly with ozone and possibly ozonolysis products. In order to be effective, waxes must quickly diffuse to the elastomer surface to form a protective film, or so-called bloom. Wax protection alone is inadequate for products, such as tires, that flex in service causing the film to break. In general, the N, N'-disubstituted p-phenylenediamines are the most effective commercial antiozonants, and continue to enjoy widespread growth, especially for tire applications. Certain dihydroquinolines, thioureas, metal dithiocarbamates, and N, N'-diaryl-substituted p-phenylenediamines, such as N, N'-diphenyl-p-phenylenediamine, also have weak antiozonant activity.

The effectiveness of antiozonants is also increased through their combined use (reactive antiozonants and blooming materials). With dual use, the amount of reactive antiozonant needed to provide adequate protection in tires is reduced. The reactive antiozonants are thought to protect the tire from direct oxidation while the waxes protect the rubber during static rest periods.[23]

PPDs with wax are much less toxic than the dibutyl analog, and the presence of the longer chain alkyl groups markedly reduces the volatility. The IPPD system maintains the high activity of the dialkyl- system, but it is quite volatile and is easily extracted from the rubber vulcanite through contact with acid rain. Today, the use of 6PPD in the United States is far greater than that of all the other phenylenediamines combined.[23]

2.3.7 Flame Retardants

Flame retardants are added to rubber as a fire prevention function. Flame retardants such as halogens, metal hydroxides, and phosphorous (or a combination of materials) are added to the rubber composition. To prevent degradation of the rubber and reduce the amount of additive required for the process, red phosphorus is used as the fire retardant in

conjunction with SBR (and other comparable rubbers) and rubber that contains a nitrile group. The nitrile group containing elastomer consist of rubber, such as, acrylonitrile-butadiene rubber (NBR) and acrylonitrile-styrene-butadiene terpolymer (ABS), that have a nitrile group content between 15-45% by weight.[12]

2.3.8 Structural Materials

Structural materials include synthetic fabrics such as rayon, nylon, and polyester which may have steel and brass coated steel integrated into them. Steel beads are also used to tie down the fabric. These materials form the plies that give the tire structural integrity. They are bonded to the rubber by adhesive systems discussed previously. Steel is bonded to rubber as ligands with mercaptobenzoylthiazole systems. Synthetic fabrics are bonded with dry systems dispersed in the rubber based on dihydric phenols and resorcinol.

3.0 Environmental and Health Effects Based on Composition and the Vulcanization Process

This sections of the report will discuss the environmental and health effects of tire compositions. It will also discuss the environmental and health effects identified with the vulcanization process when manufacturing tires. Environmental effects associated with waste tire recycling, reuse and disposal options will be discussed later in this report.

3.1 Effects Based on Composition

Various raw materials used in the manufacturing of tires have been documented to pose adverse health and environmental effects. Natural rubber alone poses a dangerous fire hazard and when heated to decomposition emits toxic fumes of SO_X.[21] Base materials used in polymer rubber production, such as butadiene and styrene, are suspected human carcinogens, and many of the polymer additives can cause systemic toxic effects. In the proceeding text, the effects of specific individual compounds associated with a tire's composition will be discussed as well as certain effects that tires may cause on the environment.

Monomers and Polymers:

Isoprene is a mild toxic by the pathway of inhalation. It also reacts with air and ozone to form dangerous peroxides. Butadiene is a confirmed carcinogen and teratogen in animals and a suspected human carcinogen. Inhalation of high concentrations of butadiene can cause unconsciousness and death. Human systemic effects of butadiene by inhalation include coughing and hallucinations. Styrene is a suspected carcinogen. It has been found to be poisonous by ingestion, inhalation, and intravenous routes. Human systemic effects of styrene include eye and olfactory irritation. All three of these monomers are dangerous fire hazards when exposed to heat, flame or oxidizers. The most stable of these compounds is styrene but still biological half-lives are small.

The styrene-butadiene polymer is an eye irritant and questionable carcinogen. This polymer, much like the monomer from which it is derived, is a dangerous fire hazard.

Antiozonants and Antioxidants:

Most of the antiozonants are phenylenediamine derivatives. The phenylenediamines are poisonous by ingestion routes. They are a skin irritants and questionable animal carcinogens. The p-isomer is more toxic and a stronger irritant than the o- and m-isomers of phenylenediamine. They are combustible when exposed to heat or flame.[21]

Studies show that concentrations of antioxidant in tires rapidly decreases between production and several months of use indicating that it breakdowns or escapes into the environment. The antioxidant, PBN (N-phenyl-b-naphthylamine), is possibly carcinogenic so others are used when possible.[24]

Aromatic amines are used in the rubber industry as inhibitors of the rubber degradation which occurs with aging through processes mainly caused by oxidation and ozonolysis.[25] Aniline is a suspected animal carcinogen and a poison. It is also a skin and severe eye irritant. Diphenylamine is a poison by ingestion, but it has not been identified as a carcinogen. When heated, diphenylamine emits highly toxic fumes of NO_X. The inhibitor, o-toluidine, is a suspected human carcinogen and confirmed animal carcinogen. It is moderately toxic by ingestion and when heated emits highly toxic fumes of NO_X.[21]

Tire Filler:

The tire filler, carbon black, is mildly toxic by ingestion, inhalation and skin contact. It is a questionable animal carcinogen, and in high concentrations it is a nuisance dust. The tiny particulates of carbon black contain some molecules of carcinogenic materials; however, the carcinogens are apparently held tightly and are not eluted by hot or cold water, gastric juices, or blood plasma.[21]

Zinc oxide is added to tire rubber at relatively high concentrations. Zinc oxide is moderately toxic to humans by ingestion. Some human systemic effects associated with the inhalation of zinc oxide are chills, fever, tightness of the chest, and coughing. When mixed with chlorinated rubber, an explosion has occurred.[21] Although not discussed in the articles of the literature search, zinc oxide will not leach out of tire rubber at concentrations that exceed Soluble Threshold Leachate concentrations under the California Assessment Manual.

Tires have been historically manufactured with appreciable amounts of lead oxide. Lead oxide was used during vulcanization processes and has been used frequently in European countries. Lead oxide is moderately toxic by ingestion and is combustible by chemical reaction with reducing agents. When heated to decomposition, lead oxide emits toxic fumes of lead.[21] Analysis of combustible waste tires shows lead at concentrations of 100 ppm and zinc at concentration of 26,000 ppm in sample tire rubber combustion products.[26]

Mercaptans can form SO_X when decomposed[21], and many can react with water to produce flammable vapors. There is no likelihood that these compounds would form with the decomposition of tires. These compounds are not environmentally stable at small molecular weights. Oxides of sulfur, however, should always remain a concern for thermal tire decomposition.

Paraffin wax is a confirmed animal carcinogen. When heated to decomposition, paraffin wax emits acrid smoke and irritating fumes.[21]

Softeners that are used in the largest concentration are pyrolytic oils. The higher the aromatic content of the oil the more easily it disperses into the rubber. Softeners were not described fully in the literature, but they are assumed to have properties similar to that of diesel and petroleum oils. Petroleum is a questionable carcinogen and a dangerous fire hazard. These materials have high aquatic toxicity and can be released into the environment at high concentrations during partial pyrolysis. The release of these oils under landfill conditions and other non-thermal conditions were not studied within the literature reviewed.

3.2 Effects of Vulcanization

Large air contaminant fractions are released during the vulcanization process. Operators working in the vulcanization areas are exposed, even though at low concentrations, to curing fumes containing not only the antidegradant introduced in rubber compounding, but also other aromatic amines which are formed probably as thermodegradation products throughout the manufacturing process. Compounds in working areas are antiozonants and decomposition products from antiozonants and accelerators. The compounds include aniline, o-toluidine, diphenylamine, 6PPD, and 7PPD.[25] Studies have indicated a low dispersion of 6PPD and 7PPD (exposures up to respectively 1 and 0.3 $\mu g/m^3$) in the vulcanized areas and higher concentrations of the other aromatic amines: up to 10 $\mu g/m^3$ of aniline and up to about 1 $\mu g/m^3$ of o-toluidine and diphenylamine. Moreover, as expected, high exposures to IPPD and 6PPD (ca. 1 mg/m^3) were found when these solid raw materials were weighed, owing to the lack of any technical prevention.[25]

Two other compounds of concern in air emissions from rubber processing plants are thioureas and the secondary alkyl nitroamines. Many thioureas and nitroamines produce cancer in animals.[27]

4.0 Recycling, Reuse and Disposal of Waste Tires

Tire recycling, reuse and disposal are discussed here to provide an overview as to the magnitude of the waste disposal problems and the various paths at which the tires enter

into the environment. Subsequent sections of this report will discuss the environmental effects associated with waste tire recycling, reuse and disposal.

4.1 Recycling and Reuse of Waste Tires

In order to prevent waste rubber and in particular discarded automobile tires from damaging the environment, it is highly desirable to recycle this material. However, the total mass quantity of tires currently recycled in a given year (not including reuse, retreading, or combustion) is less than 7% of the annual tire generation rate.[10] A majority of the markets for recycled tire products can be expanded; but even if these markets reached their full potential, the number of tires generated each year would continue to far exceed the demand for scrap and used tires. Only a small portion of the waste tires are retreaded, and a very small portion is devulcanized by tedious processes.[28] The asphalt highway construction business holds the greatest potential for the demand of scrap and used tires in the form of ground rubber.[10]

The reuse options for waste tires are significantly affected by the tire's particle size. Some of the recycling applications for tires based on particle size are shown in Table 4. Some recycling alternatives use whole tires, thus requiring no extensive processing, while other alternatives require that tires be split, punched, or shredded to make new products.

Recycling of waste rubber from tires can be carried out by grinding the tire and adding the waste rubber particles to rubber mixtures for manufacturing new products. This process, however, leads to a strong deterioration of the desired physical properties of the rubber. Yet, another method of recycling is to reclaim the waste rubber in which the network formed by vulcanization is thermally degraded. The reclaimed material can be added to rubber mixture for manufacturing new products. This process also leads to a loss of the desired physical properties of the rubber, in comparison with virgin polymers.[29]

Table 4. Alternative Applications for Waste Tires based on Particle Size[10]

Particle Size	Applications
Whole Tire:	Artificial reefs and breakwaters
	Playground equipment
	Erosion control
	Highway crash barriers
Split or Punched Tire:	Gaskets, seals, washers, shims, and insulators
	Floor mats, belts and shoe soles
	Dock bumpers
	Muffler hangers
Shredded Tire:	Lightweight road construction material
	Playground gravel substitutes
	Sludge composting
Ground Rubber:	Rubber and plastic products (e.g., molded floor mats, mud guards, carpet padding, and plastic adhesives)
	Rubber railroad crossings
	Additives for asphalt pavements

In some recycling applications, removal of the metal bead in the waste tire is not required. For example, processed waste tires (or chipped tires) can be used as a lightweight fill material without requiring the removal of the metal from the rubber chips. Normal construction machinery can successfully operate on top of fill material consisting of tire chips provided that precautions are taken to prevent exposed wires at the edge of the chips from puncturing the tires of the machinery.[30] Other recycling applications require the removal of the steel bead. Splitting of tires requires removal of the steel bead prior to stamping or punching. Manufacturing of crumb rubber and the use of tire chips as a substitute for playground gravel requires the tires to be shredded and magnetic separators be used to remove all steel fragments. In addition to removal of steel beads, several recycling applications require other modifications to the tire, such as, removal of polyester fragments and colorizing the rubber material.[10]

Tires can be used as fuel alternatives. Combustion facilities currently using tires as fuel include: (1) power plants; (2) tire manufacturing plants; (3) cement kilns; (4) pulp and paper plants; and (5) small package steam generators.[10] In addition to fuel alternatives, pyrolysis of tires can be performed to chemically alter the materials of the tire or to derive various products such as carbon black. Burning tires whole obviates the need for expensive shredding operations. However, the burning of whole tires requires a relatively sophisticated high temperature combustion facility to keep emissions within environmental limits. It also requires equipment capable of handling the whole tires and feeding them into the combustion chamber. Most plants currently burning tires for fuel, excluding cement kilns, do not have the capability to burn whole tires. Instead the tires are shredded into chunks ranging from 2 to 6 inches in size prior to being introduced as a fuel. Typically, rubber chunks contain steel wire from the tire beads and steel belts. If the combustion process requires removal of the wire, the cost for combustion is increased. The wire removal from rubber chunks is an expensive process, which requires fine shredding and the use of powerful magnets.[10]

4.2 Disposal of Waste Tires

Tires that are not recycled or reused are usually shredded and disposed of in landfills, or stockpiled whole.[10] Stockpiling whole tires creates two significant hazards: mosquitoes and fires. Due to their shape and impermeability, tires managed in stockpiles tend to hold water for long periods of time. This stagnant water provides an ideal breeding ground for mosquitoes and sites for mosquito larvae development. Tire stockpiling has contributed to the introduction of non-native mosquito species as used tires are imported from other countries to the United States. These new mosquito species are often more difficult to control and spread more disease.[10]

Stockpiling whole tires also poses a significant fire hazard. These fires, some of which may be started intentionally, generate large amounts of heat and smoke and are difficult to extinguish. This is due to the fact that: (1) tires, in general, have more heat energy by weight than does coal (37,600 kJ/kg vs. 27,200 kJ/kg)[31]; and (2) there is a 75% void space present in a whole waste tire, which makes it difficult to either quench the fire with water or cut off the oxygen supply.[30] Some tire fires have burned continuously for months, such as the 9-month Rhinehart tire fire in Winchester, VA.[31, 6] In addition, tire

fires cause damage to surrounding areas. For example, in New Jersey a tire blaze beneath an elevated highway melted the asphalt.[6]

The landfilling of whole tires consume a large volume of landfill space because the tires are relatively incompressible and 75% of the space a tire occupies is void.[30, 10] This void space provides potential sites for gas collection and harboring of rodents. In landfills, waste tires capture explosive methane gas and "float" upward sometimes shooting to the surface with tremendous force and piercing the landfill cover.[6, 10] The primary advantage to landfilling whole tires is that processing costs are avoided. However, landfills' bad experience with whole scrap tires has led to extremely high tipping fees or total bans on whole tires.[10]

Shredding or splitting of tires is becoming increasingly common as part of the disposal process.[30, 10] Shredded tires stored above ground pose less of a hazard than do whole tires. Shredding eliminates the buoyancy problem and makes tires into a material that can easily be landfilled. Shredding can reduce a tire's volume up to 75%. This volume reduction can also reduce transportation costs because fewer trips are required and maximum hauling weights may be achieved more easily.[10] The main disadvantage of shredding waste tires before landfilling is that an extra processing step is required.[10]

5.0 Environmental and Health Effects Based on Tire Reuse and Disposal

This section of the report will discuss the environmental effects associated with waste tire recycling, reuse and disposal options. The report will identify potential hazards and environmental effects with combusting, pyrolyzing, and irradiating tires during the recycling and reuse activities. Further discussions will identify the environmental effects as a result of disposing of tires. Such disposal topics will include exposing tires to aqueous media, degradation of tires in air, and open burning of tires.

5.1 Combustion of Tires in Cement Kilns

The high heating value of tires (approximately 14,000 BTU/lb) make waste tires an effective supplemental fuel for cement kilns. Waste tires supplement coal and/or other

fuels in the cement kiln heating process. Tire derived fuels are consistent fuels. They are constructed within a narrow range of materials and have low moisture levels. However, tires can not exceed 30% of the kiln fuel without adversely altering the chemistry of the cement's curing process.[6]

The supply of tire-derived fuel for cement kilns is broken into two general categories: whole and processed. The basic advantages for using whole tires is: (1) they can be obtained at a positive expense (i.e., kiln operator's can receive a modest tip fee for accepting the whole tire); (2) the feed/weighing system is simplified (simple hooks can be used for weighing and loading the material); and (3) the acquisition process is simplified (whole tires can be picked up from the point of generation and brought directly to the kiln in a covered truck). The major difference between whole and processed tires in this process is the heating value. The less wire (bead and belt) in tire derived fuels, the higher the heating value.[33]

The high temperatures (typically around 2600°F) and long residence times inherent in the operation of cement kilns provide a sufficient disposal technique for waste tires with limited emissions. The solid ash constituents from the combustion of tires (i.e., the steel from the tire beads and belts) are absorbed and used by the cement kiln product. Normally iron ore is added to the cement operation. Since tires already contain iron from the beads and steel belts, the addition of iron ore is no longer required.[32]

The Scrap Tire Management Council reviewed four air emission reports concerning waste tires that fuel cement kilns. In general, test results have shown that tire derived fuels have no additional adverse effect on emissions when compared to coal. In fact, test results indicate a net reduction of SO_X, NO_X and particulate matter. Many technical considerations under the Clean Air Act that effect tire fuel industries have yet to be determined. Testing protocols and emissions standards have not been developed for all the listed potential emissions.[33]

5.2 Pyrolysis of Waste Tires

Pyrolysis is the process of thermally degrading a substance into smaller, less complex molecules. Pyrolysis is also known as destructive distillation, thermal depolymerization,

thermal cracking, coking, and carbonization.[10] High-molecular-weight substances cannot be purified by physical processes such as distillation, extraction, or crystallization; they can be recycled only by pyrolyzing the macromolecules into smaller fragments.[34]

Pyrolysis of scrap waste tires is complicated because rubbers are poor thermal conductors and the degradation of macromolecules requires considerable amounts of energy. The most common method of pyrolysis is a rotary kiln where the waste must reside in the kiln for 20 minutes or more. The large temperature gradients inside the rotary kiln results in a diverse set of products. To reduce the number of components produced, the pyrolyzing unit should have excellent heat and mass transfer properties and maintain a constant temperature throughout the chamber.

Pyrolysis produces three principal products: pyrolytic char, oil, and gas. The quality and quantity of these products depend upon the reactor temperature and design. Table 5 shows the approximate product distribution as a function of pyrolysis reactor temperature. Table 6 shows the range of composition and properties of the product. Char is a fine particulate composed of carbon black, ash, clay fillers, sulfur, zinc oxide, calcium and magnesium carbonates, and silicates.[10] Other char by-products of pyrolysis may include steel (from steel-belted radial tires), rayon, cotton, or nylon fibers from tire cords. Pyrolytic oils consists of heavy oils (hydrocarbon molecules with 8 or more carbons), light oils (hydrocarbon molecules with 3-7 carbons), benzene and toluene.[10] Pyrolytic gases are typically composed of paraffins and olefins with carbon numbers from one to five.[10] Table 7 shows the chemical composition of pyrolytic gas.[10] Pyrolytic gas also contains non-condensed light oils. The amount of light oils is approximately 2% of the total pyrolytic gas volume. Table 8 shows the chemical composition of light oil condensed from pyrolytic gas at 0°C.[10]

Table 5. Product Distribution as a Function of Pyrolysis Reactor Temperature[10]

Reactor Temperature (°C)	Gas, %	Oil, %	Char, %
500	6	42	52
600	10	50	40
700	15	47	38
800	31	40	29

Table 6. Products of Waste Tire Pyrolysis[35]

Product	Composition	Properties
Gas	Hydrocarbon mixture, low sulfur content	Calorific value 19-45 MJ m^{-3} (500-1,200 Btu ft^{-3})
Oil	Contains less than 1% sulfur	Calorific value 42 MJ kg^{-3} (18,000 Btu lb^{-3})
Char (Solid)	Contains 2-3% sulfur and approx. 4-5% zinc	Calorific value 28-33 MJ kg^{-3} (12,000-14,000 Btu lb^{-3})

Table 7. Chromatographic Analysis of Pyrolytic Gas from Shredded Automobile Tires with Bead Wire[10]

Constituent	Volume %
Hydrogen	47.83
Methane	29.62
Ethane	18.52
Propane	5.70
Propylene	8.82
Isobutylene	0.73
Isobutane	0.34
Butane	0.23
Butene-1	0.14
trans-Butene-2	0.07
iso-Butene-2	trace
Pentane	not detected
1,3-Butadiene	not detected

Table 8. Chromatographic Analysis of Light Oil Condensed from Pyrolytic Gas at 0ºC[10]

Constituent	Volume %
Toluene	11.05
Benzene	8.83
1-Hexene	5.85
Hexane	4.07
8-Methyl-8-Butene*	3.55
trans and cis-8-Hexene	3.42
Styrene	3.03
Ethyl Benzene	3.33
Xylene	4.18
3,3-Dimethyl-1-Butene	1.11
8-Methyl Butane*	1.04
2,8-Dimethyl Butane	1.04
8-Methyl-1,3-Butadiene*	1.85
Cyclopentane	1.48
Other	46.17

* **Note:** Constituent chemical name *may* be erroneous. Reference 10 was verified, but allegedly this chemical formation cannot exist.

Table 9. Emission Estimates from Pyrolysis Facility, Conrad Industries[10]

	Concentration ($\mu g/m^3$)	Emission Rate[b] (lbs per MMBtu)
Particulate	2,500	1×10^{-4}
Particulate Matter associated with metals		
Aluminum	1.51	6.7×10^{-8}
Chromium	0.82	3.7×10^{-8}
Iron	9.89	43.9×10^{-8}
Magnesium	0.45	2.0×10^{-8}
Manganese	0.09	0.4×10^{-8}
Mercury	0.05	0.2×10^{-8}
Nickel	2.95	13.1×10^{-8}
Potassium	1.84	8.2×10^{-8}
Sodium	18.62	82.7×10^{-8}
Zinc	0.65	2.9×10^{-8}
Semi-Volatile Organic Compounds		
Bis-(2-ethy-hexyl)phthalate	10.2	45.3×10^{-8}
Butyl Benzyl-phthalate	1.7	7.5×10^{-8}
Di-n-butyl-phthalate	0.9	4.0×10^{-8}
Naphthalene	2.87	12.7×10^{-8}
Phenol	1.4	6.2×10^{-8}
Volatile Organic Compounds		
Benzene	20.2	c
Ethylbenzene	24.1	c
Toluene	30.8	c
Xylenes	16.2	c
Sulfur Dioxide	310,500	7.7×10^{-2}
Nitrogen Oxides	210,000	9.7×10^{-3}

a These emission estimates reflect the composition of pyrolytic gas, which is either burned in the process as fuel or (for the excess pyrolytic gas) vented to the facility's flare. These estimates do not reflect atmospheric emissions.

b These emission rates were calculated by taking the average concentrations reported for the compound and multiplying it by the average flow rate for the test runs. An energy input value of 31 MMBtu was used to calculate lbs/MMBtu.

c Flow rates were not reported. Thus, pounds of emissions per hour could not be calculated.

Pyrolytic units are expected to have minimal air pollution impacts because most of the pyrolytic gas generated in the pyrolysis process is burned as fuel. Additional pyrolytic gas may be vented to a flare system. Assuming complete combustion, the decomposition products of the pyrolytic gas are water, carbon dioxide, carbon monoxide, sulfur dioxide, and nitrogen oxides. Table 9 shows an estimate of the emissions from a pyrolysis facility. The estimates do not reflect atmospheric emissions.

Emissions of volatile organic compounds (VOCs) and particulates are from fugitive sources. VOC fugitive emissions occur from leaks due to worn or loose packing around pump shafts and valve stems, from loose pipe connections (flanges), compressors, storage tanks, and open drains. VOC fugitive emissions can be significantly reduced by specifying components (e.g., pumps, valves, and compressors) specifically designed to minimize fugitive emissions. Fugitive emissions of particulate occur during the handling and processing of char. Operations such as screening, grinding and processing cause particulate matter (PM_{10}) emissions and can be controlled with dust collectors and baghouses. Fugitive emissions can also be reduced by training operators and mechanics in ways to reduce fugitive emissions, good supervision, and good maintenance practices.[10] Quantitative estimates of fugitive emissions were not available.

5.3 Irradiation of Waste Tires

When exposing waste tires to microwaves in a microwave oven, copious amounts of gray gas are produced by the heating action on the tires. The composition of the gases generated during the irradiation process was not identified in the literature. The gases generated in the oven must be removed and sent to a cleaning/scrubber apparatus. After irradiating the tire, the tire can be compressed using hydraulic press into a fine black powder having a particle size of talcum powder. The metal strips contained in the tire can be recovered intact.[36]

5.4 Environmental Effects of Tires and Tire Rubber as It Relates to Aqueous Media and Leaching

High levels of zinc and cadmium were detected in the Rhine river near Bonn and Strasbourg, Germany in 1988. The major source of the aqueous contamination was attributed to automobile tires that served as a source of fuel for the German cement industry. The river received the metals through air deposition from the burning of tires and storm water runoff from roads which accumulated the metals through tire wear. However, the conclusion that tires are the source of the cadmium contamination is weak. Zinc oxide is understood to be used as an activator additive for tires in large quantities. Cadmium is not a specific additive, but zinc ore contains as much as 1% cadmium.[37] Thus, the cadmium impurity in the tire could range from 4 to 200 ppm depending on the zinc ore impurity concentration (from about 0.1% and 1%), and the amount of zinc oxide used in the rubber composition (from about 0.5% to about 3%). Metal testing performed on tires and tire chips show very little cadmium; so the validity that tires are the major contributor to significantly high levels of cadmium in the Rhine river is questionable.

Once released to the environment, metals ions associated with a tire's composition are relatively mobile and can migrate to ground and surface waters through soil leaching and runoff. But in most cases, the concentrations of metals that leached from tires and tire chips are very minute. Consequently, the impact of metals on the environment from tire leaching is relative small. Metals leached from tire stockpiles have been studied and analyzed and the results appear below in Table 10. Metals and metal oxides recovered from the thermal oxidation of tires have a higher potential to impact the environment and should be recovered or stabilized.

Table 10. Trace Metals from Waste Tire Stockpile Leachate

Metal Constituent§	Concentration (ppm)
Aluminum	300 to 700
Antimony	.015
Arsenic	not found
Barium	not found
Beryllium	.0009
Cadmium	.015
Chromium	100
Cobalt	100 to 300
Copper	not found
Indium	not found
Manganese	not found
Mercury	.009
Molybdenum	1 to 500
Nickel	not found
Selenium	150
Tellurium	not found
Thallium	not found
Tin	.01
Tungsten	not found
Uranium	.04
Vanadium	.009 to 1
Zinc	15000

§ Arsenic, Barium, Copper, Indium, Manganese, Nickel, Tellurium, Thallium, and Tungsten are found in raw coal. Aluminum, Cobalt, Selenium, and Zinc were metals that exist higher in tires that in coal, molybdenum values fell within the range of coal concentrations, other metals listed fall below coal values.

A study of the leaching of tire rubber from waste piles was published in 1992 by the U.S. Department of Commerce, National Technical Information Service. The study included the construction of various waste piles (or embankments) at the Dane County land fill in Madison, Wisconsin. The embankments were constructed with varying amounts of earth and tires. One such embankment contained 50% tire chips and 50% sand in alternating 1 foot lifts. The embankment was 6 feet high with an apex area of approximately 2,800 ft^2 and a base area of 7,200 ft^2. Two lysimeters were placed in the centers of the

embankment at 30 feet and 90 feet in an overall fill length of about 180 feet. A geotextile cap was placed on the top of the embankment. Extraction Procedure (EP) toxicity tests were conducted on collected samples. The test results showed that the concentrations of hazardous constituents detected in the samples did not exceed the concentration values necessary to be defined as hazardous waste. In fact, manganese was the only analyte which the study indicated as an abnormally high concentration. Table 11 shows water quality tests extracted from the most central lysimeter.

Table 11. Lysimeter Readings From A Tire Embankment

Analyte	Value in 1990	Value in 1991
pH	7.7	7.7
Alkalinity (mg/l)	533	705
Barium (µg/l)	210	350
BOD (mg/l)	14	70
Calcium (mg/l)	170	340
Chloride (mg/l)	400	1400
COD (mg/l)	170	560
Conductivity (µohm/µm)	-	5150
Iron (mg/l)	0.05	0.7
lead (µg/l)	<3	22
Magnesium (mg/l)	150	390
Manganese (µg/l)	270	3200
Sodium (mg/l)	230	200
Sulfate (mg/l)	140	450
Total Solids (mg/l)	2000	4630
Zinc (µg/l)	46	540
Hardness (mg/l)	1100	2500

There is evidence that antioxidants leach from tires. Certain PPD (phenyl phenylenediamine) type antioxidants are leached by water from the surface of rubber vulcanite. Monsanto observed that surface concentrations of IPPD in vulcanite were substantially reduced when exposed to running water. A complete loss of IPPD occurred from SBR vulcanite in water at 85°C in 30 days.[8] Losses of antioxidants and antiozonants were reported to be as high as 90% during monsoon seasons where tires

were used; but, there was not evidence of controlled experimentation.[24] The amount of antioxidant lost due to water leaching is dependent on the molecular weight of the PPD.[8] An increase in the molecular weight of an antioxidant decreases the loss of antioxidant.

The loss of antiozonant activity has been observed more in water of lower pH.[8] This is due to the fact that the solubility of antiozonants in water increased as the pH of the water was lowered. Another study suspended thin test probes of NR vulcanite containing IPPD, 6 PPD, and DTPD in water with a pH of 4 for various time durations. The study recorded that after 15 days, at an original concentration of 3 parts of antiozonant per hundred parts of rubber, the vulcanite lost 87.7% of the IPPD, 44.5% of the 6PPD and 1.17 % of the DTPD.[8]

Although antioxidants are leached by water, the largest loss of antioxidants occurs during the curing process of the tire. Antioxidants can also be lost due to elevated temperatures while tires are in storage or during use and due to diffusion as the tire ages.

There has been a long term study conducted on tires immersed in sea water. The study concluded that after 42 years tires constructed of polyisoprene and immersed at a depth of 80 feet showed very little degradation. Analytical tests on the tires identified that the tire rubber absorbed enough water to equal 5% of its mass.[38] Concentrations of rubber, carbon black, sulfur, zinc oxide, mercaptobenzothiazole, and stearic acid were within ±10% of those that would be found in the original tire composition. Antioxidants were also analyzed in the tires, but any loss of these compounds could not be confirmed. The iron bead was also analyzed. Trace metals were detected, indicating the bead was a mild steel, and no oxidation appeared to have occurred. The analysis results of the tires immersed in sea water appears in Table 12.

Table 12. Sea Water Concentrations Near Tire Deposits at 80 feet

Parameter	Concentration or Value
Sodium	12300 ppm
Magnesium	1900 ppm
Potassium	590 ppm
Calcium	410 ppm
Strontium	9 ppm
Iron	0.83 ppm
Lead	0.44 ppm
Manganese	0.12 ppm
Copper	0.11 ppm
Zinc	0.07 ppm
Chloride	15000 ppm
Sulfate	2000 ppm
Dissolve Oxygen	8.8 ppm at 80 feet 9.7 ppm at sea level 11 for nearby tap water
Temperature	8°C at 80 feet, 13°C at sea level
pH	7.8 at 80 feet and at sea level

Evaluation of Table 12 shows that tire rubber maintains its composition under a relatively corrosive environment. During the experiment, the oxygen available for oxidation was only reduced slightly from local tap water, and the tire was maintained under a cool environment. Ozone levels as well as UV penetration at 80 feet are not appreciable.[39]

The study identified that there was some decrease in the desired structural properties of the rubber including an increase in hardness. The increase in hardness may be primarily due to the absorption of moisture as opposed to a loss of rubber material compounds to the environment. Percent changes in physical properties are given in Table 13.

Table 13. Changes in Physical Properties due to Long Term Immersion

Parameter	% change
Tensile Strength	-3%
Tensile Modulus	23%
Elongation at Break	-15%
Tear Strength	no change
Hardness	16%
Compression	-68%

Aside from the sea water immersion study, other studies have concluded that tires lose adhesion properties with elevated humidity.[40] But this adhesion reduction is probably due to moisture absorption rather than a loss or decay of material compounds in rubber. Humidity aging can be controlled with adjustments in sulfur and accelerator additives. Compounds containing small amounts of sulfur show a decrease in adhesion with increasing amounts of the accelerator additives. However, compounds containing large amounts of sulfur maintain high adhesion even with large amounts of accelerator additives.

5.5 Environmental Effects of Tires and Tire Rubber as It Relates to Degradation from Oxidation in Air

Atmospheric ozone (O_3) is, by far, the most damaging factor on rubbers. The failure of rubber tires in service is often the direct result of O_3. Atmospheric ozone degrades polydiene rubbers by reacting directly with the polymer chain. Ozone attacks the double bond of the polymer and forms an intermediate organoperoxide (carbonyl) and an aldehyde (if terminal carbon) or ketone. The intermediate organoperoxide bonds with secondary ozonides to form stable organoperoxides and organohydroperoxides. Induced surface cracking or alternatively fatigue or mechanical failure is initiated by the surface cracks produced by O_3 attack.

Antioxidants and antiozonants work together to prevent this oxidation. There are 12 compounds formed as reaction products from ozone-6PPD reactions. These compounds

are non-volatile substances ranging in molecular weight from 184 to 548. These compounds all have nitrogen and benzene functional group.[9, 23]

Air emissions due to the degradation from ozone are not expected to exists at measurable amounts. Small aldehydes may be admitted into the air. Air emissions of concern (if any) should focus on thermal treatment systems such as pyrolizers and incinerators.

5.6 Environmental and Health Effects of Open Burning

Results suggest that the open burning of scrap rubber tires poses potential environmental and health effects. Because of the frequent occurrence of unwanted combustion at tire disposal sites and the potential environment and health risks posed by such combustion, prudence would suggest that such sites be reduced or eliminated in size and number.[31]

Considerable research has been performed on the mutagenic and carcinogenic properties of chemicals associated with the rubber industry. These studies have shown that a wide variety of mutagens and carcinogens are present in the rubber industry and that carcinogenic and other types of health effects have been associated with rubber workers. Many chemicals, some of which are mutagens and carcinogens, have been identified in the emissions from both the controlled and uncontrolled burning of rubber tires[31]; however, no studies on the mutagenicity of emissions produced by the open burning of tires was provided in the articles reviewed.

The organic products of incomplete combustion (PICs) are present in emissions from all combustion processes and, in general, have been found to be carcinogenic in humans and rodents and to be mutagenic in bacteria and mammalian cells.[31] Mutagenicity bioassays, especially the Salmonella mutagenicity assay, have been shown to be useful for evaluating the health effects of airborne mutagens and potential carcinogens present in the PICs from a variety of combustion emissions. Such bioassays have been used to characterize PIC-impacted urban air as well as emissions from the combustion of municipal and hazardous waste, polyethylene plastic, wood smoke, and automotive and diesel exhaust.[31] The mutagenic emission factor for the open burning of tires was 3-4 orders of magnitude greater than that for the combustion of oil, coal, or wood in utility boilers; it was most similar to values for the open burning of wood and plastic. Open

burning, regardless of feed stock of fuel, appears to result in greater mutagenic emission factors than does controlled combustion as provided by various types of incinerators or boilers. However, caution must be exercised in extrapolating these bioassay results in bacterial to potential health risks in humans. Further bioassay studies in mammalian cells and rodents would be necessary to provide a clearer understanding of the biological effects of these emissions to higher organisms, including humans.[31]

The emissions from stockpile tire fires affect not only the atmosphere but also the land and groundwater due to the liquefaction of the rubber during the combustion process.[31] In addition, water on tire fires often increases the production of pyrolytic oil and provides a mode of transportation to carry the oils off-site and speed up contamination of soils and water.[30]

Operators of tire stockpiles take precautions to prevent tire fires. Generally, this involves providing fire lanes between the segments of the tire pile. Some of the better prepared tire piles have also provided emergency water supplies for fighting potential fires.[6] It is also necessary to provide surveillance to keep sources of flames away from the tires, particularly guarding against arsonous intruders. Operators of tire stockpiles often provide security measures such as watchman, guard dogs, chain link fences, and bright lighting at night.[32]

If the agricultural lands polluted with heavy metals such as cadmium are no longer limed, the pH of the soils, previously maintained at levels of 6 or higher, could decline rapidly over a period of decades, resulting in an increase in the mobility of trace metals in the top soil. It is projected that the pH of forest soils in the lower Rhine Basin could decline to levels of about 4.0 by the year 2000. Abandoned agricultural land polluted with heavy metals has an enhanced uptake of heavy metals in new vegetation. This could harm wildlife and increase leaching to groundwaters for drinking-water supplies.[37]

5.7 Parameters to Determine Environmental Pathways

Materials used to manufacture tires and materials found in thermal processing of tires were briefly evaluated based on environmental pathways. A general discussion of these materials and their fate in the environment is given in this section. Some key compounds

along with many of the pertinent parameters related to environmental fate will be quantified by standard estimating techniques. The environmental effects for many of these materials are not known, nor were they eluded to in any of the literature. Some toxicity effects are discussed in Section 3 and 5 of this report.

The parameters discussed in this section are water solubility (S), biological concentration factors (BCF), and soil adsorption (K_{OC}). These parameters were calculated based on correlations of related compounds and chemical structure. When available, physical properties were used in the estimate of other parameters. Some compounds were not evaluated because they are not tire materials specific, pose little or no environmental risk, or have well established properties far beyond what is discussed here. Compounds not evaluated are hydrogen, methane, ethane, propane, propene, butanes, butenes, pentanes, hexane, hexenes, nitrogen oxides, and sulfur oxides. Metals are also well studied and are not evaluated here. Metal toxicity is fairly well known and their environmental fate has been diligently studied. Table 14 below shows a few key chemicals that were evaluated and various parameters that were calculated. Solubility was correlated as a function of soil sorption and biological accumulation based on functional groups similar to those found in rubber compounds.[39]

Table 14. Estimated Values for Solubility, Soil Adsorption, and Biological Concentration

Compound	Log S	S (ppm)	Log Koc	Koc (ml/g)	Log BCF	BCF (g/g)
benzene	3.21	1,611	1.27	18	-0.16	0.7
benzothiazole	3.64	4,338	1.16	15	-0.28	0.5
bis(2-ethyl-hexyl)phthalate	-0.41	0.39	3.64	4,371	2.49	312
1,3-butadiene	3.43	2,690	1.06	11	-0.40	0.4
dibutylphthalate	-0.42	0.38	3.57	3,675	2.41	257
ethylbenzene	1.97	93	2.02	105	0.68	4.8
formaldehyde	3.08	1,200	1.11	13	-0.34	0.5
2-mercaptobenzothiazole	4.17	14,725	0.92	8	-0.55	0.3
naphthalene	1.75	56	2.19	154	0.87	7.4
phenol	4.23	17,116	0.75	6	-0.74	0.2
p-phenylene diamine	4.58	38,000	0.59	4	-0.92	0.1
resorcinol	5.21	160,645	0.25	2	-1.30	0.1
styrene	1.95	89	2.03	107	0.69	4.9
toluene	2.54	347	1.67	47	0.29	2.0
xylene	1.97	93	2.02	105	0.68	4.8

A review of Table 14 shows that, compared with the other tire compounds, phthalates have a larger biological concentration factor; thus, a higher degree of accumulation in aquatic organisms. Table 14 also shows that soil sorption would be high for phthalates and moderately substituted aromatics and polynuclear aromatics. Compounds higher in molecular weight that are accelerators tend to be relatively reactive in the environment and decompose to smaller aromatic and heterocyclic compounds. (e.g., Substituted phenylene diamine is reactive to oxygen and also has a short biological half-life.) Compounds formed by ozonation and oxygenation of phenylene diamine derivatives are complex aromatics in which health effects are not studied.[9]

Environmental pathways can only be predicted for some tire rubber compounds. The literature reviewed provided only a small amount of information concerning tire leaching

and emission. Waste tire products in long term storage or processed in thermal treatment units have been under limited study. Detailed pathways analysis for waste tire storage and processing were not discovered in our literature investigation. Based on comparable waste component, it would appear that waste tire pathways can be predicted based on similar circumstances with municipal landfills and coal burning facilities.

6.0 CEQA Evaluation Factors

As stated under the California Environmental Quality Act (CEQA), the policy of the State of California is that public agencies should not approve a project as proposed if there are feasible alternatives or feasible mitigation measures available which would substantially lessen the significant environmental effects of the project. (See Section 21000 of California's Public Resources Code). In order to adhere to this policy, an assessment of a proposed waste tire activity should be conducted to evaluate the following:

- all substantial, adverse environmental impacts that the proposed activity may cause;
- all irreversible environmental impacts that the proposed activity may cause;
- any feasible mitigation measures that would reduce such substantial adverse environmental impacts; and
- any feasible alternatives, including design alternatives, to the proposed project that would reduce such substantial adverse environmental impacts.

Based on the findings of the literature search conducted for this report, the potential environmental impacts of a waste tire processing facility will depend largely upon the processes employed by the facility. Each type of storage, handling, size reduction, destruction, or recycling activity a facility operates will have a unique potential impact on the environment. Table 15 provides recommendations of some issues that should be evaluated under an environmental assessment of different waste tire processes.

Table 15. Recommended Issues for Evaluation

Proposed Activity	Evaluate	Reasons for Evaluation
Stockpiling (whole tires)	Stagnant Water Mitigation Measures Fire Prevention Measures Fire Control Capabilities	Minimize mosquito breeding ground Reduce the risk of fire Reduce impact of potential fires
Stockpiling (shredded or chopped tires)	Fire Prevention Measures Fire Control Capabilities Stormwater Runoff Control for particulates	Reduce the risk of fire Reduce impact of potential fires Reduce the risk of surface water and soil contamination
Stockpiling (crumb or granulated tires)	Fire Prevention Measures Fire Control Capabilities Stormwater Runoff Control for particulates Dust Suppression Measures	Reduce the risk of fire Reduce impact of potential fires Reduce the risk of surface water and soil contamination Reduce particulate emissions due to wind
Volume Reduction (shredding/ chopping)	Particulate Emissions Particulate Control Measures	Evaluate impact of particulate release Evaluate effectiveness of particulate control
Combustion	Emissions of Priority Pollutants and Particles of Incomplete Combustion (PIC) Metal Emissions Air Pollution Control Measures	Evaluate impact of emissions of priority pollutants and PICs Evaluate impact of metal emissions Evaluate effectiveness of air pollution control system
Landfilling	Volume Reduction Methodology Fire Prevention Measures Fire Control Capabilities	Evaluate volume reduction technology for environmental impacts (see Volume Reduction) Reduce the risk of fire Reduce impact of potential fires

The findings of the literature search did not reveal the potential for significant environmental impacts resulting from waste tire land application (i.e., use as road bed material), ocean disposal, or reuse in oceans as artificial reefs. Information on the environmental impacts of retreading or remolding tires was also not found; however, the New Source Performance Standards (NSPS) established under the Federal Clean Air Act regulate emissions of volatile organic compounds from facilities of the tire manufacturing industry conducting the following operations: undertread cementing, sidewall cementing, tread end cementing, bead cementing, green tire spraying, Michelin-A operation, Michelin-B operations, and Michelin-C automatic operations. The sources of volatile organics from these operations are the cements and green tire spray. The regulations and definitions of these operations can be found in Title 40, Code of Federal Regulations (CFR), Part 60, Subpart BBB.

The Federal Clean Water Act establishes provisions applicable to discharges of process wastewater pollutants resulting from the production of pneumatic tires and inner tubes in

tire and inner tube plants. These provisions are found in Title 40 CFR Part 428, Subpart A. Further review of these regulations should be conducted to determine their applicability to retread operations.

7.0 Recommendations for Future Work

7.1 Additional Literature Review

The scope of the literature search for this report was limited to published articles and chemical references. A majority of the articles focused on the performance of tires and the effect of the environment on tires versus the effect of tires on the environment. Information pertaining to the physical behavior of chemical additives associated with the rubber and tire manufacturing industry was found to be limiting. Reports directly related to the effects of waste tires on soil and the effects of soil acidity and alkalinity on tires were not found in the literature search. No literature was found directly identifying the chemical kinetics associated with tire components exposed to different environmental media, including rates of diffusion, environmental partitioning of components, and component by-products. Reports on the leaching potential of tire additives did not formally address whether or not hazardous constituents are produced from the leaching of the antiozonants and antioxidants.

Although the reports from the tire manufacturing industry do not contain all of the valuable chemical property data required to identify the behavior of tires in the environment, the tire manufacturing industry may possess this data. It is recommended that corporations within the tire manufacturing industry be directly contacted and requested to supply chemical property data on tires and tire additives. A description of the tests performed to obtain the data and available studies on the environmental impacts of tires should also be requested.

Similarly, contacts should be made with the cement manufacturing industry and tire pyrolysis operations to obtain air source testing data related to tire combustion. This data could be used to evaluate stack and fugitive emissions. The data should include: a description of the methodology used to sample for the emissions; the type of air pollution control methods employed by the emission source; the physical form of the tire as burned; the type of tire burned; and additional fuels used to combust the tire. An analysis of the ash

removed from the combustion process would also be helpful to evaluate environmental impacts due to secondary waste from combustion processes.

The Resource Conservation and Recovery Act (RCRA) allows the U.S. Environmental Protection Agency (EPA) to address releases to ground water and all other environmental media through corrective action at all solid waste management units located at facilities requiring a RCRA permit. The corrective action process includes the identification and release characterization for all environmental media from solid waste management units such as tire stockpiles. It is recommended that a review of EPA records be performed to identify and obtain information on corrective action activities associated with solid waste management units strictly consisting of waste tires. The information may include sampling and analysis data of environmental media in the vicinity of a waste tire management area revealing the potential for contaminated leachate and the chemical speciation of the leachate from the management area.

The chemical additives associated with the tire manufacturing industry are very unique. Consequently, it is unclear whether existing analytical methods are sufficient to evaluate environmental media for all of these specific chemicals. A comparison of the chemicals versus available analytical methods should be performed to determine areas where analytical methods are deficient in accuracy and precision. The analytical methods reviewed should include EPA's SW-846, "Test Methods for Evaluating Solid Waste," and methodologies used or recommended by the tire manufacturing industry. Chemicals determined to lack sufficient analytical methods may require the development of new or modified analytical methods.

An extensive search on the toxicological effects of many of the chemicals used to manufacture tires was not performed in the literature search associated with this report. It is recommended that an additional literature search be conducted to evaluate the environmental and human health effects of the identified tire additives and polymers.

7.2 Laboratory Work

As gaps of information are identified from performing the above literature review recommendations, laboratory investigations are recommended on the effects of waste

tires on the environment. Recommended laboratory investigations include analyzing the degradation of waste tires with their effects on soil, water and air under various conditions and combinations of conditions. The conditions should include soil and water acidity, soil and water alkalinity, ultra violet radiation, high and low temperatures, tire particle size, and tire contact time with environmental media. Two specific laboratory investigations are provided below.

1. The leaching studies identified in the literature review relating to antioxidants and antiozonants appear inconsistent. According to the information, these materials migrate to a tire's exposed surface and are either degraded or released to the environment. The measurements performed to reach this conclusion analyzed how much of the materials remained in the tire rubber. However, the studies did not demonstrate a consistent approach in verifying the actual demise of the antidegradants. Laboratory studies should be performed to determine the actual rate of the antidegradant's reactivity and/or loss. Experiments should focus on the amount of antidegradant released to the environment (leach media), instead of the amount lost from the tire rubber.

2. Partitioning coefficients and transport phenomena parameters of the binders, accelerators and antidegradants should be measured. The literature search identified only one paper on the diffusivity of antiozonants from tire rubber samples, but the article was neither consistent nor comprehensive. Experiments may be performed to determine solubilities, soil-water-air partitioning coefficients, octanol/water coefficients, vapor pressures, diffusivities, and environmental half-lives. Additional toxicology studies can be performed to determine bioconcentration factors.

7.3 Field Work

The practice of stockpiling tires is still occurring in the United States. Sampling environmental media associated with stockpiles of tires is possible. The collection of soil and stormwater runoff from a number of stockpiles of different ages is recommended. The collected media should be sampled and analyzed for metals to validate former tests. The collected media can also be sampled and analyzed for tire additive chemicals. Air samples

may also be collected to determine release concentrations of tire compounds from a stockpile. Air samples should be collected at various temperatures and solar exposures.

The validity of the laboratory work performed on pollutant fate and biological concentration of tires used for ocean reefs should be researched thoroughly. The bioaccumulation of chemical additives in aquatic life has been evaluated based on the literature review. Field experiments should be performed.

7.4 Recommendations for Best Environmental Management Practices

Based on the literature review, tires in deep, cold salt water do not appear to deteriorate. Consequently, tires used as artificial ocean reefs are a potential reuse technique provided that additive compounds are not determined to accumulate in aquatic life.

The disposal/recycling industry should be encouraged to shred whole tires. This is important for disposal dynamics. Shredding provides easy handling and better compaction in landfills than whole tires. Shredded tires have a lower fire hazard than whole tires and do not allow for the accumulation of stagnant water in stockpiles. The most significant obstacle to shredding appears to be economical.

The evaluation of mitigation measures for waste tire processing is difficult to determine at this time. Analysis of the literature displays a positive light on tire projects such as cement kiln fueling, recovery of materials from pyrolysis, artificial reefs, rubber and road fillers, and other projects. It was understood from the literature that direct disposal of tires provides for the most harm to the environment and neighboring communities based on the harboring of pests, the reduction of landfill capacity, and potential fire hazards. The evaluation of any waste tire project will depend on the processes employed by the project facility.

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Examination of Crumb Rubber Produced From Recycled Tires

Connecticut Agricultural Experiment Station (CAES) and Environment and Human Health Inc.

AC005 (8/07)

EXAMINATION OF CRUMB RUBBER PRODUCED FROM RECYCLED TIRES

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Introduction

In June 2007 the Department of Analytical Chemistry at the Connecticut Agricultural Experiment Station (CAES) was contacted by Environment and Human Health Inc. (EHHI), a non-profit organization headquartered in the greater New Haven area, to ascertain if our laboratory would be willing to examine crumb rubber produced from used tires. The product in question has been gaining widespread use as an enhancement on athletic fields constructed from artificial turf; other applications, such as on play areas for children, are also common. Private citizens questioned EHHI as to the human health and environmental neutrality of the product. The data to answer the inquiries were not available (Anderson et al., 2006).

Figure 1 shows the crumb rubber infill on a synthetic turf field. The photo is of an actual field installed in Connecticut and was provided to us by EHHI.



Figure 1.

Given time and personnel limitations, the Department of Analytical Chemistry at the CAES agreed to conduct a very modest study of the material. Funding in the amount of $2000 was received from EHHI to offset the cost of items such as analytical and instrumental supplies and chemical standards. This fact sheet contains scientific information, described in detail below, derived from the preliminary study. The experiments were conducted by Dr. Mehmet Isleyen, with contributions from Dr. Saim Ozdemir, both visiting scientists from Sakarya University, Engineering Faculty, Environmental Engineering Department, Sakarya, Turkey, and with

substantial input from William Berger of the Department of Analytical Chemistry. Dr. MaryJane Incorvia Mattina, the head of the Department of Analytical Chemistry, supervised the work.

Approach

It was deemed that answers to the following questions could be obtained within the time limitation imposed:

1. Are compounds volatilizing or out-gassing from the tire crumbs?
2. What is the identity of the volatilized compounds derived from the tire crumbs?
3. Can organic or elemental components be leached from the tire crumbs by water?

Experimental Details and Data

The crumb rubber examined is shown in Figure 2 and was provided to our laboratory by EHHI; the scale at the top of the photo is in centimeters (2.54cm/inch). Most of the crumbs were black, irregularly shaped particles <3mm in any dimension, although smaller particles may be seen in the photo. The material also contained lesser amounts of white crumbs similar in physical appearance to the black particles and presumed to be tire-derived rubber. The product was examined as received without any previous exposure to field conditions.



Figure 2.

Because of the substantial interest in this project, considerably more experimental details are provided in this fact sheet than is typical for such a publication. Experiments were conducted in the laboratory under conditions which approximated field conditions for parameters such as temperature and leaching solvent. The method relied on solid phase micro-extraction (SPME), a well-known and reliable analytical technique (Zeng and Noblet and references therein). The SPME fiber used was coated with 100µm thick polydimethylsiloxane (Supelco number 57342-U).

1. Are compounds volatilizing or out-gassing from the tire crumbs?

To obtain the data to answer this question 0.25g of tire crumbs were transferred to a glass, 2mL automated liquid sampling (ALS) vial. The vial was capped and the septum pierced with the SPME needle. The SPME fiber was exposed for 42 minutes to the headspace over the tire crumbs while the vial was warmed in a heating block to 60 ºC. At the end of this period the

SPME fiber was removed from the vial and desorbed in the inlet of a gas chromatograph (GC, Hewlett Packard model 6890) at 260 ºC. A 30m X 0.25mm DB-5MS+DG column (J&W Scientific) was interfaced to the mass spectrometer (MS, Hewlett Packard model 5973) detector. The GC oven was programmed as follows: initial temperature 40 ºC for 5 min, ramped at 2 ºC/min to50 ºC, ramped at 5 ºC/min to 160 ºC, ramped at 10 ºC/min to 300 ºC and held for 10 min. Figure 3 shows a portion of the total ion chromatographic (TIC) trace typically obtained from several replicates of this experiment. Peaks were identified using high probability matching of the actual mass spectrum with that in the NIST library supplied with the software.

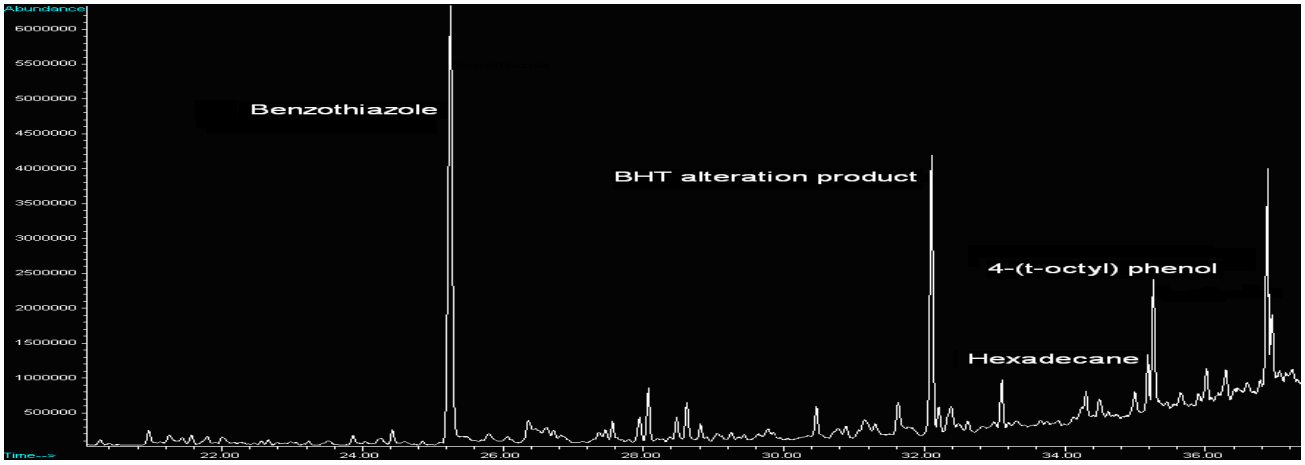
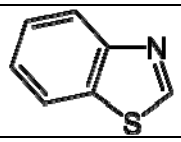
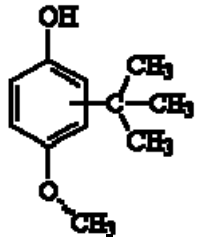
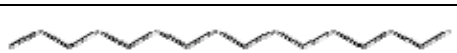
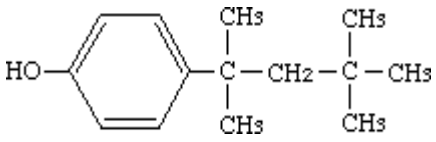


Figure 3.

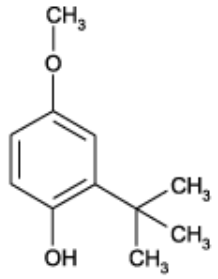
Using this approach of spectral matching several compounds were identified, some of which are summarized in Table 1:

Table 1. Organic Compounds Volatilizing from Tire Crumbs

NAME	CAS NUMBER	RETENTION TIME (min)	STRUCTURE
Benzothiazole	95-16-9	25.2	
Butylated hydroxyanisole	25013-16-5	32.7	
n-hexadecane	544-76-3	35.2	
4-(t-octyl) phenol	140-66-9	35.3	

2. What is the identity of the volatilized compounds derived from the tire crumbs?
In order to confirm positively the four compounds cited in Table 1 which have good match between the archived NIST spectrum and the spectrum recorded in this experiment, authentic standards were purchased from Sigma Aldrich. Solutions of the compounds were prepared in methanol and used to spike approximately 0.6 grams clean glass beads in 2 mL ALS vials. The same SPME procedure described above to collect volatile compounds from the tire crumbs was used to collect volatile compounds from the headspace over the spiked glass beads. The GC/MS analytical settings were also the same. The identity of the four compounds was confirmed with retention time (RT) match as well as mass spectral match. In order to assure that the compounds were not artifacts from laboratory background nor from any of the supplies used in the method, the following experiments were performed: (i) several consecutive desorptions of the SPME fiber in the GC inlet; (ii) SPME analysis of the headspace over clean glass beads in an ALS vial; (iii) SPME analysis of the headspace over glass beads in an ALS vial spiked only with methanol. None of the four compounds listed above was detected in any one of these three trials.

A comment must be made regarding butylated hydroxyanisole. Analysis of the purchased standard (Sigma catalogue number B1253-5G) resulted in detection of three peaks: RT=32.1, RT=32.5, RT=32.7 (major component). It should be noted that the structure matching this CAS number does not indicate a specific position of attachment of the t-butyl group relative to the hydroxyl group as shown above in Table 1. However, CAS 121-00-6 does correspond to 3-t-butyl-4-hydroxyanisole having the structure



Based on the mass spectral library match, we conclude that the compounds at RT 32.5 and 32.7 correspond to the two diastereomers of butylated hydroxyanisole. A search of the literature strongly suggests that the compound at RT 32.1, which has ions at m/z 236, 221, 205, 180, 165, 137, is 2,6-di-t-butyl-4-hydroxy-4-methyl-2,5-cyclohexadien-1-one (Brumley et al., 1989) designated as an alteration product of 2,6-t-butyl-4-methylphenol (BHT). Peaks at the three RTs for analysis of the standard were found as well in the analysis of the tire crumbs.

Experiments were conducted to determine approximate gas phase concentrations of the organic compounds which volatilized or out-gassed from the crumb rubber. In this trial standards at different concentrations were spiked onto glass beads in ALS vials and the SPME procedure conducted. Calibration curves were constructed using the spiked standards from which gas phase concentrations of the compounds of interest in the vapor phase over the tire crumbs were determined. We make the assumption that due to the non-porous nature of the glass beads, the entire amount of the organic compound spiked onto the glass beads volatilized into the gas phase in the ALS vial. From the original amount spiked and the volume in the vial remaining after the volume of the beads is subtracted, we can calculate the amount of the compound in the

headspace over the tire crumbs. These data in Table 2 should be considered a first approximation.

Table 2. Vapor phase concentrations of compounds out-gassed from crumb rubber

Compound	ng/mL air	ng/(mL air) normalized per gram of tire
Benzothiazole	225.87	866.72
Hexadecane	1.58	6.04
4-(tert-Octyl)-phenol	5.64	21.63
Butylated hyroxyanisole or BHT alteration product	13.89	53.32

3. Can organic and elemental components be leached from the tire crumbs by water?
To determine if materials of interest are extractable from the crumbs, portions of the crumb rubber were soaked over time in distilled, deionized water at ambient laboratory temperature in capped high density polyethylene (HDPE) jars. Approximately 17g of crumbs were soaked statically in 50mL water for seven weeks. After this period the leachate was filtered and 1.5mL transferred to ALS vials. The same SPME procedure was carried out as described above. A typical TIC trace for the headspace analysis is shown in Figure 4.

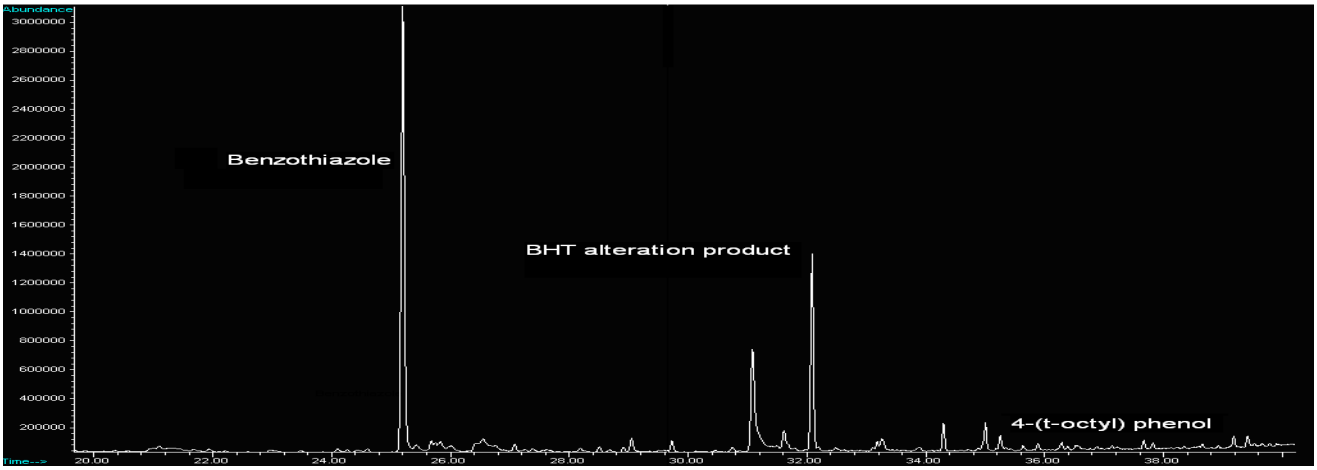


Figure 4.

Figure 4 should be compared with Figure 3. Although relative amounts of the compounds of interest differ under the two experimental conditions, the same compounds are noted in both Figures. If the SPME fiber is immersed directly into the leachate rather than exposed to the headspace over the leachate and then desorbed in the GC inlet, the same set of compounds as shown in Figure 4 was detected.

We now provide the experimental procedures used to determine if elements are leachable into aqueous solution from the crumbs. In this case 2.0 grams of crumbs were transferred into 40mL of water in 50mL centrifuge tubes. The tubes were sealed and agitated on a wrist action shaker at ambient temperature for 18 hours. Following this agitation the tubes were centrifuged for 10 minutes at 3000rpm and the leachate was analyzed using inductively coupled plasma mass spectrometry (ICP/MS, Agilent model 7500ce). In a second regime the leaching water was acidified to pH 4.2 prior to the 18 hour agitation. This procedure is based on conditions

recommended in EPA SW-846 Method 1312. Pertinent data, averages of four replicates for each trial, are presented in Table 3.

Table 3. Elements leached into water from crumb rubber

Element	Amount in water (µg/kg tire)	Amount in acidified water (µg/kg tire)
Zinc	20957	55010
Selenium	246	260
Lead	1.85	3.26
Cadmium	0.07	0.26

Conclusions

The laboratory data presented here support the conclusion that under relatively mild conditions of temperature and leaching solvent, components of crumb rubber produced from tires (i) volatilize into the vapor phase and (ii) are leached into water in contact with the crumbs. We note with interest that when we placed the black crumbs in direct sunlight at an exterior air temperature of 88 ºF, a thermometer inserted directly into the crumbs registered 55 ºC (=131 ºF). Selection of 60 ºC, therefore, is not beyond a reasonable temperature range accessible under field conditions.

Based on these data further studies of crumb rubber produced from tires are warranted under both laboratory, but most especially field conditions. In particular examination of compounds volatilizing from the crumbs under exterior conditions and collected at varying heights and seasonal conditions at installed fields should be compared with background levels. It is also logical to determine airborne particulate matter deriving from the product under the same conditions.

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

Emissions and Evaluation of Health Effects of PAH's and Aromatic Mines From Tyres

Danish Environmental Protection Agency

DANISH MINISTRY
OF THE ENVIRONMENT
Environmental
Protection Agency

Emissions and evaluation of health effects of PAH's and aromatic mines from tyres

Nils H. Nilsson, Anders Feilberg and Kirsten Pommer
Danish Technological Institute

Survey of Chemical Substances in Consumer Products, No. 54 2005

The Danish Environmental Protection Agency will, when opportunity offers, publish reports and contributions relating to environmental research and development projects financed via the Danish EPA.

Please note that publication does not signify that the contents of the reports necessarily reflect the views of the Danish EPA.

The reports are, however, published because the Danish EPA finds that the studies represent a valuable contribution to the debate on environmental policy in Denmark.

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Preface

The project ”Migration and assessment of health effects of PAHs and aromatic amines from tyres” has been carried out in the period from 15 Th. April to 1 Th. November 2004. This report describes the results of the study.

The project was carried out by the Danish Technological Institute, Materials Division. MSc, PhD, Nils H. Nilsson was manager of this project and the liaison between the Institute and the National Agency of Environmental Protection.

Kim Munck Christensen has contributed to the project with regard to selection of tyres and playground adoption in connection with the selection of tyres.

M.Sc. Anders Feilberg, Chemistry and Water Technology has been responsible for the laboratory analysis and the migration studies.

B.Sc. Kirsten Pommer has been responsible for the screening and health impact (consumer exposure) and risks assessment in the project together with M.Sc. Ole Chr. Hansen.

The project manager has been responsible for the interviews carried out, the purchase of tyres and playground tiles to the project, information search and as expert in rubber materials and rubber technology.

The reference group consisted of Frank Jensen (chairman), the National Agency of Environmental protection, and Nils H. Nilsson, the Danish Technological Institute.

The purpose of the project was to focus on the problematic substances that occur in tyres in relation to their use as playing tools or as playing ground fall protection. Later a screening phase for problematic substances like PAHs and aromatic amines and migration/exposure experiments conducted under “worst case conditions” have been carried out. Finally, health screening based on the results from the migration tests. Finally, health screening based on the migration tests completed the project.

Summary and conclusions

On behalf of the National Agency of Environmental Protection, the Danish Technological Institute has gathered information regarding the consumption pattern of tyres and fall protection tiles based on rubber granulate from discarded tyres in relation to the use of the products at playgrounds.

The investigation has shown that tyres are used at playgrounds to various extends. Preferably discarded passenger car tyres are used for swings but also cheep new tyres from the Far East are used. Lorry tyres are also used for swings for more than one child at the same time, but interviews confirm that the use is limited. At some playgrounds fairly huge amounts of tyres are used for tight-rope walking. Both lorry and passenger car tyres are used for this purpose. One gets as a common rule the tyres free as the owner then save money for the state imposed taxes for dispose.

A limited use of tyres for sandpit takes place. Only discarded and worn-out tractor tyres are used. They are offered free of charge.

It is possible for the consumers to buy passenger car tyres in DIY centres. They are equipped with mounting and robes for easy installation in the stands by the consumers.

In total 20 tyres and two different types of falling protection tiles base don granulated rubber from tyres were purchased. The aim was to screen the falling protection tiles and the tyres for content of PAHs and aromatic amines. The tyres purchased comprised as well worn- out tyres as new tyres intended for use for passenger cars, lorries and tractors.

For the initial semi quantitative screening analysis for PAHs and aromatic amines in total 18 tyres and two impact absorbing playground surfacing have been investigated. Based on the results from the screening analysis six tyres have been selected for quantitative analysis of the content of PAHs and aromatic amines. Further migration studies have been carried out with six selected samples. Also a full scale experiment with a worn-out tractor tyre used for sandpit. In this experiment migration of PAHs and aromatic amines to sand has been studied.

The results of the investigations are summarised below:

- The rubber from all the investigated tyres contains a row of PAHs, among these the carcinogenic chemical substance benz(a)pyrene. The amount varies.
- Benz(a)pyrene can be used as a PAH-indicator.
- The rubber from all the investigated tyres contains high concentrations of aromatic amines belonging to the chemical substance group para-phenylene-diamines. The para-phenylene-diamines are added to the rubber to prevent degradation due to ozone attack.
- Migration studies with artificial sweat have revealed that only the most water soluble PAHs migrate from the tyre rubber to the sweat.

- The aromatic amines in a similar way migrate from the tyre rubber to sweat.
- Full scale migration study with a worn-out tractor tyre used as out door sandpit has revealed that the added aromatic amines migrate to the sand. By a comparison between the PAH profile in the tyre and the composition /profile of PAH in the sand it must preliminarily be concluded that migration from the tyre is not a significant source for the PAH contamination of the sand. The results indicate that the PAH content in the sand origin from atmospheric deposition.

Health Assessment

The PAHs and aromatic amines, detected in the migration tests in contact with artificial skin and full scale tests of sandbox sand and for certain identified in the chemical analysis, were estimated in greater detail to assess the health risks proportional to the exposure of the user (child).

The following substances had migrated in the laboratory tests.

Table 0.1. Detected mean values for migration of components (ng cm^{-2})

Test type	Vans, used, tread	Impact absorbing playground surfacing , new	Car, used, side rubber	Car, used, tread	Car, new, tread	Car, used, tread
Test no	2	5	10	11	13	19
Fluoranthene	0.03	0.03	0.05	0.03	0.3	0.05
Pyrene	0.04	0.03	0.8	0.06	0.5	0.07
6PPD *)	0.95	5.1	19	44	50	0.7
IPPD **)	5.8	0.5	0.4	IP	0.1	10

”IP” means ”not detected”
*) 6PPD =1,4-benzenediamine N-(1,3-dibutyl)-N´-phenyl
**) IPPD = N-isopropyl-N´-phenyl-4-phenylendiamine

Worst case is that a skin area of 200 cm^2 on the thighs of a child is exposed for an hour five times a week during one year.

The following substances were detected in the full scale test with the sandpit of tractor tyre in the mentioned concentrations.

Table 0.2. Detected values for content of components in sand (µg kg^{-1} (wet weight))

	Ref. initial	Ref. 15/8	Test 15/8
Fluoranthene	1.67	2.89	10.12
Pyrene	1.12	3.64	12.57
Benz(a)anthracene	0.25	0.50	1.02
Chrysene	1.42	1.96	2.27
Benz(b+j+k)fluoranthene	0.10	0.22	0.25
Benz(e)pyrene	0.06	0.14	0.18
Benz(a)pyrene	0.03	0.07	0.09
Dibenz(ah)anthracenee	IP	0.01	IP
Indeno(1,2,3-cd)pyrene	0.02	0.05	0.08
Benz(ghi)perylene	0.03	0.11	0.15
6PPD	IP	IP	109.84
IPPD	IP	IP	4.56

”IP” means ”not detected”

By way of comparison the results from the sand before migration test are included (ref. initial) and the result from plastic covered side of the tractor tyre with plastic film (ref. 15/8). The migration test has been carried out during July, 4 and August, 15 2004. During the period the test samples have been exposed to some rather unusually heavy pour downs. The total rainfall for the period was 84 mm (DMI, Viby J. station).

Worst case scenario is that a child weighing 10 kg ingests 10 g of sand five times a week for half a year and that 100 % of the substances in the sand are absorbed in the body of the child.

Some PAH compounds and amine compounds have been detected in sand exposed to discarded tyre and in migration tests, where artificial sweat has been in contact with discarded tyres. The substances have been identified and quantified.

The following substances have been identified and quentified:

Table 0.3. Identified chemical components in the contact exposure experiments

Migration test, artificial sweat	Exposed to sand	
Fluoranthene	Fluoranthene	Benzo(b+j+k)fluoranthene
Pyrene	Pyrene	Benzo(e)pyrene
6PPD	6PPD	Benzo(a)pyrene
IPPD	IPPD	Dibenz(ah)anthracene
	Benzo(a)anthracene	Indeno(1,2,3-cd)pyrene
	Chrysene	Benzo(ghi)perylene

It was expected to find more PAHs in the migration test. This expectation was based on the results from studies on PAH migration to soil from rubber particles due to wear of tyres from traffic. On the other hand, there has former not been focus on the amino-compounds, 6PPD and IPPD, with respect to migration from used tyres before.

The four substances found in the migration test and benzo(a)pyrene was assessed. A screening including the other substances was performed.

The assessment showed:

- Fluoranthene causes no acute health effects. Related to long term exposure damages to liver and kidneys have been seen in animal studies. A child may be exposed to 10 ng per day per kg b.w. and with a NOAEL of 125 mg/kg this results in a MOS of more than a million.
- Pyrene may be toxic by ingestion and causes mild irritation to skin. Pyrene is not classified as a carcinogen. No data on reproduction or mutagenicity was available. A child may be exposed to 13 ng per day per kg b.w. and with a NOAEL of 75 mg/kg it results in a MOS of more than a million.
- 6PPD may be irritating to skin and a potential sensitizer. Long term effects such as haematological changes and ongogenic effects as well as effects on reproduction have been observed. A child may be exposed to 100 ng per day per kg b.w. and with a NOEAL of 4 mg/kg, it results in a MOS of 10.000.
- IPPD may be toxic if swallowed in large quantities. Skin contact may cause sensitization. Data on long term effects, except for developmental toxicity, has not been found. A child may be exposed to 200 ng per day per kg b.w. and with a NOAEL of 62.5 mg/kg it results in a MOS of 100.000.

- Benzoe(a)pyrene is a substance that may cause cancer as well as genetic and developmental effects. A child may be exposed to 0.1 ng/kg b.w. per day. Compared with a NOAEL of 3 mg/kg it results in a MOS of more than one million.
- The other identified PAHs causes the same type of health effects as benzo(a)pyrene but with a lower risk level. A child may be exposed to in total 4 ng/kg b.w. per day of these PAHs. Comparing this with a NOAEL of 3 mg/kg it results in a MOS of 750.000.

From these results it can be concluded that the potential health risk related to use discarded tyres on playgrounds is insignificant.

Although the MOS is high for all the identified components it is notable that the lowest MOS are found for the two identified amino-compounds.

1 Introduction

Tyres are used both of private consumers and by childcare institutions as playing tools, among these as sandpits. A risk exists that children can be exposed for chemical substances liberated from the tyres. Exposure can take place by contact with the skin, e.g. when the tyres are used as seats for swings or for sandpits. In the last application exposure to potential liberated chemical substances can also take place orally in case the playing smaller children put sand in the mouth or eat it.

In many of the formularies used for tyres mineral oils are used as plasticizers. The basic structures of the hydrocarbons which occur in mineral oils are n-paraffines, iso-paraffines, naphtenes (aliphatic cyclic hydrocarbons) and aromatics (cyclic unsaturated hydrocarbons). The mineral oil based plasticizers are classified based on their viscosity / density constant. Based on this constant the oils are classifies as highly aromatic, relative aromatic, naphtenics, relative naphtenics and paraffinics. In particular the highly aromatic oils can contain a considerable amount of polycyclic hydrocarbons (PAHs). Some of the PAHs are classified as carcinogenic. One should mention that t least in Western Europe the trend is to replace the highly aromatic oils with naphtenics in the tyre formularies. The latter types are mainly composed of cyclo aliphatic hydrocarbons, but contain also PAHs but in reduced amounts.

Problems regarding PAHs in relation to the use of aromatic mineral oil based plasticizers for tyre formularies have among other scientific sources been considered in an article by L. von Meyerinck *et al.* and by R. Wommelsdorff, 1999. Baumann (1997) has investigated the PAH-content in a number of high aromatic oils in different tyres as well as the liberation of PAHs due to wear particles from the tyres in relation to the traffic. The same issue, but in a broader scope, has been discussed by the scientific committee for toxicity, ecotoxicity and the environment (CSTEE, 2004). The complete title of the document from CSTEE, 2004 is to be found in the reference list.

The latter two references have some open questions left in relation to the health and environmental impact due to tyres and caused by the wear particles from the tyres as a result of the traffic on the roads. Both references focus primarily on the potential risk due to the adverse influence from PAHs, due to known carcinogenity or suspected carcinogenity.

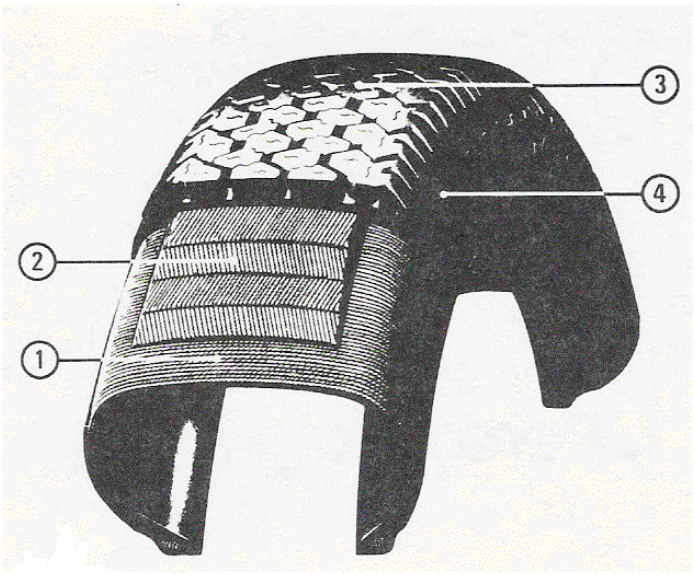
However considerable amounts of protective agents are added to rubber formularies for tyres besides the plasticizing oils. The protective agents are added because the types of rubber used for the manufacturing of tyres are easily degraded by exposure to different weather conditions as mainly rubber raw materials with unsaturation in the polymer chains. This unsaturation means that degradation easily takes place due to breakage of the chains by exposure to light, high temperature, oxygen and ozone. In particular the side wall rubber has to be well protected due to high heat build up due to mechanical stress due to flex movements. Ozone is a very strong oxidation agent. Ozone primarily attacks rubber under mechanical stress. The degradation due to ozone attack already takes place at the very low ozone

concentration in outdoor air (normal level 10-50 ppb). Aromatic amines are added to the rubber formularies to prevent this attack. This is different from plastic where phenolic antioxidants are sufficient for protection (phenolic based antioxidants are also used in rubber). P-phenylene derivatives are very common used in rubber formularies for tyres, but also other aromatic amines are used. During the vulcanisation process aniline might be formed from the antiozonants. Aniline is an aromatic amine which is classified as carcinogenic.

The amounts of p-phenylenediamines and aromatic amines will be present in the rubber formularies in significant higher amounts than is the case for the PAHs. This can be calculated from information about rubber formularies for tyres found in the open literature. It is further foreseen that the p-phenylenediamines will be present in much higher concentrations on the surface of the rubber as they are tailor-made to have a reduced solubility in the rubber. Due to the low solubility they will migrate to the surface of the tyres. Their presence at the surface will protect the tyre from ozone degradation.

The formulation of the problem is however complex. This is due to the fact that many different types of tyres and with different rubber formularies are produced. And there are several different producers as well. The formularies are not open to the public as fare as one deals with commercial rubber compounds for tyres. It is however possible to find examples of standard formularies in the open literature for tyres (Ciullo, 1999). It is expected that these formularies are rather close to the formularies used in commercial formularies for tyres.

A tyre typically consists of rubber based on seven rubber formularies. The most important formularies are the compounds used for the thread, the sidewall and the inner liner. The thread is frequently produced from SBR rubber with a small amount of butadiene rubber added. For the thread used for lorries and trucks natural rubber is added to the rubber compound due to the excellent elasticity and wearing qualities. The sidewall rubber typically is composed of natural rubber and butadiene rubber. However EPDM is also used in the side wall formularies. The inner liner is typically produced from butyl rubber due to the high tightness against air. In total the manufacture of tyres comprise approximately 35 separate processes and in total 50-100 different raw materials (different rubber types and rubber chemicals). During vulcanisation chemical reactions take place and new chemical compounds are formed. The rubber chemistry of the tyre is as one can imagine very complex.



Radial tyre
1. Carcass layer
2. Stabilizing belt
3. Tread
4. Side wall rubber

It is foreseen that exposure and contact with chemical compounds in the rubber during use of tyres as playground equipment mainly will happen from the tread and the sidewall rubber.

In Table 1.1 formularies for the tread for a passenger car and for a lorry are listed.

Table 1.1. Examples of tread rubber formularies with a content of high aromatic mineral oils as plasticizers.

	Passenger car tyre formulary for summer tyres phr	Passenger car tyre formulary for winter tyres phr	Tyre for lorries Formulary 1 phr	Tyre for lorries Formulary 2 Phr
Natural rubber		50		80
SBR-rubber	80	40	75	
Butadiene rubber	20	10	25	20
Carbon Black A		25	55	45
Carbon Black B	75	45		
High aromatic mineral oil	35	45	10	20
Zinc oxide	3	4	5	5
Stearic acid	1.5	2	2	3
Antioxidants/ Antiozonants	1	1	1.5	1.5
Wax	1	1		
Accelerators	1.5	1.5	1	1
Sulphur	2	2	1.5	2
Parts in total	220	226.5	176	177.5

It has to be mentioned that the Amount of rubber polymer always is quoted to 100 parts in a formulary (phr = parts per hundred). The amount of an ingredient can be calculated from the total amount of parts. The amount of high aromatic mineral oil based plasticizer added to a passenger car tyre is par example according to the listed formulary above 35/220 %w/w = 15.9% w/w.

Tractor- and caterpillar tyres have tread formularies close to the ones listed for tyres for lorries.

Higher amounts of antioxidants/antiozonants areas foreseen added to the sidewall rubber in comparison with the tread. As mentioned before the reason for higher protection is the heat build up and the high mechanical wear due flex movements. To prevent ageing of the rubber by weathering (UV light, oxygen, ozone and temperature) such a higher level of protection is needed.

According to a survey made by Baumann (1997) the concentration in plasticizers base don high aromatic mineral oil plasticizers the amount of PAHs in the plasticizers varies between 98 mg /kg and 1,350 mg/kg. A permit limit set to 50 ppm for benz (a) pyrene at the time for the survey made was not excessed for any of the plasticizers analysed.
The content of PAHs in the tyres investigated varied between 11.4 mg/kg and 147.2 mg/kg. As expected the amount of lower molecular weight chemical compounds in worn tyres is lower than for new tyres.

In the survey migration of some of the other rubber chemicals or added to the rubber in tyres (or their degradation products) was measured. This part of the investigation dealt with the migration of p-phenylenediamine, aniline and some benzothiazoles. The latter are typically used as accelerators for cross linking of rubber used for tyres. The investigation did not include a migration study like the one dealt with in this project.

Empirically the amount of p-phenylenediamines added to rubber formularies for tyres is approximately 1% w/w. This adds up to 10 g/kg tyre. The amount of PAHs in tyres is according to calculations made on standard rubber formularies for tyres in the order of 10-100 lower under presumption that the PAH content in the plasticizers is in the range from 100 mg/kg to 1,000 mg /kg.

CSTEE (2004) has listed a little different range of concentrations for PAHs in tyres, but the order is in accordance with the findings made by Baumann´s in his study. It has to be mentioned that CSTEE (2004) state that a fairly good correlation exists between the total amount of PAHs in the tyres and the content of benz(a)pyrene (BaP).

2 Collection of tyres

The consumer's pattern for the use of tyres as playground equipment has been revealed by making interviews with dealers for playground equipment, responsible persons for playgrounds e.g. inspectors and companies who offers turnkey solutions for playgrounds. A representative number of tyres which are used as playground equipment was purchased based on the information obtained regarding the consumer's pattern for the use of tyres for playgrounds. The samples purchased included different types of tyres (passenger car tyres, lorry tyres and tractor tyres) and tyres produced by different manufactures. Both worn and brand new tyres were purchased. In supplement to the tyres impact absorbing playground surfacing based on granulated worn tyres were purchased as well.

In the collection / purchase phase it was checked up on the possibility to get information with regard to the use of plasticizers based on high aromatic mineral oils in the tyres. If such information is not easily accessed a screening for PAHs was performed.

2.1.1 Content of PAHs in the collected tyres – knowledge available

The contacts made to the dealers of tyres made it clear that they in fact did not know the meaning of PAHs or high aromatic mineral oils (HA). To get information about the formularies of the rubber compounds used for the tyres from the dealers was as one can imagine not possible. On the Nordic Rubber Conference 2004 (NRC 2004) in Tampere, Finland Nokia informed that new tyres with reduced and low content of PAHs would be labelled in such a way that the consumers would know if they were going to purchase a "Green tyre. Nokia was in a process to substitute the high aromatic mineral oil based plasticizers with low aromatic oils. Nokia still had problems with the substitution in summer tyres due to problems with the functional properties of the formularies. This is in accordance with information (HA oils in automotive tyres, 2003). From this information one knows that Gislaved Däck AB produced a HA free winter tyre already in 1997. The source explains that the problem with summer tyres is that the braking distance on wet road is 75 80 % longer than on dry surface. It has to be compared with the best HA plasticized summer tyres where the difference in braking distance only was 20 - 25 % between summer and winter tyres.

2.1.2 Consumer's pattern

Based on the interviews with suppliers of playground equipment it must be concluded that the biggest amount of tyres used in playgrounds is worn passenger tyres. Typically the tyres have a rim diameter to either 13" or 14" tyres and they are 140-170 mm in width. One is informed that the tyres are washed down before use. It is also controlled that the steel wire reinforcement of the tyres do not penetrate the tread due to excessive worn. The tyres are often painted with a water based painting. As the painting after some time flake off the suppliers have chosen to follow an advice from Danish Technological Institute. The advice is to paint the tyres with a black painting

in stead of the blue and red colours previously used. By doing this it makes the flake off less visible as the tyres are black themselves due to the carbon black.

A certain use of new tyres for playgrounds also takes place. The new tyres are cheap passenger car tyres often produced in the Far East. Bridgestone and Continental passenger car tyres have been mentioned. The rim diameter is 13´´ and the profile height is 65% compared to the width.

It was stressed that tyres are popular as swings because one can avoid damages to the teeth's. Such damages are well known accidents from swings base don wood.

Lorry tyres are used only in limited amounts for swings. In those cases they are used for more than one child at the same time. More common is the use of lorry tyres for tight rope walking and crawl tunnels. Only worn lorry tyres are used and in general they are purchased for free.



Tractor tyres in limited amounts are used for sand pits. These tyres are all worn. One of the interviewed dealers of tractor tyres informed that it mainly were men which purchased tractor tyres for sand pits. Women were less interested because the child's clothes might be smudged due to rubber dust.

2.2 Purchased tyres and impact absorbing playground surfacing

Based on the information obtained from the interviews of playground equipment suppliers and playground inspectors with regard to the consumer pattern of the use of tyres and falling protection tiles for playgrounds Danish Technological Institute has purchased the below in Table 2.1listed samples of tyres. In the table is listed the type of tyre, the country where production of the tyre took place, worn or new and where the sample has been cut for the analysis. If more than one sample has been taken from the same tyre a separate laboratory marking has been made.

Table 2.1. Samples of tyres and impact absorbing playground surfacing for screening analysis

Sample no.	Mark	Type	Country	New/worn	Sample taken
1	Continental	Lorry	Germany	New	Tread
2	Continental	Lorry	Belgium	Worn	Tread
3	Michelin	Lorry		Worn	Side wall
4	Pirelli	Lorry		Worn	Side wall
5	Ergo Floor	Impact absorbing playground surfacing	Denmark	New	Upper face
6	Bilgutex	Impact absorbing playground surfacing	Denmark	New	Upper side
7	Taurus	Tractor	Hungary	New	Side wall
8	Pirelli	Tractor	Italy	New	Side wall
9	Roadstone	Passenger car	Korea	New	Side wall
10	Roadstone	Passenger car	Korea	Worn	Side wall
11	Roadstone	Passenger car	Korea	Worn	Tread
12	Nokia	Passenger car	Finland	New	Side wall
13	Nokia	Passenger car	Finland	New	Tread
14	Continental	Passenger car	Germany	New	Tread
15	Michelin	Passenger car	Great Britain	New	Tread
16	Michelin	Passenger car	Germany	Worn	Tread
17	Continental	Passenger car	South Africa	Worn	Tread
18	MarixGlacial	Passenger car	Italy	Worn	Tread
19	Barum Brilliant	Passenger car	Czech Republic	Worn	Tread
20	Hankook	Passenger car	Korea	Worn	Tread
21	Kumho Powerstar	Passenger car	Korea	Worn	Tread
22	Good Year	Passenger car	Italy	Worn	Tread

The amount and the types of PAHs in the tyres can differ depending on the supplier and the mineral oil used for the manufacturing of the tyre. The time for production and the location of the manufacturing plant (Europe or The Far East) might also influence the PAH pattern and amount in the tyre.

3 Chemical analysis

3.1 Analytical methods and sample preparation

3.1.1 Introduction

Methods based on gas chromatography, high pressure liquid chromatography or thin layer chromatography are suitable for the analysis of PAHs and aromatic amines in tyres or in fall protection tiles as well as migration of these substances to a contact medium. To perform the analysis a suitable sample prepa- ration is needed (downsizing of the tyre, extraction and concentration). Selection of method depends on the selectivity and detection limits of the method. All the three mentioned chromatographic methods could be used without problems (e.g. detection limits) so far the analysis is to be performed directly on the tyres. It is however judged that the highest selectivity is obtained in the quantitative analysis for individual chemical substances in the tyres and as migrants in the contact medias by using GC/MS analysis with deuterated internal standards added. For this reason GC/MS analysis has been the chosen method for all PAH analysis. The same has been the case for the analysis of p-phenylenediamines and aromatic amines. In the initial screening phase for aromatic amines thin layer chromatography combined with identification based on colour reaction with iodine has been the method used due to its simplicity.

3.1.2 Sample preparation and methods of analysis

3.1.2.1 Sample preparation

Tyres contain high amounts of steel cord as reinforcement. This makes sampling rather difficult. For the passenger car tyres it was possible to cut the samples by mean of a big band saw with diamond coated blade. Samples from the side wall of tractor and lorry tyres were cut by mean of a drilling machine with a special saw bit. The last samples were circular with a average diameter of 70 mm.

Samples from the tread from tractor and lorry tyres were cut by mean of a hobby knife.

The samples cut for the screening analysis and the quantitative analysis was pulverized after the rubber was cut free from the steel reinforcement with a hobby knife. The pulverization was made in a Tekmar A-10 laboratory mill. Before the milling the rubber samples were cut into small bites and cooled with liquid nitrogen. Further cooling was made by pouring a small amount of liquid nitrogen in the milling chamber before the milling bladders were activated. By this milling procedure a very fine rubber powder is obtained because the rubber at the low temperature get stiff and due to the stiffness easily is pulverized by the rotating milling bladders.



Passenger car tyre, sampling from tread



Tractor tyre, sampling from side wall

3.1.2.2 Extraction and cleaning up

The pulverized rubber samples from the tyres or the contact medium (sand, artificial sweat) were extracted one hour at 30 C with dichloromethane (CH_2Cl_2) in an ultrasound bath. This extraction was followed by an extraction with a mixture of dichloromethane and acetone (volume percent 50/50). These solvents are used on a routine base for the extraction of PAH and other polycyclic hydrocarbons from soth particles and organic aerosols (Feilberg, 1999; Feilberg et al., 2001). Due to the experience with this procedure it was adapted to the extraction of the tyres. The addition of acetone is made to assure that the more polar chemical components are efficiently extracted. The internal standards were added in the first extraction step. Two deuterated PAHs, pyrene-d_{10} and benzo(a)pyrene-d_{12} were used. The combined extracts were concentrated by mean of stream of N_2 at 40ºC to a final volume of approximately 1 ml. Then 2 ml cyclohexane was added and the extract was once again concentrated to 1 ml. This concentrate can be used directly for the analysis of aromatic amines as well as of the dominating PAHs. The analysis of other PAHs among these the most genotoxic e.g. benzo(a)pyrene demands a further cleaning up of the concentrate due to interfering substances in the complex matrix. To remove the interferences from the initial tyre extracts the following method base don a liquid-liquid extraction was used (Feilberg, 1999; Feilberg et al., 2001):

The concentrated cyclohexane extract was extracted with a mixture of dimethylformamide (DMF) and water (volume percent 90/10). By this first extraction step the PAHs and semi polar as well as polar chemical substances are separated from the most apolar substances (hydrocarbons). In the next step the DMF/water mixture is adjusted to a water content of 50 % by further addition of water. The PAH-fraction in this solvent mixture will inter the cyclohexane phase. The more polar chemical substances will remain in the DMF/water mixture. Each step in the procedure is carried out three times. The combined cyclohexane extracts are concentrated to a convenient volume (typically 1 ml). The concentrate (1 µl) is then injected into the injection port of the GC-MS instrument.

The recovery of PAHs for the method has former been determined to be in the range 75-100 % (Feilberg, 1999). The internal standards added in the first extraction step compensated for loses during the dedicated purification /concentration method.

The extracts were used for the screening analysis as well as for the quantitative investigations (see below).

The concentrations of the aromatic amines are so high, that it is not necessary to carry out a purification of this fraction. The analysis for aromatic amines was accordingly made directly on the crude solvent extracts of the tyres.

3.1.2.3 Gaschromatography with mass spectroscopic detection (GC-MS)

Equipment and parameters used:

GC:	HP 6890
Capillary column:	30 m x 0.25 mm x 0.25 µm RTX-5 (poly(di(5% phenyl/95 %methyl)siloxane))
Temperature programme:	80 °C (1.0 min.), ramp to 320 °C at 10 °C/min., hold for 5 min.
Injection temperature:	280 °C

Injection volume:	1 µl
Interface:	270 °C
Carrying gas:	Helium, constant flow: 1.5 ml min^{-1}
MS:	HP 5973
Detection:	m/z 50-350

The PAHs were identified and quantified based on their molecular-ion and by comparison of the retention times with retention times of authentic standards. The aromatic amines were identified and quantified based on the dominant ion (molecular ion or fragmentation ion).

Calibration has been made based on standard solutions of the chemical substances analysed in different concentrations within the measuring interval. Internal standards were added. The calibration curves obtained all showed a sati factoring linearity with regression coefficients (R2) > 0.99. The analytical results are reported with an estimated uncertainty equal to 10%.

The detection limits for pure solutions were on the instrument used for the analysis in the order of 1-20 pg substance injected. This corresponds to detection limits in the range 0.1-2 ng/ml for concentrated samples with a final volume of 100 µl. The detection limit for an amount of sample equal to 500 mg tyre will be in the range 0.2-4 µg/kg. Theoretically it is possible to obtain lower detection limits by extracting a higher amount of tyre rubber or by further concentration of the final volume to an even smaller volume (e.g. 10 µl). From a practical point of view the gain in detection limits will depend on the purity and complexity of the sample.

The detection limits for the different types of samples are estimated from the actual samples and thus compensate for the purity, composition and concentration steps as will as the amount of sample extracted. The individual detection limits are stated in the following section with the presentation of the results. The actual detection limits are estimated from the concentration which equals a signal – noise ratio of 3.

3.1.2.4 TLC with Iodine visualisation

The rubber powder (2 g) is weighed. The powder is transferred to a 100 ml glass bottle and is extracted with 50 ml dichloromethane for one hour after transfer of the bottle to a shaking bath. The extract is decanted from the rubber powder and further 10 ml dichloromethane is added to the bottle which is shaken for a short time. The dichloromethane is decanted and combined with the first extract.

The dichloromethane extract is concentrated by mean of a rotational evaporator at maximum 30 °C to approximately 1 ml. The concentrate is transferred to a little test tube, which can be sealed with a tight lid. The original glass bottle is flushed with a little dichloromethane and transferred to the test tube. The amount is adjusted to 2 ml in final volume

The thinlayer chromatographic screening for antiozonantes has been performed according to the principles in ISO 4645 (1995)"Rubber and rubber products - Guide to the identification of antidegradants – Thin layer chromatographic methods". The elution solvent used correspond to method A in the standard: n-heptane:ethylacetate 90:10 (volume percent).
The thin layer plates used for the analysis are Merck (article 1.11798) 20 x 20 cm Silica gel 60 F 254 with concentration zones. 5 µl of the solutions and

standards listed below are put on the plates. After the plates have been developed in the chosen elution solvent, the solvent is allowed to evaporate in a hood before visual judgement.

The TLC plates are first judged under UV light, then visually after one hour and finally after treatment with iodine in a chromatographic developing tank. The results from the visual inspection and the iodine treated TLC plates were documented as photos.

The references used for the TLC screening of aromatic amines are listed in Table 3.1.

Table 3.1. References used for the TLC-screening

Sample mark	CAS-number	Short name	Chemical name
A	26603-23-6	ODPA	Oktylated diphenylamine
B	-		Bisdiphenylamine
C	106-50-3		P-Phenylendiamine
D	93-46-9	DNPD	N,N´-di-beta-naphtyl-p-phenylen-diamine
E	74-31-7	DPPD	N,N´-diphenyl- p-phenylenamine
F	793-24-8	6PPD	(1,3-dimethyl-butyl) N´-isopropyl-N´-phenyl-p-phenylendiamine
E	101-72-4	IPPD	N´-isopropyl-N´-phenyl-p-phenylendiamine
F	90-30-2	PAN	1- Naphtyl phenyl amine
G	-	TMQ	2,2,4-trimethyl-1,2-dihydroquinoline

The reference substances were dissolved in dichloromethane as 1% solutions (0.1 g /10 ml).

3.2 Screeningsanalysis

3.2.1 GC/MS analysis. Results

The relative amounts determined of three typical PAHs from the screening analysis of the tyres are listed in the Figure 3.1 below.

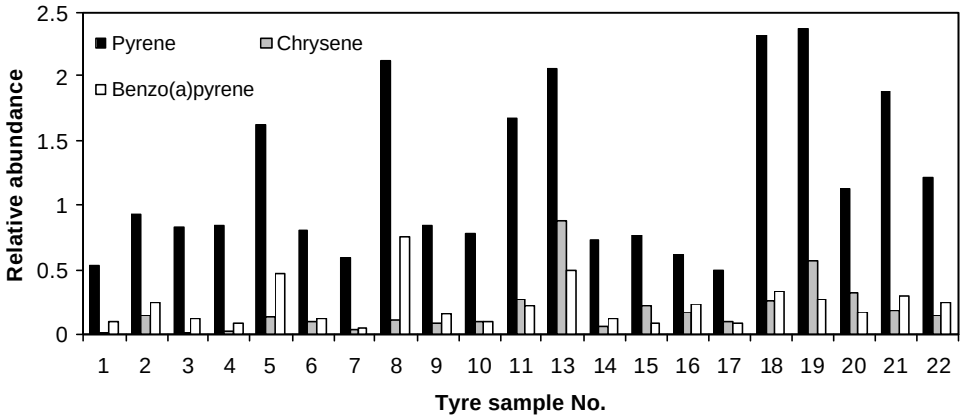


Figure 3.1. Relative amounts of selected PAHs in samples taken from the investigated tyres

A number of PAHs as well as aromatic amines were identified in all samples from the tyres.

The PAHs and aromatic amines identified and detected in this investigation are listed in Table 3.1 below.

Table 3.1. Statistics on identified and detected PAHs and aromatic amines

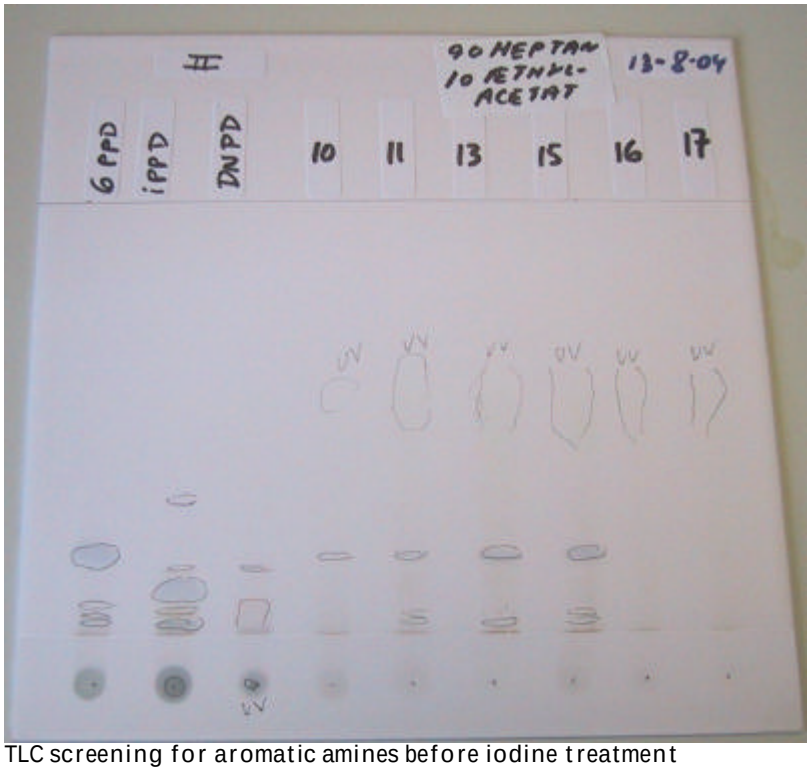
Chemical substance	Number of samples
Fluoranthene	21
Pyrene	21
Benzo(a)fluorine	0
Benz(a)anthracene	20
Chrysene	21
Benzo(b+j+k)fluoranthene	20
Benzo(e)pyrene	21
Benzo(a)pyrene	21
Indeno(1,2,3-cd)pyrene	16
Benzo(ghi)perylene	21
Dibenz(ah)anthracene	4
Dibenz(aj)anthracene	0
Aniline	0
p-Phenylendiamine	0
N-(1,3-dimethylbutyl)-N´-phenyl-p-phenylendiamine (6PPD)	21
N-isopropyl-N´-phenyl-p-phenylendiamine (IPPD)	18
N,N´-diphenyl-p-phenylendiamine (DPPD)	9
1-naphthyl-phenyl-amine (PAN)	1
N,N´-di-beta-naphthyl-p-phenylen-diamine (DNPD)	0

To get a better judgement of the relative content of PAHs in the tyres and to help the selection of tyres for quantitative analysis internal standards were added to the samples at the first extraction step. For selected PAHs the relative amount is presented as the chromatographic signal (the area below the peak) divided with the signal from the internal standard. The relationship is shown in Table 3.1. The most volatile components among the investigated PAHs i.e. fluoranthene og pyrene (molecular weight 202), are found in the highest concentrations. Dibenzo(ah)anthracene is identified in 4 of the 21 samples investigated. Benzo(a)fluorene and dibenz(aj)anthracene has not been detected in any of the samples investigated.

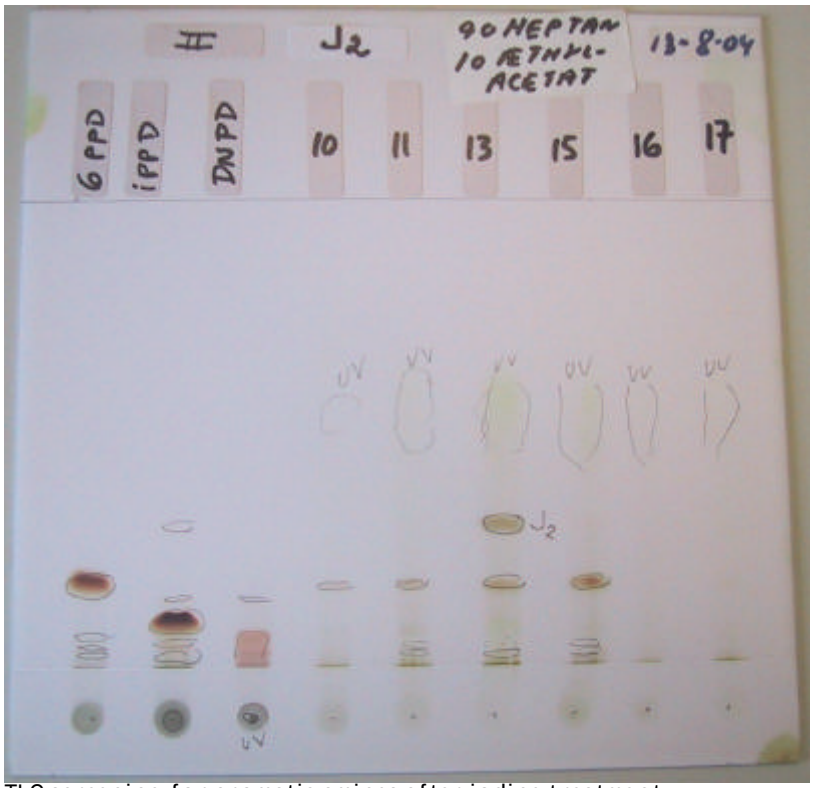
The following aromatic amines were in addition detected in the tyre solvent extracts: 6PPD, IPPD, DPPD, PAN. The most significant chemical component was 6PPD, while IPPD was present in most of the samples. For a few samples a higher signal was obtained for IPPD than for 6PPD.

3.2.2 TLC analysis, results

The results from the thin layer chromatographic screening are in accordance with the results from the GC/MS screening, both with regard to the concentration level and identity of the chemical substances. In total 13 screenings were performed by TLC. The photos below illustrate results from the screening.



TLC screening for aromatic amines before iodine treatment



TLC screening for aromatic amines after iodine treatment

3.3 Quantitative analysis

3.3.1 Selection of tyres for quantitative analysis

Base don the results from the initial screening analysis the following samples were selected for the quantitative analysis for content of PAHs and aromatic amines.

Table 3.2. Selected samples for quantitative analysis

Sample mark	Sample No.
Continental lorry, worn, tread	2
Ergofloor faldunderlagsflise, new	5
Roadstone, passenger car. worn, side wall	10
Roadstone, passenger car. worn, tread	11
Nokia, passenger car. new, tread	13
Barum Brilliant, passenger car , worn, tread	19

3.3.2 Results

The quantitative results for content of PAHs and aromatic amines in tyres are presented in Table 3.3.

The results for three selected PAHs, pyrene, chrysene og benzo(a)pyrene as well as the total amount of PAHs are illustrated graphically in Figure 3.2.

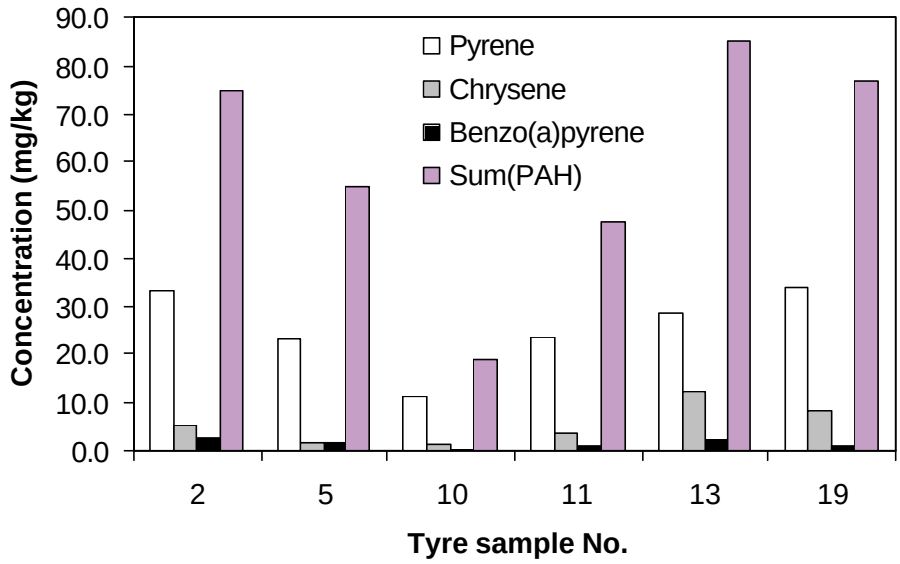


Figure 3.2. Concentration of selected PAHs and the sum of all the PAHs in the 6 samples taken from tyres for quantitative analysis.

The quantitative analysis confirms that the dominating PAHs are the ones who have a relative low molecular weight. Pyrene alone counts for approximately 50% of the total amounts of PAHs detected. The highest concentration of ? PAHs is recognised in a new passenger car tyre (sample no. 13). The lowest concentration is detected in side wall rubber from a worn passenger car tyre (sample no.10).

The aromatic amines are present in much higher concentrations. This finding is not very surprising because these substances are added to the tyres in high concentrations to prevent degradation of the rubber. The dominant chemical substance is in general 6PPD, but IPPD is also present in considerable amounts. The highest concentration of 6PPD has been measured in a new

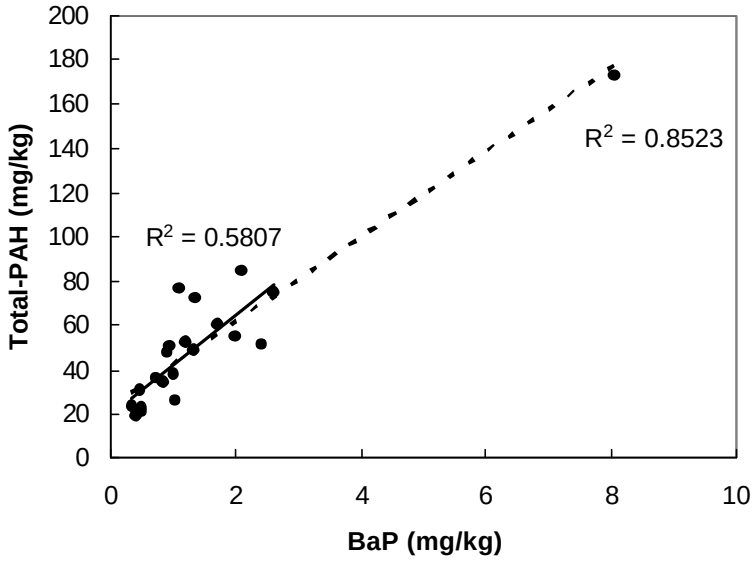
passenger car tyre (sample no. 13). The lowest amounts of aromatic amines has been measured in an impact absorbing playground surfacing (sample no. 5).

Table 3.3. Found concentrations of individual chemical substances in tyres (mg/kg)

Sample no.	2	5	10	11	13	19	Detec-tion limit
Fluoranthene	15.4	10.6	2.1	4.7	16.0	13.4	0.02
Pyrene	33.2	23.2	11.4	23.6	28.8	34.0	0.02
Benz(a)fluorene	ID	ID	ID	ID	ID	Id	0.02
Benz(a)-antracene	0.9	1.2	0.2	1.0	ID	0.8	0.07
Chrysene	5.3	2.0	1.4	3.7	12.3	8.2	0.07
Benz(b+j+k)fluoranthene[a]	2.1	3.0	0.3	1.9	1.9	1.7	0.04
Benz(e)pyrene	5.9	4.1	0.9	3.8	9.6	9.2	0.04
Benz(a)pyrene	2.6	2.0	0.4	0.9	2.1	1.1	0.06
Dibenz(a,j)anthracene	ID	ID	ID	ID	ID	ID	0.13
Dibenz(a,h)anthracene	0.8	ID	ID	ID	1.3	ID	0.13
Indeno(1,2,3-c,d)pyrene	1.0	1.4	0.2	0,7	2.0	1.1	0.08
Benz(ghi)perylene	7.3	7.0	2.1	6.9	10.7	7.0	0.15
DPPD	0.0	7.7	ID	ID	1.2	37.6	1[b]
6PPD	259.0	235.7	1957.3	1297.3	2477.6	262.6	1[b]
IPPD	340.6	3.6	39.2	19.5	3.2	355.5	1[b]
PAN	IP	4.3	IP	IP	IP	IP	1[b]

[a]Benz(b+j+k)fluoranthene represents the sum of benz(b)fluoranthene, benz(j)fluoranthene and benz(k)fluoranthene.

[b] The detection limits for the aromatic amines are based on the not concentrated samples as the capacity of the instrument is excessed, if these substances are analysed after concentration.
"IP" means " not detected"



Figur 3.2 Correlation between the sum of PAH´s and benz(a)pyrene. The stiplede line represents a linear regression base don all numbers while the solid line represents a linear regression, where the sample with the highest concentrations is excluded.

It is often assumed that benz(a)pyrene is a PAH-indicator of relevance. A statistical investigation has been made to confirm if this is also the case for the content of PAHs in rubber formulations for tyres. In Figur 3.2 a plot of the concentrations of analysed PAHs from all 21 samples analysed has been made. The total PAH has been plotted against the corresponding concentrations of benzo(a)pyrene. The correlations found are statistical signifikant (P<0,005; n=20/21), either one omit the sample with a very high

amount of PAH (tractor tyre) or include the sample in the statistic. The correlation between the individual PAHs and benzo(a)pyren is also signifikant ($P<0,05$; $n=15-21$). It must be concluded that benzo(a)pyrene is useful as indicator for the PAH content in tyres.

3.4 Migration tests

3.4.1 Selection of tyres for the migration tests

Based on the results from the initial screening analysis the following samples were selected for the migration studies. The selection was done not only due to the screening analysis but also based on the results from the quantitative analysis. The migration study includes the migration of PAHs as well as aromatic amines.

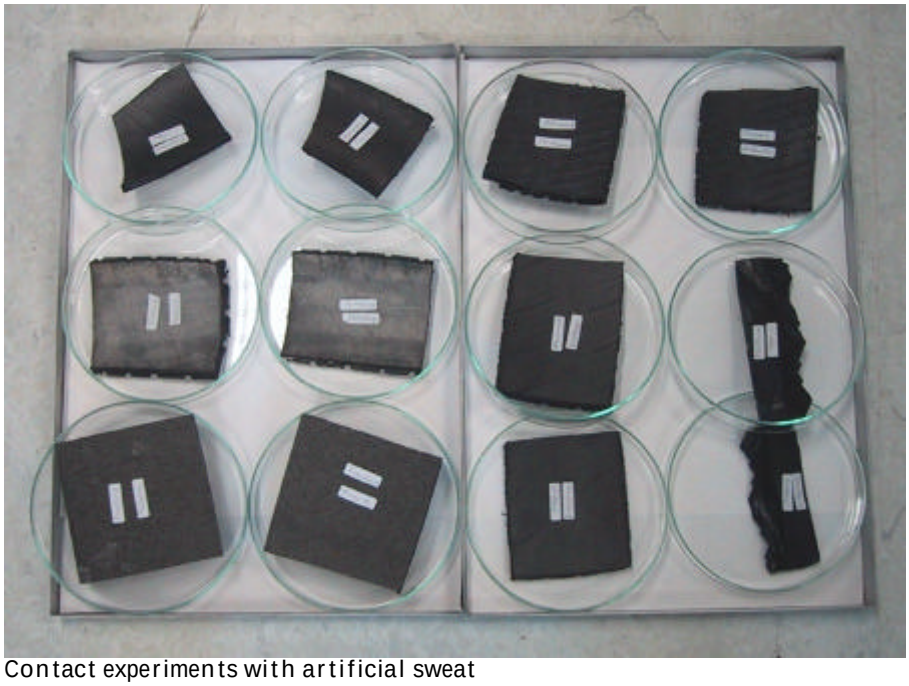
Table 3.4. Samples selected for migration tests

Sample name	Sample number
Continental lorry, second-hand, tread	2
Ergofloor impact absorbing playground surfacing, new	5
Roadstone, passenger car. Second-hand, tread	10
Roadstone, passenger car. Second-hand, tread	11
Nokia, passenger car. New, tread	13
Barum Brilliant, passenger car , second-hand, tread	19

It was decided at an early stage that the second-hand tractor tyre from Pirelli should be used for the full scale experiment.

3.4.1.1 Experimental details

A known area of the sample was exposed to artificial sweat for one hour at 30 C. The artificial sweat was prepared according to ISO 12870:1997 (E) ”Øjenoptik, Brillestel, Grundlæggende krav og prøvningsmetoder pkt. 8.5.1.5 Artificial sweat solution. The artificial sweat is composed of 50 g lactic acid and 100 g sodium chloride dissolved in 900 ml water according to quality 3 i ISO 3696 and diluted to a 1 l final volume. The area/volume of artificial sweat during contact exposure was in a ratio as specified in Table 3.5 below. As the tyres have different pattern and geometries the ratio has been determined in such a way that the contact was one- sided. After the exposure period the rubber surface was rinsed with artificial sweat and finally with demineralised water. The amounts of rinsing liquids used are listed in Table 3.5. The experiments were conducted as double determinations.



Contact experiments with artificial sweat

The combined fractions of artificial sweat and distilled water are washed to a final volume according to the scheme below, are filtered through a filter paper and extracted twice with 2 times 30 – 50 ml of methylenechloride. The methylenechloride phase is dried over dry sodium sulphate for 2 hours. After filtration the methylenechloride phase is concentrated to a final volume of 1 ml internal standard is added to the first extract.

Table 3.5. Experimental parameters for the migration tests

Sample mark	Sample number	Weight, g	Area, cm2	Contact-sweat, ml	Rinsing-sweat, ml	Rinsing-water, ml
Continental llorry, second-hand, tread	2	59.25 61.61	59.7 65.8	60 60	50 50	50 50
Ergofloor falling protection tiles, new	5	553.43 532.32	141.5 137.8	60 60	50 50	50 50
Roadstone, passenger car. Second-hand, sidewall	10	66.28 60.74	83.6 80.0	100-120 100-120	30 30	50 50
Roadstone, passenger car. Second-hand, tread	11	152.41 167.25	125.0 135.1	120 120	40 40	50 50
Nokia, passenger car. new, tread	13	179.90 174.44	125.4 123.3	200 200	50 50	50 50

Sample mark	Sample number	Weight, g	Area, cm2	Contact-sweat, ml	Rinsing-sweat, ml	Rinsing-water, ml
Barum Brilliant, passenger car, second-hand, tread	19	153.82 151.53	122.2 116.9	100 100	30 30	50 50

The combined fractions for each sample of contact sweat, rinsing sweat and rinsing water were filtered through filter paper to remove lose rubber particles. The filtrate was extracted twice with two times 30-50 ml methylenechloride. The methylenechloride phase was dried two hours over dehydrated sodium sulphate.

The methylenchloride phase was filtered from the sodium sulphate and concentrated to a final volume of 1 ml. The concentrate was analysed for PAHs and aromatic amines after addition of internal standard to the original extract.

3.4.1.2 Results

The concentrated extract was quantitatively analysed for content of PAHs and aromatic amines. The results are recorded in Table 3.6 below:

Table 3.6. Migration of identified chemical substances. Found concentrations (ng cm-^{2}) and with corresponding detection limits (DL). The results are reported as a mean value of two samples ± 1 standarddeviation.

Sample no.	2	5	10	11	13	19	DL
Fluoran-thene	0.033 ± 0.012	0.029 ± 0.009	0.052 ± 0.009	0.033 ± 0.004	0.277 ± 0.074	0.049 ± 0.006	0.0006
Pyrene	0.036 ± 0.020	0.032 ± 0.006	0.082 ± 0.039	0.059 ± 0.008	0.487 ± 0.021	0.066 ± 0.008	0.0009
6PPD	0.948 ± 0.120	5.083 ± 0.232	19.267 ± 8.678	44.101 ± 32.277	49.496 ± 20.282	0.735 ± 0.063	0.005
IPPD	5.817 ± 0.187	0.502 ± 0.035	0.401 ± 0.042	ID	0.118 ± 0.167	10.197 ± 0.773	0.005

”ID” means ”not detected”

Table 3.6 illustrates that measurable amounts of the following chemical substances has been detected:

- Fluoranthene
- Pyrene
- 6PPD
- IPPD

Other PAHs and aromatic amines were not detected.

The results reveal that a significant higher migration of the more water soluble amines takes place in comparison with the PAHs. This finding is not only due to a higher amount of amines in the tyres, but also due to the higher solubility of the aromatic amines in water. The water solubility is higher as a consequence of the two nitrogen atoms in the molecules.

3.4.2 Full scale experiment

3.4.2.1 Experiment details

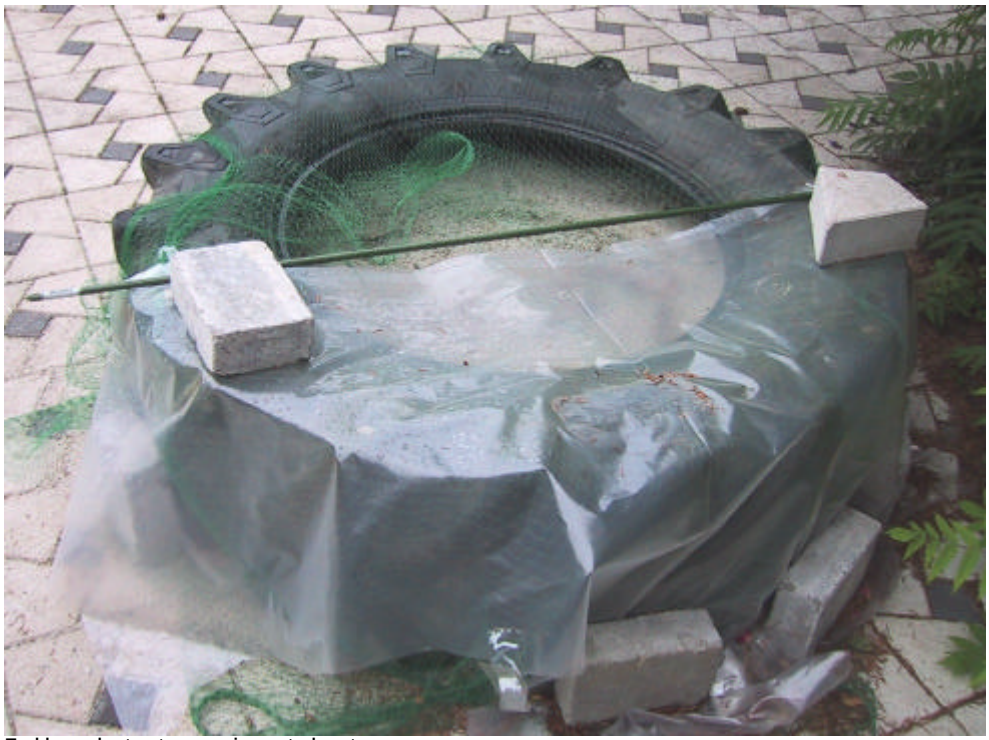
The tractor tyre was after a sample was taken for quantitative analysis for PAHs and aromatic amines installed in a cement tile based sun yard. The sun yard was situated in Hoejbjerg, south of Aarhus approx. 35 m from a not very busy road. The traffic is not very frequent as "bumps" prevent usually traffic. The road is due to the bumps mainly used by the inhabitants along the road.

The rubber from the tractor tyre was analysed quantitatively for content of PAHs and aromatic amines. The results are presented in Table 3.7.

Table 3.7. Content of PAHs and aromatic amines in Pirelli tractor tyre.

Chemical substance	Concentration mg/kg
Fluoranthene	37.4
Pyrene	75.6
Benz(a)anthracene	2.8
Chrysene	4.1
Benzo(b+j+k)fluoranthene	8.0
Benzo(e)pyrene	10.3
Benzo(a)pyrene	8.1
Indeno(1,2,3-cd)pyrene	4.4
Benzo(ghi)perylene	21.5
? (PAH)	172.7
N-(1,3-dimethylbutyl)-N´-phenyl-p-phenylendiamine (6PPD)	535.8
N-isopropyl-N´-phenyl-p-phenylendiamine (IPPD)	5.9
N,N´-diphenyl-p-phenylendiamine (DPPD)	36.4

The tractor tyre was filled with sand until approx. 15 cm from the upper edge. A sample blind was drawn from the sand before start of the experiment. Half part of the sandpit was covered by a PE foil with the aim of being able to draw reference samples not influenced by rainfall.



Full scale test experimental set-up

Samples of the sand were then taken for analysis of the migration of PAHs and aromatic amines during the exposure period. The samples were drawn at the edge of the tractor tyre, where it was easily seen that rain water has dripped and made marks in the sand. The size of the samples of sand drawn for analysis was approximately 500 g sand for the individual samples drawn. In total three samplings were made. The experiment was initiated 4 July 2004 and the samples were drawn 11 July, 4 Th. August and 15Th. August 2004. When the samples were drawn 11 July, the PE foil was not protecting the ½ part of the sand pit due to a heavy storm. For this reason no reference sample could be drawn this day. The exposure period was very rainfull. From DMI information on the precise amount of rain has been obtained during the exposure experiment. I hele perioden faldt der 84 mm of rain has been measured on DMI´s weather station 22361, renseanlægget, Viby J. The station is located within a radius of 5 km from Højbjerg. In the first exposure period 4/7-11/7 2004 the rainfall was 56 mm. From 11/7-4/8 2004 the rainfall was 24 mm. In the last period of exposure a rainfall of 4 mm was recorded. The 3.2 mm of the 4 mm was registered shortly before the sampling (13/8 2004).

Influence from sun and heat also influence the migration. On one hand the sun might in a photochemical way influence the migration; on the other hand heat will promote the migration of PAHs as well as of aromatic amines.

The analytical results are presented in Table 3.8 below:

Table 3.8. Found values for content of individual chemical substances in sand (µg kg^{-1} (wet weight)) with corresponding detection limits (DL).

	Ref. start	Sample 11/7	Sample 4/8	Ref. 4/8	Sample 15/8	Ref. 15/8	DL
Fluoranthene	1.67	3.78	2.76	5.40	10.12	2.89	0.002
Pyrene	1.12	6.01	4.20	6.31	12.57	3.64	0.004
Benz(a)anthracene	0.25	0.42	0.33	0.47	1.02	0.50	0.008
Chrysene	1.42	1.15	1.08	1.71	2.27	1.96	0.008
Benz(b+j+k)fluoranthene	0.10	0.19	0.15	0.22	0.25	0.22	0.002
Benz(e)pyrene	0.06	0.11	0.07	0.13	0.18	0.14	0.002
Benz(a)pyrene	0.03	0.09	0.06	0.07	0.09	0.07	0.002
Dibenz(ah)anthracene	IP	IP	0.01	IP	IP	0.01	0.001
Indeno(1,2,3-cd)pyrene	0.02	0.06	0.05	0.05	0.08	0.05	0.001
Benz(ghi)perylene	0.03	0.12	0.09	0.12	0.15	0.11	0.001
6PPD	IP	33.44	21.91	5.88	109.84	IP	0.1
IPPD	IP	2.47	0.71	0.43	4.56	IP	0.1

In Figure 3.3 A-C. the change in concentration pf PAHs and aromatic amines with time is illustrated for pyrene, benzo(a)pyrene and 6PPD.

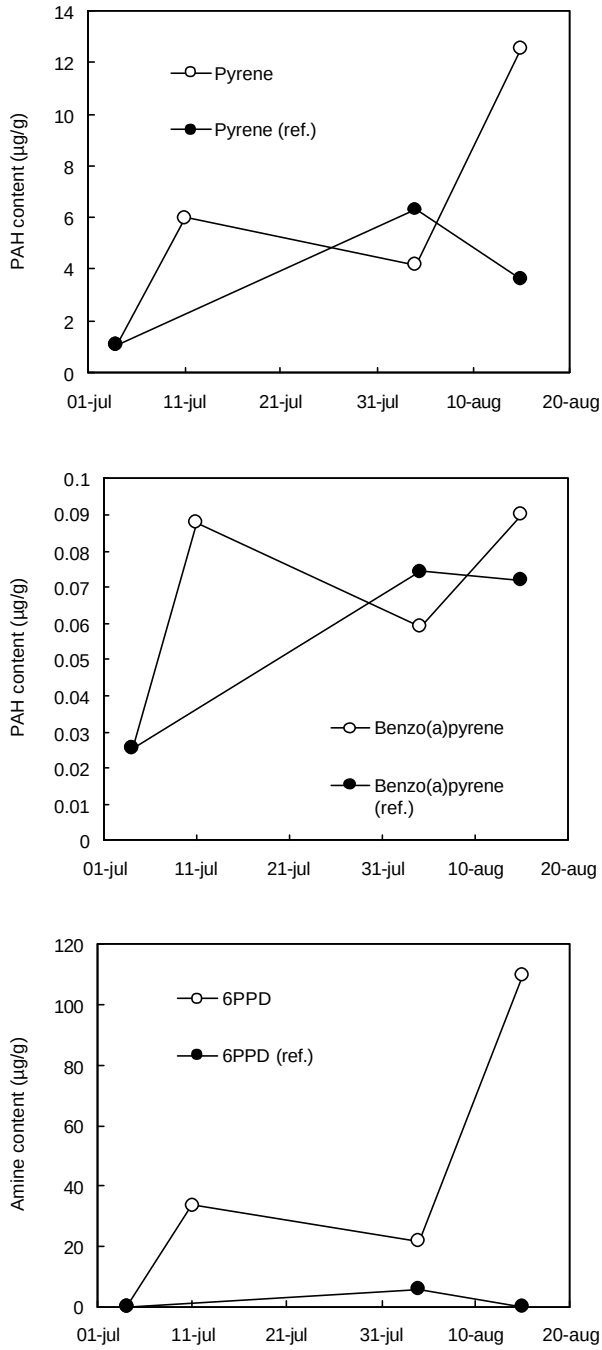


Figure 3.3 A-C. Change in concentration (wet weight) of selected PAHs and 6PPD with time in the sand covered by PE foil sand. O Represents samples of sand exposed to rain, while ● represents samples protected against rain with PE foil (ref.).

From the figures it can be seen that a rise in the concentration of the PAHs and aromatic amines happens when one compares the actual concentrations with the initial concentrations. As can be seen a rise in the concentration of PAHs and amines happens in all cases when one compares with the initial concentration. Aromatic amines were as expected not detected in the sand before exposure to the tractor tyre. In the case of PAHs a rise in concentration is observed both for the sample taken where the sand is uncovered and where the sand was protected with PE foil against exposure to rain.

In principle three ways for the contamination of the sand with PAHs are possible: migration from the tractor tyre, atmospheric dry deposition and atmospheric wet deposition (rain water).

The observation made that a rise in concentration in both covered and uncovered sand however indicates that the content of PAH in the sand during exposure is not explained by migration of PAHs from the tyre. The rise in the concentration can not alone be explained as due to wet deposition from the atmosphere.

A more detailed information regarding PAH sources is obtained by a study of the mutual concentrations of PAHs with the same molecular weight. They will possess approximately the same volatility and water solubility. The mutual concentrations of fluoranthene and pyrene, benz(a)anthracene and chrysene, benzo(a)pyrene and benzo(e)pyrene, benzo(b+j+k)fluoranthene and benz(e)pyrene, indeno(1,2,3-cd)pyrene and benzo(ghi)perylene is illustrated in Figure 3.4 In Figure 3.4 one can se that the mutual concentrations of PAHs in the tyre deviates from the mutual concentrations in the sand. The mutual concentrations of PAHs in the samples drawn from the sand are similar, if one excludes benz(a)anthracene and chrysene. If the migration from the tyre should be the only or dominating source for the contamination of the sand the concentrations in Figure 3.4 should be comparable with the PAH profile for the tyre. It is easily seen that this is not the case. It should be mentioned that the uncertainty in the PAH profile for the same sample can be neglected as most of the uncertainties from the sample preparation is not existing due to the addition of deuterated internal standards. The results depicted in Figure 3.4 underline that the PAH contamination of the sand primarily is due to deposition and only to a minor degree if any to the migration from the tyre.

Based on all the results of the experiment it is judged that atmospheric dry position is the most important source for the PAHs.

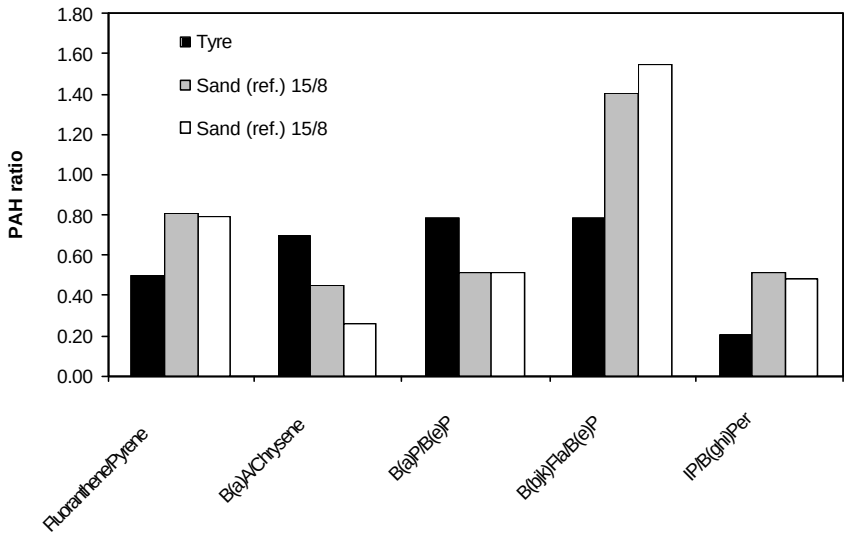


Figure 3.4. PAH ratio in full scale experiment

It must be stressed that a final conclusion regarding the contribution from the different sources mentioned above demands a more comprehensive investigation and more analytical measurements.

The concentrations of the two aromatic amines detected in the sand 6PPD and IPPD are in all measurements considerable higher in the sand exposed to rain in comparison to the sand covered by the PE foil (reference sand). As one can exclude atmospheric deposition it must be concluded that the aromatic amines migrate from the tyre to the sand due to the exposure to rain water and heat. This conclusion is a logical consequence of the much higher solubility in water of the aromatic amines compared to the PAHs.

Furthermore the aromatic amines are present in much higher concentrations in the tyre and tailor-made to migrate to the surface of the rubber to protect the rubber against degradation from the weather conditions.

4 Health Assessment

4.1 Introduction

In this section, potential health effects from the detected substances in tyres are assessed. The assessment is based upon these scenarios that were chosen and carried out in phase 1 of the project.

The focus of the assessment is aimed towards toddlers and children, who are the major groups for exposure.

For each of the identified and quantified substances information of the substances identity as well as chemical and physical properties are presented. This will include data on material state, melting point, boiling point, density, vapour pressure and solubility.

A search in the open literature has been performed. Focus has been on the ability of skin absorption and effects by oral intake. The most important test results, the effects and circumstances are presented. The aim was to find data for NOAEL/LOAEL (No or low adverse effect levels) for the selected substances or other relevant data if available. Special focus was on potential long term effects, especially carcinogenic effects.

4.1.1 Scenarios

Regarding exposure, two scenarios are selected:

A. One scenario, where toddlers and children were exposed by skin contact. It is assumed that parts of the person's arms, hands, legs and feet are exposed for one hour daily, and that the exposed area is 200 cm^2. As a worst case scenario, a toddler with a body weight of 10 kg was selected.

B. One scenario, where toddlers are exposed by oral intake of polluted sand. It is assumed that a toddler is able to eat up to 10 grams of polluted sand per day.

The exposure scenarios are defined according to the EU's Technical Guidens Document (TGD, 2003).

The exposure from scenario A is calculated by:

Intake per day per kg b.w. = [M × A × H × F] / b.w. {equation 1}

b.w.: Body weight (kg)
M: Migrated amount of substance ($mg/cm^2 \times h$)
A: Exposed skin area (cm^2)
H: Time of exposure per day (hours)
F: Fraction absorbed

Equation 1 can be reduced to:

Intake per day per kg body weight (mg/kg)

= M × F × 20 (mg/kg) {equation 2}

Exposure from scenario B can be calculated by:

Intake per day per kg b.w. = [C × W × F] / b.w {equation 3}

b.w.: Body weight (kg)
C: Concentration in sand (mg/kg)
W: Weight of sand eaten (gram)
F: Fraction absorbed

Intake per day per kg b.w. = C × F × 0.001 (mg/kg) {equation 4}

The variables M and C in equation 2 and 4 are measured (see chapter 3). In scenario A the variable F is assumed to be 10 percent if $\log K_{ow}$ is higher than 4 and 100 percent if $\log K_{ow}$ is equal to or less than 4. For scenario B - oral exposure - F is assumed to 100 percent (TDG, 2003).

Based upon the estimated intake in the two scenarios it will be possible to point out the potential health risks for toddlers and children when they are using tyres on a playground.

4.1.2 Identified substances

In the tests of the sand exposed to a tyre the following substances were identified:

- Fluoranthene
- Pyrene
- 6PPD
- IPPD
- Benzo(a)anthracen
- Chrysene
- Benzo(b+j+k)fluoranthene
- Benzo(e)pyrene
- Benzo(a)pyrene
- Dibenz(ah)anthracene
- Indeno(1,2,3-cd)pyrene
- Benzo(ghi)perylene

In the migration tests the following substances were identified

- Fluoranthene
- Pyren
- 6PPD
- IPPD

The first four substances identified in the sand are also found in the migration test. These are the most important substances and will be assessed both with respect to dermal and oral uptake. These are assessed in section 4.2. The

substance benzo(a)pyrene is also included, because it has been used as a marker for PAH-compounds.

The other substances are detected in the test of the sand in relatively small amounts (see chapter 3). They are evaluated with respect to oral uptake and the potential effects for this group of substances compared with the other four substances. The results are described in section 4.3.

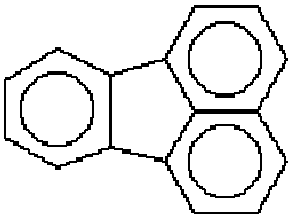
4.2 Selected substances

These substances were both identified in the analysis of sand and in the migration tests.

4.2.1 Fluoranthene

4.2.1.1 Identity

Name	Fluoranthene
CAS-number.	206-44-0
EINECS number.	205-912-4
Molecular formula	$C_{16}H_{10}$
Molecular structure	



Molecular weight	202.26 grams/mole
Synonyms	1,2-(1,8-Naphthalenediyl)benzene 1,2-(1,8-Naphthylene)benzene 1,2-Benzacenaphthene Benzene, 1,2-(1,8-naphthalenediyl)- Benzene, 1,2-(1,8-naphthylene)- Benzo(jk)fluorine

Fluoranthene exists as pale yellow needles or plates. The substance has a meting point of 111 ?C, a boiling point of 375 ?C and a density of 1.252 at 0/4 ?C (Lide 1995; ATSDR 1990).

Fluoranthene is almost insoluble in water (IARC, 1983), but is soluble in alcohol, ether, benzene and acetic acid (Lide, 1995). It has a vapour pressure of 1.9 x 10^{-3} mm Hg at 25 ?C and a log K_{OW} of 5.2 (U.S.EPA, 1987).

4.2.1.2 Detected quantities

The test result from the analysis of un-exposed sand showed that the sand contained 1.7 µg fluoranthene per kg. After exposure in 2 month the content of fluoranthene was 10.1 µg per kg. This means that 8.4 µg per kg originates from the tyre.

From the migration test the results showed a migration of about 0.05 ng /(cm^2 ×hour) for most of the samples. One sample showed a migration of 0.28 ng /(cm^2 ×hour).

4.2.1.3 Function of the substance
The substance fluoranthene does not have any technical function as such. It is a component in high aromatic oils used as a plasticizer in the rubber mixture.

4.2.1.4 Classification and TLVs
Fluoranthene is not classified in the Annex 1 of Directive 67/548/EEC.

No threshold limits for the substance has been found.

4.2.1.5 Health Effects
The health effects are described in the report "Toxicity Summary for Fluoranthene" by Faust, 1993. Although this report is relatively old a search in IRIS and HSDB provide the same results.

Acute toxicity
Acute toxicity data for animals include

- an oral test on LD_{50} of 2000 mg/kg for rats
- a dermal LD_{50} of 3180 mg/kg for rabbits
- an interavenous LD_{50} of 100 mg/kg for mice

These data do not indicate any serious health hazard based on acute toxicity.

Fluoranthene has been shown to be photosensitising, enhancing erythema elicited by ultraviolet radiation in guinea pig skin. Also irritation to the eyes of rabbits has been shown.

No data on inhalation were available.

Sub-chronic toxicity
In a sub-chronic study (U.S.EPA, 1988) mice were administered 0, 125, 250 or 500 mg/kg per day for 13 weeks. At doses of 250 mg/kg produced kidney damages, increased liver weights, and increased liver enzyme levels. These effects were also seen at doses of 125 mg/kg but were not considered statistically significant or adverse.

Based on this study NOAEL and LOAEL were determined to:

NOAEL: 125 mg/kg/day
LOAEL: 250 mg/kg/day

To derive the sub-chronic Reference dose, RfD an uncertainty factor of 300 is used, reflecting a factor of 10 for intra- and interspecies variation and a factor of 3 for lack of reproductive/developmental toxicity and data for a second species.

RfD, sub-chronic, oral: 0.4 mg per kg per day.

No information regarding inhalation or dermal exposure was available.

Chronic toxicity
Fluoranthene is not classified as carcinogen to humans, because of no human data and inadequate data from animal tests.

The primary target organs are the kidneys and the liver. Information on other target organs was not available.

The sub-chronic study has been used for determination of a chronic RfD using a safety factor of 3000, - where a safety factor of 10 is used for using a sub-chronic test.

RfD, chronic, oral: 0.04 mg per kg per day = 40 µg per kg per day

In IRIS it is stated that the confidence in the RfD is low, because of medium confidence in the principal study and low confidence in the database.

Some tests where animals were painted with a fluoranthene solution are reported and showed no development of skin tumours. The tests are, however, judged inadequate, because no increases in tumour incidences were observed and the tested group sizes were small.

4.2.1.6 Exposure scenarios

Here is assumed 100percent absorption (F) for oral intake and 10 percent for dermal exposure based on a high log K_{ow} (5.2).

A child will by oral intake be exposed to:

Intake per day per kg b.w. = C × F × 0.001
= 10.1 µg/kg × 1× 0.001
= 0.01 µg/kg

By dermal exposure is assumed that the intake will be:

Intake per day per kg b.w. = M × F × 20
= 0.28 ng/kg ×0.1× 20
= 0.56 ng/kg

4.2.1.7 Assessment

The substance fluoranthene causes a potential health risk related to long tern exposure. This is based on test with mice where damages to liver and kidneys have been observed. Fluoranthene is a substance, which does not cause any acute heath effects, or irritations based on the available information.

A reference dose of 40 µg per kg b.w. per day by oral intake has been determined. The scenarios showed:

- oral intake by children will not exceed 0.01 µg per kg b.w. per day
- dermal uptake by children will not exceed 0.0005 µg per kg b.w. per day

Compared with the NOAEL a margin of safety (MOS) can be estimated to more than 1.000.000.

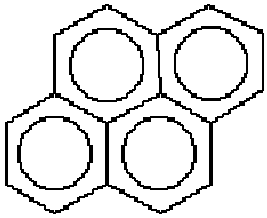
Conclusion

It can be concluded that the potential health risk from fluoranthene is insignificant.

4.2.2 Pyrene

4.2.2.1 Identity

Name	Pyrene
CAS-number.	129-00-0
EINECS number.	204-927-3
Molecular formula	$C_{16}H_{10}$
Molecular structure	



Molecular weight	202.26 grams/mole
Synonyms	Benzo(def)phenanthrene
	CCRIS 1256
	Pyren [German]
	beta-Pyrene

Pure pyrene is colourless crystals with a melting point of 151°C and a boiling point of 404 °C. The density of the substance is 1.271 grams/cm^3 at 23°C (Lide, D.R. 1995).

The vapour pressure of the substance is 8.92×10^{-5} mmHg at 25°C (Piat, 1996).

The partition coefficient log K_{OW} is 4.88 (Hansch *et at.*, 1995) and the solubility in water is 0.135 mg/litre at 25°C (Mackay and Shiu, 1977). The substance is soluble in alcohol, ether, benzene, carbon disulphide and toluene.

4.2.2.2 Detected quantities

The test result from the analysis of sand shows that the sand contained 1.1 µg pyrene per kg. After exposure in 2 month the content of pyrene was 12.6 µg per kg. This means that 11.5 µg per kg originates from the tyre.

From the migration test the results showed a migration of about 0.06 ng /(cm^2 × hour) for most of the samples. One sample showed a migration of 0.49 ng /(cm^2 × hour).

4.2.2.3 Function of the substance

The substance does not have any technical function as such. It is a component in high aromatic oils that are used as a plasticizer in the rubber mixture.

4.2.2.4 Classification and TLV's

Pyrene is not classified in the Annex 1 of Directive 67/548/EEC.

OSHA (1994) has issued a threshold limit value of 0.2 mg per m^3 at 8 hours.

4.2.2.5 Health Effects

Acute toxicity
Limited data regarding acute toxicity has been found. These show that pyrene has a mild irritating effect and may be toxic by ingestion.

Rabbit, skin, 24 H	500 mg, Mild irritation	Marhold, 1972
Rat, oral, LD_{50}	2700 mg/kg	Gigiena Truda, 1971
Mouse, oral, LD_{50}	800 mg/kg	Gigiena Truda, 1971
Rabbit, inhalation, LC_{50}	170 mg/m^3	Gigiena Truda, 1971

In Lewis, 1996, pyrene is also mentioned as an irritant to skin. Persons with existing skin disorders may be more susceptible to the effects of coal tar pitch volatiles (Mackison *et al.*, 1981).

Sub-chronic toxicity
In the IRIS data base is presented a 13 week-test on sub-chronic toxicity for mice (U.S. EPA, 1989). In the test a group of 20 males and 20 females were gavaged with 0, 75, 125 or 250 mg/kg/day. Damages to the kidneys (nephropathy) were observed in all dosage groups. The kidney lesions were described as minimal or mild in all dosage groups. Based on the results of this study, NOAEL was considered to be 75 mg/kg/day and LOAEL were 125 mg/kg/day.

Chronic toxicity
Pyrene is not classifiable as to human carcinogenicity (classification D) based on no human data and inadequate data from animal tests (U.S. EPA, 2000).

Data for chronic RfD is derived based on the sub-chronic study described above (U.S. EPA, 1989). An uncertainty factor of 3000 reflects 10 each for intra- and interspecies variability, 10 for the use of a sub-chronic study for chronic RfD derivation, and an additional 3 to account for the lack of both toxicity studies in a second species and developmental/reproductive studies. The value for RfD is 0,03mg/kg/day, and the value is assessed having low confidence.

Compared with this, the average daily intake of pyrene for women in Japan has been estimated as 0.98 ug/day (Tamakawa K *et al.*, 1987).

Regarding dermal exposure a 0.3% solution of pyrene obtained by synthesis was applied in benzene twice weekly on the back skin of 40 mice (strain, age and sex unspecified). The longest observation time was 680 days. No skin lesion was reported. A 5% solution of pyrene (purity unspecified; solvent not indicated) was applied three times weekly for one year to mouse skin (strain, age and sex unspecified). No skin tumour was observed. A 5% solution of pyrene was also applied for one year on mouse skin previously treated with a tumour initiating dose of benzo(a)pyrene. No skin tumour was observed (IARC. 1983).

4.2.2.6 Exposure scenarios
It is assumed that 100 percent is absorbed by oral intake and 10 percent by dermal exposure based on a high value for log K_{OW} (4.9). A child will by oral intake be exposed to:

Intake per day per kg b.w.	= C × F × 0.001
	= 12.6 µg/kg × 1 × 0.001
	= 0.013 µg/kg

By dermal exposure it is assumed that the intake will be:

Intake per day per kg b.w.	= M × F × 20 (mg/kg) = 0.49 ng/kg × 0.1× 20 = 0.98 ng/kg

4.2.2.7 Assessment

Pyrene is not classified as a carcinogen (classification D). No data where available for other effects such as reproductive effects or mutagenicity. Pyrene may be toxic by ingestion and may cause mild irritations to skin.

A reference dose of 30 µg per kg b.w. per day by oral intake has been determined. The scenarios showed:

- Oral intake by children will not exceed 0.01 µg per kg b.w. per day
- Dermal uptake by children will not exceed 0.0001 µg per kg b.w. per day

Compared with the NOAEL of 75 mg/kg per day MOS is more than 1.000.000.

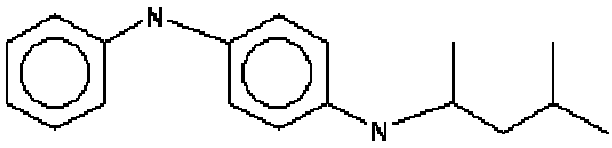
Conclusion

It can be concluded that the potential health risk from pyrene is insignificant.

4.2.3 6PPD

4.2.3.1 Identity

Name	1,4-Benzenediamine, N-(1,3-dimethylbutyl)-N'-phenyl-
CAS-number.	793-24-8
EINECS number.	212-344-0
Molecular formula	$C_{18}H_{24}N_2$
Molecular structure	



Molecular weight	268.40 grams/mole
Synonyms	6PPD N-(1,3-Dimethylbutyl)-N'-phenyl-1,4-phenylene-diamine Santoflex 13 Santoflex N-Phenyl-N'-(1,3-dimethylbutyl)-p-phenylene-diamine

6PPD is a dark, violet solid substance at room temperature. Its melting point is 50°C (Lewis, 1997). The boiling point is given by Bayer AG in a data sheet to 230°C at 13.3 hPa. The density of the substance is 1.07 (Lewis, 1997).

The vapour pressure is given at 200°C to 8.7 hPa and at 300°C93 hPa (IUCLID, 2000).

The partition coefficient log K_{OW} is estimated to 5.4 (IUCLID, 2000).

Data on solubility is very limited. In water the solubility of 6PPD is given to 1.1 ppm. Data on solubility in other media has not been found (IUCLID, 2000).

4.2.3.2 Detected quantities
The test result from the analysis of sand shows that the sand contained no 6PPD before exposure to the tyre. After exposure in 2 month the content of 6PPD was 110 µg per kg.

From the migration test the results showed a migration of amounts from 0.74 ng/(cm^2 × hour) to 49.5 ng /(cm^2 × hour).

4.2.3.3 Function of the substance
6PPD is added to the rubber mixture to prevent ozonation reactions.

4.2.3.4 Classification and TLV's
6PPD is not classified in the Annex 1 of Directive 67/548/EEC.

No threshold limit value has been found.

4.2.3.5 Health Effects
Information on 6PPD has been found in the IUCLID dataset and in the databases in TOXNET.

Acute toxicity
A number of data for acute oral and dermal toxicity is given by IUCLID.

The lowest data for LD_{50}, oral, rat is 2,500 mg/kg.

For skin exposure on rabbits, LD_{50}> 7940 mg/kg and a LD_{O} of 3160-5010 mg/kg were reported.

No data on inhalation was found.

Bayer has reported some Draize tests, where rabbits were exposed for 24 hours and examined after 72 hours. Doses of 12.5 and 125 mg 6PPD dispersed in 0.5 gram vaseline caused slightly irritation where as 25 mg 6PPD in 0.5 ml olive oil caused moderate irritation. Tests showed also slightly eye irritations (IUCLID, 2000).

From the above-mentioned data it is seen that 6PPDcauses no serious health effects by oral intake or dermal exposure. The substance may be an irritant to skin.

Sub-chronic toxicity
In a 13 week test with rats oral doses of 19, 75 and 188 mg/kg were administered daily. Mild anemia was seen in mid- and high-dose rats. Reduction in white blood cell counts were seen in females at all levels. Elevations in serum proteins and cholesterol as well as body weight depressions were noted in the mid- and high-dose rats. (IUCLID, 2000).

Chronic toxicity
Data from UICLID indicate that 6PPD is a potential sensitizing substance. Some people, previously exposed to rubber samples, reacted positive in a patch-test. One reported test included 50 human volunteers, who were patch-tested with 50 % w/v 6PPD in dimethylphthalate; - 5 of the 50 individuals

showed reactions in the 3-week induction phase and 5 of 5 showed reactions in the challenge phase.

In a two years study with rats oral doses of 8, 23 and 75 mg/kg were administered daily. The results showed reduced body weight for both sexes at the high dose level and increased kidney and spleen weights for females at the high dose level (Stevens *et al.*, 1981).

In a 12 month study, rats were given 4, 20 or 120 mg/kg (oral feed) daily. The NOEL for chronic toxicity was determined to be 4 mg/kg based on decrease in body weight and haematological changes at the mid- and high- dose level. A NOEL for oncogenic effects was determined to be at least 120 mg/kg (IUCLID, 2000).

The reproductive and developmental toxicity was tested by a Japanese Pharmaceutical Laboratory. The test showed that NOAEL for reproduction is at least 1.000 mg/kg.

- In one test male and female rats were orally given doses of given 40, 200 and 1000 mg/kg per day. Males were treated 42 or 49 days including 28 days before mating and females were treated for 14 days before mating, through the mating period and until 7 days of gestation. Neither the foetuses nor the parents were affected. The NOAEL for reproductivities and fetal development was determined to be 1000 mg/kg(Chihara *et al.*, (1), 1998).

- In a similar test pregnant rats were exposed orally from day 7 through day 17 of gestation. No effects on the foetuses were observed and the NOAEL for dams and foetuses was determined to be 1000 mg/kg (Chihara *et al.*, (2), 1998).

- In another similar test the effects on the rats and their offspring's were examined, when the mothers were orally exposed from day 7 of gestation through day 21 of lactation. No effects on the offspring were observed and the NOAEL on development of the offspring was determined to be 1000 mg/kg (Chihara *et al.*, (3) 1998).

4.2.3.6 Exposure scenarios

Here is assumed 100 percent absorption by oral intake and 10 percent by dermal exposure because of a high value for log K_{OW} (5.4).

A child will by oral intake be exposed to:

Intake per day per kg b.w. = C × F × 0.001
= 110 µg/kg × 1 × 0.001
= 0.11 µg/kg

By dermal exposure is assumed that the intake will be:

Intake per day per kg b.w.	= M × F × 20 (mg/kg) = 50 ng/kg × 0.1 × 20 = 0.10 µg/kg

4.2.3.7 Assessment

The substance 6PPD may be irritating to skin and eyes and is a potential sensitizer to skin. The substance has a low acute toxicity by oral and dermal exposure.

The following values for chronic effects have been found:

NOEL for effects on blood	4 mg/kg
NOEL for oncogenic effects	more than 120 mg/kg
NOAEL for reproduction	more than 1.000 mg/kg

No other data, as for instance on carcinogenicity, has been found.

The scenarios showed:

- Oral intake by children will not exceed 0.1 µg per kg b.w. per day
- Dermal uptake by children will not exceed 0.1 µg per kg b.w. per day

Compared with the NOEL of 4 mg/kg per day MOS is more than 10.000.

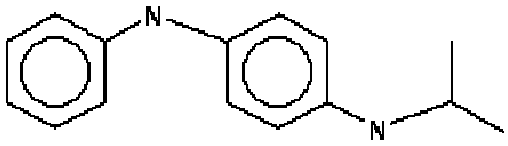
Conclusion

It can be concluded that the potential health risk from 6PPD is insignificant.

4.2.4 IPPD

4.2.4.1 Identity

Name	N-isopropyl-N'-phenyl-4-phenylenediamine
CAS-number.	101-72-4
EINECS number.	202-969-7
Molecular formula	$C_{15}H_{18}N_2$
Molecular structure	



Molecular weight	226.35 grams/mole
Synonyms	IPPD 1,4-Benzenediamine, N-(1-methylethyl)-N'-phenyl- 4-Isopropylaminodiphenylamine Santoflex 36

The substance IPPD is dark grey to black flakes. It has a melting point of 75°C (Ashford, 1994). The boiling point is determined by Bayer to be 161°C at 1 mmHg (IUCLID, 2000).

The density is 1.07 g/cm^3 at 20°C. The vapour pressure is 0.00093 hPa at 50°C and 2.1 hPa at 180°C. Log K_{OW} is measured to be 3.9 (IUCLID, 2000).

The only available data on solubility is that IPPD is soluble in aromatic solvents and insoluble in water.

4.2.4.2 Detected quantities
The test result from the analysis of sand shows that the sand contained no IPPD before exposure to the tyre. After exposure in 2 month the content of IPPD was 4.6 µg per kg.

From the migration test the results showed a migration of 0 to 10.2 ng/(cm^2 × hour).

4.2.4.3 Function of the substance
IPPD is added to the rubber mixture to prevent ozonation reactions.

4.2.4.4 Classification and TLV's
The substance is included in the Annex 1 of Directive 67/548/EEC with the classification:

Xn;R22-R43	Harmful; Harmful if swallowed - May cause sensitization by skin contact
N;R50/53	Dangerous to the environment; Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment

No TLV's or other standards have been found.

4.2.4.5 Health Effects
Information on IPPD has been found in the IUCLID dataset and in the databases in TOXNET.

Acute effects
The following information was found in IUCLID.

Several tests to determine an oral LD_{50} has been reported. The data varies from 555 to 1,620 mg/kg for rats and 1,122 to 3,030 mg/kg for mice.

No data is given for inhalation.

The acute dermal toxicity for rabbits LD_{50} is found to be more than 7,500 mg/kg. A test regarding adsorption showed no skin penetration after immersing the tails of mice ¾ in a 50% oil solution.

A path test on human volunteers showed that 20 out of 50 persons showed skin irritation after repeated skin contact. The dose level was not indicated. Moderate eye irritation was observed on rabbits after exposure to 100 mg in 24 hours.

Sub-chronic effects
An inhalation study on rats for 15 days with an exposure of 300-400 mg/m^3 in 2 hours daily is reported in IUCLID. Observations showed unchanged body weight, some changes in the nervous system and malfunction of the liver.

In another study rats were orally fed for 90 days with doses of 0, 180 mg/kg, 360 mg/kg and 720 mg/kg. Lower body weight gains were observed in the high-exposure group of males. In the mid- and high exposure groups of males and in all females increased liver weight were noted. Increased spleen and kidney weights were observed in high-exposure females and mild anaemia was found in mid- and high-exposure animals. Based on the observed organ

weight changes, a NOEL was not established, while a NOEL for treated males was 180 mg/kg.

In a 4 week study dose levels of 0, 500, 1000, 1750 and 2500 mg/kg was tested. The species used were not mentioned. The result showed that at dose levels of 1000 mg/kg and above decreases in body weight gain, haematological effects, evaluations in total serum protein as well as increased liver and spleen weights were noted. The NOEL was considered to be approximately 500 mg/kg.

Chronic effects
In IUCLID, tests on sensitization has been reported. Humans with contact dermatitis caused by rubber reacted positive with IPPD in varies tests.

Regarding genetic toxicity a number of Ames test has been reported in the CCRIS data base as well as in the IUCLID data set, - all except one showing a negative result.

Tests on carcinogenicity and reproduction have not been found.

Data for developmental toxicity has been given in a test on rats. Female rats were exposed from day 6 to day 15 of gestation with the dose levels 0, 12.5, 62.5 and 125 mg/kg per day. The test method followed OECD Guide-line 414. At the two highest dose levels decrease in food consumption on day 6-9 of gestation was observed. Increased skeletal findings following fetal examination were observed. The delayed developmental effects noted at 12.5 62.5 mg/kg were not considered to be adverse effects. Based on the findings a NOAEL was determined to be 125 mg/kg per day for maternal effects. For effects on the foetus a LOAEL was determined to be 125 mg/kg and a NOAEL to 62.5 mg/kg per day (IUCLID).

4.2.4.6 Exposure scenarios
Here is assumed 100 percent absorption both for oral and dermal exposure. Log K_{OW} is 3.9, and therefore it can be discussed if F for dermal exposure should be less than 100 percent.

A child will by oral intake be exposed to:

Intake per day per kg b.w. = C × F × 0.001
= 4.6 µg/kg × 1 × 0.001
= 4.6 ng/kg

By dermal exposure is assumed that the intake will be:

Intake per day per kg b.w. = M × F × 20 (mg/kg)
= 10.2 ng/kg × 1 × 20
= 204 ng/kg

4.2.4.7 Assessment
IPPD may be toxic if swallowed in large quantities. Skin contact may cause sensitization. Data on long term effects, except for developmental toxicity, has not been found. A NOEAL for maternal effects is 125 mg/kg per day and for effects on the foetuses the NAOEL is 62.5 mg/kg.

The value for NOEAL of 62.5 mg/kg per day can be compared with the scenarios:

- Oral intake by children will not exceed 5 ng per kg b.w. per day
- Dermal uptake by children will not exceed 200 ng per kg b.w. per day

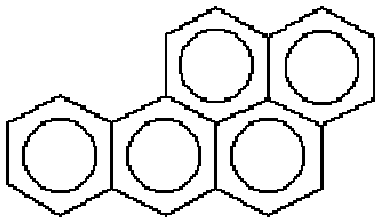
Comparing the NOAEL with the scenarios MOS is more than 100.000.

Conclusion
It can be concluded that the potential health risk from IPPD is insignificant.

4.2.5 Benzo(a)pyrene

4.2.5.1 Identity

Name	Benzo(a)pyrene
CAS-number.	50-32-8
EINECS number.	200-028-5
Molecular formula	$C_{20}H_{12}$
Molecular structure	



Molecular weight	252.32 grams/mole
Synonyms	Benzo(def)chrysene
	3,4-Benzopyrene
	4,5-Benzpyrene
	6,7-Benzopyrene

Benzo(a)pyrene is pale yellow crystals. The melting point is 179°C and the boiling point is 310°C at 10 mmHg. The density is 1.351 g/cm^3.

The partition coefficient for benzo(a)pyrene log K_{OW} is 5.97 (Hänsch *et al.*, 1995).

The vapour pressure is very low, 5.5×10^{-9} mm Hg at 25°C (extrapolated value) (Murray JJ *et al.*, 1974).

The solubility for benzo(a)pyrene in water is 1.6 µg/litre at 25°C. The substance is soluble in aromatic hydrocarbons such as benzene, toluene and xylene and sparingly soluble in alcohols.

4.2.5.2 Detected quantities
The test result from the analysis of sand shows that the sand contained 0.03 µg per kg of benzo(a)pyrene before exposure to the tyre. After exposure in 2 month the content was 0.09 µg per kg.

No benzo(a)pyrene was detected in the migration test.

4.2.5.3 Function of the substance
The substance benzo(a)pyrene does not have any technical function as such. It is a component in high aromatic oils used as a plasticizer in the rubber mixture.

4.2.5.4 Classification and TLV's

The substance is included in the Annex 1 of Directive 67/548/EEC (29. amendment) with the classification:

Carc2;R45	Toxic; May cause cancer
Mut2;R46	Toxic; May cause heritable genetic damage
Rep2;R60-61	Toxic; May impair fertility. May cause harm to the unborn child
R43	May cause sensitization by skin contact (included in 29.ATP)
N;R50/53	Dangerous to the environment; Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment

The Danish TLV for polyaromatic hydrocarbons (particles, soluble in benzene) is 0.2 mg/m^3 (At-vejledning C.0.1). The regulation from OSHA states as well a TWA of 0.2 mg/m^3 (1994). Other countries have issued a lower limit, for instance Norway 0.04 mg/m^3 (1999), Poland 0.003 mg/m3 (1999), and Finland 0.01 mg/m^3(1999).

4.2.5.5 Health effects

Data regarding benzo(a)pyrene has been found SCF's report on Polycyclic Aromatic Hydrocarbons in food (SCF, 2002), HSDB, IRIS and other databases.

Acute toxicity

Very few data on acute toxicity is given. In RTECS, the following data is found:

TDL_O	Rat, intraperitoneal	40 mg/kg	(1968)
TDL_O	Rat, intraperitoneal	100 mg/kg	(1979)
TDL_O	Mouse, intraperitoneal	80 mg/kg	(1979)
TDL_O	Rat, oral	100 mg/kg	(2001)

Subacute toxicity

In a 90-days study on rats liver weight was identified as the critical effect and a NOAEL of 3 mg/kg b.w. was determined (Kroese *et al.*, 2001 SCF, 2002).

Treatment of male rats by gavage for 35 days with 3, 10, 30 or 90 mg/kg b.w. induced various immunotoxic effects such as decrease in thymus and lymph nodes weight, decreased absolute and relative B cell numbers in the spleen and decreased numbers of red and white blood cells. The NOAEL for immunotoxicity of benzo(a)pyrene was 3 mg/kg b.w. per day (De Jong *et al.*, 1999).

Chronic toxicity

IARC (1987) has classified the substance as probably carcinogenic to humans (group 2A) based on sufficient evidence of carcinogenicity in animals. The U.S. EPA has included benzo(a)pyrene in the IRIS data-base and here the substance is classified B2: Probable human carcinogen.

In a report from RIVM (Baars *et al.*, 2001) on re-evaluation of human-toxicological maximum permissible risk levels the following data on benz(a)pyrene is provided

- RIVM developed an oral cancer risk estimate CR (oral) for benzo(a)pyrene of 0.5 µg/kg × day. This value was based on tumour development in a variety of organs and tissue (Kroese *et al.*, 2001) in a two year study with Wistar rats. The result is converted to a risk specific dose (RSD) of 0.05 µg/kg × day.

- Based upon occupational inhalation exposure to PAH-mixtures resperatory effects were noted in humans and a LOAEL for non-carcinogenic effects were estimated to 0.1 µg/m^3.

Among other PAHs benzo(a)pyrene was considered genotoxic with positive results in assays *in vitro* and *in vivo*. Positive results were also shown at germ cell level (SCF, 2002).

Data from animals and humans regarding reproductive and developmental effects are insufficient for risk assessment. Although adverse effects in animals have generally been seen only at relatively high doses of benzo(a)pyrene the values of NOAEL have not been established (SCF, 2002).

4.2.5.6 Exposure scenarios

Only the scenario regarding oral intake is relevant while the substance was not detected in the migration tests.

A child will by oral intake be exposed to:

Intake per day per kg b.w. = C × F × 0.001
= 0.09 µg/kg × 1 × 0.001
= 0.1 ng/kg

4.2.5.7 Assessment

Benzo(a)pyrene is a substance that may cause cancer as well as genetic and developmental effects.

NOEAL were for a sub-chronic test estimated to 3 mg/kg b.w. per day. Based on oral cancer risk RIVM has estimated a risk specific dose (RSD) of 50 ng/kg b.w. per day.

Comparing the findings in the test of the sand with the RSD it is seen that the RSD is about 500 times higher than the findings. Compared with the NOAEL of 3 mg/kg, a MOS of more than 1.000.000 is estimated.

Conclusion

The potential health risk from exposure of benzo(a)pyrene is insignificant.

4.3 Other identified substances

4.3.1 Identification

4.3.1.1 Detected quantities

Besides the substances described in the previous section a number of other substances have been identified and quantified in the sand exposed to tyres. These substances are presented in Table 4.1..

Table 4.1. Additional substances identified in sand

Name	CAS-number	Max-content µg/kg wet weight	Content at start µg/kg wet weight
Benz(a)antracene	56-55-3	1.02	0.25
Dibenz(a,h)antracene	53-70-3	-	-
Benz(e)pyrene	192-97-2	0.18	0.06
Benz(b)fluoranthene	205-99-2	0.25	0.10
Benz(j)fluoranthene	205-82-3		
Benz(k)fluoranthene	207-08-9		
Benz(ghi)perylene	191-24-2	0.15	0.03
Crysene	218-01-9	2.27	1.42
Indeno(1,2,3-cd)pyrene	193-39-5	0.08	0.02

Because dibenz(a,h)antracene was not detected in the analysis, this substance is omitted in the following assessment.

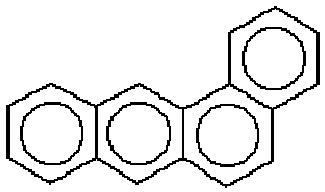
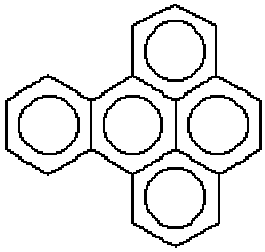
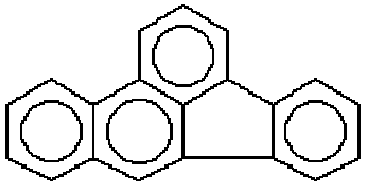
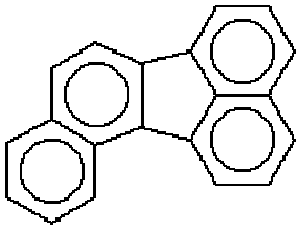
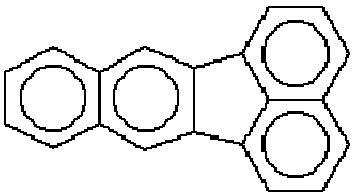
4.3.1.2 Identity

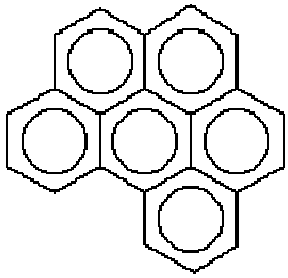
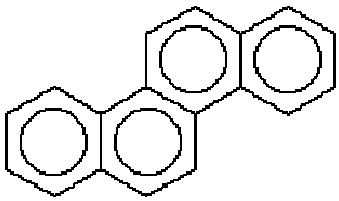
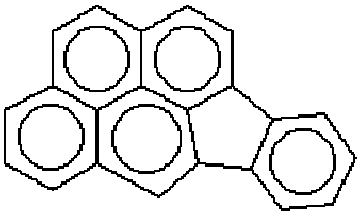
In Table 4.2 basic data for the selected substances are shown. Compared to benzo(a)pyrene the structure of the substances in Table 4.2 is similar. Benzo(a)pyrene consist of five aromatic rings. It is the same for benzo(e)pyrene. Benz(a)antrancen and crysene consists of 4 aromatic rings and benz(ghi)perylene of six aromatic rings. The fluoranthenes consist of 4 aromatic rings and a 5-ring and indeno(1,2,3-cd)pyrene of 5 aromatic rings and a 5-ring.

As can be seen from Table 4.2 the molecular weight for the substances is about 250 gram per mole, the melting point is above 150°C and log K_{OW} is above 5 for the substances where data for this parameter were found. These values are equivalent to the data for benzo(a)pyrene.

Regarding classification most of the substances are classified Carc. Cat. 2; R45 N;R50/53. Crysene is also classified for mutagenicity, Cat. 3. Benz(g,h,i)perylene is only classified with respect to the environment and indeno(1,2,3-cd)pyrene were not included in the Annex I of Directive 67/548/EEC. This indicates, that, based on classification, none of the substances included in Table 4.2 are more hazardous than benzo(a)pyrene.

Table 4.2. Properties of selected substances identified in sand

Name and properties		Formula
Name	Benz(a)antracene	
CAS-number	56-55-3	
EINECS no.	200-280-6	
Molecular weight	228.29 gram per mole	
Melting point	160 °C	
Log K_{OW}	5.79	
Classification	Carc.Cat.2;R45 N;R50/53	
Name	Benzo(e)pyrene	
CAS-number	192-97-2	
EINECS no.	205-892-7	
Molecular weight	252.32 gram per mole	
Melting point	179 °C	
Log K_{OW}	5.97	
Classification	Carc.Cat.2;R45 N;R50/53	
Name	Benzo(b)fluoranthene	
CAS-number	205-99-2	
EINECS no.	205-911-9	
Molecular weight	252.32 gram per mole	
Melting point	168 °C	
Log K_{OW}	6.60	
Classification	Carc.Cat.2;R45 N;R50/53	
Name	Benzo(j)fluoranthene	
CAS-number	205-82-3	
EINECS no.	205-910-3	
Molecular weight	252.32 gram per mole	
Melting point	166 °C	
Log K_{OW}	NA	
Classification	Carc.Cat. 2;R45 N;50/53	
Name	Benz0(k)fluoranthene	
CAS-number	207-08-9	
EINECS no.	205-916-6	
Molecular weight	252.32 gram per mole	
Melting point	217 °C	
Log K_{OW}	6.84 (estimated)	
Classification	Carc.Cat.2;R45 N;R50/53	

Name	Benzo(ghi)perylene 1,12-Benzoperylene	
CAS-number	191-24-2	
EINECS no.	205-883-8	
Molecular weight	276.34 gram per mole	
Melting point	277 °C	
Log K_{OW}	6.63	
Classification	N;R50/53 ×1	
Name	Crysene	
CAS-number	218-01-9	
EINECS no.	205-923-4	
Molecular weight	228.29 gram per mole	
Melting point	258.2 °C	
Log K_{OW}	5.73	
Classification	Carc.Cat.2;R45 Mut.Cat.3;R68 N;R50/53	
Name	Indeno(1,2,3-cd)pyrene	
CAS-number	193-39-5	
EINECS no.	205-893-2	
Molecular weight	276.35 gram per mole	
Melting point	163.6 °C	
Log K_{OW}	NA	
Classification	NA	

NA: Not available
×1): From the Advisory List on Self-classification from the Danish Environmental Protection Agency, 2001

4.3.2 Evaluation

4.3.2.1 Screening of health effects

In Baars *et al.* (2001) data for some of the most common PAHs is provided. In Table 4.3. an overview of the genotoxicity and carcinogenicity for selected PAHs is given. No data were available for benz(e)pyrene.

Table 4.3. Genotoxicity and carcinogenicity for selected PAHs (Baars *et al*., 2001)

Substance	CAS no.	Genotoxicity IPCS (1998)	Carcinogenicity IPCS(1998)	Carcinogenicity IARC(1983)
Benzo(a)pyrene	50-32-8	+	+	2A
Benz(a)anthracene	56-55-3	+	+	2A
Benzo(b)fluoranthene	205-99-2	+	+	2B
Benzo(j)fluoranthene	205-82-3	+	+	2B
Benzo(k)fluoranthene	207-08-9	+	+	2B
Benzo(g,h,i)perylene	191-24-2	+	-	3
Crysene	218-01-9	+	+	3
Indeno(1,2,3-c,d)pyrene	193-39-5	+	+	2B

IPCS classification
+ positive
- negative

IARC classification:
2A compound is probably carcinogenic to humans
2B compound is possibly carcinogenic to humans
3 compound is not classiciable as to its carcinogenicity to humans

IARC has assessed benzo(e)pyrene (IARC, 1987) and found inadequate evidence of carcinogenicity. It was placed in group 3.

In the conclusion (Baars *et al.*, 2001) a table of risk estimation for selected PAHs using the parameter MPR, maximum permissible risk is shown as a measure of the potential risk. The data is provided in Table 4. for the actual substances except benz(e)pyrene, which were not included in the Dutch study.

Table 4.4. Value for Maximum Permissible Risk (Baars *et al.*, 2001)

Substance	CAS no.	Maximum Permissible Risk, MPR	
		Type	Value
Benzo(a)pyrene	50-32-8	CRoral	0.5
Benz(a)anthracene	56-55-3	CRoral	5
Benzo(b)fluoranthene	205-99-2	CRoral	5
Benzo(j)fluoranthene	205-82-3	CRoral	5
Benzo(k)fluoranthene	207-08-9	CRoral	5
Benzo(g,h,i)perylene	191-24-2	TDI	30
Crysene	218-01-9	CRoral	50
Indeno(1,2,3-c,d)pyrene	193-39-5	CRoral	5

CRoral : $1{:}10^4$ excess lifetime cancer risk for oral exposure; µg/kg b.w. per day
TDI: tolerable daily intake ; µg/kg b.w. per day

As can be seen from Table 4. the MPR is the lowest for benzo(a)pyrene and 10 to 100 times higher for the other substances.

No values for NOAEL have been found for the substances included in Table 4..

The data in Table 4.3. and Table 4. indicates that benzo(a)pyrene is more toxic than the other PAH-substance described in this section.

4.3.2.2 Exposure scenario

In the analysis of the sand altogether 13 PAHs were identified and quantified. The 3 substances, fluoranthen, pyrene and benzoe(a)pyrene has already been assessed. In Table 4.5. is shown the amount of these substances and the sum of the other substances.

Table 4.5. Amount of PAHs in sand

Substance	CAS no.	Maximum Amount
Fluoranthene	206-44-0	10 µg/kg
Pyrene	129-00-0	12.6 µg/kg
Benzo(a)pyrene	50-32-8	0.1 µg/kg
Other PAHs	-	4 µg/kg

If it is assumed that a child will be exposed to 10 grams of sand per day with the content of 4 µg/kg of different PAHs, a child will by oral intake be exposed to:

Intake per day per kg b.w. = C × F × 0.001
= 4 µg/kg × 1 × 0.001
= 4 ng/kg

4.3.2.3 Assessment

Most of the identified PAHs are potential carcinogenic. Of the nine substances two are classified as group 2A (probably carcinogenic) four in group 2B (possible carcinogenic) by IARC and tree in group 3 (inadequate evidence of carcinogenicity). Crysene is as well a potential mutagenic substance.

The data found for the nine PAHs indicate that these have the same type of effects as benzo(a)pyrene, but that the risk is lower.

The NOAEL level for benzo(a)pyrene is determined to be 3 mg/kg b.w. per day based on a sub-chronic study. RIVM has estimated a risk specific dose (RSD) of 50 ng/kg b.w. per day.

Comparing the result of the exposure scenario, where the nine PAHs are added together, with the NOAEL for benzo(a)pyrene gives a MOS of 750.000. The RSD of 50 ng/kg per day is higher than the values estimated from the scenarios.

Conclusion
Taking into account, as most of the nine PAHs has a risk level lower than benzo(a)pyren it can bee concluded that the potential health risk from the actual exposure to these PAHs in the observed amounts is insignificant.

4.4 Conclusion

Some PAHs and amino-compounds have been found in two scenarios. One was sand exposed to discarded tyres and the other was migration tests, where artificial sweat was exposed to discarded tyres. The substances have been identified and quantified in the performed tests.

The following substances were identified:

In migration tests		In test of exposed sand
Fluoranthene	Fluoranthene	Benzo(b+j+k)fluoranthene
Pyrene	Pyrene	Benzo(e)pyrene
6PPD	6PPD	Benzo(a)pyrene
IPPD	IPPD	Dibenz(ah)anthracene
	Benzo(a)anthracene	Indeno(1,2,3-cd)pyrene
	Chrysene	Benzo(ghi)perylene

It was expected to find more PAHs in the migration test. On the other hand, there has been no focus on the amino-compounds, 6PPD and IPPD, with respect to migration from used tyres before.

The four substances found in the migration test and benzo(a)pyrene was assessed. A screening including the other substances was performed.

The assessment showed:

- Fluoranthene causes no acute health effects. Related to long term exposure damages to liver and kidneys have been seen in animal studies. A child may be exposed to 10 ng per day per kg b.w. and with a NOAEL of 125 mg/kg this results in a MOS of more than a million.
- Pyrene may be toxic by ingestion and causes mild irritation to skin. Pyrene is not classified as a carcinogen. No data on reproduction or mutagenicity was available. A child may be exposed to 13 ng per day per kg b.w. and with a NOAEL of 75 mg/kg it results in a MOS of more than a million.
- 6PPD may be irritating to skin and a potential sensitizer. Long term effects such as haematological changes and ongogenic effects as well as effects on reproduction have been observed. A child may be exposed to

100 ng per day per kg b.w. and with a NOEAL of 4 mg/kg, it results in a MOS of 10.000.

- IPPD may be toxic if swallowed in large quantities. Skin contact may cause sensitization. Data on long term effects, except for developmental toxicity, has not been found. A child may be exposed to 200 ng per day per kg b.w. and with a NOAEL of 62.5 mg/kg it results in a MOS of 100.000.
- Benzoe(a)pyrene is a substance that may cause cancer as well as genetic and developmental effects. A child may be exposed to 0.1 ng/kg b.w. per day. Compared with a NOAEL of 3 mg/kg it results in a MOS of more than one million.
- The other identified PAHs causes the same type of health effects as benzoe(a)pyrene but with a lower risk level. A child may be exposed to in total 4 ng/kg b.w. per day of these PAHs. Comparing this with a NOAEL of 3 mg/kg it results in a MOS of 750.000.

From these results it can be concluded that the potential health risk related to use discarded tyres on playgrounds is insignificant.

Although the MOS is high for all the identified components it is notable that the lowest MOS are found for the two identified amino-compounds.

Abbreviation list

Carc	Carcinogen
CCRIS	Chemical Carcinogesis Research Information System
DL	Detection limit
HA	High aromatic mineral oil
HDSB	Hazardous Substance Data Bank
IP	Not detected
IRIS	Integrated Risk Information System
IUCLID	International Uniform Chemical Information Database
LC_{50}	Mortality rate concentration 50 percent
LD_{0}	Low mortality rate dose
LD_{50}	Mortality rate dose 50 percent
LOAEL	Lowest adverse effect level
LOEL	Lowest effect level
MOS	Marginal of safety
Mut	Mutagenic effects
NOAEL	No adverse effect level
NOEL	No-effect level
OSHA	Occupational Health and Safety Administration, USA
PAH	Polycyclic aromatic hydrocarbons
Rep	Reproduktive effects
RfD	Reference dose
RFD	Risici specific dose
RTECS	Registry of Toxic Effects of Chemical Substances
TDL_{O}	Lowest dose no effect
TLV	Treshold limit values

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

Environmental Compatibility Concept According to DIN 18035

Test Procedures And Background

SGS Institut Fresenius

Environmental Combatibility Concept according to DIN 18035
Test procedures and background

SGS Institut Fresenius in Berlin have been dealing with the testing of artificial play grounds and infill material on the basis of recycled tyres for several years. The investigations of these materials are part of the German quality assurance. We were asked to inform about the German test procedure in line with the German norm DIN 18035.

Investigations of the release of hazardous substances in synthetic surfaces for indoor sport areas were commissioned by the German authorities in the 1990's. As a result, there were no relevant dangers on the basis of the release of "particulate dust". Volatile organic compounds and heavy metals by use of artificial playgrounds were not identified.
A draft of a standard exists for synthetic turf areas and synthetic surfaces since 2002 and respectively since 2004

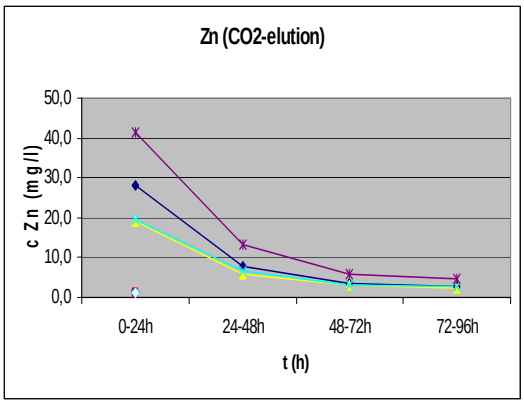
- DIN E 18035-6 synthetic surfaces for outdoor sports areas
- DIN E 18035-7 synthetic turf surfaces for outdoor sports areas

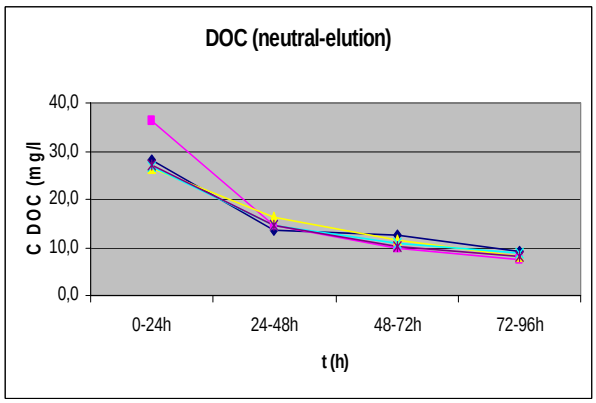
.
The aims for the environmental checks are, that the health of residents in the environment and users of this playground are not effected by release of hazardous volatile gases and particles in the air, ground- and surface water.

The Quality Assurance should fulfil these requirements. In general, we distinguish between performance tests by the producer and surveillance tests to achieve conformity of products.
The Quality Assurance should fulfil these requirements. In general, we distinguish in environmental checks between performance tests and regulat tests to achieve conformity of products.

- the RAL Label GZ 943 from the German Institute for Quality Assurance and Labelling
- DINCertco – Institute for Conformity Assessment

Rubber products could contain a multitude of compounds, partly of very high concern. Substances that are used in large amounts are reinforcing agents such as carbon black, aromatic oils and solvents, vulcanisation agents, activators and metal compounds
Especially the spectrum of organic compounds is very complex. That's why the description of the release of water-soluble organic compounds is done by the lump parameter DOC. Chlorinated paraffin and other halogenated organic compounds in rubber products can sometimes be found, which are detected also by the lump parameter EOX. Long-range soluble heavy metals are determined by an acid elution with permanent CO2-gassing according to a Swiss waste investigation method. Additionally, a neutral elution with a L/S ratio 10:1 characterized the amounts of easily available Zinc cations.
The used 48 h elution is very different from the commonly applied 24 h-elution method in soil and waste investigation. The goal of the 24h up to 48 h elution is the recording of the mobilisation of dangerous compounds and not the recording of a short-term soluble peak. As you can see in the charts, during the first 24 h there are brief disposels of organic compounds and Zn, which is shown for the leachate behaviors of selected tyre granules.





The next point is the toxicity test. The Nitrification test or luminescence bacteria test will be used for the examination of the toxicity in the 48 h neutral elution. Currently, there are no assessments in the field of synthetic surfaces and infill materials in synthetic turf areas. The toxicity assay is needed only for elastic baselayers and synthetic turf.

The preparation of test bodies (2 cm edge length) of the synthetic surfaces is of great importance. The cutting edges must be sealed by a binder, so that only the mobilisation of the surfaces can be recorded.

The assessment is based on the German Legislation. Limiting values for heavy metals and organic lump parameters are derived from the German Soil Protection law and the guide for recycling of mineral products. Groundwater is the point of compliance for both.

The groundwater quality is also the focus of testing according DIN 18035. Currently, there are no requests to investigate the release of particulate dust, volatile organic compounds and organic compounds in skin contact such as PAH. This method will be confirmed by current studies especially from Scandinavia. Individual investigations of amount and composition of PM 10 / PM 2,5 particular dust and the VOC releases have shown, that the release of hazardous substances in the air to be of little importance versus an exposure of the soil/ground water-system. On the next Chart there are the environmental requirements according to DIN 18035, on the left side for synthetic turf areas, on the right side for synthetic surfaces. According to DIN 18035-7 the turf, the infill material and the elastic base layer is tested separately. The meassurement of Zn in neutral eluat is carried out only for the infill material. The toxicity assay is needed only for elastic baselayers and synthetic turf. Synthetic surfaces and infill materials in synthetic turf areas currently will only be investigated for collection of experience.

parameter	synthetic turf surfaces			synthetic surfaces		
	origin [mg/kg]	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]	origin [mg/kg]	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]
DOC		< 20 / < 40			< 20 / < 40	
EOX	<100			<100		
Pb			<0.04			<0.04
Cd			<0.005			<0.005
Cr			<0.05			<0.05
Cr-VI			<0.008			<0.008
Hg			<0.001			<0.001
Zn		< 0,5*	< 3			< 3
Sn			<0.05			<0.05
Toxicity			< 50 %**			collection experience

On the next chart the assessment of the concentrations is documented according to DIN 18035. For the organic lump parameters DOC a range of 20 up to 40 mg/l is tolerable, if the concentration of EOX exceeds the 100 mg/kg level there is an elemination of the use as well as the indicated concentrations for DOC > 40 mg/l or Zn > 1 in neutral respectively > 20 mg/l in acid leachat. The last point is only valid for infill materials.

parameter	48 h leachat neutral [mg/l]	48 h leachat acid [mg/l]	remark	ko condition
DOC	> 20 / < 40		consideration EOX	
	> 40			x
EOX				EOX > 100 mg/kg
Zn *	> 0.5 / < 1.0		tolerable	
		> 3.0 / < 20.0	tolerable	
	> 1			x
		> 20		x

The following generalisations from the multitude of existing results are possible.

In general for turf material there are no difficulties. The toxicity is clearly less than 50 %. In induvidual cases we found a DOC larger than 20 mg/l or sometimes larger than 40 mg/l. Perhaps it‘s caused by oils in the production process. Zn is not a problem for turf. Sometimes we found Zn in the bottom of the fabric, possible caused by latex coating.

In general base layers contain tire granules in bigger pieces than the infill material, which is bonded in polyurethane. Thats why, we found low concentrations of Zn and DOC and no toxicity.

In the case of infill material we distinguished in SBR, EPDM und thermoplastic tyre material. Technical and agricultural used tyre products (SBR) should be baned, here we found partly extrem Zn-concentrations in neutral and acid leachates. 75 % of all of the investigated SBR infill materials are nontoxic (<50 %). By the majority the zn-values are kept in neutral and acid leachates

Sulphur linked EPDM contain lower than 0.2 % Zn, but all the samples are toxic in the luminescence bacteria test, probably by benzothiazolic compounds.

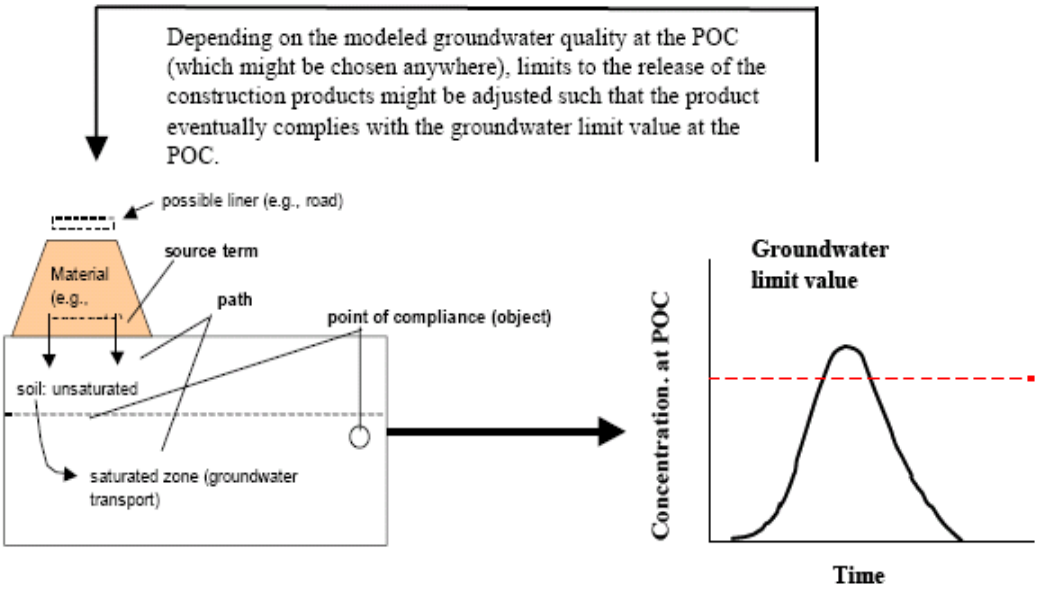
Peroxid linked EPDM contain barely Zn and there are not toxic. In some cases we found DOC in the range up to 40 ppm, probably caused by monomers. In the analysis of thermoplastics there are only a little number of investigated samples. In all cases we found for each parameter no exceeding of the limiting values.

All requirements are fulfilled for synthetic surfaces. But it should be noted, that all the samples are toxic in the luminescence bacteria test, probably by benzothiazolic compounds. Currently, there is no assesment for synthetic surfaces.

What are the points of criticism from the literature?

1. The question is if the measured concentrations by the used extraction methods are comparable to the amounts that are released from sports areas after each rainfall.
2. The importance of the use of CO2 saturated water as an extraction solvent is questioned.
3. The preparation method of test bodies (edge length of 2 cm) is very complicated and prone to errors.
4. The importance of the use of toxicity tests is questioned

The general question is, where is the point of compliance: ground water or quality of the leachate. The German soil protection law uses the concept of “threshold value”. The threshold value for Zn is 0,5 mg/l. If the concentration of Zn exceeds the 0.5 mg/l-level actions must be taken. In the view of the precautionary principle, the layer between saturated and unsaturated zone as the point of compliance is unacceptable. The soil protection law appoints the leachat as the point of compliance. This approach complies with the German concept of the reutilisation of soils and construction debris, in which the limiting values for Zn in the region of 0.15 up to 0.6 mg/l depends on the contamination sensitivity of the ground water.



One point of criticism is the eluation with CO2 saturated Water. The aim for this test is the determination of the long-term mobilisated concentration of heavy metals. This method of a pH dependance elution is accepted in the new european directions for example in the investigation of waste or construction materials . Specially for the charakterisation of granular products the pH-dependence test is recommended. But it's true, nobody uses the antiquated method with CO2 saturated water anymore.

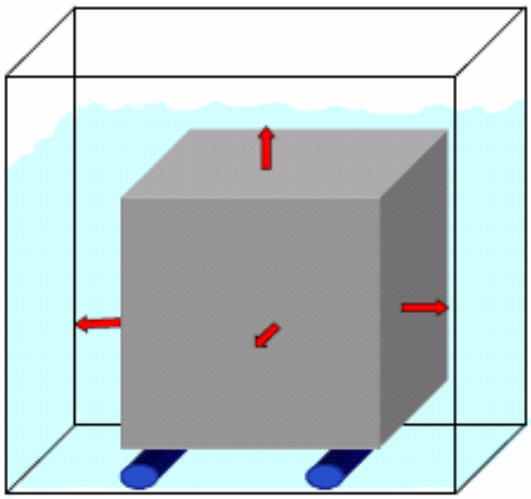
test	**brief description**	**level**
prEN14429	**pH-dependence test**, on granular or size reduced products	characterisation
prEN14405	column test, on granular products	characterisation
EN12457-2	batch test (natural pH), granular products	compliance
EN12457-3	serial batch test, granular products	characterisation
wi292040	dynamic monolith leaching test (DMLT, tank test)	characterisation
wi292010	compliance tests, monoliths	compliance
EN1250	tank test for preserved wood (monoliths)	compliance

The preparation of test bodies by sealing is indeed complicated but necessary concerning mentioned causes. It should be considered, that by a modification of the sample size a sealing is not necessary. For example a change of the size from a edge lengt 2 cm up to 20 cm reduces the impact of the sealing failure to about the factor to 10. This procedure requires a new elution procedure according to the test described in a current ECN-study.

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TEST CONDITIONS:
First step: pre-equilibration
for 48 hrs at liquid to
volume ratio: 5
Second step: leaching
at low L/V ratio (1) for 24 hrs
Then contact times: 2, 4, 8,16, 32 and 64 days
Leachant: demineralised water (own pH)

Expression of results in mg/m^2 (cumulative) against time
CGLT = Compacted Granular Leach Test



In Germany soil and ground water assessment toxicity tests will play a growing role. Currently in Germany there is a new soil protection law in the pipeline including toxicity tests. 86 terristric and 26 aquatic test systems are checked at the moment. The problems of generalisation from the lab into the environmental systems are known and demand furthermore research. Currently it's possible, that luminiscense bacteria, daphnia and green alga tests are relevant for the path soil into groundwater

What is the outlook for the future on my opinion?
The German proposal should be discussed in the context of the upcoming European standardisation in the field of TC 217; workgroup 6

A change of the elution methods is necessary. The Percolation method such as CEN/TS 14405 should be considered as well as the batch test such as EN 12457 for L/S ratio from 2 or 10 l/kg.

It is be wise to change the method for the characterisation from the saturated CO2 Elution-test into the pH-dependence test such as prEN 14429.

The use of the tank test in the field of elution monolithic products such as synthetic surfaces is recommended. By the change of the sample size sealing failuers become marginal.

There is no necessity to exceed the parameter list for investigation. The lump parameters DOC as a marker for the leaching organic compound is useful. Perhaps it would be wise to

connect the necessity for an toxicity test with the result of the DOC. It’s imaginable to use a luminescens bacteriaria test with an attenuation level GL 8, if the DOC exceeds the 10 ppm-level.

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Artificial Turf Pitches

An Assessment of the Health Risks For Football Players

Norwegian Institute of Public Health and the Radium Hospital

Artificial turf pitches –
an assessment of the health risks for football players

Prepared by:
Norwegian Institute of Public Health and the
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Oslo, January 2006

Artificial turf pitches – an assessment of the health risks for football players

Introduction

Sports halls with artificial turf pitches are used for indoor football. Artificial turf pitches consist of artificial turf fibre and rubber granulates. Rubber granulates can be one of several main types: recycled rubber (ground car tyres), thermoplastic elastomer or EPDM rubber. Recycled rubber granulates can be produced in a variety of qualities (coarse-ground/fine-ground, different chemical compositions/different additives). Two types of artificial turf fibre are also used (split fibre and monofibre). Information on the occurrence and concentrations of chemical substances in rubber granulate and in sports hall air is based on the report by the Norwegian Institute for Air Research (NILU) entitled "Measurement of air pollution in indoor artificial turf sports halls" of January 2006 (TA number: TA-2148/2006). The assessment of the potential risk of cancer and gentoxicity was undertaken by Tore Sanner of the Radium Hospital.

Given the large number of substances which were identified in the rubber granulates and during the degassing of volatile organic compounds (VOC), it was decided to use worst case scenarios where quantities within each substance category (PCBs, PAHs, phthalates, alkyl phenols and VOCs) were summed and the lowest no observed adverse effect (NOAEL) value was used (when available) for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). Such an approach will clearly overestimate the health risk. We have chosen the highest analysis values as regards recycled rubber granulate because this type of rubber granulate contains the largest quantities of potentially hazardous substances and leads to the highest measured values in sports hall air. An analytical detection limit was chosen in cases where no measured value was available.

Nine exposure scenarios were used: adults, juniors, older children and children.

- inhalation exposure: adults, junior, older children and children (Scenarios 1-4)
- skin exposure: adults, junior, older children and children (Scenarios 5-8)
- oral exposure: children (Scenario 9).

Exposure levels were based on inhalation values (inhalation volumes during training sessions/matches) and skin exposure (mg/cm^2 deposited on the skin). As regards oral exposure (swallowing), we have assumed that up to 1.0 gram of rubber granulate can be swallowed per training session/match.

Exposure duration and frequency are based on information from the managers of the Valhall and Manglerudhallen sports halls in Oslo and Nordlandshallen and Skarpehallen in Tromsø. On the basis of this information, we selected worst case scenarios for the various age groups. These worst case scenarios are based on the highest measured values and the longest/most frequent training/match periods that are used.

Exposure scenarios

As regards the choice of exposure scenarios, four main types of scenario were used for training sessions and matches on artificial turf pitches: adults (≥20 years, 20-40 years was used for the assessment of cancer risk), juniors (16-19 years), older children (12-15) and children (7 -11 years). Exposure times and the type of activity (training and matches) were based on information obtained from the following sports halls: Valhall and Manglerudhallen in Oslo and Nordlandshallen and Skarpehallen in Tromsø. The pattern of use will vary from pitch to pitch and geographic location will be an important factor as regards the times of the year during which indoor pitches are used. Exposure will take place through the inhalation of volatile compounds and particles, through particles coming into contact with the skin (skin exposure is of little importance as regards volatile compounds) and to some extent through swallowing (assumed to apply largely to children).

Inhalation

The exposure characterisation covers four main scenarios: adults who play/train, juniors who play/train, older children who play and train and children who play/train and play cup tournaments. The respiration volumes are based on information from the Norwegian University of Sport and Physical Education and assume maximum exertion during training sessions. The inhalation volumes used are: adults 6 m^3/hour, junior 4.8 m^3/hour, older children 3.6 m^3/hour and children 1.8 m^3/hour. For comparative purposes, the US EPA uses a figure of 3.63 m^3/hour for physically demanding work for adults and 2.23 m^3/hour for children (6-13 years). The EU uses a figure of 2.6 m^3/hour for physically demanding work. The scenarios are described below and are based on information concerning patterns of use of sports halls with artificial turf.

- Scenario 1: Adults who train and play matches indoors (Skarphallen, Tromsø):
  - Body weight = 70 kg
  - Inhalation volume during training/match = 6 m^3/hour
  - Duration per week = 20 hours
  - Duration in months = 6 months

  In addition to the above, there are also six hours of matches per week for six months.

  This indicates a weekly exposure volume (m^3/week) of: 156 m^3/week for a total of 6 months, 2.23 m^3/kg body weight/week, **0.32 m^3/kg body weight/day.**

- Scenario 2: Juniors who train and play matches indoors (2 x Valhall):
  - Body weight = 65 kg
  - Inhalation volume during training/match = 4.8 m^3/hour
  - Duration per session = 2 hours
  - Number of sessions per week = seven sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1 x Valhall, three sessions per week)

In addition to the above, there are also two matches of two hours per month for three months.

This indicates a weekly exposure volume (m^3/week) of: 75 m^3/week for a total of 16 weeks, 1.11 m^3/kg body weight/week, **0.16 m^3/kg body weight/day**.

- Scenario 3: Older children who train and play matches indoors (Nordlandshallen and Skarpehallen in Tromsø):
  - Body weight = 50 kg
  - Inhalation volume during training/match = 3.6 m^3/hour
  - Duration per week = 10 hours
  - Duration in months = 6

  In addition to the above, there are also two hours of matches per week for six months.

  This indicates a weekly exposure volume (m^3/day) of: 43.2 m^3/week for a total of six months. 0.86 m^3/kg body weight/week**, 0.12 m^3/kg body weight/day**.

- Scenario 4a: Children who train and play matches indoors (Nordlandshallen and Skarpehallen in Tromsø):
  - Body weight = 30 kg
  - Inhalation volume during training/match = 1.8 m^3/hour
  - Duration per week = 10 hours
  - Duration in months = 6

  In addition to the above, there are two hours of matches per week for six months.

  This indicates a weekly exposure (m^3/day) of: 21.6 m^3/week for a total of six months. 0.72 m^3/kg body weight/week**, 0.10 m^3/kg body weight/day**.

- Scenario 4b: Children who play cup tournaments indoors (Valhall):
  - Body weight = 30 kg
  - Inhalation volume during matches 1.8 m^3/hour
  - Inhalation volume with light exertion = 0.8 m^3/hour
  - Time spent in hall, light exertion per cup tournament = 17 hours
  - Time spent in hall, playing matches per cup tournament = 7 hours
  - Number of cup tournaments per year = 2 cups
  - Duration of cup tournament: 2.5 days

  This indicates an average exposure volume of: 10.48 m^3/day for a total of 5.0 days per year. **0.35 m^3/kg body weight/day**, five days per year.

Skin contact

During training sessions and matches on artificial turf pitches, there may also be some uptake via the skin. Dust/particles which are released from the rubber granulate (primarily during use) will come into contact with bare skin. Some exposure from covered skin can also be expected, but this will be significantly lower than for bare skin. The skin area which is assumed to be exposed on an adult is: parts of the legs (25% of 2070 cm^2), thigh (1980 cm^2), arms (2570 cm^2), hands (840 cm^2) and head (face, 1180 cm^2). In total, this represents approximately 7100 cm^2. If it is assumed that the body area approximately correlates with body weight, juniors and older children have a skin surface which could potentially be exposed of 6600 and 5100 cm^2 respectively, while the corresponding figure for children (30 kg) is 3000 cm^2. Where there is no clear evidence that lower skin uptake levels are likely (e.g. for phthalates, 5%), an uptake of 100% is used as a worst case.

One problem when calculating uptake through the skin of chemicals in particles/dust is determining the quantity of particles/dust that is deposited on the skin (specified as mg/cm^2). The worst case scenario for children playing on soil has been specified as being 10 mg/cm^2. As regards exposure of the hands from soil in connection with rugby matches for example, the default value is specified as being 0.2 – 1.0 mg/cm^2. It is not entirely clear what value should be used for people who use artificial turf pitches. In this study, 1.0 mg/cm^2 has been chosen as regards the calculation of skin exposure. In addition, 100% skin absorption has been used for chemicals for which there is no specific information concerning skin uptake. A realistic uptake is probably of the order of < 1% to 10% depending on the substance. This means that the uptake that is calculated here is clearly higher than the actual value.

- Scenario 5: Adults who train and play matches indoors:
  - Body weight = 70 kg
  - Skin surface which is exposed = 7100 cm^2
  - Duration per session = 4 hours
  - Number of sessions per week = 5 sessions
  - Duration in months = 6 months

  In addition to the above, there will be six hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place. Total skin exposure per week: 42 600 mg rubber granulate/week and 608 mg rubber granulate/kg body weight/week, **87 mg rubber granulate/kg body weight/day.**

- Scenario 6: Juniors who train and play matches indoors:
  - Body weight = 65 kg
  - Skin surface which is exposed = 6600 cm^2
  - Duration per session = 2 hours
  - Number of sessions per week = 7 sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1x Valhall, three sessions per week)

In addition to the above there will be two matches of two hours per month for three months. It is assumed that these matches are played during the same period in which the training sessions take place.

Total skin exposure per week: 49 500 mg rubber granulate/week and 762 mg rubber granulate/kg body weight/week, **109 mg rubber granulate/kg body weight/day.**

- Scenario 7: Older children who train and play matches indoors:
  - Body weight = 50 kg
  - Skin surface which is exposed = 5100 cm^2
  - Duration per session= 2.5 hours
  - Number of sessions per week = 4 sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1x Valhall, three sessions per week)

  In addition to the above there are two hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place.

  Total skin exposure per week: 25 500 mg rubber granulate/week and 510 mg rubber granulate/kg body weight/week, **73 mg rubber granulate/kg body weight/day.**

- Scenario 8a: Children who train and play matches indoors:
  - Body weight = 30 kg
  - Skin surface which is exposed = 3000 cm^2
  - Duration per session: 2.5 hours
  - Number of sessions per week: 4
  - Duration in months: 6

  In addition to the above there are two hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place.

  Total skin exposure per week: 15 000 mg rubber granulate/week and 500 mg rubber granulate/kg body weight/week, **71 mg rubber granulate/kg body weight/day.**

- Scenario 8b: Children who play cup tournaments indoors:
  - Body weight = 30 kg
  - Skin surface which is exposed = 3000 cm^2
  - Time spent in hall, light exertion per cup tournament = 17 hours
  - Time spent in hall, playing matches per cup tournament = 7 hours
  - Number of cup tournaments per year = 2 cup tournaments

- Number of matches per cup tournament: 7
- Duration per cup tournament: 2.5 days

It is assumed that the children will shower between each match, so that their skin is exposed on seven occasions during a cup tournament. Normal time spent in the hall is not considered to lead to significant skin exposure. This indicates an average exposure (mg/day) of: **280 mg rubber granulate/kg body weight/day** for a total of five days.

Oral intake
It is assumed that children who play and train on artificial turf pitches can also be exposed to the rubber material that is used by placing it in their mouth and then chewing and possibly also swallowing it. We do not have any indication of how much rubber material may be involved, but it will probably be of the order of 0.5-1 grams per match/training session. In a worst case assessment, it is reasonable to assume a value of 1 gram per match/training session and that 100% of what is swallowed is taken up via the gastrointestinal trackt.

- Scenario 9a: Children who train and play matches indoors:
  - Body weight = 30 kg
  - Quantity swallowed per training session/match = 1.0 gram
  - Assumed uptake = 100%
  - Number of sessions per week = 4
  - Duration in months = 6
  - Total number of times per year = 64

  In addition to the above, there will be one match per week for six months.

  This indicates a repeated exposure per week of: 5 grams of rubber granulate and 0.71 grams/day, and **23.7 mg/kg body weight/day** with a duration of six months.

- Scenario 9b: Children who play cup tournaments indoors:
  - Body weight = 30 kg
  - Quantity swallowed per match = 1.0 gram
  - Assumed uptake = 100%
  - Number of exposures per year = 14 times (7 matches per cup tournament, two cup tournaments per year)

This indicates an acute exposure per cup tournament of: 7.0 gram, 2.8 gram/day (one cup tournament lasts 2.5 days) and **93.4 mg rubber granulate/kg body weight/day** for five days a year.

Measurements and calculations
Many different chemical substances have been demonstrated in samples of rubber granulate and during the degassing of these samples which are classified as hazardous.

The results of analyses of two different types of elastomer, one type of recycled rubber granulate, one type of EPDM rubber granulate, one type of thermoplastic elastomer and two types of artificial turf fibre are available. Leaching studies have also been carried out on various types of rubber granulate and artificial turf fibre, in addition to the degassing from rubber granulate. As the content of hazardous chemicals in the EPDM rubber was clearly lower than that for the recycled rubber granulates, it was decided not to include EPDM rubber granulate in the following risk assessment.

Based on the content of hazardous substances to health and the degree of exposure, it is concluded that oral exposure resulting from training/playing on pitches based on artificial turf fibre will not cause any increased health risk. The assessment of health risk is therefore related to exposure which is due to particles/dust and degassing from the rubber granulate itself. To assess the health risk, data from the sample of recycled rubber granulate which showed the highest concentrations of hazardous substances was used.

Analyses of rubber granulates and artificial turf fibres were undertaken by AnalyCen AS whilst at NILU analyses were carried out for selected elements and organic compounds. Leaching from artificial turf fibre and rubber granulates was carried out using standardised methods. The leaching of heavy metals into water was measured by adding 200 grams of rubber granulate or artificial turf fibre to 2 litres of water and leaving the solid material in contact with the water for 24 hours. To measure the leaching of organic compounds, 1 litre of water and 100 grams of rubber granulate were used with a contact time between the water and granulate of 48 hours. As regards degassing from rubber granulate, 2 grams of rubber granulate heated to 70^{o}C for 30 minutes were used. The quantity of airborne dust was determined gravimetrically after it had been collected on a quartz filter. A distinction was made between particle sizes (PM10 and PM2.5). For more information on the analyses, see the NILU report of January 2006. Uncertainty in the measurements is of the order of 10 – 30%.

Inhalation

Degassing of volatile organic compounds (VOC)

The degassing of organic compounds was measured for recycled rubber granulate and one type of EPDM rubber granulate. Selected alkylated benzenes and two chlorinated compounds were measured. Degassing from the EPDM rubber was clearly lower than that from the other rubber granulates. In total, this was in the order of 250-400 µg/kg of granulate. The degassing was investigated at a temperature of 70^{o}C, which is well above the likely temperature of the hall. The values quoted are therefore higher than would be expected during normal use of artificial turf pitches. These values will not be used in the risk assessment because measurements of indoor air are available for artificial turf pitches.

Measurements are available for VOC from a number of indoor artificial turf pitches during training sessions. In Manglerudhallen, 234 chemical compounds were found (concentration > 0.1 µg/m^3, of which 29 were identified), which gave a total VOC of

approx. 716 µg/m^3. Four-fifths of the sampling period was carried out with full ventilation in the hall, which means that the concentration of VOC must have been higher before ventilation was commenced, possibly as high as 1000 µg/m^3. This is the result from just one measurement. Concentrations varied from approx. 85 to 0.8 µg/m^3. For 14 of these compounds, the concentration was in the range 10-85 µg/m^3. 4-Methyl-2-pentanone, benzothiazole, isomers of xylene, toluene, octenal, acetone, styrene and dodecane were among these compounds. During the second sampling period, a total VOC of approx. 230 µg/m^3 was measured. People often begin to complain about the air quality when the total VOC is higher than 100-200 µg/m^3. It can be concluded that the rubber granulate is the main source of the VOCs which were measured in the hall. Subsequent samples in the hall (roof hatches and windows closed, temperature of 15^{o}C) showed a total VOC of 255 µg/m^3. Under conditions where the temperature inside the hall was again 20^{o}C, a total VOC of 732 µg/m^3 was measured.

In Østfoldhallen, where new factory-made granulate was used, the concentration of VOC was relatively low (approx. 150 µg/m^3), even during exertion. This level is not uncommon in general indoor environments. A number of sources are assumed to contribute to the VOC measured inside the hall (artificial turf, rubber granulate, timber in the hall and road traffic outside the hall).

For the Valhall artificial turf pitch, a mean total VOC of 234 µg/m^3 was measured, whilst in the second half of the measurement period, 290 µg/m^3 was measured. It is concluded that the main source of VOC in the hall is the rubber granulate.

In the subsequent risk assessment, a total VOC concentration in the hall air of 716 µg/m^3 was chosen as a worst case scenario. This value was chosen because it is based on measurements taken under conditions which can occur in the hall. Measurements in both Østfoldhallen and Valhall indicate values 2.5 to 3 times lower however.

Based on these scenarios, the total uptake of VOC through inhalation (assuming 100% uptake) has been calculated. The resulting figures are shown in the table below.

Table 1: Uptake of total VOC via the lungs

Scenarios	**Exposure** weeks	**Inhalation volume** m^3/kg body weight/day	**Concentration of VOC in hall air** µg/m^3	**Uptake** %	**Uptake VOC** µg/kg body weight/day
Adults	26*	0.32	716	100	**229**
Junior	16*	0.16	716	100	**115**
Older children	26*	0.12	716	100	**86**
Children training + matches	26*	0.10	716	100	**72**
Children Cup tournament	0.7**	0.35	716	100	**251**

* Repeated exposure

** Single exposure

The table below shows the measured concentrations and classification of volatile organic compounds (VOC) in artificial turf halls with recycled rubber granulate. Many of these substances are not classified. This does not however mean that the substances cannot constitute a health risk; simply that no toxicological information is available or the substance has not been assessed with regard to classification. The substances which have been identified vary from hall to hall, and there is no clear link between the concentrations of total VOC which have been measured in a hall and the concentrations of many of the individual volatile compounds.

Table 2: Concentrations ≥ 2.0 µg/m^3 of volatile compounds (VOC) in artificial turf halls with recycled rubber granulate

Substance	**CAS no.**	**Classification (health)**	**Concentration** µg/m3
Toluene	108-88-3	R38-48/20-63-65-67	85.0*, 15.3**
Butenylbenzene (isomers)	-	-	82.5*
Benzoic acid	65-85-0	-	81.0*, 19.3**
Diethenylbenzene (isomers)	-	-	65.7*
p- and *m*-Xylene	106-42-3	R20/21-38	25.5*, 9.6**
Ethylbenzene aldehyde (isomers)	53951-50-1	-	34.7*
Benzothiazole	95-16-9	-	15.7*, 31.7**
1,1'-Biphenyl	92-52-4	R36/37/38	15.6*
Acetone	67-64-1	R36-66-67	15.3*, 9.5**
o-Xylene	95-47-6	R20/21-38	13.1*
4-Methyl-2-pentanone	108-10-1	R20-36/37	12.7*, 12.7**
3-Phenyl-2-propenal	104-55-2	-	10.2*
Pentenylbenzene (isomers)	-	-	7.3*
Pentanedioic acid dimethyl ester	1119-40-0	-	6.8*
Ethylbenzene	100-41-4	R20	6.7*, 3.3**
Styrene	100-42-5	R20-36/38	6.1*, 3.2**
Hexenylbenzene (isomers)	-	-	15.5*
Ethylcyclohexane	1678-91-7	-	5.6*
Formaldehyde	50-00-0	R23/24/25-34-40-43	5.5*, 6.5**
2-Butoxyethanol	111-76-2	R20/21/22	5.3*
Unidentified naphthalene derivative	-	-	9.3*
Octane	111-65-9	R38-65-67	4.6*
Undecane	1120-21-4	-	4.6*, 3.1**
Acetaldehyde	75-07-0	R36/37-40	4.3*, 2.9**
Nitromethane	75-52-5	R22	4.1*
1-Propylbenzene	673-32-5	-	4.0*
Alpha-pinene	80-56-8	-	10.5**
Cyclohexanone	108-94-1	R20	9.8**
Junipene	475-20-7	-	7.2**
Acetic acid	64-19-7	R35 < 0% no class.	4.3**
Decane	124-18-5	-	5.0**

Dodecane	112-40-3	-	3.7**
1,2,3-Trimethylbenzene	95-63-6	R20-36/37/38	3.2**
Limonene	138-86-3	R38-43	2.6**
2-Methylnaphthalene	91-57-6	-	2.5**
Benzene	71-43-2	R45-46-36/38-48/23/24/25-65	2.4**
3-Carene	13466-78-9	-	2.2**
Pentadecane	629-62-9	-	2.2**
2,3-Dihydreo-1,1,3,-trimethyl-3-phenyl-1H-indene	3910-35-8	-	2.1**
Hexanal	66-25-1	-	2.0**
1,2-Propanediol	57-55-6	-	2.0**
1-Methoxy-2-propanol	107-98-2	-	2.0**

* Total identified VOC 590 µg/m^3, Manglerudhallen
** Total identified VOC 190 µg/m^3, Valhall

As is apparent from the table above, most of the substances which have been classified have been classified on the basis of acute toxicity and irritation. Only a few substances have been classified with regard to possible long-term effects and allergies.

Table 3: Estimated uptake through inhalation of selected volatile compounds based on concentrations measured in the hall air for artificial turf pitches in which recycled rubber granulate is used.

Compounds	**Concentration** µg/m^3	**Estimated uptake through inhalation** µg/kg body weight/day				
		Adults (0.32 m^3/kg/day)	**Juniors** (0.16 m^3/kg/day)	**Older children** (0.12 m^3/kg/day)	**Children training** (0.10 m^3/kg/day)	**Children cup tournaments** (0.35 m^3/kg/day)
Toluene	85.0	27.2	13.6	10.2	8.5	29.8
Butenylbenzene	82.5	26.4	13.2	9.9	8.3	28.9
Benzoic acid	81.0	25.9	13.0	9.7	8.1	28.4
Diethenylbenzene	66.7	21.3	10.7	8.0	6.7	23.3
p- and *m*-Xylene	25.5	8.2	4.1	3.1	2.6	8.9
Ethylbenzene aldehyde	34.7	11.1	5.6	4.2	3.5	12.0
Benzothiazole	31.7	10.1	5.1	3.8	3.2	11.1
1,1'-Biphenyl	15.6	5.0	2.5	1.9	1.6	5.5
Acetone	15.3	4.9	2.5	1.8	1.5	5.4
o-Xylene	13.1	4.2	2.1	1.6	1.3	4.6
4-Methyl-2-pentanone	12.7	4.1	2.1	1.5	1.3	4.5
3-Phenyl-2-propenal	10.2	3.3	1.7	1.2	1.0	3.6
Styrene	6.1	2.0	1.0	0.7	0.6	2.1
Formaldehyde	6.5	2.1	1.1	0.8	0.7	2.3
Acetaldehyde	4.3	1.4	0.7	0.5	0.4	1.5
Alpha-pinene	10.5	3.4	1.7	1.3	1.1	3.7
Limonene	2.6	8.3	4.2	0.3	0.3	0.9
Benzene	2.4	0.8	0.4	0.3	0.2	0.8

Amongst the substances in the table above, there are compounds which have either been classified as allergy-triggering through skin contact or where on the basis of structural similarity with known allergens it is reasonable to assume that they could lead to contact allergy. Many of the substances can act as an irritant to the skin, eyes and mucous membranes. The concentration of volatile irritating compounds is however so low that it is unlikely that they would cause irritation during training, matches or other time spent in the halls. As regards acute effects, the estimated uptake via the lungs is of the order of 1 – 40 µg/kg body weight/day. For comparative purposes, the doses which have been shown to lead to acute poisoning are more than 1000 times higher than those estimated for exposure as a result of inhalation in indoor halls.

Our assessment is that exposure (through inhalation) to volatile organic compounds (VOC) as a result of using halls in which recycled rubber granulate is used will not cause an increased health risk as regards the harmful effects of short-term exposure (acute poisoning and irritation). The degree to which repeated exposure (inhalation) could constitute a health risk has been assessed on the basis of information concerning NOAEL values and the type of harmful effect for each individual substance and the degree of exposure.

Airborne dust

The quantity of airborne dust in indoor environments is influenced by many factors such as level of exertion and the room's shape, ventilation and building materials. In Manglerudhallen, a PM10 of 40 µg/m^3 and a PM2.5 of 17 µg/m^3 were measured during ventilation. The corresponding mean values for outdoor air in the Oslo study are 21 µg/m^3 and 7 µg/m^3 respectively. In Østfoldhallen, the PM10 level was 31 µg/m^3 whilst the PM2.5 level was 10 µg/m^3. In Valhall, the PM10 level was 32 µg/m^3 whilst the PM2.5 level was 19 µg/m^3. By comparison, it is noted that the average concentration of PM10 in homes, nurseries and schools is of the order of 20 µg/m^3. In both Manglerudhallen and Valhall, it is assumed that the main source of airborne dust is recycled rubber granulate. In Manglerudhallen, 30% of the PM10 fraction and 50% of the PM2.5 fraction was rubber dust.

In the subsequent risk assessment, the highest measured level for PM10 of 40 µg/m^3 was selected as regards respirable dust (particles).

The table below shows estimated intake scaled up in relation to the PM10 fraction through the inhalation of dust/particles.

Table 4: Estimated intake of PM10 via the lungs

Scenarios	**Exposure** weeks	**Inhalation volume** m^3/kg body weight/day	**Concentration of PM10 in hall air** µg/m^3	**Intake** %	**Intake PM10** µg/kg body weight/day
Adults	26*	0.32	40	100	**12.8**
Junior	16*	0.16	40	100	**6.4**
Older children	26*	0.12	40	100	**4.8**
Children training/matches	26*	0.10	40	100	**4.0**
Children cup tournaments	0.7**	0.35	40	100	**14.0**

* Repeated exposure
** Single exposure

Table 5: Estimated intake via the lungs of PCBs, PAHs, phthalates and alkyl phenols in the PM10 based on the concentration of these substance groups in recycled rubber granulate

Scenarios	**Exposure** weeks	**Intake PM10** µg/kg body weight/day	**Total content in recycled rubber granulate** pg/µg rubber granulate				**Estimated uptake** pg/kg body weight/day			
			PCBs	**PAHs**	**Phthalates**	**Alkyl phenols**	**PCBs**	**PAHs**	**Phthalates**	**Alkyl phenols**
Adults	26*	12.8	0.202	76	118	55	**2.6**	**973**	**1510**	**704**
Junior	16*	6.4	0.202	76	118	55	**1.3**	**486**	**755**	**352**
Older children	26*	4.8	0.202	76	118	55	**1.0**	**365**	**566**	**264**
Children training/matches	26*	4.0	0.202	76	118	55	**0.8**	**304**	**472**	**220**
Children cup tournaments	0.7**	14.0	0.202	76	118	55	**2.8**	**1064**	**1652**	**770**

* Repeated exposure
** Single exposure

Table 6: Estimated intake of PAHs based on measured values of PAHs in the PM10 fraction in artificial turf halls where recycled rubber granulate is used (uptake set at 100%)

Scenarios	**Exp.** weeks	**Inhalation volume** m^3/kg body weight/ day	**Concentration of PAH in PM10 in hall air** ng/m^3	**Concentration of phthalates in PM10 in hall air** ng/m^3	**Intake PAH** pg/kg body weight/day	**Intake phthalates** pg/kg body weight/day

Adults	26*	0.32	10.8	134.4	**3456**	**43 000**
Junior	16*	0.16	10.8	134.4	**1728**	**21 500**
Older children	26*	0.12	10.8	134.4	**1296**	**16 130**
Children training/matches	26*	0.10	10.9	134.4	**1080**	**13 400**
Children cup tournaments	0.7**	0.35	10.8	134.4	**3780**	**47 000**

** Repeated exposure*
*** Single exposure*

It appears that the quantity of PAH based on measurements of PAH in the PM10 fraction is approximately three times higher than the figure estimated on the basis of total PM10 and the concentration which was measured in the recycled rubber granulate. The extent to which this is due to actual differences, or differences in the analysis results as regards concentrations of PAH in the granulate and in the PM10 fraction of the granulate or the result of other sources contributing PAH to the PM10 fraction has not been clarified. If the measurements of PAH in the PM10 fraction are used as a basis, the uptake of PAH is of the order of 2-5 µg/kg body weight/day. There are no specific PM10 values as regards PCBs or alkyl phenols. For these, values estimated on the basis of concentration in the rubber granulate and the total quantity of PM10 which is assumed to be taken up via the lungs must be used.

A daily uptake of 3800 pg PAH/kg body weight is used as a worst case scenario in the subsequent risk characterisation. For PCB, a value of 3 pg/kg body weight was used, whilst values of 47000 pg/kg and 800 pg/kg body weight were used for phthalates and alkyl phenols respectively. Given the very small quantities of this type of compounds which are taken up per day, it can be concluded that they do not constitute an increased health risk.

Phthalates
Measurements in hall air of phthalates in µg/m^3 taken from the NILU report is hown in table 7.

Table 7: Measurements of phthalates in hall air

Phthalate	**µg/m^3**
di-butylphthalate (DBP)	0.38
di-ethylphthalate (DEP)	0.09
di-isobutylphthalate (DIBP)	0.13

Total	**0.6**

Total content of phthalates in rubber granulates from Byggforsk (worst case measurement from 2-4 samples) is shown in table 8.

Table 8: Content of phthalates in rubber granulates

Phthalate	**Rubber granulate (mg/kg)**
Di-methylphthalate (DMP)	< 1.0
Di-ethylphthalate (DEP)	< 1.0
Di-butylphthalate (DBP)	3.9
Benzylbutylphthalate (BBP)	2.8
Di-ethylhexylphthalate (DEHP)	29.0
Di-n-octylphthalate (DOP)	< 1.0
Di-isononylphthalate (DINP)	78.0
Di-isodecylphthalate (DIDP)	< 1.0
Total	**117.7**

• Scenario 1: adults who train and play matches indoors:

They inhale 0.32 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.19 µg/kg body weight/day.

• Scenario 2: Juniors who train and play matches indoors:

They inhale 0.16 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.10 µg/kg body weight/day.

• Scenario 3: Older children who train and play matches indoors:

They inhale 0.12 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.07 µg/kg body weight/day

• Scenario 4a: Children who train and play matches indoors:

They inhale 0.10 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.06 µg/kg body weight/day

• Scenario 4b: Children who play cup tournaments indoors:

They inhale 0.35 m^3/kg body weight/day for five days a year.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.21 µg/kg body weight/day for five days a year.

Alkyl phenols
Alkyl phenols were below the detection limit in the air measurements from Manglerudhallen, Valhall and Østfoldhallen undertaken by NILU. In the calculations, the detection limit of 0.01 to 0.05 µg/m^3 was used as a starting point (the detection limit for phthalates has been used).

Total content of alkyl phenols in rubber granulates, Byggforsk (worst case measurement from two-four samples) is shown in table 9.

T*able 9: the content of alkyl phenols in rubber granulates*

Alkyl phenol	**Rubber granulates (µg/kg)**
4-t-octylphenol	33700
4-n-nonylphenol	< 5
Iso-nonylphenol	21600
Total	**55305**

• Scenario 1: adults who train and play matches indoors:

They inhale 0.32 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.016 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 2: Juniors who train and play matches indoors:

They inhale 0.16 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.008 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 3: Older children who train and play matches indoors:

They inhale 0.12 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.006 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 4a: Children who train and play matches indoors

They inhale 0.10 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.005 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 4b: Children who play cup tournaments indoors:

They inhale 0.35 m^3/kg body weight/day for five days a year.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day, over a total of five days per year, is therefore 0.018 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

Skin contact
Of the total quantity of chemicals which exist in the form of particles/dust, only a limited proportion will be available for uptake into the body through the skin. Studies of leaching from rubber particles have been carried out on behalf of Byggforsk in which leaching from 100 grams of rubber granulate/fibre was measured after contact for 48 hours with 1 litre of deionised water. If it is assumed that the quantity of chemical substances which is available for uptake via the skin corresponds to what has been found for leaching into water, it is possible to estimate approximately how much will be available for skin uptake. The degree of leaching into water will depend on how the substance is bound to the rubber granulate (strongly bound or not) and the substance's physical-chemical properties (e.g. water solubility). In our calculation of skin exposure, we chose to use the leaching factor which gives the most leaching. Based on analyses carried out on behalf of Byggforsk and results for total organic carbon, it was decided to use a leaching figure of 60 mg/litre/100g of rubber granulate. This corresponds to 0.06% of the weight of the rubber granulate. Based on the analysis data, leaching has been calculated at 0.8 x 10^{-6}% for total PCBS, 1 x 10^{-6}% for total PAHs, 30 x 10^{-6} % for total phthalates and 5 x 10^{-6}% for total alkyl phenols.

Table 10 shows the estimated quantities of PCBs, PAHs, phthalate and alkyl phenol which are assumed to be available for skin uptake following exposure to rubber granulate particles and dust

Scenario	**Particle/dust exposure (mg/kg body weight/day**	**PCBs ng/kg body weight/day**	**PAHs ng/kg body weight/day**	**Phthalates ng/kg body weight/day**	**Alkyl phenols ng/kg body weight/day**
		Bioavailability 0.8 x 10^{-6}%	Bioavailability 1 x 10^{-6}%	Bioavailability 30 x 10^{-6}%	Bioavailability 5 x 10^{-6}%
Adults	87	0.7	0.87	26.10	4.35
Junior	109	0.87	1.09	32.70	5.45

Older children	73	0.58	0.73	21.90	3.65
Children training/matches	71	0.57	0.71	21.30	3.55
Children cup tournaments	280*	2.24*	2.8*	84.00*	14.00*

* Short-term exposure (total of approximately five days per year)

As is apparent from the table above, exposure via the skin is extremely low. In reality, it will be much lower still for many of the substances. This particularly applies to phthalates, where uptake through the skin is of the order of 5% of the component which is available for uptake.

Oral intake

It must be assumed that children in particular could swallow some rubber granulate during matches or training sessions. It has been assumed that this will amount to no more than approximately 1 gram per training session/match. 100% uptake from the gastro-intestinal trackt is also assumed. The oral intake for children has been estimated on the basis of these assumptions.

Phthalates

Scenario 9a, children who train and play matches indoors swallow 23.7 mg of rubber granulate/kg body weight/day. The quantity of phthalate in rubber granulate is 118 ng/mg rubber granulate. Children are therefore exposed to **2.8 µg phthalate/kg body weight/day** over 6 months.

Scenario 9b, children who play cup tournaments indoors swallow 93.4 mg of rubber granulate/kg body weight/day over five days a year. The quantity of phthalate in rubber granulate is 118 ng/mg of rubber granulate. Children are therefore exposed to **11.0 µg phthalate/kg body weight/day** over five days a year.

Alkyl phenols

Scenario 9a, children who train and play matches indoors swallow 23.7 mg of rubber granulate/kg body weight/day. The quantity of alkyl phenols in rubber granulate is 55.3 ng/mg of rubber granulate. Children are therefore exposed to **1.3 µg alkyl phenols/kg body weight/day** over 6 months.

Scenario 9b, children who play cup tournaments indoors swallow 93.4 mg of rubber granulate/kg body weight/day over five days a year. The quantity of alkyl phenols in rubber granulate is 55.3 ng/mg of rubber granulate. Children are therefore exposed to **5.2 µg of alkyl phenols/kg body weight/day** over five days a year.

Assessment of harmful effects

VOC

Volatile organic compounds can cause a variety of adverse effects on health. The effect will depend on whether one is exposed sufficiently and the duration/frequency of the exposure. Unfortunately, there is little or no information available on the potential health hazards posed by many of these substances. Examples of harmful effects include damage to the nervous system, liver, kidney, blood-forming organs, genetic material and reproductive organs as well as allergy and cancer. The table below shows the classification and relevant NOAEL values for a number of VOCs which have been identified in the gas phase (the hall air) in artificial turf pitches in which recycled rubber granulate is used.

Table 11: Classification and NOAEL (C) values for selected VOCs

Substance	**Classification**	**NOAEL(C)**	**Effect**
Toluene	R38-48/20-63-65-67	340 mg/kg/day* 390 mg/kg/day* 150 mg/m^3 **	Reduced sperm quality in rats Neurological effects in rats (hearing) Headaches, irritation and tiredness in humans
Butenylbenzene	No information found.	No information found.	No information found.
Benzoic acid	No information found.	 550 mg/kg/day* (one dose) 5 mg/kg/day*	Inhalation causes irritation in the nose and throat, and particles in the eyes and on the skin of humans. Reduced weight in rats, otherwise no effects concerning neurotoxicity. Increased number of resorptions in rats
Xylenes	R20/21-38	20 ppm* (87 mg/m^3) 50 – 100 ppm* (220 – 440 mg/m^3) 50 ppm* (220 mg/m^3)	Irritation of eyes and airways in humans Neurological effects in humans Reduced number of red and white blood cells in rats
Styrene	R20-36/38	150 ppm* (640 mg/m^3)	Reduced body weight and delayed development in offspring
Formaldehyde	R23/24/25-34-40-43		*Effects on humans*

		0.5 mg/m^3* 0.06 mg/m^3** 0.12 mg/m^3** 0.45 mg/m^3* 1.0 – 1.8 mg/m^3*	Effect in the nasal cavity Eye irritation Airway irritation Airway contractions Nasal cancer
Benzene	R45-46-36/38-48/23/24/25-65	Acceptable air concentration for life-long exposure (RfC) = 30 µg/m^3; RfD = 4 µg/kg/day	Effects on bone marrow, reduced number of red and white blood cells. Neurological and reproducitve effects at slightly higher doses
Limonene	R38-43	5.6-6.6 g/kg body weight** 10 mg/kg/day*	Liver toxicity Irritation
Benzothiazole	The substance is assumed to cause allergic reactions	Intravenously in mice = 95 mg/kg body weight**	Moderate acute toxicity, no chronic toxicity data found.

* Repeated exposure
** Single exposure

Total VOC

Total VOC (the sum of the concentrations of selected organic compounds defined on the basis of their volatility and analysis and estimation method) were used in assessments of indoor air quality. The levels of this collective parameter vary considerably between indoor environments and is also strongly affected by static and variable indoor sources. As total VOC represents the sum of many different chemical compounds with different properties, total VOC levels do not provide a basis for a health risk assessment. In normal indoor air assessments, abnormally high levels will however result in an assessment of whether there are specific sources and if so how these sources can be reduced on the basis of a general desire to minimise exposure to chemicals. In the analyses that are available, total VOC levels are significantly higher than those which NILU found in general indoor environments without any special sources which liberate volatile organic compounds to the atmosphere. It is also concluded in the NILU report that the composition of individual chemicals in the total VOC samples indicates that the rubber granulate used in the pitches is an important contributor to total VOC. This is because small particles on the pitch surface give the rubber granulate a large surface area, enabling volatile chemicals in the material to evaporate into the air over time. Other common examples which contribute to elevated total VOC levels as in this case are rooms with wooden panels on the walls and rooms with recently carpeted floors. Total VOC levels also remain high for a long time after rooms have been refurbished.

As the air samples taken from these halls also indicate a mixture of many organic compounds, none of the individual substances will occur in concentrations which give cause for concern over health effects. It is however possible that individual substances or mixtures of substances could contribute to odours or mucous membrane irritation which particularly sensitive individuals may notice even at these relatively low levels. This could contribute to the perception of poor, heavy or "dry" air. As smell is part of mankind's warning system for possible dangers, the possibility of some people reacting with symptoms such as tiredness or headaches must be kept open. In this type of indoor area, where people voluntarily spend time on enjoyable activities, such links must be assumed to be unlikely.

There is no adequate scientific basis for concluding that short or extended periods of time spent in an atmosphere with total VOC levels equivalent to those which were measured in indoor halls with artificial turf could lead to adverse effects on health.

The most important reason for "poor air" in sports halls is body odour linked to physical activity. This is the reason why sports halls have more demanding requirements for ventilation than other premises.

PCBs
PCB (polychlorinated biphenyls) is a complex group of chemicals, some of which have dioxin-like effects. Exposure to PCBs is associated with a broad spectrum of health effects in animals. Amongst the harmful effects of PCB exposure in animals are cancer and effects on the immune, reproductive, nervous and hormonal systems. PCBs are classified as harmful (Xn) and can be accumulated in the body as a result of repeated exposure (R33). The IARC (International Agency for Research on Cancer) classifies PCBs as possibly being carcinogenic in humans. We have chosen to compare the exposure levels for PCBs with a no observed adverse effect level based on reproductive effects (NOAEL = 5 µg/kg body weight/day).

Benzene
Benzene is a carcinogenic substance which has been found to cause leukaemia in humans. The WHO Air Quality Guidelines for Europe (WHO Regional Publications, European Series, No. 91, Copenhagen 2000) has recommended that when estimating lifetime cancer risk, a level of 1.7 $\mu g/m^3$ benzene should be assumed to cause a lifetime cancer risk of 10^{-5}. As regards cancer risk, it has been assumed that it is impossible to identify a threshold risk value, i.e. any exposure will cause a certain degree of risk.

PAHs
Polycyclic aromatic hydrocarbons (PAHs) or tar compounds is a collective term for a large number of chemical substances which are formed during combustion. The substance group PAH contains a number of mutagenic substances, some of which are demonstrably or probably carcinogenic. Benzo(a)pyrene (BaP) is the most studied PAH compound. It has been shown to be carcinogenic in animal experiments both after inhalation and as a result of intake through food. When assessing the cancer risk due to

exposure to PAH, it is therefore common to use BaP as an indicator and calculate the cancer risk on the basis of the concentration of BaP in air or food.

Many PAHs are classified as carcinogenic substances in cancer category 2, whilst B(a)P is classified as carcinogenic R45 category 2, R46 Mut. category 2. and Repro category 2 R60 and R61. We have chosen B(a)P as a worst case and used the measured values and a $NOAEL_{BaP}$ = 40 mg/kg/body weight/day for fertility as a basis.

Phthalates
Some of the most harmful phthalates are DEHP, DBP and BBP. In animal experiments, these have been shown to cause adverse effects on reproduction, particular in young male animals, covering both reproductive ability and embryo development. In the EU, DEHP, DBP and BBP are classified in category 2 for reproductive effects, which means that the use of these phthalates in consumer products is regulated. As phthalates are present in many consumer products which are used indoors, a possible link has been found between exposure to phthalates in house dust and asthma/allergy illnesses in children, but this link has yet to be clarified. In table 12 below the No Observed Adverse Effect Levels (NOAEL) for testicular toxicity/fertility and effects on the development of embryos for DEHP, DBP and BBP are shown.

Table 12: NOAEL for testicular toxicity/fertility and embryo development

Phthalate	**NOAEL Fertility/testicular toxicity mg/kg body weight/day**	**NOAEL Embryo development mg/kg body weight/day**
DEHP	4.8	4.8
DBP	52	50.0
BBP	100	50.0

A NOAEL of 4.8 mg/kg body weight is used in the subsequent risk characterisation of phthalates.

Alkyl phenols
In animal experiments, alkyl phenols such as 4-nonylphenol and 4-t-octylphenol have been shown to have properties equivalent to the female sex hormone oestrogen. This means that it can disrupt the hormonal balance in animals, which in turn can affect development of the experimental animals' ability to reproduce. In the EU, 4-nonylphenol is classified in category 3 for effects on reproduction, whilst 4-t-octylphenol is not classified in the EU with regard to possible effects on reproduction. Classification in category 3 means that the use of alkyl phenols in consumer products is not regulated. As 4-nonylphenol is the alkyl phenol which is associated with the most concerns, the no observed adverse effect level (NOAEL) for this alkyl phenol will be used in the risk assessment. In accordance with the EU's risk report for 4-nonylphenol, the NOAEL value for effects on the development of reproductive organs is 15 mg/kg body weight/day. In

animal experiments, it has been assumed that only 10% of 4-nonylphenol is absorbed, and is thus bioavailable. The NOAEL value used in the risk assessment for exposure to alkyl phenols will therefore be 1.5 mg/kg body weight/day.

Allergy

With regard to contact allergy (allergic contact dermatitis), for the substances which are assumed to be contact allergens, the decisive exposure factor is not body dose, but the dose per unit area of the skin (i.e. a dose which sensitises if it is applied in a concentrated form over a small area of the skin will not sensitise if it is spread over a larger skin area). In general, at the exposure levels that apply to artificial turf pitches the dose will be low and distributed over most of the body. The only exception could be in shoes, where dust can collect over time, so the changing/cleaning of footwear could be one aspect to remember in connection with training on artificial turf.

As regards airway allergies, latex (natural rubber) is a potent allergen and latex allergy is not uncommon. Car tyres can contain large quantities of latex, and emissions of latex from road traffic due to tyre wear are very high compared to other allergens. However, no increased occurrence of latex allergy has been demonstrated in individuals who live near busy roads compared with people who leave further away from such roads. The explanation given is that the bioavailability of latex is low in car tyre dust and/or that the latex allergens are deactivated during the vulcanisation process, etc. Sensitisation to IgE-mediated allergy can take place via the skin, but probably mostly occurs via the mucous membranes in the airways. Much of the dust that is deposited in the nose/throat will probably be swallowed. The effect of swallowing allergen-carrying dust in an allergy context is uncertain; it will probably induce tolerance/reduce the development of an allergy rather than promote allergy development. The quantity of dust which is deposited in the airways will depend on the size distribution. The estimated uptake of PM10 via the lungs is of such an order of magnitude that even if only a small proportion consists of an immune-active latex allergen, the dose in an allergen context would be large and the risk of sensitisation would be real (1 µg of allergen deposited on the mucous membranes represents a significant individual dose). No data is available on the immune-active latex allergen content of the dust, and the data that is available concerning latex from car tyre wear must be said to be reassuring. In the absence of data on the latex allergen content of dust, the possibility of a risk of latex allergy development as a result of regular training on artificial turf pitches cannot however be eliminated on the basis of the information that is available on car tyres. Similarly, the possibility that people who already have a latex allergy could suffer an acute asthma attack and other allergy symptoms as a result of inhaling dust from such artificial turf pitches cannot be eliminated. This can be of particular concern when it occurs in connection with vigorous physical activity.

Latex in dust can be measured to some extent, although it is open to discussion as to whether and if so how much biologically active latex allergen (the natural rubber allergen) is present even if latex is demonstrated. Experience of asthma and allergies caused by the use of such artificial turf pitches will therefore be of considerable importance for the assessment, if such experience exists.

However, a recently published study found slightly higher concentrations of individual phthalates in dust at home in children with asthma or allergy symptoms. This has resulted in considerable attention being directed at phthalate exposure. The results are important and provide interesting information, but at the present time there is no certain evidence on which to claim that phthalates can contribute to the development of asthma and allergies in the population.

Risk assessment

Inhalation

VOC

Table 13: MOS values for exposure scenarios 1-4

Substance	**NOAEL(C)**	**Effect**	**Exposure/scenario/VOC Scenarios 1-4 (μg/kg body weight/day)**	**Margin of Safety /MOS Scenarios 1-4**
Toluene	340 mg/kg/day*	Reduced sperm quality in rats	Scenario 1: 27.2 Scenario 2: 13.6 Scenario 3: 10.2 Scenario 4a: 8.5 Scenario 4b:29.8	Scenario 1: 12 500 Scenario 2: 25 000 Scenario 3: 33 300 Scenario 4a:40 000 Scenario 4b:11 400
Butenyl-benzene	No values found	No data found		
Benzoic acid	5 mg/kg/day*	Increased number of resorptions in rats	Scenario 1: 25.9 Scenario 2: 13.0 Scenario 3: 9.7 Scenario 4a: 8.1 Scenario 4b:28.4	Scenario 1: 193 Scenario 2: 385 Scenario 3: 515 Scenario 4a: 617 Scenario 4b: 176
Xylenes	50 ppm* (220 mg/m^3) Scenario 1: 70.4 mg/kg/day Scenario 2: 35.2 mg/kg/day Scenario 3: 26.4 mg/kg/day Scenario 4a: 22.0 mg/kg/day Scenario 4b: 77.0 mg/kg/day	Neurological effects in humans	Scenario 1: 12.3 Scenario 2: 6.2 Scenario 3: 4.7 Scenario 4a: 3.9 Scenario 4b:13.5	Scenario 1: 5700 Scenario 2: 5700 Scenario 3: 5600 Scenario 4a: 5600 Scenario 4b: 5700
Styrene	150 ppm* (640 mg/m^3) (42.9 mg/kg body weight/day***)	Reduced body weight and delayed development in offspring.	Scenario 1: 2.0 Scenario 2: 1.0 Scenario 3: 0.7 Scenario 4a: 0.6 Scenario 4b 2.1	Scenario 1: 21 500 Scenario 2: 43 000 Scenario 3: 61 300 Scenario 4a: 71 500 Scenario 4b 20 400
Formaldehyde	0.5 mg/m^3* Scenario 1: 0.16 Scenario 2: 0.08	Effects on humans	Scenario 1: 2.1 Scenario 2: 1.1 Scenario 3: 0.8	Scenario 1: 76* Scenario 2: 73* Scenario 3: 75*

	Scenario 3: 0.06 Scenario 4a: 0.05 Scenario 4b: 0.18 0.06 mg/m^3**	Effect on nasal cavity and bronchial contractions Eye irritation	Scenario 4a: 0.7 Scenario 4b: 2.3	Scenario 4a: 72* Scenario 4b: 78*
Benzene	Acceptable air concentration for life-time exposure (RfC) = 30 µg/m^3; RfD = 8.57 µg/kg/day	Effects on bone marrow, reduced white blood cell counts Neurological and reprotoxic effect at slightly higher doses	Scenario 1: 0.8 Scenario 2: 0.4 Scenario 3: 0.3 Scenario 4a: 0.2 Scenario 4b: 0.8	For all scenarios (1 to 4b), exposure is well below the reference value of 8.57 µg/kg/day.
Limonene	10 mg/kg/day*	Irritation	Scenario 1: 8.3 Scenario 2: 4.2 Scenario 3: 0.3 Scenario 4a: 0.3 Scenario 4b: 0.9	Scenario 1: 1200 Scenario 2: 2400 Scenario 3: 33 000 Scenario 4a: 33 000 Scenario 4b 11 000
Benzo-thiazole	Intravenously in mice = 95 mg/kg body weight**	Moderate acute toxicity, no chronic toxicity data found.	Scenario 1: 10.1 Scenario 2: 5.1 Scenario 3: 3.8 Scenario 4a: 3.2 Scenario 4b:11.1	Scenario 1: 9400 Scenario 2: 19 000 Scenario 3: 25 000 Scenario 4a: 30 000 Scenario 4b: 8600

* repeated exposure
** single exposure
*** Conversion values for rats: respiration frequency 85.5/min, tidal volume 0.86 ml, weight 400 grams, exposure 6 hours/day

Total VOC

It is impossible to carry out a health risk assessment on the basis of measurements of total VOC. It is possible that individual substances or mixtures of substances could contribute to odours or mucous membrane irritation which sensitive individuals are able to detect even at these relatively low levels. This could lead to the perception of "poor", heavy or "dry" air. As smell is part of mankind's warning system for possible dangers, the possibility of some people reacting with symptoms such as tiredness or headaches must be kept open.

Allergy

On the basis of the analysis data, substances were found in the VOC fraction which are classified as contact allergens. However, the concentrations of these substances are so low that they could not cause a contact allergy in individuals using the halls. One possible exception is the deposition of rubber dust on shoes where dust can collect over time.

As regards airway allergies, latex (natural rubber) is a potent allergen and latex allergy is not unusual. Car tyres can contain large quantities of latex, and emissions of latex caused by road traffic due to tyre wear are very high in an allergen context. However, no increased occurrence of latex allergy has been found in individuals who live near busy roads compared with people who live further away from such roads. The explanation given is that the bioavailability of latex in car tyre dust is low and/or that latex allergens are deactivated during the vulcanisation process, etc. No data on the concentration of immune-active latex allergen in the dust is available, and the data that is available concerning latex from the wear of car tyres must be considered to be reassuring. In the absence of data on concentrations of latex allergen in the dust, the possibility of a risk of developing a latex allergy as a result of regular training on artificial turf pitches cannot be eliminated on the basis of the available information on car tyres. Similarly, the possibility that people who already have a latex allergy could suffer an acute asthma attack and other allergy symptoms as a result of inhaling dust from such artificial turf pitches cannot be eliminated. This can be of particular concern when it occurs in connection with vigorous physical activity.

As regards exposure to phthalates in indoor air, some studies indicate that some phthalates could have an adverse effect on the health of those who are exposed, but there is currently insufficient evidence to claim that phthalates contribute to the development of asthma and allergies in the population.

Cancer

Benzene

The total inhalation volume during training in sports halls has been estimated as a "worst case" exposure for the age group 7 – 40. For all age groups, it has been assumed that individuals train for six months a year in indoor halls.

Children 7 – 11 years: 1.8 m^3/hr x 10 = 18 m^3/week for 26 weeks = 468 over 5 years.
Total: 2340 m^3
Juniors 12 – 15 years: 3.6 m^3/hr x 12 = 43.2m^3/week for 26 weeks = 1123 over 4 years.
Total: 4492 m^3
Juniors 16 – 19 years; 4.8 m^3/hr x15.6= 75 m^3/week for 26 weeks = 1950 over 4 years.
Total: 7800 m^3
Adults 20 – 40 years: 6.0 m^3/hr x 26 =156 m^3/week for 26 weeks = 4056 over 20 years.
Total: 81120 m^3

In October 2005, NILU took three measurements of benzene in Manglerudhallen (1.7, 2.2 and 2.3 µg/m^3), two measurements in Valhall (2.1 and 2.4 µg/m^3) and two measurements in Østfoldhallen (1.8 and 2.0 µg/m^3). When these measurements are corrected for benzene in the surrounding air, it is apparent that the "worst case" exposure based on benzene released from artificial turf in the hall is 1.4 µg/m^3 benzene. The US EPA's new guidelines for estimating cancer risk assume that children in the age group 2 - 15 are three times more sensitive than adults. In the calculations below we have taken this into account by multiplying the inhalation volume by three. The WHO's risk estimate is based

on the inhalation of 1.7 μg/m^3 of benzene for 70 years. If it is assumed that the average air intake is 20 m^3 per day, inhalation of a benzene quantity of (20 x 365 x 70 x 1.7) 8.7 x 10^5 μg of benzene would correspond to a lifetime leukaemia risk of 10^{-5}. In connection with training in sports halls with artificial turf, the "worst case" inhaled benzene would be ([{2340 + 4492} x 3 + 7800 + 81120] x 1.4) 1.5 x 10^5. The maximum "worst case lifetime cancer risk" is therefore (1.5 x 10^5/8,7 x 10^5) **0.2 x 10^{-5}**. It is generally accepted that calculations performed in this way represent a maximum risk and that the actual risk will very probably be lower. A risk as low as that calculated above is considered by the authorities of most countries who carry out quantitative cancer risk assessments to be negligible or tolerable.

PAHs

The Norwegian Pollution Control Authority (SFT) commissioned NILU to analyse 38 individual PAH compounds, including BaP, in three sports halls. These analyses were carried out on both the gas phase and airborne dust, PM10. BaP was substantially demonstrated in PM10. No measurements were taken outside the halls. NILU has however stated that the tar compounds which were measured including BaP in the PM10 fraction were in all probability caused by PAH penetrating from the surroundings through open windows or by being sucked into the ventilation system. The results of the BaP measurements in the sports halls are shown in Table 14.

Table 14: Measurements of BaP in sports halls

Sports hall	**BaP in PM10 (ng/m^3)**	**BaP in gas phase (ng/m^3)**
Valhall	0.56	< 0.01[x]
Østfoldhallen	0.38	0.01
Manglerudhallen	1.15	0.02

[x] Detection limit 0.01 in the gas phase

The WHO Air Quality Guidelines for Europe (WHO Regional Publications, European Series, No. 91, Copenhagen 2000) state that the annual average level of BaP in major European cities is in the range 1 – 10 ng/m^3. The EU has set a limit for BaP of 1 ng/m^3 which will apply from 2010 (?). The WHO Air Quality Guidelines for Europe has recommended that, when estimating lifetime cancer risk, it should be assumed that a level of 1.2 ng/m^3 BaP will give a lifetime cancer risk of 10^{-4}.

NILU concludes that the PAH values measured are due to PAH in the surrounding air. This means that using halls with artificial turf does not cause any additional risk of cancer caused by PAH exposure.

Airborne dust

A daily uptake of 3800 pg PAH/kg body weight was used as a worst case scenario. A daily uptake of 3 pg/kg body weight was used for PCB, with the corresponding values for

phthalates and alkyl phenols being 47 000 pg/kg body weight and 800 pg/kg body weight respectively. On the basis of the very small quantities of this type of compound which are taken up per day, it can be concluded that this type of compound does not cause any increased health risk.

Phthalates

The exposure calculations were based on the total exposure measurements for phthalates taken by NILU. As a worst case scenario, the lowest NOAEL value was used, i.e. 4.8 mg /kg body weight/day based on effects on fertility and embryo development in experimental animals exposed to DEHP. In table 15 the Margin of Safety (MOS) for the various scenarios is shown.

Table 15: The MOS values for scenarios 1-4 following exposure to phthalates

Scenario	**Total-phthalate mg/kg body weight/day**	**NOAEL fertility/embryo development mg/kg body weight/day**	**MOS**
Adults (1)	0.00019*	4.8	25 000
Junior (2)	0.0001*	4.8	48 000
Older children (3)	0.00007*	4.8	69 000
Children (4a)	0.00006*	4.8	80 000
Children (4b)	0.00021**	4.8	23 000

*Repeated exposure
** Single exposure

Alkyl phenols

The detection limit for phthalates/alkyl phenols of 0.05 µg/m^3 was used as exposure. The NOAEL value for 4-nonylphenol of 1.5 mg/kg body weight/day was used. This is based on the disruption of genitalia development. The table shows the Margin of Safety (MOS) for the various scenarios.

Table 16: The MOS values for scenarios 1-4 following exposure to alkyl phenols

Scenario	**Detection limit alkyl phenols µg/kg body weight/day**	**NOAEL disruption of genitalia development mg/kg body weight/day**	**MOS**
Adults (1)	0.016*	1.5	94 000
Junior (2)	0.008*	1.5	190 000
Older children (3)	0.006*	1.5	250 000
Children (4a)	0.005*	1.5	300 000
Children (4b)	0.018**	1.5	83 000

*Repeated exposure
**Single exposure

Skin contact
As Table 10 shows, exposure to PCBs, PAHs, phthalates and alkyl phenols via the skin is extremely low and is measured in ng/kg body weight/day. No risk characterisation was therefore carried out for this exposure path for effects other than cancer.

Skin exposure to benzene will be far less than inhalation exposure and will not represent a cancer risk. During activity on artificial turf, players may be exposed to tar compounds through direct contact. It is well known that tar compounds (PAHs) can cause cancer through skin exposure. The small quantities of tar compounds that players could come into contact with are however so small that they would not represent a cancer risk.

Oral intake

Phthalates
Scenario 9a, children who train and play matches indoors are assumed to swallow a maximum of 2.8 µg phthalate/kg body weight/day over 6 months. This gives a Margin of Safety (MOS) value of 1700.

Scenario 9b, children who play cup tournaments indoors are assumed to swallow 11.0 µg phthalate/kg body weight/day over five days a year. This is assumed to be as a single exposure and not a repeated exposure as in scenario 9a. The estimated phthalate exposure of 11.0 µg /kg body weight/day is well below LD_{50} values for phthalates.

Alkyl phenols
Scenario 9a, children who train and play matches indoors are assumed to swallow 1.3 µg alkyl phenols/kg body weight/day over 6 months. This gives a Margin of Safety (MOS) value of 1150.

Scenario 9b, children who play cup tournaments indoors are assumed to swallow a maximum of 5.2 µg alkyl phenols/kg body weight/day over five days a year. This is assumed to be a single exposure and not a repeated exposure as in scenario 9a. The estimated alkyl phenol exposure of 11.0 µg /kg body weight/day is well below the exposure levels which have been shown to cause damage through a single exposure to alkyl phenols.

Summary

Inhalation
VOC
It is concluded that exposure to (inhalation of) volatile organic compounds (VOC) as a result of using halls in which recycled rubber granulate is used will not cause any increased health risk as regards acute harmful effects (acute poisoning and irritation). The extent to which repeated exposure (inhalation) could cause an elevated risk of other types

of harmful effects was assessed specifically on the basis of information concerning NOAEL values and the harmful effects of selected individual substances which have been identified in the VOC fraction. Unfortunately, no information is available on harmful effects for many of the substances which were identified in the VOC fraction. It is therefore not possible to carry out a complete risk assessment for VOCs, but on the basis of the total VOC measured in the halls, there would appear to be no cause for concern. As regards selected substances, MOS values range from 71 500 to 72. It is not possible to draw an unequivocal conclusion as to whether the concentrations of VOC in the hall could cause an increased risk of asthma/allergy. Substances have been identified which are classified as allergens, but these occur in extremely low concentrations (see the specific section on allergies below).

Total VOC

It is not possible on the basis of the information on total VOC to carry out a complete health risk assessment, but the levels of this parameter that were measured indicate that the health risk is insignificant. It is however possible that individual substances or mixtures of VOCs could contribute to odours or mucous membrane irritation which some hypersensitive people could perceive as unpleasant even at these relatively low levels. These are reversible effects and would not cause any permanent discomfort.

Airborne dust/PAH/PCB

As a worst case scenario, a daily uptake of 3800 pg PAH/kg body weight was used. A value of 3 pg/kg body weight was used for PCB, whilst the corresponding value for phthalates was 47000 pg/kg body weight and for alkyl phenols 800 pg/kg body weight. Given that such small quantities of this type of compound can be taken up each day, it can be concluded that these compounds do not constitute any elevated health risk.

Phthalates

For adults, juniors, older children and children with repeated exposure to phthalates, the MOS values were 25 000, 48 000, 69 000 and 80 000 respectively. The exposure to total phthalates in measurements by NILU and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. It can be concluded that this exposure will not cause any elevated health risk for adults, juniors, older children or children. For children who are exposed to phthalates in connection with cup tournaments five days a year (single exposure), it is concluded that this exposure will not cause any increased health risk.

Alkyl phenols

For adults, junior, older children and children with repeated exposure to alkyl phenols, the MOS values were 94 000, 190 000, 250 000 and 300 000 respectively. The detection limit for alkyl phenols of 0.05 $\mu g/m^3$ and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. It can be concluded that this exposure will not cause any increased health risk for adults, juniors, older children or children. For children who are exposed to alkyl phenols in connection with cup tournaments five days a year (single exposure) it is concluded that this exposure will not cause any increased health risk.

Skin contact
As is apparent from Table 10, exposure to PCBs , PAHs, phthalates and alkyl phenols via the skin is extremely low and is measured in ng/kg body weight/day. It is therefore concluded that skin exposure to recycled rubber granulate will not cause any increased health risk.

Oral intake

Phthalates
For children who put in their mouth and chew/swallow recycled rubber granulate during training sessions/matches (repeated exposure), the MOS value was 1700 for phthalates. The worst case exposure for total phthalates in recycled rubber granulate and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. On the basis of this it can be concluded that this exposure will not cause any elevated health risk. For children who put in their mouth and chew/swallow recycled rubber granulate during cup tournaments lasting five days a year (single exposure), it is concluded that exposure to phthalates will be low and that this will not cause any elevated health risk.

Alkyl phenols
For children who put in their mouth and chew/swallow recycled rubber granulate during training sessions/matches (repeated exposure) the MOS value was 1150 for alkyl phenols. The worst case exposure to total alkyl phenols in recycled rubber granulate and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. On the basis of this it can be concluded that this exposure will not cause any increased health risk. For children who put in their mouth and chew/swallow recycled rubber granulate during cup tournaments lasting five days a year (single exposure), it is concluded that exposure to alkyl phenols will be low and that this will not cause any increased health risk.

Allergy
It is unlikely that the low levels of contact allergens which have been measured in the halls could lead to the development of a contact allergy.

As regards possible airway allergies, it is known that latex (natural rubber) is a potent allergen and latex allergy is not uncommon. Car tyres can contain large amounts of latex. However, it would appear that the bioavailability of latex in car rubber dust is low and/or that latex is deactivated during the vulcanisation process. The analyses that were carried out do not contain any information on immune-active latex allergen. Due to the quantities of dust which were measured in the halls, the possibility that there is a risk of individuals developing latex allergy or that individuals who have already developed a latex allergy could suffer acute asthma attacks when using the halls cannot be eliminated.

Relatively low concentrations of phthalates have been demonstrated in the hall air. Our present knowledge of a possible link between exposure to phthalates and the development

of asthma/allergy is very inadequate and it is not possible to carry out a risk assessment in this area.

Cancer

It has been concluded that exposure to benzene and PAHs in the quantities in which they have been measured in the halls will not cause any increased risk of cancer in people using the halls.

Conclusion

Recycled rubber granulate contains many chemical substances which are potentially harmful to health. The concentrations of these substances are however extremely low, they are only leached from the rubber granulate in very small quantities and they are only present in low concentrations in the hall air. The quantities of this type of substance are consistently lower than in the other types of rubber granulate which are used. The assessment of health risk was therefore based on measurements (concentrations in the rubber granulate and in airborne dust, PM10, and VOC in the hall air) in halls in which recycled rubber granulate is used.

A number of worst case scenarios were prepared which are used in the risk characterisation. These scenarios are based on information concerning the use of the halls (matches and training sessions; frequency and duration); physiological parameters (skin surface area, inhalation volumes during exertion and body weight) and analyses (content in rubber granulate, airborne dust/PM10 and VOC). Exposure calculations were performed for adults, juniors, older children and children based on measurements of VOC, airborne dust, concentrations of chemicals in recycled rubber granulate and leaching from the granulate.

On the basis of estimated exposure values and the doses/concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults. The estimated Margins of Safety (MOS) also give no cause for concern.

As regards total VOC, higher values were measured than are normally found in homes. Values of up to 200-400 μg/m^3 fall within the normal range for housing. It is concluded that the values which were measured for total VOC do not constitute any elevated health risk but our knowledge of this area is rather inadequate. It is reasonable to assume that the relatively high VOC values could contribute to the hall air being perceived as" poor" without this in itself actually causing any elevated health risk.

As regards allergies, it is concluded that exposure to the low concentrations which were measured does not constitute any elevated risk with respect to the development of contact allergies. It is known that car tyres can contain relatively high concentrations of latex and therefore possibly also latex allergens. Latex is a potent airway allergen, but it would appear that latex in car rubber dust is either less available for uptake and/or deactivated. As no information is available concerning levels of latex in the rubber granulate that is used, it is not possible to assess the risk of developing an airway allergy. The possibility that the use of car tyres could cause exposure to latex allergens and thus lead to the development of airway allergies cannot be entirely eliminated. Studies have been carried out which indicate a link between exposure to phthalates and the development of asthma/allergies. At the present time, it is not possible to carry out a risk assessment in this area because of a lack of available knowledge.

Worst case calculations based on air measurements carried out by NILU and exposure values from the Norwegian Institute of Public Health indicate that training in sports halls does not cause any increased risk of leukaemia as a result of benzene exposure or any elevated risk as a result of exposure to polycyclic aromatic hydrocarbons.

On the basis of the exposures which have been calculated in connection with the use of indoor halls with artificial turf in which recycled rubber granulate is used, there is no evidence to indicate that the use of such halls causes an elevated health risk. A reservation must however be issued as regards the development of asthma/airway allergies, where the knowledge that is currently available is limited. This particularly applies to exposure to latex allergens, as no information is available on the occurrence of latex allergens in hall air, yet such allergens have been demonstrated in car tyre rubber. It should also be noted that little or no toxicological information is available for many of the volatile organic compounds which have been demonstrated as being present in the air in the halls. The concentrations of most substances for which insufficient information is available concerning harmful effects are extremely low and for this reason they are not expected to cause any increased health risk. However, not all organic compounds in the hall air have been identified. It is concluded that the exposure quantities which have been calculated for benzene and PAHs do not represent a cancer risk.

On the basis of the knowledge that is currently available concerning health effects and exposure linked to the use of indoor artificial turf pitches, we do not see any necessity to replace the recycled granulate at the present time. Due to a lack of knowledge as regards the possible induction of latex rubber, we recommend that recycled rubber granulate should not be used when rubber granulate is supplemented/replaced.

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An Open Letter Concerning The Potential Cancer Risk From Certain Granulate Infills From Artificial Turf

FIFA - Fédération Internationale de Football Association

cc: J. Champagne, Dr. J. Ekstrand, M. Harvey, Dr. C. Fuller, M. Timmer,
Dr. E.G Harrison, L. Bretscher, N. Fletcher

Zurich, 12 July 2006

An Open Letter concerning the potential cancer risk from certain granulate infills from artificial turf

As you will be aware both FIFA and UEFA have invested substantial resources in recent years in the development of artificial turf to ensure more people, more often have more opportunities to participate in Football at all levels of the game in a safe environment.

Both organisations have both been aware of recent reports that have suggested a potential cancer risk from certain granulate infills from artificial turf.

FIFA and UEFA have investigated this issue and analysed the risk involved. In particular we have reviewed the results of numerous studies into this issue and our findings to date are listed below:

- The list of publications which FIFA and UEFA have scrutinised is given below.

- The studies to date have concluded that "PAHs [Polynuclear Aromatic Hydrocarbons] are not released or at most negligibly released from tyre abradate" (The University of Dortmund Institute for Environmental Research 1997). Epidemiological studies conducted by the Health Effects Institute, The World Health Organisation and other investigators do not implicate tyre wear particles in ambient air as contributing to human health effects (respiratory and cardiovascular diseases)

- In general tyre abradate is a much finer particulate than the granules used as infill materials in Football Turf. The research demonstrates that the finer the particles the greater the surface area and higher potential for chemicals to leach out of the rubber.

- The majority of the studies have been on higher surface area particles and have concluded they are currently acceptable. Therefore the larger granules used in artificial turf will have even less potential for emissions. For example a study undertaken by the Danish Ministry of the Environment

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concluded that the health risk on children's playgrounds that contained both worn tyres and granulate rubber was insignificant.

The available body of research does not substantiate the assumption that cancer resulting from exposure to SBR granulate infills in artificial turf could potentially occur. For further information of the issue and the risk, please consult the references below.



Prof. Dr. Jiri Dvorak
FIFA

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Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Executive Summary

Office of Environmental Health Hazard Assessment

Contractor's Report to the Board

Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Produced under contract by: OEHHA
Office of Environmental Health Hazard Assessment

January 2007

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Additional Resources: The CIWMB suggests that in order to make an informed decision as to whether rubberized products for your playground and track are best for your needs, you should review the ASTM standard F1292, "Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment," and the Handbook for Public Playground Safety, U.S. Consumer Product Safety Commission, Pub. No. 325, and ask your playground/track contractor and/or manufacturer about any safety concerns you may have.

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The following appendices are available at www.ciwmb.ca.gov/Tires/Pubs.htm (scroll to "Research Papers")

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Appendix C: Raw Data From Skin Sensitization Testing .....

Executive Summary

In response to the California Integrated Waste Management Board's (CIWMB) need to better understand the potential health risks to children using outdoor playground and track surfaces constructed from recycled waste tires, the Office of Environmental Health Hazard Assessment (OEHHA) conducted the following studies.

- The playground surfaces were evaluated for the release of chemicals that could cause toxicity in children following ingestion or dermal contact. Three routes of child exposure to chemicals in the rubber were considered: 1) ingestion of loose rubber tire shreds (acute exposure), 2) ingestion via hand-to-surface contact followed by hand-to-mouth contact (chronic exposure), and 3) skin sensitization via dermal contact (acute exposure).
- Playground surfaces constructed from recycled tires were tested for their ability to attenuate fall-related impacts.
- The potential of these rubberized surfaces to impact the local environment, including the local ecology, was also addressed through a discussion of the published literature.

Evaluation of toxicity due to ingestion of tire shreds based on the existing literature

OEHHA found 46 studies in the scientific literature that measured the release of chemicals by recycled tires in laboratory settings and in field studies where recycled tires were used in civil engineering applications: 49 chemicals were identified. Using the highest published levels of chemicals released by recycled tires, the likelihood for noncancer health effects was calculated for a one-time ingestion of ten grams of tire shreds by a typical three-year-old child; only exposure to zinc exceeded its health-based screening value (i.e., value promulgated by a regulatory agency such as OEHHA or U.S. EPA). Overall, we consider it unlikely that a one-time ingestion of tire shreds would produce adverse health effects. Seven of the chemicals leaching from tire shreds in published studies were carcinogens, yielding a 1.2×10^{-7} (1.2 in ten million) increased cancer risk for the one-time ingestion described above. This risk is well below the *di minimis* level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

Evaluation of toxicity due to ingestion of tire shreds based on gastric digestion simulation

OEHHA conducted a gastric digestion experiment in which 22 chemicals were found to be released by tire shreds incubated for 21 hours at 37°C in a solution mimicking the gastric environment. OEHHA then compared the levels of released chemicals to their health-based screening values, assuming a young child ingested ten grams of tire shreds; all exposures were at or below the screening values suggesting a low risk of noncancer acute health effects. Five of the chemicals released by tire shreds in the gastric digestion experiment were carcinogens. If the released chemicals were ingested as a onetime event and averaged over a lifetime, the cancer risk would be 3.7×10^{-8} (3.7 in one hundred million). This risk is considerably below the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). The assumption that the risk from a onetime exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk.

Evaluation of toxicity due to chronic hand-to-surface-to-mouth activity

OEHHA performed wipe sampling of in-use playground surfaces containing recycled tire rubber; one metal (zinc) and four PAHs were measured at levels that were at least three times background. Assuming ingestion of the above five chemicals via chronic hand-to-mouth contact, exposures were below the corresponding chronic screening values, suggesting a low risk of

adverse noncancer health effects. From among the five chemicals identified by wipe sampling, the PAH chrysene is a carcinogen. Assuming playground use from 1 through 12 years of age, an increased cancer risk of 2.9×10^{-6} (2.9 in one million) was calculated due to the chronic ingestion of chrysene. This risk is slightly higher than the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). Calculation of the 2.9×10^{-6} (2.9 in one million) value does not account for many uncertainties, some of which would decrease the risk while others would increase the risk.

Testing for skin sensitization by playground surfaces made of recycled tires

Since children commonly contact these rubberized surfaces with their hands and other body parts, and since natural rubber contains the proven skin sensitizer latex, OEHHA contracted a laboratory to perform skin sensitization testing of tire-derived surfacing. Skin sensitization testing in the guinea pig was performed by Product Safety Laboratories (Dayton, NJ) with tire-derived playground surfacing as well as with the synthetic rubber EPDM; no sensitization was observed, suggesting that these surfaces would not cause skin sensitization in children, nor would they be expected to elicit skin reactions in children already sensitized to latex.

Evaluating the potential for damage to the local environment and ecology

Following a fire in a playground surface made of chipped tires at the Yulupa Elementary School in Sonoma County, soil samples from under the playground contained levels of metals, VOCs, PAHs, dioxins and furans that were at or below background, suggesting a low risk to the local ecology. Also following the Yulupa fire, the air above the burn site was judged by U.S. EPA to pose no health risks to clean-up workers, and the soil/rubber mixture removed from the site was judged not to be hazardous waste, and could therefore be deposited in a designated class III waste facility.

Groundwater in contact with tire shreds contained elevated levels of many chemicals; however, those levels rapidly approached background a few feet outside of the tire trench. Additional published studies indicate that concentrated leachate produced in the laboratory from tire shreds, crumb rubber or whole tires was toxic in 19/31 studies to a variety of organisms including bacteria, algae, aquatic invertebrates, fish, frogs and plants; however, it is unlikely that the use of shredded tires in outdoor applications such as playground surfaces would result in the leaching during rain events of high enough concentrations of chemicals to cause such effects. Further, shredded tires used in applications above the ground water table, as is the case for playground surfaces, produced no toxicity in sentinel species.

Evaluation of potential injury from falls on playground surfaces made of recycled tires

Using an accelerometer to test impact attenuation by California playground surfaces made of recycled tires, OEHHA staff visited 32 rubberized playground surfaces, to determine if the state mandated (CCR sections 65700-65750) standard for head impact (Head Impact Criterion or HIC) of ≤ 1000 was being met. Only 31 percent of rubberized playground surfaces passed the HIC standard. This is compared to 100 percent for surfaces made of wood chips, although only five surfaces of wood chips were tested. As the fall heights of playground structures increased, the underlying rubberized playground surface was more likely to fail the HIC standard; however, even at fall heights of 9-12 feet, some rubberized surfaces passed the standard. HIC values were not affected by the age of the rubberized surface, either during the first 2-3 months following installation or during the first two years. HIC values of rubberized surfaces increased with increasing surface temperature; in one playground the HIC value measured at dawn increased almost 20 percent when measured again in the afternoon during the heat of the day. These data point out the importance of testing the impact attenuation of rubberized playground surfaces to ensure that they meet the safety standards already in place.

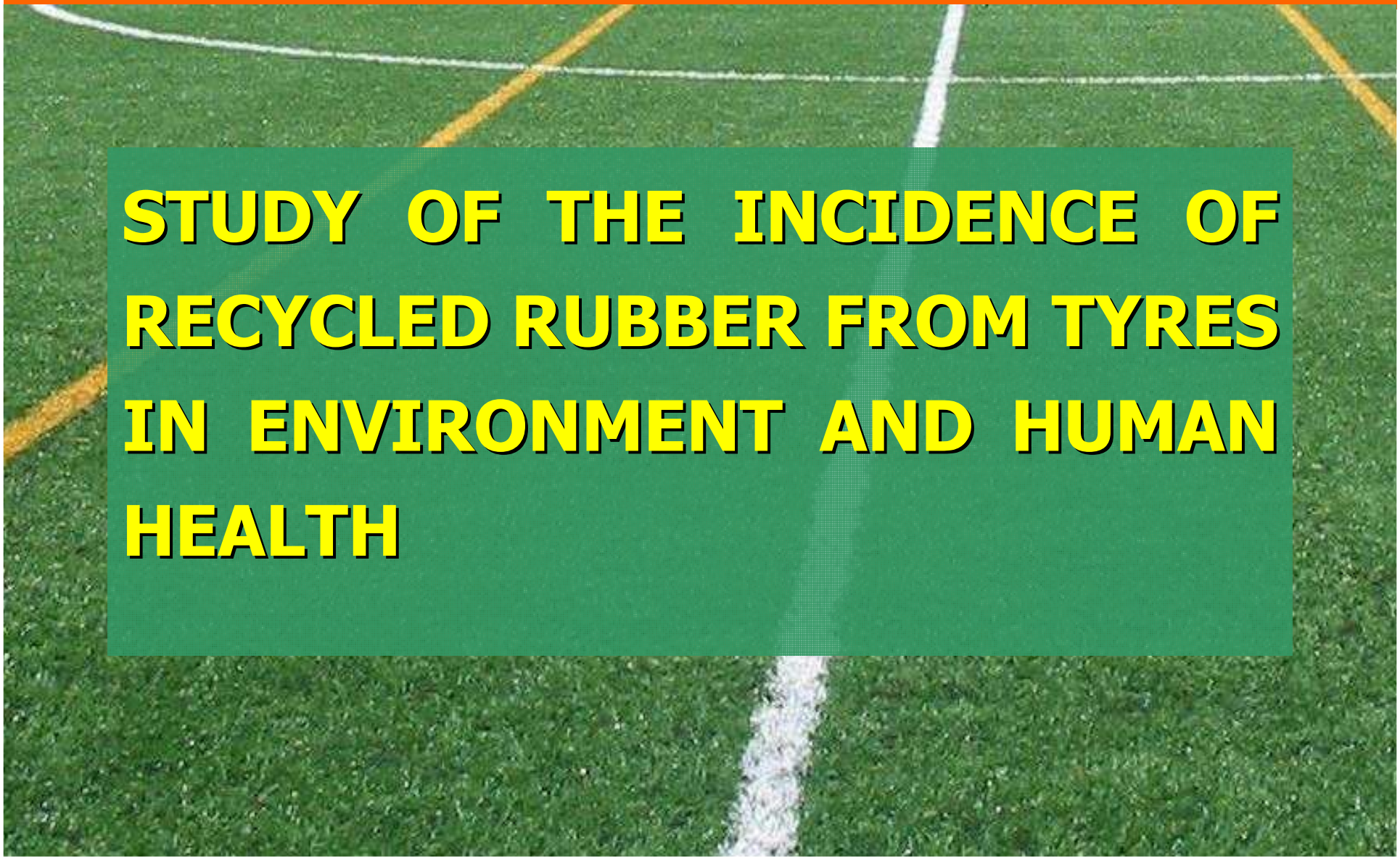
Unfortunately, our survey found a 69 percent failure rate for rubberized California playground surfaces using attenuation standards. Theoretically, failure and potential injuries could be prevented with better installation practices by contractors who had placed rubberized material too thin. Further, if the purchaser of the product would have sought certification of impact attenuation standards at the completion of the project, each playground's HIC value should have been assured. This represents a missed opportunity for prevention of playground fall injuries, which are estimated to be in the thousands and which include serious trauma such as brain injury.

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Study of the Incidence of Recycled Rubber From Tyres In Environment and Human Health

Instituto De Biomecánica De Valencia



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STUDY OF THE INCIDENCE OF RECYCLED RUBBER FROM TYRES IN ENVIRONMENT AND HUMAN HEALTH

Indice

01_ ANTECEDENTS

02_ STUDY APPROACH

03_ STUDY LEGAL FRAMEWORK

04_ STAGE I: MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.

05_ STAGE II: LEACHING EFFECT ON SOIL

06_ STAGE III: EFFECTS ON AIR

07_ CONCLUSION

Antecedents

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- In the last months, toxicity of recycled tyres has affected to artificial turf pavements because they are used like infill in this kind of pitches. In this sense, the IBV together with recycling companies and a company of installation of sports surfaces, have developed a project which allows knowing on the one hand the legislation about this product and on the other what is the real behaviour of this material.

Participants **Renecal, Alfredo Mesalles, GMN, Biosafe y Poligras**

Antecedents

INSTITUTO DE BIOMECÁNICA DE VALENCIA (IBV) & Applus

- For it, there has been selected a sample of rubber recycled by mechanical procedure in a mixture of 70 % of truck and 30 % of cars.
- Only a concrete type of rubber has been evaluated recycled because of it the results are applied to this concrete sample and to have best proved it should do the study on more types of recycled rubber

Antecedents

WHY DOES THIS PROBLEM COME UP?

- **GERMAN CONSULENCE REPPORT (INTRO):** Being alert of the risks of the content in HAP of the rubber recycled by dermal contact.

- **OPEN LETTER OF FIFA AND UEFA:** On potential risks of cancer of granulated fill for surfaces of artificial turf.

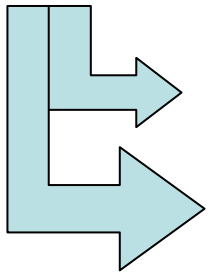
  - It presents studies that they conclude that the HAP's that contain the recycled tires, are not eliminated.
  - WHO (World Health Organization): There are no studies that relate particles of tires to problems of human health.

Study approach

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APPLUS + MEDIO AMBIENTE AFTER KNOWING:



This problematic

The recycled material composition

SUGGEST THREE STUDY STAGES:

- **STAGE I:** MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.
- **STAGE II:** LEACHING EFFECT ON SOIL.
- **STAGE III:** RECYCLED MATERIAL FFECTS ON AIR.

Study legal framework

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GENERAL CRITERIA FOLLOWED TO SELECT THE LEGISLATION TO APPLYING IN THE STUDY:

- **It is necessary to bear in mind that there does not exist legislation of direct application for the raised problem.**

- **Therefore there has been in use the legislation (first national and later European) and regulation that adapts better in each case to the raised problem.**

Study legal framework

GENERAL CRITERIA FOLLOWED TO SELECT THE LEGISLATION TO APPLYING IN THE STUDY(2):

STAGES I AND II

- **To fulfill in order the first two phases that included both the composition and the behavior of the material, it has been considered to be, on the basis of the laboratory experience, use the systematical one, analytical methodology and values limit, gathered in the wide legislative existing fan to national level, which approaches in depth both the characterization of residues and its arrangement in the environment.**

Study legal framework

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GENERAL CRITERIA FOLLOWED TO SELECT THE LEGISLATION TO APPLYING IN THE STUDY(3):

STAGE III

- **To take to end the aim of this phase it has been studied the effect of the material on the atmosphere, considering both the quality of the air and the risks generated by the possible emissions of this material.**

- **Both the evaluation of the air quality and the potential risks evaluation for the human health, have been realized on the basis of national and European legislation in force or in project, as well as in normative documents published by international recognized agencies.**

LEGAL FRAMEWORK

1. **In order to evaluate the dangerousness of the material two types of tests are realized:**

   - Analysis of metallic and organic compounds capable of enduring risks for the health and the environment.
   - Tests physicist - chemist who determine the characteristics of dangerousness of the material.

2. **The analyzed parameters are gathered in:**

   - R.D. 952/1997, of June 20 by which the regulation is modified for the execution of the Law 20/1986, of May 14, basic of Toxic and Dangerous Residues, pass by means of R.D. 833/1988, of July 20.

R.D. = Real Decree in Spain

LEGAL FRAMEWORK (2)

3. The used methodology is defined in

- R.D. 363/1995, of March 10, by which the regulation is approved on notification of new substances and classification, packed and labeled of dangerous substances.

- Order on October 13, 1989 on methods of characterization of the toxic and dangerous residues.

4. The criteria used to evaluate the dangerousness of the analyzed parameters are gathered for:

- Order MAM/304/2002, of February 8, by that are published the operations of appraisement and elimination of residues and the European list of residues.

- Order on October 13, 1989 on methods of characterization of the toxic and dangerous residues.

STAGE I: MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.

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ANALITICAL RESULTS

ANALITO	RESULT	INTERPRETATION
Barium	4 mg /Kg m.s.	Presence
Cobalt	211 mg /Kg m.s.	Presence
Copper	34 mg /Kg m.s.	Presence
lead	18 mg /Kg m.s.	Presence
Zinc	16642 mg /Kg m.s.	Presence
Benzene *	10 µg/Kg	Presence
Trichloroethene *	8 µg/Kg	Presence
Toluene *	64 µg/Kg	Presence
m+p xylene *	40 µg/Kg	Presence
Sytirene *	17 µg/Kg	Presence
Linear hydrocarbons sum**	753 µg/Kg	Presence
Cyclic hydrocarbons sum**	1115 µg/Kg	Presence
Polycyclic Aromatic Hydrocarbons (1)**	192 mg /Kg m.s.	Presence

STAGE I: MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.

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ANALITICAL RESULTS

ANALITO	RESULT	INTERPRETATION
Barium	4 mg /Kg m.s.	Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
		Presence
Polycyclic Aromatic Hydrocarbons (1)**	192 mg /Kg m.s.	Presence

- According to the R.D. 952/1997, though it is not a residue, since the last purpose of this recycled material is not the elimination, the presence of anyone of the substances detected (metals and organic compounds) in the sample awards character of dangerousness

STAGE I: MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.

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ANALITICAL RESULTS (2)

ANALITO	RESULT	INTERPRETATION
Agents oxidizers / reactivities in contact with water	Negative	H1 y H2. NEGATIVE Not explosive /Not comburent
Ignition point	> 75º C	H3. NEGATIVE Not flammable
pH	6.77 U pH	H4. NEGATIVE Not irritant
Irritability	Negative	H4. NEGATIVE Not irritant
Dermal and oral toxicity in rates	Not harmful/ Not toxic	H5 Y H6. NEGATIVE Not harmful / Not toxic
Carcinogenesis: search in bases of information of I.A.R.C. (International Agency for Research on Cancer)	<1% In weight for carcinogenic of group 3 and < 0.1 % In weight for carcinogenic of group 1 or 2	H7. NEGATIVE Not carcinogenic
Ames test	Not toxic / No mutagenic	H10 Y H11. NEGATIVE Not toxic for reproduction / Not mutagenic
Sulphurs / reactive cyanides	<100 mg/Kg / < 50 mg/Kg	H12. NEGATIVE Absence of substances that emit toxic or very toxic gases
Leaching study	H13. Studied in Stage III	
Echotoxicity test	5488 mg/L	H14. NEGATIVE Not dangerous for the environment

STAGE I: MATERIAL BEHAVIOUR ON HUMAN HEALTH AND ENVIRONMENT.

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ANALITICAL RESULTS (2)

ANALITO	RESULT	INTERPRETATION
Agents oxidizers / reactivities in contact with water	Negative	H1 y H2. NEGATIVE Not explosive /Not comburent
Ignition point	> 75º C	H3. NEGATIVE Not flammable
pH	6.77 U pH	H4. NEGATIVE Not irritant
[illegible]	[illegible]	H4. NEGATIVE Not irritant
[illegible]	[illegible]oxic	H5 Y H6. NEGATIVE Not harmful / Not toxic
[illegible]	[illegible]genic of [illegible]ight for	H7. NEGATIVE Not carcinogenic
[illegible]	[illegible]genic	H10 Y H11. NEGATIVE Not toxic for reproduction / Not mutagenic
[illegible]	< 50 mg/Kg	H12. NEGATIVE Absence of substances that emit toxic or very toxic gases
Leaching study	H13. Studied in Stage III	
Echotoxicity test	5488 mg/L	H14. NEGATIVE Not dangerous for the environment

- **The characteristics of dangerousness studied in the STAGE I are NEGATIVE**

STAGE I CONCLUSIONS

- **Due to the fact that the final use of the recycled rubber object of study is the landfill of sports surfaces installed in the exterior and before the absence of positive characteristics of dangerousness in environmental normal conditions, we can conclude that the behavior of the above mentioned material, in spite of its composition, does not induce any danger on the human health and the environment.**

STAGE II: LEACHING EFFECT ON SOIL

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LEGAL FRAMEWORK

- **In order to evaluate the leaching effects on soil that recycled tires rubber could generate, it is appealed to:**

  - Decision 2003/33/CE, of the Council, of December 19, 2002 by that there are established the criteria and procedures of admission of residues in the dumps according with the article 16 and to the attached II of the Board 1999/31/CEE (TWELVE núm. L 11, of January 16, 2003).
  - R.D. 849/86, by that the quality is regulated of spilt realized to Public Hydraulic Authority.
  - U.E.F.A. Design and Construction Recomendations

STAGE II: LEACHING EFFECT ON SOIL

ANALITICAL RESULTS

1. Effects on soil: study on solid

ENSAYO	RESULTADO	CLASIFICACIÓN 2003/33/CE
Carbono orgánico	15000 mg/Kg	Inferior a 30000 mg/Kg. INERTE
Suma de BTEX	0.137 mg/Kg	Inferior a 6 mg/Kg. INERTE
[illegible]	[illegible]Kg	Inferior a 1 mg/Kg. INERTE
[illegible]	[illegible]g	Superior a 500 mg/Kg NO INERTE

- The material overcomes the content in aliphatic hydrocarbons (C10-C40) to be considered as Inert Solid

ANALITICAL RESULTS (2)

2. Effects on soil. Study of leaching

ENSAYO	RESULTADO	CLASIFICACIÓN 2003/33/CE. Inertes	CLASIFICACIÓN 2003/33/CE. No Peligrosos
Antimonio	<0.02 mg/Kg	0.06 mg/Kg	0.7 mg/Kg.
Arsénico			
Bario			
Cadmio			
Cobre			
Cromo			
Molibdeno			
Níquel			
Plomo	<0.02 mg/Kg	0.5 mg/Kg	10 mg/Kg.
Selenio	<0.02 mg/Kg		0.5 mg/Kg.
Zinc	2.89 mg/Kg		50 mg/Kg.
Mercurio	<0.001 mg/Kg		0.2 mg/Kg.
Carbono Orgánico Disuelto	237.6 mg/Kg		800 mg/Kg.
Fenoles	1.55 mg/Kg	1 mg/Kg	-
Sólidos disueltos	560 mg/Kg	4000 mg/Kg	60000 mg/Kg.
Cloruros	<50 mg/Kg	800 mg/Kg	15000 mg/Kg.
Fluoruros	<1 mg/Kg	10 mg/Kg	150 mg/Kg.
Sulfatos	74 mg/Kg	1000 mg/Kg	20000 mg/Kg.

- **The material overcomes the content in phenols to be considered as Inert Solid**

STAGE II: LEACHING EFFECT ON SOIL

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STAGE II CONCLUSIONS

- **The material overcomes the maximum concentrations allowed in phenols and aliphatic hydrocarbons (C10-C40) to be considered as Inert Solid, And past to consider non danger material.**

- **The analyzed parameters carry out the limits stipulated by the R.D. 849/86, considering leaching as public hydraulic dump even in the most restrictive conditions gathered in the above mentioned national legislation.**

STAGE II CONCLUSIONS (2)

- **The composition of recycled rubber presents an high contain in zinc and carbon, among other compounds. In the first leaching is observed that none of the parameters listed in the UEFA recommendations exceeds the maximum values, with the exception of the carbon. The UEFA establishes a value limit for this parameter, following the methodology gathered in the norm CASH 18035-7:2002-06.**

Estudio del lixiviado bajo la norma DIN 18035-7:2002-06.

ENSAYO	RESULTADO	U.E.F.A.
Zinc	0.31 mg/L	0.5 mg/L
Carbono orgánico disuelto	11.59 mg/L	<20 mg/L

STAGE II: LEACHING EFFECT ON SOIL

STAGE II CONCLUSIONS (2)

- **The composition of recycled rubber presents an high contain in zinc and carbon, among other compounds. In the first leaching is observed that none of the parameters exceed the maximum values, with the exception of the zinc that exceeds a value limit for this parameter following the methodology gathered in the norm CASH 18035-7:2002-06.**

- **The material does not overcome the values limit of the UEFA recommendations**

Estudio del lixiviado bajo la norma DIN 18035-7:2002-06.

ENSAYO	RESULTADO	U.E.F.A.
Zinc	0.31 mg/L	0.5 mg/L
Carbono orgánico disuelto	11.59 mg/L	<20 mg/L

STAGE III: EFFECTS ON AIR

LEGAL FRAMEWORK

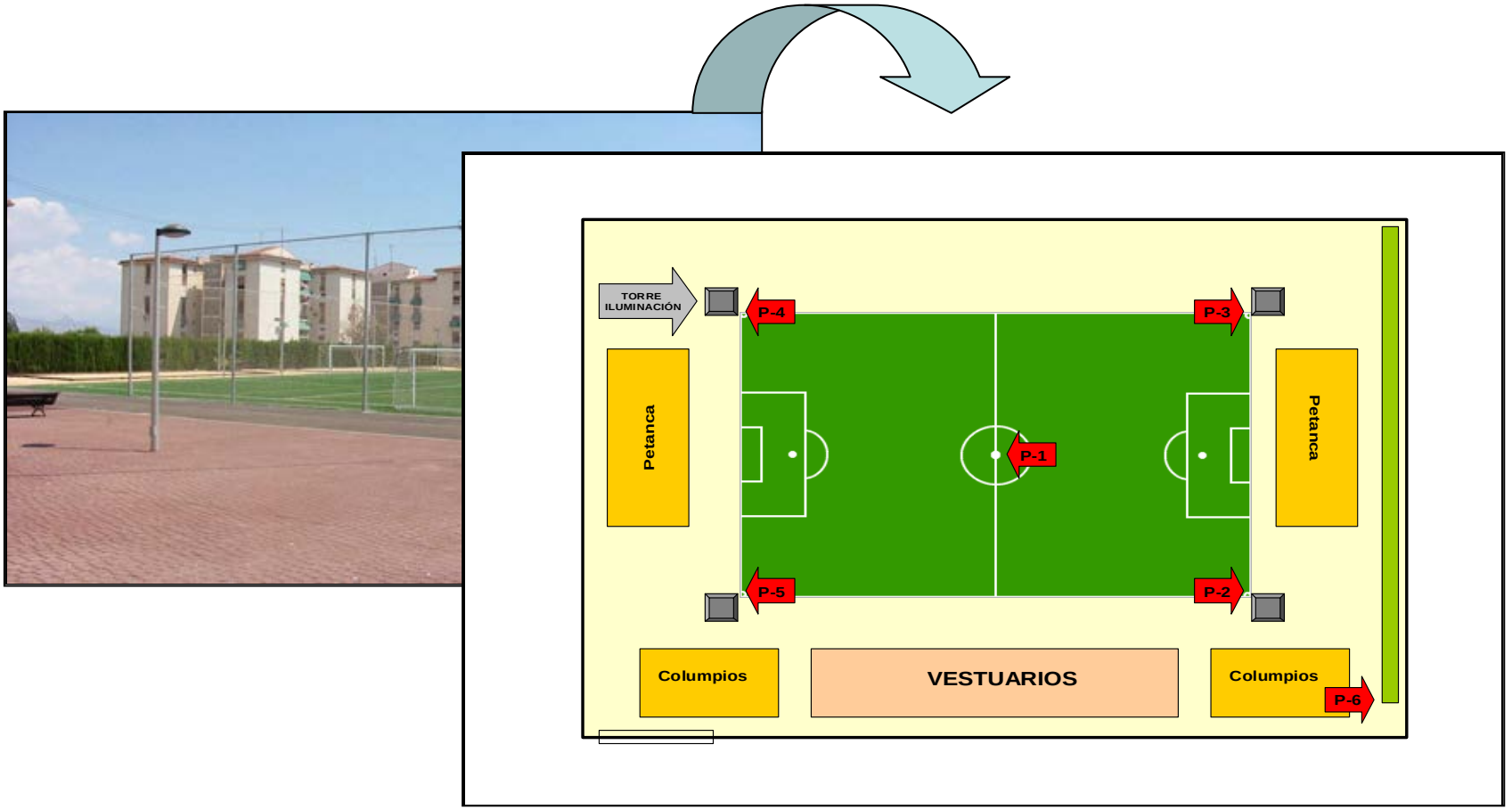
- **To evaluate the sports surface effect on the environment, they are considered two legislation or regulation types :**
  - European Legislation in force or proposal where values establish limit of the compounds analyzed in air environment.
    - Proposal of Board of the European Parliament and of the Council, relative to As, Cd, Hg, Ni and HAP's in air environment
    - Board 2000/69/CE of the European Parliament and of the Council, of November 16, 2000, about the values limit for benzene and monoxide of carbon in air environment. And transposition to the Spanish legislation
  - Limit values relative to public health published by international recognized agencies: ACGIH, OSHA, NIOSH, DFG and HSE.

STAGE III: EFFECTS ON AIR

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SAMPLING PLAN



SAMPLING PLAN (2)

ANALYZED PARAMETERS SELECTION

- The studied compounds have been selected according with tests already realized on this material type, references provided by the client, where stands out the presence of organic origin parameters due to the nature of the rubber, and high contain in sulphur, that makes admissible to determine the possible presence of hydrogen sulphur. Therefore the analyzed parameters have been the following ones:

  - **Polycyclic aromatic hydrocarbons (HAP's)**, Picked up in PUF filter by means of captator (containers) of high volume.
  - Volatile Organic Compounds (VOCs), Picked up in passive captators (containers).
  - **Hydrogen sulphide** measured "in situ" using Dräger tubes.

STAGE III: EFFECTS ON AIR

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ANALITICAL RESULTS

VOLATILE ORGANIC COMPOUNDS

Parámetro	Resultados Obtenidos (µg/m^3)					V.L. (L.E.A.A) (µg/m^3)	V.L. (N.E.S.L.) (µg/m^3)
	P-2	P-3	P-4	P-5	P-6		
Benceno	0.28	0.38	<0.01	0.19	0.19	5	-----
Tolueno	0.66	3.11	2.26	1.51	1.13	-----	TLV=188000 MAK=190000
Etilbenceno	1.13	2.17		1.32	0.94	-----	TLV=434000 MAK=440000
m,p-xileno	3.48	4.42		3.11	3.39	-----	
o-xileno	2.54	2.99		1.79	2.17	-----	

- benzene does not overcome the limit value in air according to the Board 2000/69/CE= 5µg/m^3

ANALITICAL RESULTS

POLYCYCLIC AROMATIC HYDROCARBONS

Parámetro	Resultados Obtenidos (ng/m^3)						V.L. (L.E.A.A) (ng/m^3)	V.L. (N.E.S.L.) (ng/m^3)
	P-1	P-2	P-3	P-4	P-5	P-6		
Acenafteno	0.32	0.21	0.14	0.16	0.03	0.27	-----	-----
Acenaftileno	0.21	0.13	0.07	0.07	0.03	0.09	-----	-----
Antraceno	0.46	0.43	0.25	0.22	0.02	0.19	-----	-----
Benzo-(g,h,i)-perileno	<0.52	<0.53	<0.54	<0.52	<0.52	<0.55	-----	-----
Benzo-a-antraceno	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-----	-----
Benzo-a-pireno	<0.52	<0.53	<0.54	<0.52	<0.52	<0.55	1[ab]	MAK=2000
Benzo-b-fluoranteno	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	-----	-----
Benzo-k-fluoranteno	<0.35	<0.35	<0.36	<0.35	<0.35	<0.37	-----	-----
Criseno	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-----	-----
Dibenzo-(a,h,)-antraceno	<0.35	<0.35	<0.36	<0.35	<0.35	<0.37	-----	-----
Fenantreno	6.93	6.40	4.00	3.07	0.64	4.87	-----	-----
Fluoranteno	1.14	0.83	0.86	0.51	0.10	0.75	2[C]	-----
Fluoreno	0.61	0.77	0.43	0.92	0.05	0.81	-----	-----
Indeno-(1,2,3-c,d)-pireno	<0.87	<0.88	<0.90	<0.87	<0.87	<0.92	-----	-----
Naftaleno	0.33	0.30	0.13	0.12	0.10	0.23	-----	-----
Pireno	4.17	2.20	2.22	1.51	0.30	2.06	-----	-----

STAGE III: EFFECTS ON AIR

ANALITICAL RESULTS

POLYCYCLIC AROMATIC HYDROCARBONS

Parámetro	Resultados Obtenidos (ng/m^3)						V.L. (L.E.A.A) (ng/m^3)	V.L. (N.E.S.L.) (ng/m^3)
	P-1	P-2	P-3	P-4	P-5	P-6		
Acenafteno	0.32	0.21	0.14	0.16	0.03	0.27	-----	-----
Acenaftileno	0.21	0.13	0.07	0.07	0.03	0.09	-----	-----
Antraceno	0.46	0.43	0.25	0.22	0.02	0.19	-----	-----
Benzo-(g,h,i)-perileno	<0.52	<0.53	<0.54	<0.52	<0.52	<0.55	-----	-----
Benzo-a-antraceno	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-----	-----
Benzo-a-pireno	<0.52	<0.53	<0.54	<0.52	<0.52	<0.55	[ab]	MAK=2000
Benzo-b-fluoranteno	<0.09	<0.09	<0.09	<0.09	<0.09	<0.09	-----	-----
Benzo-k-fluoranteno	<0.35	<0.35	<0.35	<0.35	<0.35	<0.37	-----	-----
Criseno	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	-----	-----
Dibenzo-(a,h,)-antraceno	<0.35	<0.35	<0.35	<0.35	<0.35	<0.37		
Pireno	4.17	2.20	2.22	1.51	0.30	2.06	-----	-----

- The benzo(a)pyrene does not overcome the limit value proposed by the European parliament = 5µg/m3 (maximum value legislated in Italy)

STAGE III: EFFECTS ON AIR

INSTITUTO DE BIOMECÁNICA DE VALENCIA

Applus Medio Ambiente

ANALITICAL RESULTS

HYDROGEN SULPHIDE

Parámetro	Resultados Obtenidos (mg/m^3)					
	P-1	P-2	P-3	P-4	P-5	P-6
Hidrógeno sulfurado en aire "in situ"	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3

- **It is not detected hydrogen sulphide emission**

STAGE III CONCLUSIONS

- **The obtained results from the parameters analyzed in the effects on air study in the football field made of artificial turf do not exceed any maximum value established so much in the European legislation of air environment, since in the regulation of labour health gathered for the elaboration of the current report.**

- **The positive results obtained in the analysis of HAPs and VOCs picked up in the realized samples are similar to the emission generated by traffic in the zone of influence.**

- **There is not detected sulphurated hydrogen in the air sampled in the installation.**


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AS GENERAL CONCLUSION, ACCORDING TO THE REALIZED TESTS, and for the sample are tested, IT CAN NOT BE CONSIDERED THE RECYCLED RUBBERS DANGEROUS FOR HUMAN HEALTH AND THE ENVIRONMENT IN ITS EMPLOYMENT AS SURFACE OF ARTIFICIAL TURF

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Environmental Compatibility
Recent Developments

OFI is the expert for material applications and building renewal

Environmental Compatibility – Recent Developments

ISSS Technical Meeting 2006

Christa Hametner,

Walter Müller ***ofi***

Introduction

Important criterias for the use of synthetic turf areas are

- Appropriate **material and technical properties** to ensure the required safety and sportfunctions
- The **environmental compatilibity** during and also after the use

Environmental and health aspects

- The possible contamination of **soil and groundwater** by leaching of soluble pollutants out of the synthetic turf areas
- Health hazard for **residents and users of sport areas** because of the release of gases and dangerous particles
- The possible release of pollutants during **disposal**, e.g. during incineration

Requirements for environmental compatibility

- A basic requirement is **legal compliance** with **national and international** laws during and after the intended use of the synthetic turf.

- On top of it **no negative impact** on soil, groundwater and air should be given at all.

National requirements

- In Austria the following directives have to be met:
  - Grundwasserschwellenwertverordnung BGBl 213/1997 (Ground Water Treshold Value Directive)
  - BGBl. 613/1992: Verordnung zur Begrenzung betreffend Sickerwasseremissionen aus Abfalldeponien (Directive for Limitation of Percolating Water Emissions from Landfills)
  - BGBl. 186/1996: Allgemeine Begrenzung von Abwasseremissionen in Fließgewässern und öffentliche Kanalisation (General Limitation of Waste Water Emmission to Stream and Public Sewers).

Technical guidelines

For the assessment of possible environmental impacts in Germany, Switzerland and Austria the following technical guidelines have been established within the last years:

- **DIN V 18035-7**: “Sports grounds – Part 7: Synthetic turf areas”, 06:2002
- **ESSM Guideline** “Sport grounds, Guideline for Environmental Compatibility of Elastics Synthetic Coverings on open air Sports Grounds”, 1997:03
- **OISS Guideline** Requirements on Synthetic turf areas, actual version 2005:01

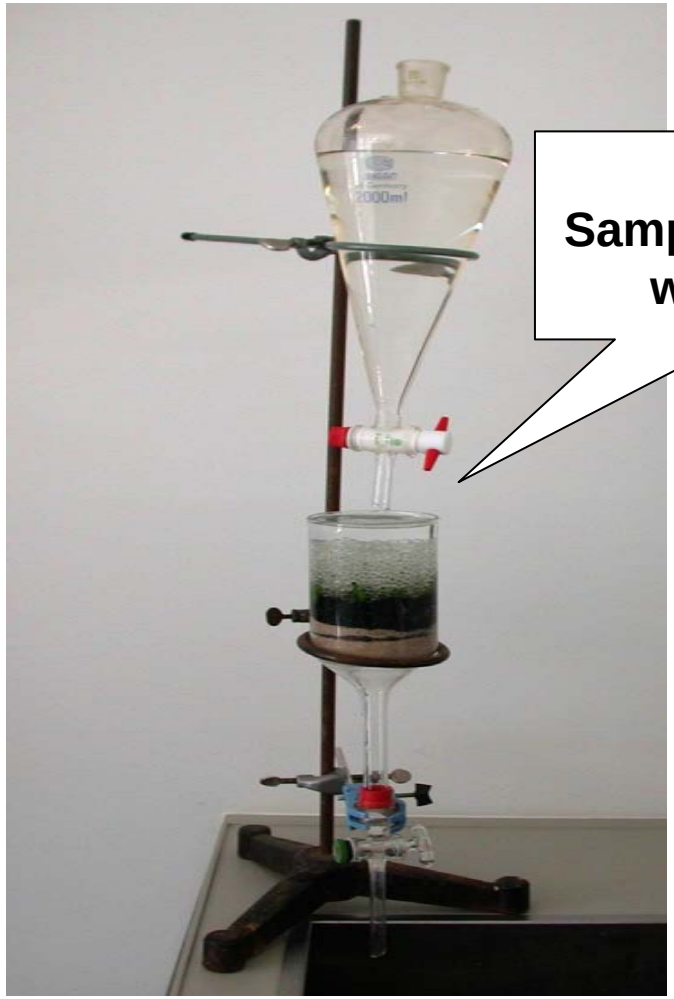
Technical guidelines

All guidelines include the analysis of **extracts from the individual system compounds**.

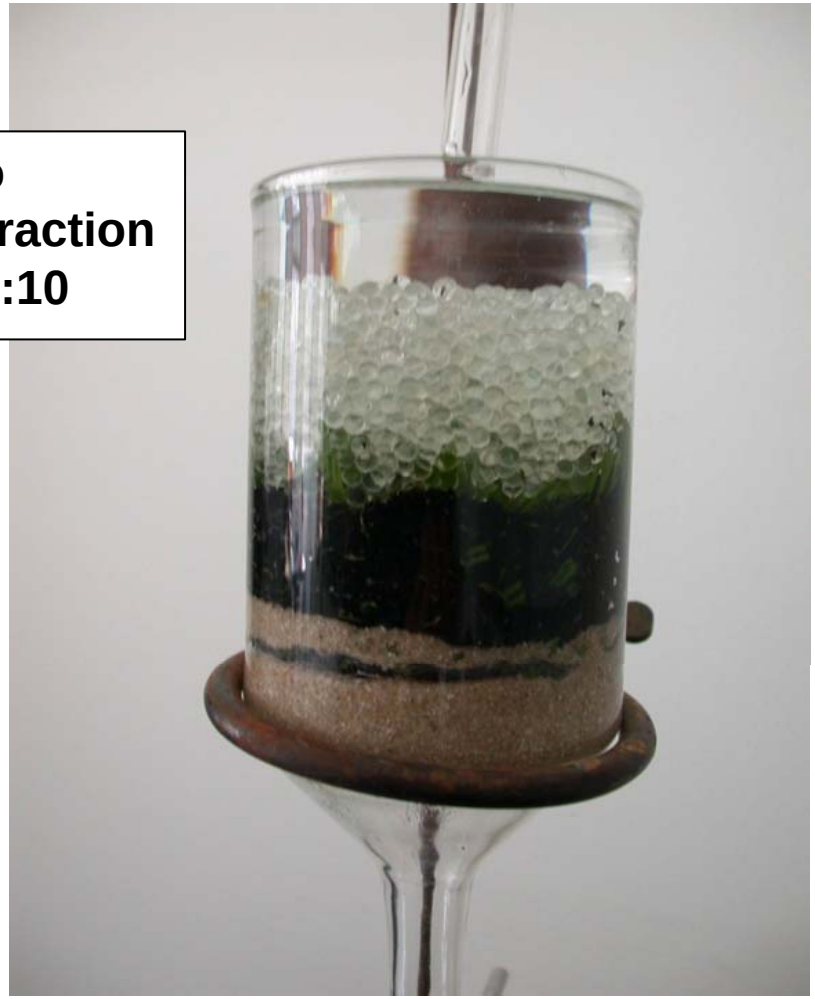
The given treshold values have to be applied to **the 2nd 24 hour extract** of the questioned material.

According to the Austrian ÖISS guideline an examination of the **whole synthetic turf system** is also permittable (**Austrian percolating test**). It may be performed alternatively if the indiviual system compounds fail the criterias.
In the case of the percolation test the extraction period is only 2 times 12 hours.

Austrian percolating test



Ratio Sample:Extraction water=1:10



Comparison of requirements

Parameter	DIN	ESSM:1997	OISS
DOC	≤ 20 mg/l	≤ 15 mg/l	≤ 20 mg/l
EOX	≤ 100 mg/l		≤ 100 mg/l
PAH			≤ 0,002 mg/l
Lead	≤ 0,04 mg/l	≤ 0,05 mg/l	≤ 0,03 mg/l
Cadmium	≤ 0,005 mg/l	≤ 0,005 mg/l	≤ 0,003 mg/l
Chrom total	≤ 0,05 mg/l	≤ 0,05 mg/l	≤ 0,03 mg/l
Chrom VI	≤ 0,008 mg/l		≤ 0,008 mg/l
Mercury	≤ 0,001 mg/l	≤ 1 mg/kg	≤ 0,001 mg/l
Zinc	≤ 3,0 /≤ 0,5 mg/l	≤ 0,2 mg/l	≤ 0,5 mg/l
Tin	≤ 0,05 mg/l	≤ 0,5 mg/l	≤ 0,05 mg/l
Toxicity	≤50% resp. Non	≤50% (80%Eluat)	LID (G_L) ≤ 4
Biological degrad.	If necessary		If necessary
Odor	descripton		description
External nature	descripton		description
Surface Tension		>55 dyn/cm	

Recent discussion points

The German; Swiss and Austrian requirements are quite similar but also **differ in some important points**:

- **Heavy metals** e**xtraction method** : carbondioxide saturated water versus the use of normal water (water quality)
- **Toxicity tests:** DIN and ESSM allow an inhibition of nitrification of maximum 50%, excepting elastic fillers in Germany (no regulations!). The ÖISS guideline requires the determination of the inhibitory effect of water samples on the light emission of Vibrio fischeri (Luminescent Bacteria test). The LID (lowest ineffective dilution) is not allowed to be higher than 4 (equals 25% v/v).

Recent discussion points

- Use of **recycling material** for elastic infillers with high variation in quality. ÖISS permits the use of these materials, but measures for quality assurance have to be proven. The conformity of the actually used materials to the requirements of the initial laboratory performance test has to be proven.
- How **suitable** are the existing test procedures ?
- What are the **real environmental impacts** of synthetic turf areas during their use?
- Recycling aspects

TURFindustry

Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Contractors Report to the Board

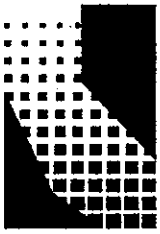
Office of Environmental Health Hazard Assessment

Contractor's Report to the Board

Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products

Produced under contract by: OEHHA
Office of Environmental Health Hazard Assessment

January 2007



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Additional Resources: The CIWMB suggests that in order to make an informed decision as to whether rubberized products for your playground and track are best for your needs, you should review the ASTM standard F1292, "Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment," and the Handbook for Public Playground Safety, U.S. Consumer Product Safety Commission, Pub. No. 325, and ask your playground/track contractor and/or manufacturer about any safety concerns you may have.

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Executive Summary

In response to the California Integrated Waste Management Board's (CIWMB) need to better understand the potential health risks to children using outdoor playground and track surfaces constructed from recycled waste tires, the Office of Environmental Health Hazard Assessment (OEHHA) conducted the following studies.

- The playground surfaces were evaluated for the release of chemicals that could cause toxicity in children following ingestion or dermal contact. Three routes of child exposure to chemicals in the rubber were considered: 1) ingestion of loose rubber tire shreds (acute exposure), 2) ingestion via hand-to-surface contact followed by hand-to-mouth contact (chronic exposure), and 3) skin sensitization via dermal contact (acute exposure).
- Playground surfaces constructed from recycled tires were tested for their ability to attenuate fall-related impacts.
- The potential of these rubberized surfaces to impact the local environment, including the local ecology, was also addressed through a discussion of the published literature.

Evaluation of toxicity due to ingestion of tire shreds based on the existing literature

OEHHA found 46 studies in the scientific literature that measured the release of chemicals by recycled tires in laboratory settings and in field studies where recycled tires were used in civil engineering applications: 49 chemicals were identified. Using the highest published levels of chemicals released by recycled tires, the likelihood for noncancer health effects was calculated for a one-time ingestion of ten grams of tire shreds by a typical three-year-old child; only exposure to zinc exceeded its health-based screening value (i.e., value promulgated by a regulatory agency such as OEHHA or U.S. EPA). Overall, we consider it unlikely that a one-time ingestion of tire shreds would produce adverse health effects. Seven of the chemicals leaching from tire shreds in published studies were carcinogens, yielding a 1.2×10^{-7} (1.2 in ten million) increased cancer risk for the one-time ingestion described above. This risk is well below the *di minimis* level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006).

Evaluation of toxicity due to ingestion of tire shreds based on gastric digestion simulation

OEHHA conducted a gastric digestion experiment in which 22 chemicals were found to be released by tire shreds incubated for 21 hours at 37°C in a solution mimicking the gastric environment. OEHHA then compared the levels of released chemicals to their health-based screening values, assuming a young child ingested ten grams of tire shreds; all exposures were at or below the screening values suggesting a low risk of noncancer acute health effects. Five of the chemicals released by tire shreds in the gastric digestion experiment were carcinogens. If the released chemicals were ingested as a onetime event and averaged over a lifetime, the cancer risk would be 3.7×10^{-8} (3.7 in one hundred million). This risk is considerably below the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). The assumption that the risk from a onetime exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk.

Evaluation of toxicity due to chronic hand-to-surface-to-mouth activity

OEHHA performed wipe sampling of in-use playground surfaces containing recycled tire rubber; one metal (zinc) and four PAHs were measured at levels that were at least three times background. Assuming ingestion of the above five chemicals via chronic hand-to-mouth contact, exposures were below the corresponding chronic screening values, suggesting a low risk of

adverse noncancer health effects. From among the five chemicals identified by wipe sampling, the PAH chrysene is a carcinogen. Assuming playground use from 1 through 12 years of age, an increased cancer risk of 2.9×10^{-6} (2.9 in one million) was calculated due to the chronic ingestion of chrysene. This risk is slightly higher than the *di minimis* risk level of 1×10^{-6} (one in one million), generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). Calculation of the 2.9×10^{-6} (2.9 in one million) value does not account for many uncertainties, some of which would decrease the risk while others would increase the risk.

Testing for skin sensitization by playground surfaces made of recycled tires

Since children commonly contact these rubberized surfaces with their hands and other body parts, and since natural rubber contains the proven skin sensitizer latex, OEHHA contracted a laboratory to perform skin sensitization testing of tire-derived surfacing. Skin sensitization testing in the guinea pig was performed by Product Safety Laboratories (Dayton, NJ) with tire-derived playground surfacing as well as with the synthetic rubber EPDM; no sensitization was observed, suggesting that these surfaces would not cause skin sensitization in children, nor would they be expected to elicit skin reactions in children already sensitized to latex.

Evaluating the potential for damage to the local environment and ecology

Following a fire in a playground surface made of chipped tires at the Yulupa Elementary School in Sonoma County, soil samples from under the playground contained levels of metals, VOCs, PAHs, dioxins and furans that were at or below background, suggesting a low risk to the local ecology. Also following the Yulupa fire, the air above the burn site was judged by U.S. EPA to pose no health risks to clean-up workers, and the soil/rubber mixture removed from the site was judged not to be hazardous waste, and could therefore be deposited in a designated class III waste facility.

Groundwater in contact with tire shreds contained elevated levels of many chemicals; however, those levels rapidly approached background a few feet outside of the tire trench. Additional published studies indicate that concentrated leachate produced in the laboratory from tire shreds, crumb rubber or whole tires was toxic in 19/31 studies to a variety of organisms including bacteria, algae, aquatic invertebrates, fish, frogs and plants; however, it is unlikely that the use of shredded tires in outdoor applications such as playground surfaces would result in the leaching during rain events of high enough concentrations of chemicals to cause such effects. Further, shredded tires used in applications above the ground water table, as is the case for playground surfaces, produced no toxicity in sentinel species.

Evaluation of potential injury from falls on playground surfaces made of recycled tires

Using an accelerometer to test impact attenuation by California playground surfaces made of recycled tires, OEHHA staff visited 32 rubberized playground surfaces, to determine if the state mandated (CCR sections 65700-65750) standard for head impact (Head Impact Criterion or HIC) of ≤ 1000 was being met. Only 31 percent of rubberized playground surfaces passed the HIC standard. This is compared to 100 percent for surfaces made of wood chips, although only five surfaces of wood chips were tested. As the fall heights of playground structures increased, the underlying rubberized playground surface was more likely to fail the HIC standard; however, even at fall heights of 9-12 feet, some rubberized surfaces passed the standard. HIC values were not affected by the age of the rubberized surface, either during the first 2-3 months following installation or during the first two years. HIC values of rubberized surfaces increased with increasing surface temperature; in one playground the HIC value measured at dawn increased almost 20 percent when measured again in the afternoon during the heat of the day. These data point out the importance of testing the impact attenuation of rubberized playground surfaces to ensure that they meet the safety standards already in place.

Unfortunately, our survey found a 69 percent failure rate for rubberized California playground surfaces using attenuation standards. Theoretically, failure and potential injuries could be prevented with better installation practices by contractors who had placed rubberized material too thin. Further, if the purchaser of the product would have sought certification of impact attenuation standards at the completion of the project, each playground's HIC value should have been assured. This represents a missed opportunity for prevention of playground fall injuries, which are estimated to be in the thousands and which include serious trauma such as brain injury.

TURFindustry

Rubber – Its Implications to Environmental Health

Hydrocarbon Rubbers

Bryan Willoughby
Independent Consultant in Polymer Chemistry

RUBBER – ITS IMPLICATIONS TO ENVIRONMENTAL HEALTH

(HYDROCARBON RUBBERS)

Bryan Willoughby
Independent Consultant
in Polymer Chemistry

WHAT IS "RUBBER"?

- A range of different types
  - commodity or specialised
  - both natural and synthetic
- Easily recognised - soft and compliant
  - compared with ceramics, metals or plastics
- Strong (usually) and very tough
  - resistant to fracture, tear, abrasion, etc.
- Capable of large-strain elasticity
  - recoverable extensions of several hundred percent possible
- Properties a result of unique molecular structure

DIFFERENT RUBBERS

- **Commodity (hydrocarbon)**
  - natural rubber (NR)
  - styrene-butadiene rubber (SBR)
  - ethylene-propylene rubbers (EPM, EPDM)
  - butadiene rubber (BR)
- **High/low permeability rubbers**
  - silicone rubber MQ, VMQ, PVMQ, FVMQ, etc) – high permeability
  - butyl (IIR), halobutyl rubbers (CIIR, BIIR) – low permeability
- **Oil-resistant rubbers**
  - nitrile (NBR), hydrogenated nitrile (HNBR) rubbers
  - acrylic rubber (ACM)
- **Fire-resistant rubbers**
  - chloroprene (“neoprene”) rubber (CR)
  - epichlorohydrin rubber (ECO)
- **High temperature rubbers**
  - fluorocarbon rubbers (FKM, FFKM)
- **Liquid castable rubbers**
  - polyurethane (EU)
  - polysulphide (T)



SUBTLE CHANGES IN MOLECULE CAN PROVIDE EITHER PLASTIC OR RUBBER

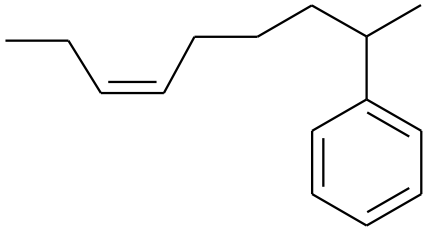
- Polyethylene, $-(CH_2-CH_2)_n-$
  - very flexible molecule,
  - but regular structure introduces crystallinity
  - polyethylene is a plastic
  - softer than many plastics
  - used in packaging, etc

- Polypropylene, $-(CH_2-CHMe)_n-$
  - stiffer than polyethylene
  - regular structure – hence crystalline
  - polypropylene is a plastic
  - good combination of stiffness, strength (and price)
  - widespread applications

- Ethylene-Propylene Copolymers
  - Irregular structure disrupts crystallinity
  - 50:50 E:P to 75:25 E:P (by wt) are rubbers
  - the basis of EPDM rubber
  - used in hose, car door & boot seals, etc.

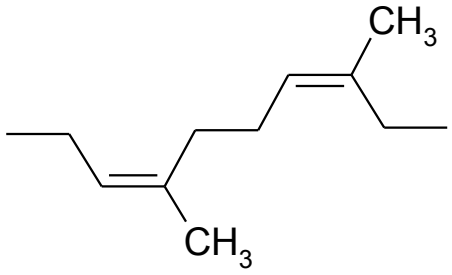


OTHER HYDROCARBON RUBBERS



styrene-butadiene rubber

SBR



natural rubber

NR

- NR polymer (a polyterpene) is obtained from the latex of the Hevea Brasiliensis tree
- SBR polymer is product of the oil industry
- Average MW can be around 500k for NR, around 100k for SBR
- These are the principal tyre rubber polymers

But why is rubber elastic?
Why the exceptional large-strain elasticity?

ELASTICITY

- Elasticity is the ability to recover from a deformation
  - when applied stress is removed, an elastic material will recover completely its original shape
- Many materials show elasticity up to a limit – beyond this additional stress causes irreversible 'plastic' flow
  - elastic limit may be measured in terms of applied strain ($\Delta l/l$)
  - for metals and ceramics, elastic limit may be <0.001% strain
  - for plastics, limit may lie at percentage values
  - for rubber limit may be at strains of several hundred of percent

But ultimate elastic performance only with **vulcanised rubbers**

Vulcanisation is post-polymerisation chemical treatment
Prior to vulcanisation, rubber is visco-elastic

EFFECT OF VULCANISATION

- Physical - vulcanisation suppresses viscous behaviour and enhances elastic behaviour
  - removes tack and reduces temperature sensitivity
  - remarkable elasticity develops
- Chemical – vulcanisation links molecules together ('crosslinking')

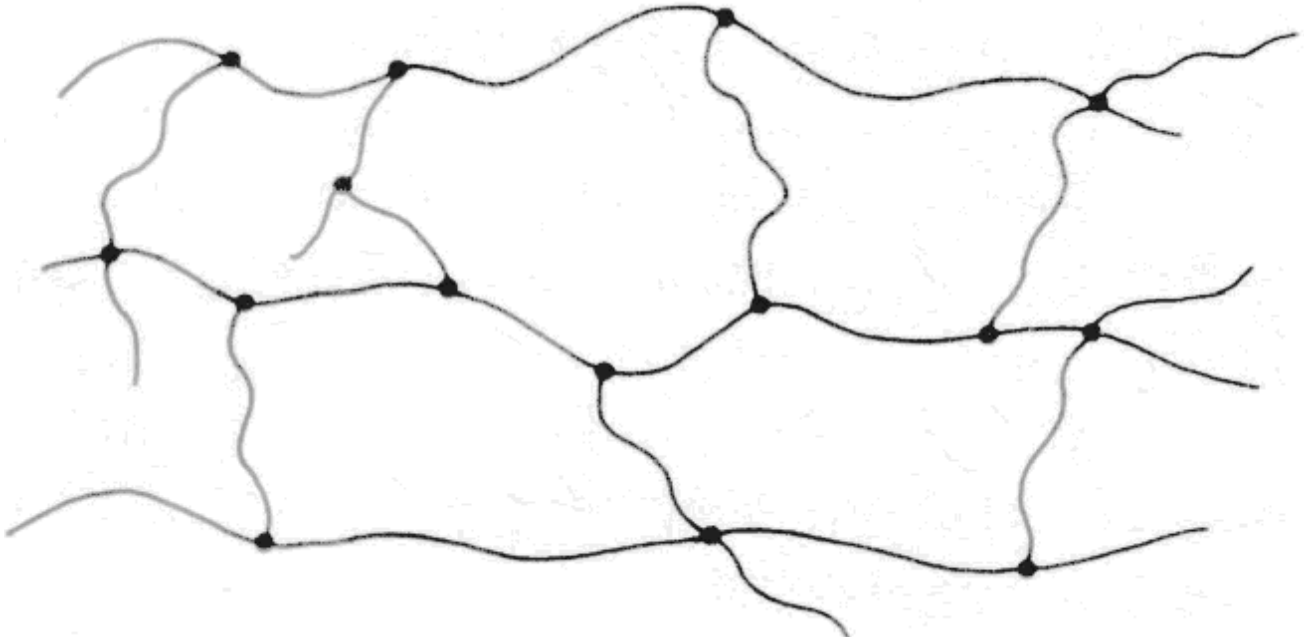
  e.g. with sulphur (simplistically)

  $$RH + S_x + RH \rightarrow R{-}S_y{-}R + H_2S$$
- Linking all the molecules together creates a single molecule of infinite molecular weight

POLYMERS OF INFINITE MW

Cannot flow, cannot be melted or dissolved

Will recover elastically from imposed strains



SULPHUR VULCANISATION USED IN TYRE RUBBERS

- Well established
  - for fine tuning product properties
  - for good control in processing

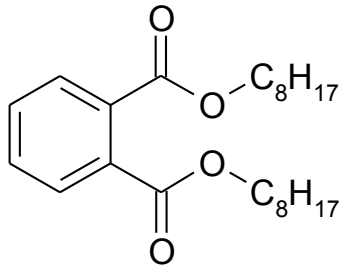
- Chemistry relies on a cocktail of chemicals:
  - vulcanising agent (sulphur)
  - accelerators and activators
  - inhibitors or retarders (stop premature reaction)
  - antioxidants (protect against heat)
  - antiozonants (protection in service)

- Other ingredients include:
  - fillers (carbon black) for reinforcement
  - softeners (process oils)

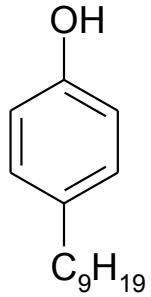


INGREDIENT MIX WELL ESTABLISHED - BUT IT DOES NOT INCLUDE

- Phthalate plasticisers
  - used in PVC and nitrile rubbers
  - don't function in hydrocarbon rubbers



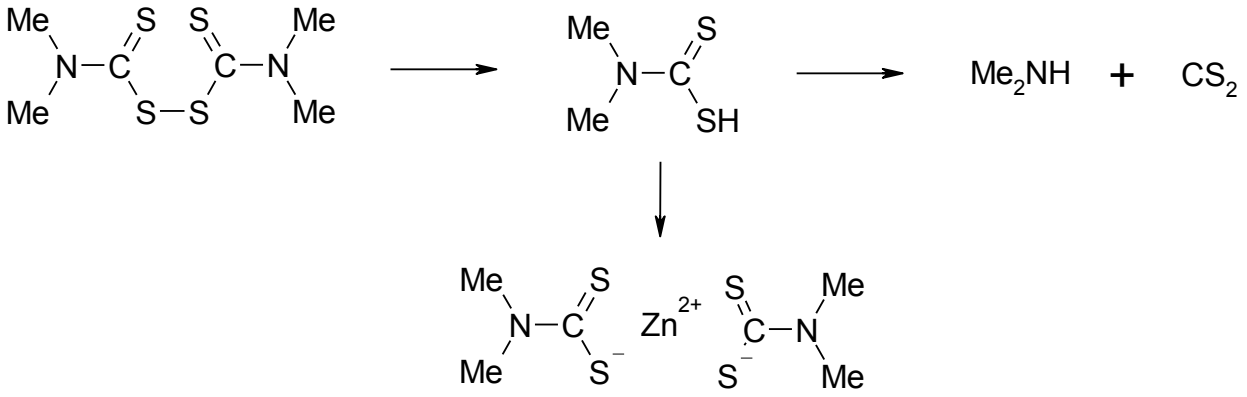
- Monoalkylphenols
  - used to make non-ionic surfactants
  - surfactants not used in tyres



- Cadmium
  - Zinc oxide is 99% pure

BUT VULCANISATION DOES CREATE NEW PRODUCTS

e.g. thiuram accelerators generate: amines, CS_2 and zinc dithiocarbamates



Other accelerators give different amines – e.g. CBS → cyclohexylamine

Amines give ketones by side-chain oxidation – e.g. 6PPD → MIBK

cyclohexylamine → cyclohexanone

LOW MW SPECIES IN VULCANISED RUBBER

Include

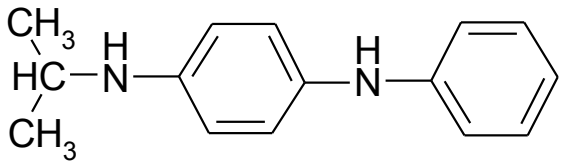
- orginal ingredients of mix
- by-products of vulcanisation

All encapsulated in a molecular network

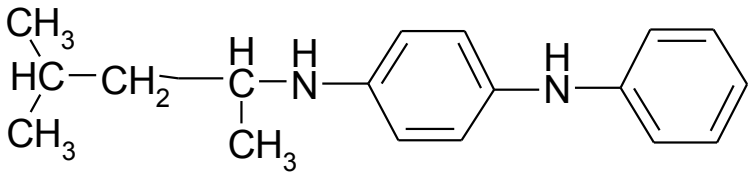
- which may hold some species in
  - i.e. organics well-solvated by network
- and squeeze other species out
  - i.e. those that try to crystallise out from solvation

Elastic properties of network force crystallisable species to the surface – vulcanised rubbers "bloom"

COMPONENTS OF BLOOM CAN INCLUDE….



IPPD



6PPD

Aromatic amine antiozanants

- N-isopropyl-N‘-phenyl-*p*-phenylenediamine (IPPD)
- N-1,3-dimethylbutyl-N‘-phenyl-*p*-phenylenediamine (6PPD)

Tyre rubber has a basic surface

Zinc salts

- Zinc dimethyldithocarbamate $(Me_2NCS_2)_2Zn$

Water leaches zinc from tyre rubber

SURFACE CHARACTER OF RUBBER

Contact dermatitis linked with skin contact with rubber

- Causative agents include the components of bloom
- Effect depends on individual sensitivity and extent of contact
- Not normally associated with transient contact
  - e.g. not associated with handgrips, matting, dinghies, etc.
- Usually seen in somebody wearing rubber
  - e.g. goggles, elasticated clothing, etc

- **Contact dermatitis not expected with rubber granulate**

Nilsson et al. (2005) looked at extraction by (synthetic) sweat
– found health risks insignificant

Consider five different health/environmental issues

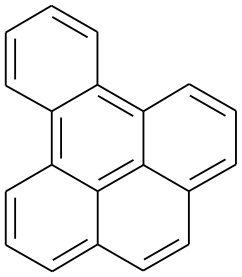
polycyclic aromatic hydrocarbons PAHs

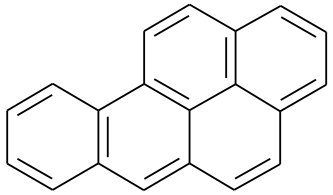
benzene

phthalates

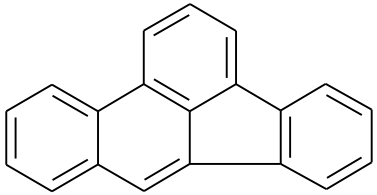
alkylphenols

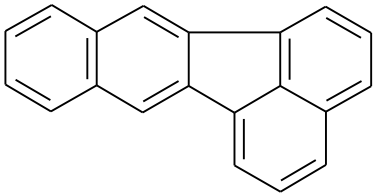
zinc

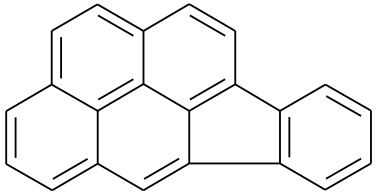


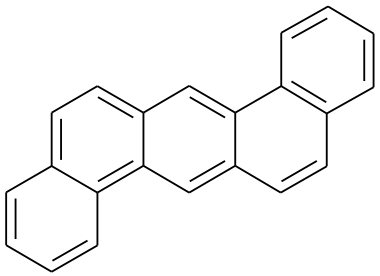


Polycyclic aromatic hydrocarbons









POLYCYCLIC AROMATIC HYDROCARBONS

- Lubricating oils are (solvent) extracted to remove aromatics
- These extracts – 'aromatic process oils' – are excellent plasticisers/ softeners for tyre rubbers
- Improve processing and product performance (wet grip etc.)

- But they are rich in PAHs
- PAH content in the range 20-30%
- And they do contain the carcinogenic (e.g. five-ring) types
- Aromatic process oils carry labelling

T	Toxic
R45	May cause cancer

Occupational health issues will see replacement of these oils

PAHs ARE IN TYRE RUBBER – DO THEY COME OUT?

1973-75 BRMA survey of airborne benzo[*a*]pyrene in ten UK tyre factories found:

- concentrations from zero to 28 ng/m^3
- no correlation with process or factory area
- strong correlation with seasons and weather

Nutt (1984) repeated this with simultaneous measurements of inside (tyre factory) and outside air

- found no excess of B[*a*]P in factory air

Willoughby (1994) analysed PAHs from laboratory vulcanisations at up to 200ºC

- found only two-to-four ring PAHs in volatiles

PAHs ARE IN TYRE RUBBER – CAN THEY LEACH OUT?

Norwegian Institute for Water Research (2005) carried leachate tests on granulate:

- found only two-to-four-ring PAHs in leachate

Log K_{ow} values

- ca. 3-4 for three-ring
- ca. 4-5 for four-ring
- ca. 6 for five-ring

- So five-ring PAH is ca. 10^6 time more likely to partition in an organic phase rather than in water
- Five-ring PAHs will stay in the vulcanised rubber

PAHs ARE ALREADY IN THE ENVIRONMENT

- **PAHs are in the air from combustion processes**
  - transport, power generation, cigarettes, etc.
- **Routinely monitored in ambient air**
  - Annual avs. for benzo[*b*]fluoranthene and benzo[*a*]pyrene ca. 1 ng/m^3 in Manchester UK
- **Carried on soot particles and washed out of air by rain**
- **Pass into rivers and lakes – and then into sediments**

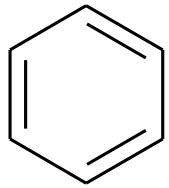
Nilsson et al (2005) studied PAHs in sand in a children's playground with used tyre components

- Found distribution of PAHs did not reflect that in tyre rubber
- Concluded that the PAHs arose from deposition from the air

Additional risks from PAHs in tyre granulate judged insignificant

BENZENE

- Present in original vulcanisate from polymer/carbon black interaction
  - polymer displaces adsorbed benzene from black surface
- May also be taken up by tyre rubber in service
  - benzene and rubber will have a strong affinity
  - affinity will work against elastic forces
  - so benzene will 'push' its way in



- Benzene has been found in air above tyre granulate

Dye et al. (2003) monitored several species in air of indoor sports halls. The smallest margin against WHO guidance values was for benzene.

Benzene max. found, 2.3 μg/m^3 WHO/EC limit, 5.0 μg/m^3

Is there a cause for concern?

BENZENE IS ALREADY IN THE ENVIRONMENT

- Unleaded gasoline contains benzene
- Up to 50% of premium gasoline can be aromatic
- Benzene is ubiquitous in urban air

Air in urban flat (Frankfurt am Main)[a]	10.2 µg/m^3 (mean)
Air in filling station (breathing zone)[b]	27 µg/m^3 (max)
Air inside vehicle (driving)[b]	120 µg/m^3 (max)

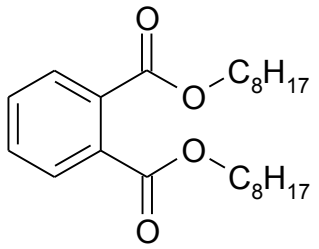
a) Heudorf & Hentschel (1995)

b) WHO (2000)

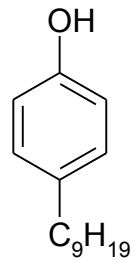
- All the above are in excess of WHO guidelines
- Sports hall air is actually below the guidance value
- Norwegian Inst of Pub Health (2006) – concluded that the levels found do not pose a cancer risk

PHTHALATES AND ALKYLPHENOLS

- Not ingredients of tyre rubber
- But various researchers have found them in leachates from tyre granulate
- Environmental concerns (endocrine disruptors)



- These must be picked up from the environment in service
  - i.e. tyres are an environmental fate for phthalates and alkylphenols



- A reminder that scrap tyre granulate will be a variable product

- Standards/testing important

ZINC

- ZnO is an activator in sulphur vulcanisation
- Forms zinc salts as a by-product of vulcanisation chemistry
- Zinc salts can bloom in vulcanisates
- Expect zinc in leachates from any sulphur vulcanisate
  - and it is found
- But care is needed to avoid spurious data from background contamination (e.g. from galvanising)

ZINC LEACHING

Lab trials - effect of pH (Liu et al., 1998)

pH 3.5	pH 5.0	pH 7.0
23.5 mg/l	17.5 mg/l	3.38 mg/l

Field trials (Humphrey and Katz, 2001)
Levels (mg/l) in trench with granulate (background in parenthesis)

	Peat	Clay	Glacial Till
Unfiltered	2.39 (0.04)	0.75 (0.18)	0.57 (0.13)
Filtered	0.065 (0.009)	0.12 (0.007)	0.076 (0.004)

Away from trench, Zn levels rapidly decay to background levels

ZINC LEACHING

Overall conclusions are:

- Tire sheds placed above or below the water table have a negligible impact on water quality

- There may be a localised environmental impact

Zinc testing should figure in quality standards

RISKS FROM RUBBER GRANULATE IN SPORTS SURFACES

- A number of species are present in rubber granulate
  - from the ingredients used
  - from reactions of vulcanisation
  - from exposure in previous use (tyres)

- Many are held in tightly within the rubber
- Some are expelled to the surface (bloom)
- There is no demonstrable health risk
- There may be a localised environmental impact

What about sustainability?

SUSTAINABILITY

SBR & EPDM polymers are products of oil industry

NR polymer is sustainable - but vulcanisate requires synthetic chemicals

A different way?



SUSTAINABILITY



400k tons per year of scrap tyres generated in the UK alone

Unsightly, unhealthy, a fire risk – and a wasted resource

If it's a suitable feedstock for sports surface granules – use it

TURFindustry

SYNTHETIC TURF
INFILL RESEARCH SOURCES

Use of End-of-Life Tyre Rubber Crumb in Sports Floors: Environmental Consequences

2006 Update

Laboratoire de Recherches et de Controle
du Caoutchouc et des Plastiques

LRCCP

Laboratoire de Recherches et de Contrôle
du Caoutchouc et des Plastiques



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Att. Mrs Boucher

Documentary report D

N°D321394/EN
15/05/2006

Use of end-of-life tyre rubber crumb in sports floors: environmental consequences. 2006 update

Documentary report D
N°D321394/EN

FIELDTURF TARKETT SAS
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Use of end-of-life tyre rubber crumb in sports floors: environmental consequences. 2006 update

Author: Catherine RIGAUD

References:

LRCCP estimate no 394.06/CR dated 05/04/2006
Acceptance according to estimate dated 13/04/2006
LRCCP report D320971

This report may only be copied in its entirety.
It consists of **9 pages and 9 appendices.**

I - INTRODUCTION

The purpose of the study is to update our knowledge about the environmental consequences, if any, of using rubber crumb from end-of-life tyres in floors for sports facilities and other play areas.

Our first documentary report, no D320971, dating from August 2002, clearly demonstrated the ecological safety of rubber from end-of-life tyres.

To facilitate understanding and comparison of the two documentary reports, we have retained a similar layout.

Moreover we have intentionally avoided using documents that could be thought to be too heavily loaded towards one technical opinion.

Some bodies (suppliers, rubber industry trade associations, ecological associations, etc) could be considered to be biased, and could be tempted to present arguments, either for or against, lacking in objectivity.

II – CONVENTIONAL BIBLIOGRAPHICAL DATA BASE

II.1 *Results*

The research equations were reconsidered, with the same technical descriptors, by adding a limit to the dates of the results, that is by specifying that the references of the documents cited must have been obtained from 2002 onwards.

The LRCCP data base only provided one interesting result, discussed in the next paragraph. Processing the English RAPRA specific polymer data base, produced 6 references, against 9 references from the American COMPENDEX engineering base.

After consultation of the sources, we observed that the references from the RAPRA data base referred either to recycling operators proposing new types of crumb as materials for use in sports floors, or tyre waste used in applications that could be considered to be almost traditional such as asphalt, submarine reefs, drainage materials, etc.

II.2 *Primary documents retained* (grouped together in the "Documents" appendix volume)

a) Updated research on the **LRCCP data base** provided us with a recent reference which seemed interesting (*appendix no 1*).

It is a document from a German environmental research Institute, entitled: "Estimation of the environmental exposition for additives in the rubber industry", by M. Gräfen, K. Hesse, and W. Baumann published in the magazine, Kautschuk Gummi Kunststoffe (Vol. 54, no 12, 2001).

However, on reading the document, its content does not appear to be directly related to our subject, since it deals with effluents emitted by plants processing rubber (including all types of elastomers) in the tyre and industrial rubber fields.

b) COMPENDEX reference no 2 (*appendix no 2)*

This **document** is the **most recent** of those appearing to merit attention. It is written collaboratively by American authors, contributing from within university bodies, institutions or companies working in the field of chemical risk. It was published in "Environmental Toxicology & Chemistry", Vol. 25, no 2, **of February 2006.**

Although the use of end-of-life tyre waste is currently widely accepted in the USA (cf. ASTM standard D6270), some states were reticent as to certain engineering applications, because of the small amount of data available about possible toxic risks presented by effluents of this waste caused by washout.

The purpose of the study was to assess the toxicity of leachate from shredded material from tyres used as road fill, and the conditions to make its incidence negligible both above and below the ground water table.

In the tyre fragments placed in situation (in 1993) pieces of metal cord were exposed intentionally. A site which did **not contain any tyre waste** was used as **comparative bench mark.** Samples were collected between October 2000 and January 2002.

Chemical analyses were made according to the methods laid down by the US EPA (the main American environmental agency) to characterise the metals and the volatile and semi-volatile organic compounds.

Toxicity tests (detailed test methods) in the water processing monitoring laboratory, showed that the survival/reproduction responses of the aquatic organisms concerned **satisfied the EPA acceptability criteria. These results were confirmed by those from a toxicity reference crossover study.**

Targeted toxicity identification assessment tests were carried out with many samples, as well as blank tests. Geochemical modelling software was used to corroborate the results obtained.

The parameters with the most effect on the dispersion of the leachates are the gradient and the hydraulic conductivity, directly linked to the flow speed of the underground water and the dilution of the leachates. The infiltration action by rain water is also taken into consideration, with the ratios, transit speeds in the ground and the nature of the ground.

The results all these tests, which were very complete and detailed, show an **insignificant incidence of the presence of tyre fragments on the characteristics of washout water above the level of the ground water table.**

Below the ground water table, observable pollution is only from the metals (especially iron) from the tyre reinforcement cords.

c) COMPENDEX Reference no 4 (*appendix no3)*

Between 1999 and 2001 the Canadian authors, one of whom belongs to Winnipeg University Civil Engineering Department, studied the thermo-mechanical behaviour of shredded material from end-of-life tyres used in underfloor thermal insulation, and its potential incidence on the quality of underground water. A 45 cm gravel layer covered the shredded tyre material, laid in five successive 15 cm layers.

In this study we find the influence of the presence of end-of-life tyre fragments on the air, ground and water, with an increase in the levels of mineral compounds (aluminium, iron and manganese) due to the presence of pieces of metal reinforcement cords.

Analysis of the organic compounds shows that their levels are below the detection thresholds indicated by the test method.

d) COMPENDEX Reference no 8 (*appendix no 4)*

This study, presented by a university academic (Civil and Environmental Engineering Department) and two co-authors specialised in horticulture, considered the absorption properties of rubber particles from tyres in relation to nitrogen and phosphorous, incorporated into the intermediate drainage layer of sandy soils and golf putting green underlayers.

Comparative analyses were done on a grass derivative. **A significant reduction in the nitrate concentration in the leachates compared with a traditional gravel layer was observed,** even though the reactive mechanism remained obscure.

The presence of particles had **no negative effect on the vegetation** (growing, density, quality or colour).

III- LRCCP DOCUMENTARY RESOURCES

The **American ASTM D 6270-98 standard**, entitled "Standard practice for use of scrap tires in civil engineering applications", was **reapproved in 2004** (*appendix no 5).*

Concerning the potential toxicity of tyre waste from washout, including by acid rain water, the same **evaluation method is retained** (USEPA Method 1311; a document of which the version has not been revised since our first report).

Consequently the results of the tests carried out to date remain valid. The levels of metals and organic compounds measured, after washing of the end-of-life tyres, are considerably lower than the maximum values laid down. **Hence end-of-life tyres are still considered as waste that is not dangerous for the environment** (§ 7.4).

IV- DATA OBTAINED VIA THE INTERNET

a) A tyre recycling programme, dating from **December 2002**, emanating from "Washington State Department of Ecology", examines the various destinations for end-of-life tyres.

In the extract supplied (*appendix no 6),* this department specifies that according to the survey of other state agencies and in-depth studies, the use of shredded end-of-life tyre material as fill does not seem to have a negative influence on the composition of gasses or effluents.

Among the examples of applications illustrating the Ford Motor/RTG programme, **rubber crumb** is **incorporated into floor coverings for school play areas, horse racing tracks and football pitches.**

b) A publication (*appendix no 7)* from "Particle & Fibre Toxicology", dating from **March 2005**, was written by a team from Milan University, involving the departments of Environmental Science & Biology.

It is considered that road transport is responsible for 80 % of the inhalable particles in urban areas. Of this only 3-7 % can be blamed on tyre and brake wear.

From this study, centred mainly on inhalable substances and the potential consequences on the respiratory tracts, we can note that the size of the ultra-fine particles likely to be toxic is between 2.5 µm and 100 nm. Tyre debris, generated by tyre wear on the roads has larger particle sizes. Only a very small percentage can be classed in the category known as the inhalable fraction. We are a long way from the crumb incorporated in the floor covering, which is a much larger size than wear debris.

However, out of the compounds dropped in eluates, zinc seems to be the one that needs to be monitored the most closely, as its level increases with a fall in the ambient pH. This influence of the acid pH was already mentioned in our first report.

c) An article published in **January 2006** in "Environmental Health Perspectives", whose authors are either university academics or health workers, relates a **very pertinent case study** (*appendix no 8*).

It is a **risk analysis** on the use of **end-of-life tyre rubber crumb in play areas,** in comparison with the use of sand or wood shavings.

In order to examine the risks, American scientific literature was reviewed as was data returned from the childcare network. **Analysis of the combined potentialities suggests that the use of rubber crumb as covering for play areas presents a very low risk both for the children and for the environment.**

The toxicity on aquatic organisms, observed in an aqueous solution extracted from a new covering, disappears for the same test done on a 3 month old mat.

The document mentions a lack of specific work on the exact subject, but the potential allergy to latex, transmitted through the skin or the air, is irrelevant as these allergens do not "survive" the vulcanisation stage necessary for the manufacture of a tyre.

d) In this previously-mentioned article, **one study** (by D. **Birkholz**, Professor in the Faculty of Medicine and Pharmacy at the University of Alberta) is mentioned which is apparently **considered as the reference** on the subject. This led us to look for the source document.

It is a Canadian technical publication of **July 2003**, which appeared in "J. Air & Waste Manag. Assoc.", entitled: Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds (*appendix no 9*).

Favoured for its shock and noise absorbing qualities and the suppleness it provides to playground flooring compared with sand or asphalt, crumb is examined from the point of view of possible effects on children's health (sensitivity, dermatitis, etc).

Workplace dangers existing in the manufacture of rubber goods (including tyres) do not need to be considered in this situation as the product used, crumb, is stabilised, aged, washed, and dust-free.

The possible danger for the children is from direct contact with the chemical compounds contained in the crumb, which could happen by ingestion or as a result of contact.

A qualitative **assessment of these risks** produced the following conclusions:

- **Ingestion on the ground is unlikely** and the gastric juices of the digestive system are not powerful enough to extract the toxic products from the crumb.
- **Inhalation is considered negligible** as the crumb does not contain volatile chemical compounds under pressure.
- **Dermatological contact presents a generally very low risk.** A more effective solvent than water would be needed to extract toxic compounds in quantity, and an adequate (non polar) carrier would be necessary to penetrate the skin and cause significant absorption.

The ecological impact, if it exists, associated with the use of crumb in play area floors, depends on mechanisms for releasing chemical products into the immediate environment and the possibility of bioaccumulation.

Consequently the second, quantitative, part of the study, tried to establish whether crumb compounds, in an aqueous environment, were toxic in relation to the aquatic environment. In vitro genotoxicity tests were carried out as well as standard biological tests with representative leachates (250 g of crumb washed in 1 L of water and then filtered).

The genotoxicity results were negative: **absence of chemical compounds likely to be chromosomically noxious**.

The biological tests indicated a moderate toxic risk for aquatic species, in the case of leachates from "fairly recent" crumb. This toxic activity falls away fast naturally, probably by dilution into non toxic compounds. The maximum duration of this "toxicity" estimated at a maximum of 3 months outdoors, makes the danger of **contamination of the crumb very low**, considering the volumes of water participating in spontaneous dilution (rain, snow, underground water, etc).

IV – CONCLUSION

As in our first study in 2002, this update mainly contains data from North America.

The large volume of end-of-life tyres linked to automobile activity, continues to motivate the managers concerned strongly because of the recycling aspect.

The American ASTM D6270 standard, issued in 1998, establishing the rules of good practice in the use of tyre waste in civil engineering, was revalidated in 2004 by the commission responsible. This document makes reference to specific tests of contamination and toxicity in relation to the environment.

For tyre waste, one of the major sources of possible contamination into the ground results from the phenomenon of washout by surface run-off water.

The main data obtained on this subject concerns the use of crumb as fill for road or other foundations.

It has been shown that this tyre waste has no toxic influence on the fauna and micro-aquatic organisms.

The only chemical elements present and potentially contaminating are metals, especially iron, from fragments of tyre reinforcing cords. We should bear in mind that these fragments are absent from rubber crumb.

More directly on the subject of sports and play area floors, the Canadian study of 2003 is the authority on the subject.

The following main points are significant:

- In the event of ingestion of crumb particles, although it is highly improbable, the particles do not present any toxicity, the digestive system is not powerful enough to extract the chemical components from the rubber.
- Inhaling is practically negligible because crumb does not give off volatile products.
- Direct contact with the skin does not present any real danger, even from the point of view of allergy.
- From the genetic point of view, biological tests have shown the absence of genotoxicity.

This data will be all the more reliable if the crumb used has been washed beforehand, to remove any easily extractible or volatile components.

This updated data confirms that the end-of-life tyre crumb is a perfectly suitable material for sports and play area floors, without any palpable danger of toxicity for users or the environment.

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Artificial Turf Pitches
An Assessment of the Health Risks For Football Players and the Environment

Dr. Christine Bjørge, Norwegian Institute of Public Health

Artificial turf pitches – an assessment of the health risks for football players and the environment.

Presentation at the ISSS Technical Meeting 2006 in Dresden, Thursday 12th to Friday 13th October2006 by Dr. Christine Bjørge, Norwegian Institute of Public Health, Oslo Norway.

Summary

Artificial turf is used for football pitches around the word. The turf has many advantages, being hard-wearing and easier to maintain than natural grass. The use of artificial turf also allows the football season to be extended, independently of the weather.

Artificial turf often contains rubber granulates from waste tyres, which contains many chemical substances of very high concern to human health and the environment. The concentrations of these substances are however extremely low, they are only leached from the rubber granulate in very small quantities and they are only present in low concentrations in the hall air. The quantities of this type of substance are consistently lower in the other types of rubber granulate which are used (e.i., EPDM rubber). The assessment of health risk was therefore based on measurements (concentrations in the rubber granulate and in airborne dust, PM10, and volatile organic compounds (VOC) in the hall air) in halls in which recycled rubber granulate is used.

A number of worst case scenarios were prepared which are used in the human health risk characterisation. These scenarios are based on information concerning the use of the halls [matches and training sessions; frequency and duration; physiological parameters (skin surface area, inhalation volumes during exertion and body weight) and analyses (content in rubber granulate, airborne dust/PM10 and VOC)] . Exposure calculations were performed for adults, juniors, older children and children based on measurements of VOC, airborne dust, concentrations of chemicals in recycled rubber granulate and leaching from the granulate.

On the basis of estimated exposure values and the doses/concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults. The estimated Margins of Safety (MOS) also give no cause for concern.

As regards total VOC, higher values were measured than are normally found in homes. Values of up to 200-400 µg/m^3 fall within the normal range for housing. It is concluded that the values which were measured for total VOC do not constitute any elevated health risk but our knowledge of this area is rather inadequate. It is reasonable to assume that the relatively high VOC values could contribute to the hall air being perceived as" poor" without this in itself actually causing any elevated health risk.

As regards allergies, it is concluded that exposure to the low concentrations which were measured does not constitute any elevated risk with respect to the development of contact allergies. It is known that car tyres can contain relatively high concentrations of latex and therefore possibly also latex allergens. Latex is a potent airway allergen, but it would appear that latex in car rubber dust is either less available for uptake and/or deactivated. As no information is available concerning levels of latex in the rubber granulate that is used, it is not possible to assess the risk of developing an airway allergy. The possibility that the use of car tyres could cause exposure to latex allergens and thus lead to the development of airway allergies cannot be entirely eliminated. Studies have been carried out which indicate a link between exposure to phthalates and the development of asthma/allergies. At the present time, it is not possible to carry out a risk assessment in this area because of a lack of available knowledge.

Worst case calculations based on air measurements carried out by NILU and exposure values from the Norwegian Institute of Public Health indicate that training in sports halls does not cause any increased risk of leukaemia as a result of benzene exposure or any elevated risk as a result of exposure to polycyclic aromatic hydrocarbons.

On the basis of the exposures which have been calculated in connection with the use of indoor halls with artificial turf in which recycled rubber granulate is used, there is no evidence to indicate that the use of such halls causes an elevated health risk. A reservation must however be issued as regards the development of asthma/airway allergies, where the knowledge that is currently available is limited. This particularly applies to exposure to latex allergens, as no information is available on the occurrence of latex allergens in hall air, yet such allergens have been demonstrated in car tyre rubber. It should also be noted that little or no toxicological information is available for many of the volatile organic compounds which have been demonstrated as being present in the air in the halls. The concentrations of most substances for which insufficient information is available concerning harmful effects are extremely low and for this reason they are not expected to cause any increased health risk. However, not all organic compounds in the hall air have been identified. It is concluded that the exposure quantities which have been calculated for benzene and PAHs do not represent a cancer risk.

On the basis of the knowledge that is currently available concerning health effects and exposure linked to the use of indoor artificial turf pitches, we do not see any necessity to replace the recycled granulate at the present time. Due to a lack of knowledge as regards the possible induction of latex rubber, we recommend that recycled rubber granulate should not be used when rubber granulate is supplemented/replaced.

An environmental risk assessment of artificial turf for sport grounds have been performed, based on an investigation of content and leaking potential of hazardous substances in the material used. It was found that recycled rubber was the major source of potentially hazardous substances. An exposure scenario where the runoff from a football field is drained to a small creek showed a positive risk of toxic effects on biota in the water phase and in the sediment. The risk was mainly attributed to zink, but also for octylphenol the predicted environmental concentrations exceeded the no environmental effect concentration. The total annual amounts of hazardous substances leaching from a normal sports ground are fairly low which means that any environmental effects are expected to be local only.

Dr. Christine Björge

Some key notes on Dr. Björge's occupation:
She works as a scientist at the Norwegian Institute of Public Health, Division of Environmental Medicine, Department of Chemical Toxicology.
Her research work is mainly related to reproductive toxicity, however, she is also involved in work related to human health risk assessment of chemicals under the Chemical Program in EU. This work includes writing and commenting on risk assessment reports of chemicals in EU and classification and labelling of chemcials in EU. Due to her knowledge of human risk assessment of chemicals she was involved in the work of the risk assessment for football players related to the use of artificial turf pitches.

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Water Quality Standards for Surface Waters of the State of Washington

Washington Administrative Code

Chapter 173-201A WAC

WATER QUALITY STANDARDS FOR SURFACE WATERS OF THE STATE OF WASHINGTON

WAC

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WAC 173-201A-010 Introduction. (1) The purpose of this chapter is to establish water quality standards for surface waters of the state of Washington consistent with public health and public enjoyment thereof, and the propagation and protection of fish, shellfish, and wildlife, pursuant to the provisions of chapter 90.48 RCW and the policies and purposes thereof.

(2) This chapter shall be reviewed periodically by the department and appropriate revisions shall be undertaken.

(3) The water use and quality criteria set forth in WAC 173-201A-030 through 173-201A-140 are established in conformance with present and potential water uses of the surface waters of the state of Washington and in consideration of the natural water quality potential and limitations of the same. Compliance with the surface water quality standards of the state of Washington require compliance with chapter 173-201A WAC, Water quality standards for surface waters of the state of Washington, and chapter 173-204 WAC, Sediment management standards.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-010, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-020 Definitions. The following definitions are intended to facilitate the use of chapter 173-201A WAC:

"Action value" means a total phosphorus (TP) value established at the upper limit of the trophic states in each ecoregion. Exceedance of an action value indicates that a problem is suspected. A lake-specific study may be needed to confirm if a nutrient problem exits.

"Acute conditions" are changes in the physical, chemical, or biologic environment which are expected or demonstrated to result in injury or death to an organism as a result of short-term exposure to the substance or detrimental environmental condition.

"AKART" is an acronym for "all known, available, and reasonable methods of prevention, control, and treatment." AKART shall represent the most current methodology that can be reasonably required for preventing, controlling, or abating the pollutants associated with a discharge. The concept of AKART applies to both point and nonpoint sources of pollution. The term "best management practices," typically applied to nonpoint source pollution controls is considered a subset of the AKART requirement. "The Stormwater Management Manual for the Puget Sound Basin" (1992), may be used as a guideline, to the extent appropriate, for developing best management practices to apply AKART for storm water discharges.

"Background conditions" means the biological, chemical, and physical conditions of a water body, outside the area of influence of the discharge under consideration. Background sampling locations in an enforcement action would be up-gradient or outside the area of influence of the discharge. If several discharges to any water body exist, and enforcement action is being taken for possible violations to the standards, background sampling would be undertaken immediately up-gradient from each discharge. When assessing background conditions in the headwaters of a disturbed watershed it may be necessary to use the background conditions of a neighboring or similar watershed as the reference conditions.

"Best management practices (BMP)" means physical, structural, and/or managerial practices approved by the department that, when used singularly or in combination, prevent or reduce pollutant discharges.

"Biological assessment" is an evaluation of the biological condition of a water body using surveys of aquatic community structure and function and other direct measurements of resident biota in surface waters.

"Bog" means those wetlands that are acidic, peat forming, and whose primary water source is precipitation, with little, if any, outflow.

"Carcinogen" means any substance or agent that produces or tends to produce cancer in humans. For implementation of this chapter, the term carcinogen will apply to substances on the United States Environmental Protection Agency lists of A (known human) and B (probable human) carcinogens, and any substance which causes a significant increased incidence of benign or malignant tumors in a single, well conducted animal bioassay, consistent with the weight of evidence approach specified in the United States Environmental Protection Agency's Guidelines for Carcinogenic Risk Assessment as set forth in 51 FR 33992 et seq. as presently published or as subsequently amended or republished.

"Chronic conditions" are changes in the physical, chemical, or biologic environment which are expected or demonstrated to result in injury or death to an organism as a result of

repeated or constant exposure over an extended period of time to a substance or detrimental environmental condition.

"Created wetlands" means those wetlands intentionally created from nonwetland sites to produce or replace natural wetland habitat.

"Critical condition" is when the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or characteristic water uses. For steady-state discharges to riverine systems the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

"Damage to the ecosystem" means any demonstrated or predicted stress to aquatic or terrestrial organisms or communities of organisms which the department reasonably concludes may interfere in the health or survival success or natural structure of such populations. This stress may be due to, but is not limited to, alteration in habitat or changes in water temperature, chemistry, or turbidity, and shall consider the potential build up of discharge constituents or temporal increases in habitat alteration which may create such stress in the long term.

"Department" means the state of Washington department of ecology.

"Director" means the director of the state of Washington department of ecology.

"Drainage ditch" means that portion of a designed and constructed conveyance system that serves the purpose of transporting surplus water; this may include natural water courses or channels incorporated in the system design, but does not include the area adjacent to the water course or channel.

"Ecoregions" are defined using EPAs *Ecoregions of the Pacific Northwest* Document No. 600/3-86/033 July 1986 by Omernik and Gallant.

"Fecal coliform" means that portion of the coliform group which is present in the intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within twenty-four hours at 44.5 plus or minus 0.2 degrees Celsius.

"Geometric mean" means either the nth root of a product of n factors, or the antilogarithm of the arithmetic mean of the logarithms of the individual sample values.

"Ground water exchange" means the discharge and recharge of ground water to a surface water. Discharge is inflow from an aquifer, seeps or springs that increases the available supply of surface water. Recharge is outflow downgradient to an aquifer or downstream to surface water for base flow maintenance. Exchange may include ground water discharge in one season followed by recharge later in the year.

"Hardness" means a measure of the calcium and magnesium salts present in water. For purposes of this chapter, hardness is measured in milligrams per liter and expressed as calcium carbonate ($CaCO_3$).

"Irrigation ditch" means that portion of a designed and constructed conveyance system that serves the purpose of transporting irrigation water from its supply source to its place of use; this may include natural water courses or channels incorporated in the system design, but does not include the area adjacent to the water course or channel.

"Lakes" shall be distinguished from riverine systems as being water bodies, including reservoirs, with a mean detention time of greater than fifteen days.

"Lake-specific study" means a study intended to quantify existing nutrient concentrations, determine existing characteristic uses for lake class waters, and potential lake uses. The study determines how to protect these uses and if any uses are lost or impaired because of nutrients, algae, or aquatic plants. An appropriate study must recommend a criterion for total phosphorus (TP), total nitrogen (TN) in µg/l, or other nutrient that impairs characteristic uses by causing excessive algae blooms or aquatic plant growth.

"Mean detention time" means the time obtained by dividing a reservoir's mean annual minimum total storage by the thirty-day ten-year low-flow from the reservoir.

"Migration or translocation" means any natural movement of an organism or community of organisms from one locality to another locality.

"Mixing zone" means that portion of a water body adjacent to an effluent outfall where mixing results in the dilution of the effluent with the receiving water. Water quality criteria may be exceeded in a mixing zone as conditioned and provided for in WAC 173-201A-100.

"Natural conditions" or "natural background levels" means surface water quality that was present before any human-caused pollution. When estimating natural conditions in the headwaters of a disturbed watershed it may be necessary to use the less disturbed conditions of a neighboring or similar watershed as a reference condition.

"Nonpoint source" means pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the National Pollutant Discharge Elimination System program.

"Permit" means a document issued pursuant to RCW 90.48.160 et seq. or RCW 90.48.260 or both, specifying the waste treatment and control requirements and waste discharge conditions.

"pH" means the negative logarithm of the hydrogen ion concentration.

"Pollution" means such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state as will or is likely to create a nuisance or render such waters harmful, detrimental, or injurious to the public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish, or other aquatic life.

"Primary contact recreation" means activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

"Secondary contact recreation" means activities where a person's water contact would be limited (wading or fishing) to the extent that bacterial infections of eyes, ears, respiratory or digestive systems, or urogenital areas would normally be avoided.

"Shoreline stabilization" means the anchoring of soil at the water's edge, or in shallow water, by fibrous plant root complexes; this may include long-term accretion of sediment or peat, along with shoreline progradation in such areas.

"Storm water" means that portion of precipitation that does not naturally percolate into the ground or evaporate, but flows via overland flow, interflow, pipes, and other features of a storm water drainage system into a defined surface water body, or a constructed infiltration facility.

"Storm water attenuation" means the process by which peak flows from precipitation are reduced and runoff velocities are slowed as a result of passing through a surface waterbody.

"Surface waters of the state" includes lakes, rivers, ponds, streams, inland waters, saltwaters, wetlands and all other surface waters and water courses within the jurisdiction of the state of Washington.

"Temperature" means water temperature expressed in degrees Celsius (°C).

"Treatment wetlands" means those wetlands intentionally constructed on nonwetland sites and managed for the primary purpose of wastewater or storm water treatment. Treatment wetlands are considered part of a collection and treatment system, and generally are not subject to the criteria of this chapter.

"Trophic state" means a classification of the productivity of a lake ecosystem. Lake productivity depends on the amount of biologically available nutrients in water and sediments and may be based on total phosphorus (TP). Secchi depth and chlorophyll-a measurements may be used to improve the trophic state classification of a lake. Trophic states used in this rule include, from least to most nutrient rich, ultra-oligotrophic, oligotrophic, lower mesotrophic, upper mesotrophic, and eutrophic.

"Turbidity" means the clarity of water expressed as nephelometric turbidity units (NTU) and measured with a calibrated turbidimeter.

"Upwelling" means the natural process along Washington's Pacific Coast where the summer prevailing northerly winds produce a seaward transport of surface water. Cold, deeper more saline waters rich in nutrients and low in dissolved oxygen, rise to replace the surface water. The cold oxygen deficient water enters Puget Sound and other coastal estuaries at depth where it displaces the existing deep water and eventually rises to replace the surface water. Such surface water replacement results in an overall increase in salinity and nutrients accompanied by a depression in dissolved oxygen. Localized upwelling of the deeper water of Puget Sound can occur year-round under influence of tidal currents, winds, and geomorphic features.

"USEPA" means the United States Environmental Protection Agency.

"Wetlands" means areas that are inundated or saturated by surface water or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. Wetlands do not include those artificial wetlands intentionally created from nonwetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas to mitigate the conversion of wetlands. (Waterbodies not included in the definition of wetlands as well as those mentioned in the definition are still waters of the state.)

"Wildlife habitat" means waters of the state used by, or that directly or indirectly provide food support to, fish, other aquatic life, and wildlife for any life history stage or activity.

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-020, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-020, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-030 General water use and criteria classes. The following criteria shall apply to the various classes of surface waters in the state of Washington:

(1) **Class AA (extraordinary).**

(a) General characteristic. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, spawning, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam, oyster, and mussel rearing, spawning, and harvesting.

Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(vi) Commerce and navigation.

(c) Water quality criteria:

(i) Fecal coliform organisms:

(A) Freshwater - fecal coliform organism levels shall both not exceed a geometric mean value of 50 colonies/100 mL and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.

(B) Marine water - fecal coliform organism levels shall both not exceed a geometric mean value of 14 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 43 colonies/100 mL.

(ii) Dissolved oxygen:

(A) Freshwater - dissolved oxygen shall exceed 9.5 mg/L.

(B) Marine water - dissolved oxygen shall exceed 7.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 7.0 mg/L, natural dissolved oxygen levels may be degraded by up to 0.2 mg/L by human-caused activities.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature shall not exceed 16.0°C (freshwater) or 13.0°C (marine water) due to human activities. When natural conditions exceed 16.0°C (freshwater) and 13.0°C (marine water), no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C.

Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=23/(T+5) (freshwater) or t=8/(T-4) (marine water). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.

For purposes hereof, "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a human-caused variation within the above range of less than 0.2 units.

(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department (see WAC 173-201A-040 and 173-201A-050).

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(2) **Class A (excellent).**

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, spawning, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam, oyster, and mussel rearing, spawning, and harvesting.

Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(vi) Commerce and navigation.

(c) Water quality criteria:

(i) Fecal coliform organisms:

(A) Freshwater - fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 mL.

(B) Marine water - fecal coliform organism levels shall both not exceed a geometric mean value of 14 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 43 colonies/100 mL.

(ii) Dissolved oxygen:

(A) Freshwater - dissolved oxygen shall exceed 8.0 mg/L.

(B) Marine water - dissolved oxygen shall exceed 6.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 6.0 mg/L, natural dissolved oxygen levels may be degraded by up to 0.2 mg/L by human-caused activities.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature shall not exceed 18.0°C (freshwater) or 16.0°C (marine water) due to human activities. When natural conditions exceed 18.0°C (freshwater) and 16.0°C (marine water), no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C.

Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=28/(T+7) (freshwater) or t=12/(T-2) (marine water). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.

For purposes hereof, "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) or 7.0 to 8.5 (marine water) with a human-caused variation within the above range of less than 0.5 units.

(vi) Turbidity shall not exceed 5 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 10 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department (see WAC 173-201A-040 and 173-201A-050).

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(3) **Class B (good).**

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for most uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (industrial and agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam, oyster, and mussel rearing and spawning.

Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(vi) Commerce and navigation.

(c) Water quality criteria:

(i) Fecal coliform organisms:

(A) Freshwater - fecal coliform organism levels shall both not exceed a geometric mean value of 200 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 400 colonies/100 mL.

(B) Marine water - fecal coliform organism levels shall both not exceed a geometric mean value of 100 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 200 colonies/100 Ml.

(ii) Dissolved oxygen:

(A) Freshwater - dissolved oxygen shall exceed 6.5 mg/L.

(B) Marine water - dissolved oxygen shall exceed 5.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 5.0 mg/L, natural dissolved oxygen levels may be degraded by up to 0.2 mg/L by human-caused activities.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature shall not exceed 21.0°C (freshwater) or 19.0°C (marine water) due to human activities. When natural conditions exceed 21.0°C (freshwater) and 19.0°C (marine water), no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C.

Incremental temperature increases resulting from point source activities shall not, at any time, exceed t=34/(T+9) (freshwater) or t=16/(T) (marine water). Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C.

For purposes hereof, "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.

(v) pH shall be within the range of 6.5 to 8.5 (freshwater) and 7.0 to 8.5 (marine water) with a human-caused variation within the above range of less than 0.5 units.

(vi) Turbidity shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department (see WAC 173-201A-040 and 173-201A-050).

(viii) Aesthetic values shall not be reduced by dissolved, suspended, floating, or submerged matter not attributed to natural causes, so as to affect water use or taint the flesh of edible species.

(4) **Class C (fair).**

(a) General characteristic. Water quality of this class shall meet or exceed the requirements of selected and essential uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (industrial).

(ii) Fish (salmonid and other fish migration).

(iii) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(iv) Commerce and navigation.

(c) Water quality criteria - marine water:

(i) Fecal coliform organism levels shall both not exceed a geometric mean value of 200 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 400 colonies/100 mL.

(ii) Dissolved oxygen shall exceed 4.0 mg/L. When natural conditions, such as upwelling, occur, causing the dissolved oxygen to be depressed near or below 4.0 mg/L, natural dissolved oxygen levels may be degraded by up to 0.2 mg/L by human-caused activities.

(iii) Temperature shall not exceed 22.0°C due to human activities. When natural conditions exceed 22.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C.

Incremental temperature increases shall not, at any time, exceed t=20/(T+2).

For purposes hereof, "t" represents the maximum permissible temperature increase measured at a mixing zone boundary; and "T" represents the background temperature as measured at a point or points unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge.

(iv) pH shall be within the range of 6.5 to 9.0 with a human-caused variation within a range of less than 0.5 units.

(v) Turbidity shall not exceed 10 NTU over background turbidity when the background turbidity is 50 NTU or less, or have more than a 20 percent increase in turbidity when the background turbidity is more than 50 NTU.

(vi) Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department (see WAC 173-201A-040 and 173-201A-050).

(vii) Aesthetic values shall not be interfered with by the presence of obnoxious wastes, slimes, aquatic growths, or materials which will taint the flesh of edible species.

(5) **Lake class.**

(a) General characteristic. Water quality of this class shall meet or exceed the requirements for all or substantially all uses.

(b) Characteristic uses. Characteristic uses shall include, but not be limited to, the following:

(i) Water supply (domestic, industrial, agricultural).

(ii) Stock watering.

(iii) Fish and shellfish:

Salmonid migration, rearing, spawning, and harvesting.

Other fish migration, rearing, spawning, and harvesting.

Clam and mussel rearing, spawning, and harvesting.

Crayfish rearing, spawning, and harvesting.

(iv) Wildlife habitat.

(v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).

(vi) Commerce and navigation.

(c) Water quality criteria:

(i) Fecal coliform organism levels shall both not exceed a geometric mean value of 50 colonies/100 mL, and not have more than 10 percent of all samples obtained for calculating the geometric mean value exceeding 100 colonies/100 mL.

(ii) Dissolved oxygen - no measurable decrease from natural conditions.

(iii) Total dissolved gas shall not exceed 110 percent of saturation at any point of sample collection.

(iv) Temperature - no measurable change from natural conditions.

(v) pH - no measurable change from natural conditions.

(vi) Turbidity shall not exceed 5 NTU over background conditions.

(vii) Toxic, radioactive, or deleterious material concentrations shall be below those which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic conditions to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department (see WAC 173-201A-040 and 173-201A-050).

(viii) Aesthetic values shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste.

(6) **Establishing lake nutrient criteria.**

(a) The following table shall be used to aid in establishing nutrient criteria:

(WAC 173-201A-030, Table 1) See table on following page.

Ch. 173-201A-030, Table 1

Coast Range, Puget Lowlands, and Northern Rockies Ecoregions:

Trophic State	If Ambient TP (µg/) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Action Value		
>20	lake specific study may be initiated	

Cascades Ecoregion:

Trophic State	If Ambient TP (µg/) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Action Value		
>10	lake specific study may be initiated	

Columbia Basin Ecoregion:

Trophic State	If Ambient TP (µg/) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Upper mesotrophic	>20-35	35 or less
Action Value		
>35	lake specific study may be initiated.	

Lakes in the Willamette, East Cascade Foothills, or Blue Mountain ecoregions do not have recommended values and need to have lake-specific studies in order to receive criteria as described in (c)(i) of this subsection.

(b) The following actions are recommended if ambient monitoring of a lake shows the epilimnetic total phosphorus concentration, as shown in Table 1 of this section, is below the action value for an ecoregion:

(i) Determine trophic status from existing or newly gathered data. The recommended minimum sampling to determine trophic status is calculated as the mean of four or more samples collected from the epilimnion between June through September in one or more consecutive years. Sampling must be spread throughout the season.

(ii) Propose criteria at or below the upper limit of the trophic state; or

(iii) Conduct lake-specific study to determine and propose to adopt appropriate criteria as described in (c) of this subsection.

(c) The following actions are recommended if ambient monitoring of a lake shows total phosphorus to exceed the action value for an ecoregion shown in Table 1 of this section or where recommended ecoregional action values do not exist:

(i) Conduct a lake-specific study to evaluate the characteristic uses of the lake. A lake-specific study may vary depending on the source or threat of impairment. Phytoplankton blooms, toxic phytoplankton, or excessive aquatic plants, are examples of various sources of impairment. The following are examples of quantitative measures that a study may describe: Total phosphorus, total nitrogen, chlorophyll-a, dissolved oxygen in the hypolimnion if thermally stratified, pH, hardness, or other measures of existing conditions and potential changes in any one of these parameters.

(ii) Determine appropriate total phosphorus concentrations or other nutrient criteria to protect characteristic lake uses. If the existing total phosphorus concentration is protective of characteristic lake uses, then set criteria at existing total phosphorus concentration. If the existing total phosphorus concentration is not protective of the existing characteristic lake uses, then set criteria at a protective concentration. Proposals to adopt appropriate total phosphorus criteria to protect characteristic uses must be developed by considering technical information and stakeholder input as part of a public involvement process equivalent to the Administrative Procedure Act (chapter 34.05 RCW).

(iii) Determine if the proposed total phosphorus criteria necessary to protect characteristic uses is achievable. If the recommended criterion is not achievable and if the characteristic use the criterion is intended to protect is not an existing use, then a higher criterion may be proposed in conformance with 40 CFR part 131.10.

(d) The department will consider proposed lake-specific nutrient criteria during any water quality standards rule making that follows development of a proposal. Adoption by rule formally establishes the criteria for that lake.

(e) Prioritization and investigation of lakes by the department will be initiated by listing problem lakes in a watershed needs assessment, and scheduled as part of the water quality program's watershed approach to pollution control. This prioritization will apply to lakes identified as warranting a criteria based on the results of a lake-specific study, to lakes warranting a lake-specific study for establishing criteria, and to lakes requiring restoration and pollution control measures due to exceedance of an established criterion. The adoption of nutrient criteria are generally not intended to apply to lakes or ponds with a surface area smaller than five acres; or to ponds wholly contained on private property owned and surrounded by a single landowner; and nutrients do not drain or leach from these lakes or private ponds to the detriment of other property owners or other water bodies; and do not impact designated uses in the lake. However, if the landowner proposes criteria the department may consider adoption.

(f) The department may not need to set a lake-specific criteria or further investigate a lake if existing water quality conditions are naturally poorer (higher TP) than the action value and uses have not been lost or degraded, per WAC 173-201A-070(2).

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-030, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-030, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-040 Toxic substances. (1) Toxic substances shall not be introduced above natural background levels in waters of the state which have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent upon those waters, or adversely affect public health, as determined by the department.

(2) The department shall employ or require chemical testing, acute and chronic toxicity testing, and biological assessments, as appropriate, to evaluate compliance with subsection (1) of this section and to ensure that aquatic communities and the existing and characteristic beneficial uses of waters are being fully protected.

(3) The following criteria shall be applied to all surface waters of the state of Washington for the protection of aquatic life. The department may revise the following criteria on a state-wide or waterbody-specific basis as needed to protect aquatic life occurring in waters of the state and to increase the technical accuracy of the criteria being applied. The department shall formally adopt any appropriate revised criteria as part of this chapter in accordance with the provisions established in chapter 34.05 RCW, the Administrative Procedure Act. The department shall ensure there are early opportunities for public review and comment on proposals to develop revised criteria. Values are µg/L for all substances except Ammonia and Chloride which are mg/L:

	Freshwater		Marine Water	
Substance	Acute	Chronic	Acute	Chronic
Aldrin/Dieldrin	2.5a	0.0019b	0.71a	0.0019b
Ammonia (un-ionized NH3) hh	f,c	g,d	0.233h,c	0.035h,d
Arsenic dd	360.0c	190.0d	69.0c,ll	36.0d, cc,ll
Cadmium dd	i,c	j,d	42.0c	9.3d
Chlordane	2.4a	0.0043b	0.09a	0.004b

Substance	Freshwater Acute	Freshwater Chronic	Marine Water Acute	Marine Water Chronic
Chloride (Dissolved) k	860.0h,c	230.0h,d	-	-
Chlorine (Total Residual)	19.0c	11.0d	13.0c	7.5d
Chlorpyrifos	0.083c	0.041d	0.011c	0.0056d
Chromium (Hex) dd	15.0c,l,ii	10.0d,jj	1,100.0c,l,ll	50.0d,ll
Chromium (Tri) gg	m,c	n,d	-	-
Copper dd	o,c	p,d	4.8c,ll	3.1d,ll
Cyanide ee	22.0c	5.2d	1.0c,mm	-
DDT (and metabolites)	1.1a	0.001b	0.13a	0.001b
Dieldrin/Aldrin e	2.5a	0.0019b	0.71a	0.0019b
Endosulfan	0.22a	0.056b	0.034a	0.0087b
Endrin	0.18a	0.0023b	0.037a	0.0023b
Heptachlor	0.52a	0.0038b	0.053a	0.0036b
Hexachlorocyclohexane (Lindane)	2.0a	0.08b	0.16a	-
Lead dd	q,c	r,d	210.0c,ll	8.1d,ll
Mercury s	2.1c,kk,dd	0.012d,ff	1.8c,ll,dd	0.025d,ff
Nickel dd	t,c	u,d	74.0c,ll	8.2d,ll
Parathion	0.065c	0.013d	-	-
Pentachlorophenol (PCP)	w,c	v,d	13.0c	7.9d
Polychlorinated Biphenyls (PCBs)	2.0b	0.014b	10.0b	0.030b
Selenium	20.0c,ff	5.0d,ff	290c,ll,dd	71.0d, x,ll,dd
Silver dd	y,a	-	1.9a,ll	-
Toxaphene	0.73c,z	0.0002d	0.21c,z	0.0002d
Zinc dd	aa,c	bb,d	90.0c,ll	81.0d,ll

Notes to Table:

a.An instantaneous concentration not to be exceeded at any time.

b.A 24-hour average not to be exceeded.

c.A 1-hour average concentration not to be exceeded more than once every three years on the average.

d.A 4-day average concentration not to be exceeded more than once every three years on the average.

e.Aldrin is metabolically converted to Dieldrin. Therefore, the sum of the Aldrin and Dieldrin concentrations are compared with the Dieldrin criteria.

f.Shall not exceed the numerical value given by:

$$0.52 \div (FT)(FPH)(2)$$

where: $FT = 10^{[0.03(20-TCAP)]}$; $TCAP \le T \le 30$

$FT = 10^{[0.03(20-T)]}$; $0 \le T \le TCAP$

$FPH = 1$; $8 \le pH \le 9$

$FPH = (1+ 10^{(7.4-pH)}) \div 1.25$; $6.5 \le pH \le 8.0$

$TCAP =$ 20°C; Salmonids present.

$TCAP =$ 25°C; Salmonids absent.

g.Shall not exceed the numerical value given by:

$$0.80 \div (FT)(FPH)(RATIO)$$

where: $RATIO = 13.5$; $7.7 \le pH \le 9$

$RATIO =$

$(20.25 \times 10^{(7.7-pH)}) \div (1+ 10^{(7.4-pH)})$; $6.5 \le pH \le 7.7$

where:FT and FPH are as shown in (f) above except:

TCAP= 15°C; Salmonids present.

TCAP= 20°C; Salmonids absent.

h.Measured in milligrams per liter rather than micrograms per liter.

i.$\le (0.944)(e(1.128[In(hardness)]-3.828))$ at hardness= 100. Conversion factor (CF) of 0.944 is hardness dependent. CF is calculated for other hardnesses as follows: CF= 1.136672 - [(In hardness)(0.041838)].

j.$\le (0.909)(e(0.7852[In(hardness)]-3.490))$ at hardness= 100. Conversions factor (CF) of 0.909 is hardness dependent. CF is calculated for other hardnesses as follows: CF= 1.101672 - [(In hardness)(0.041838)].

k.Criterion based on dissolved chloride in association with sodium. This criterion probably will not be adequately protective when the chloride is associated with potassium, calcium, or magnesium, rather than sodium.

l.Salinity dependent effects. At low salinity the 1-hour average may not be sufficiently protective.

m.$\le (0.316)e^{(0.8190[\ln(hardness)] +3.688)}$

n.$\le (0.860)e^{(0.8190[\ln(hardness)] +1.561)}$

o.$\le (0.960)(e^{(0.9422[\ln(hardness)] -1.464)})$

p.$\le (0.960)(e^{(0.8545[\ln(hardness)] -1.465)})$

q.$\le (0.791)(e^{(1.273[In(hardness)] -1.460)})$ at hardness= 100. Conversion factor (CF) of 0.791 is hardness dependent. CF is calculated for other hardnesses as follows: CF= 1.46203 - [(In hardness)(0.145712)].

r.$\le (0.791)(e^{(1.273[In(hardness)] -4.705)})$ at hardness= 100. Conversion factor (CF) of 0.791 is hardness dependent. CF is calculated for other hardnesses as follows: CF= 1.46203 - [(In hardness)(0.145712)].

s.If the four-day average chronic concentration is exceeded more than once in a three-year period, the edible portion of the consumed species should be analyzed. Said edible tissue concentrations shall not be allowed to exceed 1.0 mg/kg of methylmercury.

t.$\le (0.998)(e^{(0.8460[\ln(hardness)] +3.3612)})$

u.$\le (0.997)(e^{(0.8460[\ln(hardness)] +1.1645)})$

v.$\le e^{[1.005(pH) -5.290]}$

w.$\le e^{[1.005(pH) -4.830]}$

x.The status of the fish community should be monitored whenever the concentration of selenium exceeds 5.0 ug/1 in salt water.

y.$\le (0.85)(e^{(1.72[\ln(hardness)] -6.52)})$

z.Channel Catfish may be more acutely sensitive.

aa.$\le (0.978)(e^{(0.8473[\ln(hardness)] +0.8604)})$

bb.$\le (0.986)(e^{(0.8473[\ln(hardness)] +0.7614)})$

cc.Nonlethal effects (growth, C-14 uptake, and chlorophyll production) to diatoms (Thalassiosira aestivalis and Skeletonema costatum) which are common to Washington's waters have been noted at levels below the established criteria. The importance of these effects to the diatom populations and the aquatic system is sufficiently in question to persuade the state to adopt the USEPA National Criteria value (36 µg/L) as the state threshold criteria, however, wherever practical the ambient concentrations should not be allowed to exceed a chronic marine concentration of 21 µg/L.

dd.These ambient criteria in the table are for the dissolved fraction. The cyanide criteria are based on the weak acid dissociable method. The metals criteria may not be used to calculate total recoverable effluent limits unless the seasonal partitioning of the dissolved to total metals in the ambient water are known. When this information is absent, these metals criteria shall be applied as total recoverable values, determined by back-calculation, using the conversion factors incorporated in the criterion equations. Metals criteria may be adjusted on a site-specific basis when data are made available to the department clearly demonstrating the effective use of the water effects ratio approach established by USEPA, as generally guided by the procedures in USEPA Water Quality Standards Handbook, December 1983, as supplemented or replaced. Information which is used to develop effluent limits based on applying metals partitioning studies or the water effects ratio approach shall be identified in the permit fact sheet developed pursuant to WAC 173-220-060 or 173-226-110, as appropri-

ate, and shall be made available for the public comment period required pursuant to WAC 173-220-050 or 173-226-130(3), as appropriate.

ee.The criteria for cyanide is based on the weak and dissociable method in the 17th Ed. Standard Methods for the Examination of Water and Wastewater, 4500-CN I, and as revised (see footnote dd, above).

ff.These criteria are based on the total-recoverable fraction of the metal.

gg.Where methods to measure trivalent chromium are unavailable, these criteria are to be represented by total-recoverable chromium.

hh.Tables for the conversion of total ammonia to un-ionized ammonia for freshwater can be found in the USEPA's Quality Criteria for Water, 1986. Criteria concentrations based on total ammonia for marine water can be found in USEPA Ambient Water Quality Criteria for Ammonia (Saltwater)-1989, EPA440/5-88-004, April 1989.

ii.Conversion factor to calculate dissolved metal concentration is 0.982.

jj.Conversion factor to calculate dissolved metal concentration is 0.962.

kk.Conversion factor to calculate dissolved metal concentration is 0.85.

ll.Marine conversion factors (CF) used for calculating dissolved metals concentrations. Conversion factors are applicable to both acute and chronic criteria for all metals except mercury. CF for mercury is applicable to the acute criterion only. Conversion factors are already incorporated into the criteria in the table. Dissolved criterion= criterion x CF

Metal	CF
Arsenic	1.000
Cadmium	0.994
Chromium (VI)	0.993
Copper	0.83
Lead	0.951
Mercury	0.85
Nickel	0.990
Selenium	0.998
Silver	0.85
Zinc	0.946

mm.The cyanide criteria are: 9.1µg/l chronic and 2.8µg/l acute and are applicable only to waters which are east of a line from Point Roberts to Lawrence Point, to Green Point to Deception Pass; and south from Deception Pass and of a line from Partridge Point to Point Wilson.

(4) USEPA Quality Criteria for Water, 1986 shall be used in the use and interpretation of the values listed in subsection (3) of this section.

(5) Concentrations of toxic, and other substances with toxic propensities not listed in subsection (3) of this section shall be determined in consideration of USEPA Quality Criteria for Water, 1986, and as revised, and other relevant information as appropriate. Human health-based water quality criteria used by the state are contained in 40 CFR 131.36 (known as the National Toxics Rule).

(6) Risk-based criteria for carcinogenic substances shall be selected such that the upper-bound excess cancer risk is less than or equal to one in one million.

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-040, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-040, filed 11/25/92, effective 12/26/92.]

Reviser's note: The brackets and enclosed material in the text of the above section occurred in the copy filed by the agency.

WAC 173-201A-050 Radioactive substances. (1) Deleterious concentrations of radioactive materials for all classes shall be as determined by the lowest practicable concentration attainable and in no case shall exceed:

(a) 1/12.5 of the values listed in WAC 246-221-290 (Column 2, Table II, effluent concentrations, rules and regulations for radiation protection); or

(b) USEPA Drinking Water Regulations for radionuclides, as published in the Federal Register of July 9, 1976, or subsequent revisions thereto.

(2) Nothing in this chapter shall be interpreted to be applicable to those aspects of governmental regulation of radioactive waters which have been preempted from state regulation by the Atomic Energy Act of 1954, as amended, as interpreted by the United States Supreme Court in the cases of *Northern States Power Co. v. Minnesota 405 U.S. 1035 (1972) and Train v. Colorado Public Interest Research Group, 426 U.S. 1 (1976).*

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-050, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-050, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-060 General considerations. The following general guidelines shall apply to the water quality criteria and classifications set forth in WAC 173-201A-030 through 173-201A-140 hereof:

(1) At the boundary between waters of different classifications, the water quality criteria for the higher classification shall prevail.

(2) In brackish waters of estuaries, where the fresh and marine water quality criteria differ within the same classification, the criteria shall be applied on the basis of vertically averaged salinity. The freshwater criteria shall be applied at any point where ninety-five percent of the vertically averaged daily maximum salinity values are less than or equal to one part per thousand. Marine criteria shall apply at all other locations; except that the marine water quality criteria shall apply for dissolved oxygen when the salinity is one part per thousand or greater and for fecal coliform organisms when the salinity is ten parts per thousand or greater.

(3) In determining compliance with the fecal coliform criteria in WAC 173-201A-030, averaging of data collected beyond a thirty-day period, or beyond a specific discharge event under investigation, shall not be permitted when such averaging would skew the data set so as to mask noncompliance periods.

(4)(a) The water quality criteria herein established for total dissolved gas shall not apply when the stream flow exceeds the seven-day, ten-year frequency flood.

(b) The total dissolved gas criteria may be adjusted to aid fish passage over hydroelectric dams when consistent with a department approved gas abatement plan. This gas abatement plan must be accompanied by fisheries management and physical and biological monitoring plans. The elevated total dissolved gas levels are intended to allow increased fish passage without causing more harm to fish populations than caused by turbine fish passage. The specific allowances for total dissolved gas exceedances are listed as special conditions for sections of the Snake and Columbia rivers in WAC 173-201A-130 and as shown in the following exemption:

Special fish passage exemption for sections of the Snake and Columbia rivers: When spilling water at dams is necessary to aid fish passage, total dissolved gas must not exceed an average of one hundred fifteen percent as measured at Camas/Washougal below Bonneville dam or as measured in the forebays of the next downstream dams. Total dissolved gas must also not exceed an average of one hundred twenty percent as measured in the tailraces of each dam. These averages are based on the twelve highest hourly readings in any one day of total dissolved gas. In addition, there is a maximum total dissolved gas one hour average of one hundred twenty-five percent, relative to atmospheric pressure, during spillage for fish passage. These special conditions for total dissolved gas in the Snake and Columbia rivers are viewed as temporary and are to be reviewed by the year 2003.

(c) Nothing in these special conditions allows an impact to existing and characteristic uses.

(5) Waste discharge permits, whether issued pursuant to the National Pollutant Discharge Elimination System or otherwise, shall be conditioned so the discharges authorized will meet the water quality standards.

(a) However, persons discharging wastes in compliance with the terms and conditions of permits shall not be subject to civil and criminal penalties on the basis that the discharge violates water quality standards.

(b) Permits shall be subject to modification by the department whenever it appears to the department the discharge violates water quality standards. Modification of permits, as provided herein, shall be subject to review in the same manner as originally issued permits.

(6) No waste discharge permit shall be issued which results in a violation of established water quality criteria, except as provided for under WAC 173-201A-100 or 173-201A-110.

(7) Due consideration will be given to the precision and accuracy of the sampling and analytical methods used as well as existing conditions at the time, in the application of the criteria.

(8) The analytical testing methods for these criteria shall be in accordance with the *"Guidelines Establishing Test Procedures for the Analysis of Pollutants" (40 C.F.R. Part 136)* and other or superseding methods published and/or approved by the department following consultation with adjacent states and concurrence of the USEPA.

(9) Nothing in this chapter shall be interpreted to prohibit the establishment of effluent limitations for the control of the thermal component of any discharge in accordance with Section 316 of the federal Clean Water Act (33 U.S.C. 1251 et seq.).

(10) The primary means for protecting water quality in wetlands is through implementing the antidegradation procedures section (WAC 173-201A-070).

(a) In addition to designated uses, wetlands may have existing beneficial uses that are to be protected that include ground water exchange, shoreline stabilization, and storm water attenuation.

(b) Water quality in wetlands is maintained and protected by maintaining the hydrologic conditions, hydrophytic vegetation, and substrate characteristics necessary to support existing and designated uses.

(c) Wetlands shall be delineated using the Washington State Wetlands Identification and Delineation Manual, in accordance with WAC 173-22-035.

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-060, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-060, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-070 Antidegradation. The antidegradation policy of the state of Washington, as generally guided by chapter 90.48 RCW, Water Pollution Control Act, and chapter 90.54 RCW, Water Resources Act of 1971, is stated as follows:

(1) Existing beneficial uses shall be maintained and protected and no further degradation which would interfere with or become injurious to existing beneficial uses shall be allowed.

(2) Whenever the natural conditions of said waters are of a lower quality than the criteria assigned, the natural conditions shall constitute the water quality criteria.

(3) Water quality shall be maintained and protected in waters designated as outstanding resource waters in WAC 173-201A-080.

(4) Whenever waters are of a higher quality than the criteria assigned for said waters, the existing water quality shall be protected and pollution of said waters which will reduce the existing quality shall not be allowed, except in those instances where:

(a) It is clear, after satisfactory public participation and intergovernmental coordination, that overriding considerations of the public interest will be served;

(b) All wastes and other materials and substances discharged into said waters shall be provided with all known, available, and reasonable methods of prevention, control, and treatment by new and existing point sources before discharge. All activities which result in the pollution of waters from nonpoint sources shall be provided with all known, available, and reasonable best management practices; and

(c) When the lowering of water quality in high quality waters is authorized, the lower water quality shall still be of high enough quality to fully support all existing beneficial uses.

(5) Short-term modification of water quality may be permitted as conditioned by WAC 173-201A-110.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-070, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-080 Outstanding resource waters. Waters meeting one or more of the following criteria shall be considered for outstanding resource water designation. Designations shall be adopted in accordance with the provisions of chapter 34.05 RCW, Administrative Procedure Act.

(1) Waters in national parks, national monuments, national preserves, national wildlife refuges, national wilderness areas, federal wild and scenic rivers, national seashores, national marine sanctuaries, national recreation areas, national scenic areas, and national estuarine research reserves;

(2) Waters in state parks, state natural areas, state wildlife management areas, and state scenic rivers;

(3) Documented aquatic habitat of priority species as determined by the department of wildlife;

(4) Documented critical habitat for populations of threatened or endangered species of native anadromous fish;

(5) Waters of exceptional recreational or ecological significance.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-080, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-100 Mixing zones. (1) The allowable size and location of a mixing zone and the associated effluent limits shall be established in discharge permits, general permits, or orders, as appropriate.

(2) A discharger shall be required to fully apply AKART prior to being authorized a mixing zone.

(3) Mixing zone determinations shall consider critical discharge conditions.

(4) No mixing zone shall be granted unless the supporting information clearly indicates the mixing zone would not have a reasonable potential to cause a loss of sensitive or important habitat, substantially interfere with the existing or characteristic uses of the water body, result in damage to the ecosystem, or adversely affect public health as determined by the department.

(5) Water quality criteria shall not be violated outside of the boundary of a mixing zone as a result of the discharge for which the mixing zone was authorized.

(6) The size of a mixing zone and the concentrations of pollutants present shall be minimized.

(7) The maximum size of a mixing zone shall comply with the following:

(a) In rivers and streams, mixing zones, singularly or in combination with other mixing zones, shall comply with the most restrictive combination of the following (this size limitation may be applied to estuaries having flow characteristics that resemble rivers):

(i) Not extend in a downstream direction for a distance from the discharge port(s) greater than three hundred feet plus the depth of water over the discharge port(s), or extend upstream for a distance of over one hundred feet;

(ii) Not utilize greater than twenty-five percent of the flow; and

(iii) Not occupy greater than twenty-five percent of the width of the water body.

(b) In estuaries, mixing zones, singularly or in combination with other mixing zones, shall:

(i) Not extend in any horizontal direction from the discharge port(s) for a distance greater than two hundred feet plus the depth of water over the discharge port(s) as measured during mean lower low water; and

(ii) Not occupy greater than twenty-five percent of the width of the water body as measured during mean lower low water. For the purpose of this section, areas to the east of a line from Green Point (Fidalgo Island) to Lawrence Point (Orcas Island) are considered estuarine, as are all of the Strait of Georgia and the San Juan Islands north of Orcas Island. To the east of Deception Pass, and to the south and east of Admiralty Head, and south of Point Wilson on the Quimper Peninsula, is Puget Sound proper, which is considered to be entirely estuarine. All waters existing within bays from Point Wilson westward to Cape Flattery and south to the North Jetty of the Columbia River shall also be categorized as estuarine.

(c) In oceanic waters, mixing zones, singularly or in combination with other mixing zones, shall not extend in any horizontal direction from the discharge port(s) for a distance greater than three hundred feet plus the depth of water over the discharge port(s) as measured during mean lower low water. For the purpose of this section, all marine waters not classified as estuarine in (b)(ii) of this subsection shall be categorized as oceanic.

(d) In lakes, and in reservoirs having a mean detention time greater than fifteen days, mixing zones shall not be allowed unless it can be demonstrated to the satisfaction of the department that:

(i) Other siting, technological, and managerial options that would avoid the need for a lake mixing zone are not reasonably achievable;

(ii) Overriding considerations of the public interest will be served; and

(iii) All technological and managerial methods available for pollution reduction and removal that are economically achievable would be implemented prior to discharge. Such methods may include, but not be limited to, advanced waste treatment techniques.

(e) In lakes, and in reservoirs having a mean detention time greater than fifteen days, mixing zones, singularly or in combination with other mixing zones, shall comply with the most restrictive combination of the following:

(i) Not exceed ten percent of the water body volume;

(ii) Not exceed ten percent of the water body surface area (maximum radial extent of the plume regardless of whether it reaches the surface); and

(iii) Not extend beyond fifteen percent of the width of the water body.

(8) Acute criteria are based on numeric criteria and toxicity tests approved by the department, as generally guided under WAC 173-201A-040 (1) through (5), and shall be met as near to the point of discharge as practicably attainable. Compliance shall be determined by monitoring data or calibrated models approved by the department utilizing representative dilution ratios. A zone where acute criteria may be exceeded is allowed only if it can be demonstrated to the department's satisfaction the concentration of, and duration and frequency of exposure to the discharge, will not create a barrier to the migration or translocation of indigenous organisms to a degree that has the potential to cause damage to the ecosystem. A zone of acute criteria exceedance shall singularly or in combination with other such zones comply with the following maximum size requirements:

(a) In rivers and streams, a zone where acute criteria may be exceeded shall comply with the most restrictive combination of the following (this size limitation may also be applied to estuaries having flow characteristics resembling rivers):

(i) Not extend beyond ten percent of the distance towards the upstream and downstream boundaries of an authorized mixing zone, as measured independently from the discharge port(s);

(ii) Not utilize greater than two and one-half percent of the flow; and

(iii) Not occupy greater than twenty-five percent of the width of the water body.

(b) In oceanic and estuarine waters a zone where acute criteria may be exceeded shall not extend beyond ten percent of the distance established in subsection (7)(b) of this section as measured independently from the discharge port(s).

(9) Overlap of mixing zones.

(a) Where allowing the overlap of mixing zones would result in a combined area of water quality criteria nonattainment which does not exceed the numeric size limits established under subsection (7) of this section, the overlap may be permitted if:

(i) The separate and combined effects of the discharges can be reasonably determined; and

(ii) The combined effects would not create a barrier to the migration or translocation of indigenous organisms to a degree that has the potential to cause damage to the ecosystem.

(b) Where allowing the overlap of mixing zones would result in exceedance of the numeric size limits established under subsection (7) of this section, the overlap may be allowed only where:

(i) The overlap qualifies for exemption under subsections (12) and (13) of this section; and

(ii) The overlap meets the requirements established in (a) of this subsection.

(10) Storm water:

(a) Storm water discharge from any "point source" containing "process wastewater" as defined in 40 C.F.R. Part 122.2 shall fully conform to the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section.

(b) Storm water discharges not described by (a) of this subsection may be granted an exemption to the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section, provided the discharger clearly demonstrates to the department's satisfaction that:

(i) All appropriate best management practices established for storm water pollutant control have been applied to the discharge.

(ii) The proposed mixing zone shall not have a reasonable potential to result in a loss of sensitive or important habitat, substantially interfere with the existing or characteristic uses of the water body, result in damage to the ecosystem, or adversely affect public health as determined by the department; and

(iii) The proposed mixing zone shall not create a barrier to the migration or translocation of indigenous organisms to a degree that has the potential to cause damage to the ecosystem.

(c) All mixing zones for storm water discharges shall be based on a volume of runoff corresponding to a design storm approved by the department. Exceedances from the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section due to precipitation events greater than the approved design storm may be allowed by the department, if it would not result in adverse impact to existing or characteristic uses of the water body or result in damage to the ecosystem, or adversely affect public health as determined by the department.

(11) Combined sewer overflows complying with the requirements of chapter 173-245 WAC, may be allowed an average once per year exemption to the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section, provided the discharge complies with subsection (4) of this section.

(12) Exceedances from the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section may be considered by the department in the following cases:

(a) For discharges existing prior to November 24, 1992, (or for proposed discharges with engineering plans formally approved by the department prior to November 24, 1992);

(b) Where altering the size configuration is expected to result in greater protection to existing and characteristic uses;

(c) Where the volume of water in the effluent is providing a greater benefit to the existing or characteristic uses of the water body due to flow augmentation than the benefit of removing the discharge, if such removal is the remaining feasible option; or

(d) Where the exceedance is clearly necessary to accommodate important economic or social development in the area in which the waters are located.

(13) Before an exceedance from the numeric size criteria in subsections (7) and (8) of this section and the overlap criteria in subsection (9) of this section may be allowed under subsection (12) of this section, it must clearly be demonstrated to the department's satisfaction that:

(a) AKART appropriate to the discharge is being fully applied;

(b) All siting, technological, and managerial options which would result in full or significantly closer compliance that are economically achievable are being utilized; and

(c) The proposed mixing zone complies with subsection (4) of this section.

(14) Any exemptions granted to the size criteria under subsection (12) of this section shall be reexamined during each permit renewal period for changes in compliance capability. Any significant increase in capability to comply shall be reflected in the renewed discharge permit.

(15) The department may establish permit limits and measures of compliance for human health based criteria (based on lifetime exposure levels), independent of this section.

(16) Sediment impact zones authorized by the department pursuant to chapter 173-204 WAC, Sediment management standards, do not satisfy the requirements of this section.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-100, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-110 Short-term modifications. The criteria and special conditions established in WAC 173-201A-030 through 173-201A-140 may be modified for a specific water body on a short-term basis when necessary to accommodate essential activities, respond to emergencies, or to otherwise protect the public interest, even though such activities may result in a temporary reduction of water quality

conditions below those criteria and classifications established by this regulation. Such activities must be conditioned, timed, and restricted (i.e., hours or days rather than weeks or months) in a manner that will minimize water quality degradation to existing and characteristic uses. In no case will any degradation of water quality be allowed if this degradation significantly interferes with or becomes injurious to characteristic water uses or causes long-term harm to the environment.

(1) A short-term modification may be issued in writing by the director or his/her designee to an individual or entity proposing the aquatic application of pesticides, including but not limited to those used for control of federally or state listed noxious and invasive species, and excess populations of native aquatic plants, mosquitoes, burrowing shrimp, and fish, subject to the following terms and conditions:

(a) A short-term modification will in no way lessen or remove the project proponent's obligations and liabilities under other federal, state and local rules and regulations.

(b) A request for a short-term modification shall be made to the department on forms supplied by the department. Such request shall be made at least thirty days prior to initiation of the proposed activity, and after the project proponent has complied with the requirements of the State Environmental Policy Act (SEPA);

(c) A short-term modification shall be valid for the duration of the activity requiring modification of the criteria and special conditions in WAC 173-201A-030 through 173-201A-140, or for one year, whichever is less. Ecology may authorize a longer duration where the activity is part of an ongoing or long-term operation and maintenance plan, integrated pest or noxious weed management plan, waterbody or watershed management plan, or restoration plan. Such a plan must be developed through a public involvement process consistent with the Administrative Procedure Act (chapter 34.05 RCW) and be in compliance with SEPA, chapter 43.21C RCW, in which case the standards may be modified for the duration of the plan, or for five years, whichever is less;

(d) Appropriate public notice as determined and prescribed by the director or his/her designee shall be given, identifying the pesticide, applicator, location where the pesticide will be applied, proposed timing and method of application, and any water use restrictions specified in USEPA label provisions;

(e) The pesticide application shall be made at times so as to:

(i) Minimize public water use restrictions during weekends; and

(ii) Avoid public water use restrictions during the opening week of fishing season, Memorial Day weekend, Independence Day weekend, and Labor Day weekend;

(f) Any additional conditions as may be prescribed by the director or his/her designee.

(2) A short-term modification may be issued for the control or eradication of noxious weeds identified as such in accordance with the state noxious weed control law, chapter 17.10 RCW, and Control of spartina and purple loosestrife, chapter 17.26 RCW. Short-term modifications for noxious weed control shall be included in a water quality permit issued in accordance with RCW 90.48.445, and the following requirements:

(a) Water quality permits for noxious weed control may be issued to the Washington state department of agriculture (WSDA) for the purposes of coordinating and conducting noxious weed control activities consistent with their responsibilities under chapter 17.10 and 17.26 RCW. Coordination may include noxious weed control activities identified in a WSDA integrated noxious weed management plan and conducted by individual landowners or land managers.

(b) Water quality permits may also be issued to individual landowners or land managers for noxious weed control activities where such activities are not covered by a WSDA integrated noxious weed management plan.

(3) The turbidity criteria established under WAC 173-201A-030 shall be modified to allow a temporary mixing zone during and immediately after necessary in-water or shoreline construction activities that result in the disturbance of in-place sediments. A temporary turbidity mixing zone is subject to the constraints of WAC 173-201A-100 (4) and (6) and is authorized only after the activity has received all other necessary local and state permits and approvals, and after the implementation of appropriate best management practices to avoid or minimize disturbance of in-place sediments and exceedances of the turbidity criteria. A temporary turbidity mixing zone shall be as follows:

(a) For waters up to 10 cfs flow at the time of construction, the point of compliance shall be one hundred feet downstream from activity causing the turbidity exceedance.

(b) For waters above 10 cfs up to 100 cfs flow at the time of construction, the point of compliance shall be two hundred feet downstream of activity causing the turbidity exceedance.

(c) For waters above 100 cfs flow at the time of construction, the point of compliance shall be three hundred feet downstream of activity causing the turbidity exceedance.

(d) For projects working within or along lakes, ponds, wetlands, estuaries, marine waters or other nonflowing waters, the point of compliance shall be at a radius of one hundred fifty feet from activity causing the turbidity exceedance.

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-110, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-110, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-120 General classifications. General classifications applying to various surface water bodies not specifically classified under WAC 173-201A-130 or 173-201A-140 are as follows:

(1) All surface waters lying within national parks, national forests, and/or wilderness areas are classified Class AA or Lake Class.

(2) All lakes and their feeder streams within the state are classified Lake Class and Class AA respectively, except for those feeder streams specifically classified otherwise.

(3) All reservoirs with a mean detention time of greater than 15 days are classified Lake Class.

(4) All reservoirs with a mean detention time of 15 days or less are classified the same as the river section in which they are located.

(5) All reservoirs established on preexisting lakes are classified as Lake Class.

(6) All unclassified surface waters that are tributaries to Class AA waters are classified Class AA. All other unclassified surface waters within the state are hereby classified Class A.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-120, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-130 Specific classifications—Freshwater. Specific fresh surface waters of the state of Washington are classified as follows:

(1)	American River.	Class AA
(2)	Big Quilcene River and tributaries.	Class AA
(3)	Bumping River.	Class AA
(4)	Burnt Bridge Creek.	Class A
(5)	Cedar River from Lake Washington to the Maplewood Bridge (river mile 4.1).	Class A
(6)	Cedar River and tributaries from the Maplewood Bridge (river mile 4.1) to Landsburg Dam (river mile 21.6).	Class AA
(7)	Cedar River and tributaries from Landsburg Dam (river mile 21.6) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(8)	Chehalis River from upper boundary of Grays Harbor at Cosmopolis (river mile 3.1, longitude 123°45'45" W) to Scammon Creek (river mile 65.8).	Class A
(9)	Chehalis River from Scammon Creek (river mile 65.8) to Newaukum River (river mile 75.2). Special condition - dissolved oxygen shall exceed 5.0 mg/L from June 1 to September 15. For the remainder of the year, the dissolved oxygen shall meet Class A criteria.	Class A
(10)	Chehalis River from Newaukum River (river mile 75.2) to Rock Creek (river mile 106.7).	Class A
(11)	Chehalis River, from Rock Creek (river mile 106.7) to headwaters.	Class AA
(12)	Chehalis River, south fork.	Class A
(13)	Chewuch River.	Class AA
(14)	Chiwawa River.	Class AA
(15)	Cispus River.	Class AA
(16)	Clearwater River.	Class A
(17)	Cle Elum River.	Class AA
(18)	Cloquallum Creek.	Class A
(19)	Clover Creek from outlet of Lake Spanaway to inlet of Lake Steilacoom.	Class A
(20)	Columbia River from mouth to the Washington-Oregon border (river mile 309.3). Special conditions - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed 0.3°C due to any single source or 1.1°C due to all such activities combined. Dissolved oxygen shall exceed 90 percent of saturation. Special condition - special fish passage exemption as described in WAC 173-201A-060 (4)(b).	Class A
(21)	Columbia River from Washington-Oregon border (river mile 309.3) to Grand Coulee Dam (river mile 596.6). Special condition from Washington-Oregon border (river mile 309.3) to Priest Rapids Dam (river mile 397.1). Temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9). Special condition - special fish passage exemption as described in WAC 173-201A-060 (4)(b).	Class A
(22)	Columbia River from Grand Coulee Dam (river mile 596.6) to Canadian border (river mile 745.0).	Class AA
(23)	Colville River.	Class A
(24)	Coweeman River from mouth to Mulholland Creek (river mile 18.4).	Class A
(25)	Coweeman River from Mulholland Creek (river mile 18.4) to headwaters.	Class AA
(26)	Cowlitz River from mouth to base of Riffe Lake Dam (river mile 52.0).	Class A
(27)	Cowlitz River from base of Riffe Lake Dam (river mile 52.0) to headwaters.	Class AA
(28)	Crab Creek and tributaries.	Class B
(29)	Decker Creek.	Class AA
(30)	Deschutes River from mouth to boundary of Snoqualmie National Forest (river mile 48.2).	Class A
(31)	Deschutes River from boundary of Snoqualmie National Forest (river mile 48.2) to headwaters.	Class AA
(32)	Dickey River.	Class A
(33)	Dosewallips River and tributaries.	Class AA
(34)	Duckabush River and tributaries.	Class AA
(35)	Dungeness River from mouth to Canyon Creek (river mile 10.8).	Class A
(36)	Dungeness River and tributaries from Canyon Creek (river mile 10.8) to headwaters.	Class AA
(37)	Duwamish River from mouth south of a line bearing 254° true from the NW corner of berth 3, terminal No. 37 to the Black River (river mile 11.0) (Duwamish River continues as the Green River above the Black River).	Class B
(38)	Elochoman River.	Class A
(39)	Elwha River and tributaries.	Class AA
(40)	Entiat River from Wenatchee National Forest boundary (river mile 20.5) to headwaters.	Class AA
(41)	Grande Ronde River from mouth to Oregon border (river mile 37). Special condition - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(42)	Grays River from Grays River Falls (river mile 15.8) to headwaters.	Class AA
(43)	Green River (Cowlitz County).	Class AA
(44)	Green River (King County) from Black River (river mile 11.0 and point where Duwamish River continues as the Green River) to west boundary of Sec. 27-T21N-R6E (west boundary of Flaming Geyser State Park at river mile 42.3).	Class A
(45)	Green River (King County) from west boundary of Sec. 27-T21N-R6E (west boundary of Flaming Geyser State Park, river mile 42.3) to west boundary of Sec. 13-T21N-R7E (river mile 59.1).	Class AA

(46)	Green River and tributaries (King County) from west boundary of Sec. 13-T21N-R7E (river mile 59.1) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(47)	Hamma Hamma River and tributaries.	Class AA
(48)	Hanaford Creek from mouth to east boundary of Sec. 25-T15N-R2W (river mile 4.1). Special condition - dissolved oxygen shall exceed 6.5 mg/L.	Class A
(49)	Hanaford Creek from east boundary of Sec. 25-T15N-R2W (river mile 4.1) to headwaters.	Class A
(50)	Hoh River and tributaries.	Class AA
(51)	Hoquiam River (continues as west fork above east fork) from mouth to river mile 9.3 (Dekay Road Bridge) (upper limit of tidal influence).	Class B
(52)	Humptulips River and tributaries from mouth to Olympic National Forest boundary on east fork (river mile 12.8) and west fork (river mile 40.4) (main stem continues as west fork).	Class A
(53)	Humptulips River, east fork from Olympic National Forest boundary (river mile 12.8) to headwaters.	Class AA
(54)	Humptulips River, west fork from Olympic National Forest boundary (river mile 40.4) to headwaters.	Class AA
(55)	Issaquah Creek.	Class A
(56)	Kalama River from lower Kalama River Falls (river mile 10.4) to headwaters.	Class AA
(57)	Klickitat River from Little Klickitat River (river mile 19.8) to boundary of Yakima Indian Reservation.	Class AA
(58)	Lake Washington Ship Canal from Government Locks (river mile 1.0) to Lake Washington (river mile 8.6). Special condition - salinity shall not exceed one part per thousand (1.0 ppt) at any point or depth along a line that transects the ship canal at the University Bridge (river mile 6.1).	Lake Class
(59)	Lewis River, east fork, from Multon Falls (river mile 24.6) to headwaters.	Class AA
(60)	Little Wenatchee River.	Class AA
(61)	Methow River from mouth to Chewuch River (river mile 50.1).	Class A
(62)	Methow River from Chewuch River (river mile 50.1) to headwaters.	Class AA
(63)	Mill Creek from mouth to 13th Street Bridge in Walla Walla (river mile 6.4). Special condition - dissolved oxygen concentration shall exceed 5.0 mg/L.	Class B
(64)	Mill Creek from 13th Street Bridge in Walla Walla (river mile 6.4) to Walla Walla Waterworks Dam (river mile 11.5).	Class A
(65)	Mill Creek and tributaries from city of Walla Walla Waterworks Dam (river mile 21.6) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(66)	Naches River from Snoqualmie National Forest boundary (river mile 35.7) to headwaters.	Class AA
(67)	Naselle River from Naselle "Falls" (cascade at river mile 18.6) to headwaters.	Class AA
(68)	Newaukum River.	Class A
(69)	Nisqually River from mouth to Alder Dam (river mile 44.2).	Class A
(70)	Nisqually River from Alder Dam (river mile 44.2) to headwaters.	Class AA
(71)	Nooksack River from mouth to Maple Creek (river mile 49.7).	Class A
(72)	Nooksack River from Maple Creek (river mile 49.7) to headwaters.	Class AA
(73)	Nooksack River, south fork, from mouth to Skookum Creek (river mile 14.3).	Class A
(74)	Nooksack River, south fork, from Skookum Creek (river mile 14.3) to headwaters.	Class AA
(75)	Nooksack River, middle fork.	Class AA
(76)	Okanogan River.	Class A
(77)	Palouse River from mouth to south fork (Colfax, river mile 89.6).	Class B
(78)	Palouse River from south fork (Colfax, river mile 89.6) to Idaho border (river mile 123.4). Special condition - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(79)	Pend Oreille River from Canadian border (river mile 16.0) to Idaho border (river mile 87.7). Special condition - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(80)	Pilchuck River from city of Snohomish Waterworks Dam (river mile 26.8) to headwaters.	Class AA
(81)	Puyallup River from mouth to river mile 1.0.	Class B
(82)	Puyallup River from river mile 1.0 to Kings Creek (river mile 31.6).	Class A
(83)	Puyallup River from Kings Creek (river mile 31.6) to headwaters.	Class AA
(84)	Queets River and tributaries.	Class AA
(85)	Quillayute River.	Class AA
(86)	Quinault River and tributaries.	Class AA
(87)	Salmon Creek (Clark County).	Class A
(88)	Satsop River from mouth to west fork (river mile 6.4).	Class A
(89)	Satsop River, east fork.	Class AA
(90)	Satsop River, middle fork.	Class AA
(91)	Satsop River, west fork.	Class AA
(92)	Skagit River from mouth to Skiyou Slough-lower end (river mile 25.6).	Class A
(93)	Skagit River and tributaries (includes Baker, Suak, Suiattle, and Cascade rivers) from Skiyou Slough-lower end, (river mile 25.6) to Canadian border (river mile 127.0). Special condition - Skagit River (Gorge by-pass reach) from Gorge Dam (river mile 96.6) to Gorge Powerhouse (river mile 94.2). Temperature shall not exceed 21°C due to human activities. When natural conditions exceed 21°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C, nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class AA
(94)	Skokomish River and tributaries.	Class AA
(95)	Skookumchuck River from Bloody Run Creek (river mile 21.4) to headwaters.	Class AA
(96)	Skykomish River from mouth to May Creek (above Gold Bar at river mile 41.2).	Class A
(97)	Skykomish River from May Creek (above Gold Bar at river mile 41.2) to headwaters.	Class AA
(98)	Snake River from mouth to Washington-Idaho-Oregon border (river mile 176.1). Special condition:	

(a)	Below Clearwater River (river mile 139.3). Temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9). Special condition - special fish passage exemption as described in WAC 173-201A-060 (4)(b).	
(b)	Above Clearwater River (river mile 139.3). Temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed 0.3°C due to any single source or 1.1°C due to all such activities combined.	Class A
(99)	Snohomish River from mouth and east of longitude 122°13'40"W upstream to latitude 47°56'30"N (southern tip of Ebey Island at river mile 8.1). Special condition - fecal coliform organism levels shall both not exceed a geometric mean value of 200 colonies/100 mL and not have more than 10 percent of the samples obtained for calculating the mean value exceeding 400 colonies/100 mL.	Class A
(100)	Snohomish River upstream from latitude 47°56'30"N (southern tip of Ebey Island river mile 8.1) to confluence with Skykomish and Snoqualmie River (river mile 20.5).	Class A
(101)	Snoqualmie River and tributaries from mouth to west boundary of Twin Falls State Park on south fork (river mile 9.1).	Class A
(102)	Snoqualmie River, middle fork.	Class AA
(103)	Snoqualmie River, north fork.	Class AA
(104)	Snoqualmie River, south fork, from west boundary of Twin Falls State Park (river mile 9.1) to headwaters.	Class AA
(105)	Soleduck River and tributaries.	Class AA
(106)	Spokane River from mouth to Long Lake Dam (river mile 33.9). Special condition - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(107)	Spokane River from Long Lake Dam (river mile 33.9) to Nine Mile Bridge (river mile 58.0). Special conditions:	
(a)	The average euphotic zone concentration of total phosphorus (as P) shall not exceed 25µg/L during the period of June 1 to October 31.	
(b)	Temperature shall not exceed 20.0°C, due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time exceed t=34/(T+9).	Lake Class
(108)	Spokane River from Nine Mile Bridge (river mile 58.0) to the Idaho border (river mile 96.5). Temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time exceed t=34/(T+9).	Class A
(109)	Stehekin River.	Class AA
(110)	Stillaguamish River from mouth to north and south forks (river mile 17.8).	Class A
(111)	Stillaguamish River, north fork, from mouth to Squire Creek (river mile 31.2).	Class A
(112)	Stillaguamish River, north fork, from Squire Creek (river mile 31.2) to headwaters.	Class AA
(113)	Stillaguamish River, south fork, from mouth to Canyon Creek (river mile 33.7).	Class A
(114)	Stillaguamish River, south fork, from Canyon Creek (river mile 33.7) to headwaters.	Class AA
(115)	Sulphur Creek.	Class B
(116)	Sultan River from mouth to Chaplain Creek (river mile 5.9).	Class A
(117)	Sultan River and tributaries from Chaplain Creek (river mile 5.9) to headwaters. Special condition - no waste discharge will be permitted above city of Everett Diversion Dam (river mile 9.4).	Class AA
(118)	Sumas River from Canadian border (river mile 12) to headwaters (river mile 23).	Class A
(119)	Tieton River.	Class AA
(120)	Tolt River, south fork and tributaries from mouth to west boundary of Sec. 31-T26N-R9E (river mile 6.9).	Class AA
(121)	Tolt River, south fork from west boundary of Sec. 31-T26N-R9E (river mile 6.9) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(122)	Touchet River, north fork from Dayton water intake structure (river mile 3.0) to headwaters.	Class AA
(123)	Toutle River, north fork, from Green River to headwaters.	Class AA
(124)	Toutle River, south fork.	Class AA
(125)	Tucannon River from Umatilla National Forest boundary (river mile 38.1) to headwaters.	Class AA
(126)	Twisp River.	Class AA
(127)	Union River and tributaries from Bremerton Waterworks Dam (river mile 6.9) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(128)	Walla Walla River from mouth to Lowden (Dry Creek at river mile 27.2).	Class B
(129)	Walla Walla River from Lowden (Dry Creek at river mile 27.2) to Oregon border (river mile 40). Special condition - temperature shall not exceed 20.0°C due to human activities. When natural conditions exceed 20.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(130)	Wenatchee River from Wenatchee National Forest boundary (river mile 27.1) to headwaters.	Class AA
(131)	White River (Pierce-King counties) from Mud Mountain Dam (river mile 27.1) to headwaters.	Class AA
(132)	White River (Chelan County).	Class AA
(133)	Wildcat Creek.	Class A
(134)	Willapa River upstream of a line bearing 70° true through Mailboat Slough light (river mile 1.8).	Class A
(135)	Wishkah River from mouth to river mile 6 (SW 1/4 SW 1/4 NE 1/4 Sec. 21-T18N-R9W).	Class B
(136)	Wishkah River from river mile 6 (SW 1/4 SW 1/4 NE 1/4 Sec. 21-T18N-R9W) to west fork (river mile 17.7).	Class A
(137)	Wishkah River from west fork of Wishkah River (river mile 17.7) to south boundary of Sec. 33-T21N-R8W (river mile 32.0).	Class AA

(138)	Wishkah River and tributaries from south boundary of Sec. 33-T21N-R8W (river mile 32.0) to headwaters. Special condition - no waste discharge will be permitted.	Class AA
(139)	Wynoochee River from mouth to Olympic National Forest boundary (river mile 45.9).	Class A
(140)	Wynoochee River from Olympic National Forest boundary (river mile 45.9) to headwaters.	Class AA
(141)	Yakima River from mouth to Cle Elum River (river mile 185.6). Special condition - temperature shall not exceed 21.0°C due to human activities. When natural conditions exceed 21.0°C, no temperature increase will be allowed which will raise the receiving water temperature by greater than 0.3°C; nor shall such temperature increases, at any time, exceed t=34/(T+9).	Class A
(142)	Yakima River from Cle Elum River (river mile 185.6) to headwaters.	Class AA

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-130, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-130, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-140 Specific classifications—Marine water. Specific marine surface waters of the state of Washington are classified as follows:

(1)	Budd Inlet south of latitude 47°04'N (south of Priest Point Park).	Class B
(2)	Coastal waters: Pacific Ocean from Ilwaco to Cape Flattery.	Class AA
(3)	Commencement Bay south and east of a line bearing 258° true from "Brown's Point" and north and west of line bearing 225° true through the Hylebos waterway light.	Class A
(4)	Commencement Bay, inner, south and east of a line bearing 225° true through Hylebos waterway light except the city waterway south and east of south 11th Street.	Class B
(5)	Commencement Bay, city waterway south and east of south 11th Street.	Class C
(6)	Drayton Harbor, south of entrance.	Class A
(7)	Dyes and Sinclair Inlets west of longitude 122°37'W.	Class A
(8)	Elliott Bay east of a line between Pier 91 and Duwamish head.	Class A
(9)	Everett Harbor, inner, northeast of a line bearing 121° true from approximately 47°59'5"N and 122°13'44"W (southwest corner of the pier).	Class B
(10)	Grays Harbor west of longitude 123°59'W.	Class A
(11)	Grays Harbor east of longitude 123°59'W to longitude 123°45'45"W (Cosmopolis Chehalis River, river mile 3.1). Special condition -dissolved oxygen shall exceed 5.0 mg/L.	Class B
(12)	Guemes Channel, Padilla, Samish and Bellingham Bays east of longitude 122°39'W and north of latitude 48°27'20"N.	Class A
(13)	Hood Canal.	Class AA
(14)	Mukilteo and all North Puget Sound west of longitude 122°39' W (Whidbey, Fidalgo, Guemes and Lummi islands and State Highway 20 Bridge at Deception Pass), except as otherwise noted.	Class AA
(15)	Oakland Bay west of longitude 123°05'W (inner Shelton harbor).	Class B
(16)	Port Angeles south and west of a line bearing 152° true from buoy "2" at the tip of Ediz Hook.	Class A
(17)	Port Gamble south of latitude 47°51'20"N.	Class A
(18)	Port Townsend west of a line between Point Hudson and Kala Point.	Class A
(19)	Possession Sound, south of latitude 47°57'N.	Class AA
(20)	Possession Sound, Port Susan, Saratoga Passage, and Skagit Bay east of Whidbey Island and State Highway 20 Bridge at Deception Pass between latitude 47°57'N (Mukilteo) and latitude 48°27'20"N (Similk Bay), except as otherwise noted.	Class A
(21)	Puget Sound through Admiralty Inlet and South Puget Sound, south and west to longitude 122°52'30"W (Brisco Point) and longitude 122°51'W (northern tip of Hartstene Island).	Class AA
(22)	Sequim Bay southward of entrance.	Class AA
(23)	South Puget Sound west of longitude 122°52'30"W (Brisco Point) and longitude 122°51'W (northern tip of Hartstene Island, except as otherwise noted).	Class A
(24)	Strait of Juan de Fuca.	Class AA
(25)	Totten Inlet and Little Skookum Inlet, west of longitude 122°56'32" (west side of Steamboat Island).	Class AA
(26)	Willapa Bay seaward of a line bearing 70° true through Mailboat Slough light (Willapa River, river mile 1.8).	Class A

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-140, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-140, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-150 Achievement considerations. To fully achieve and maintain the foregoing water quality in the state of Washington, it is the intent of the department to apply the various implementation and enforcement authorities at its disposal, including participation in the programs of the federal Clean Water Act (33 U.S.C. 1251 et seq.) as appropriate. It is also the intent that cognizance will be taken of the need for participation in cooperative programs with other state agencies and private groups with respect to the management of related problems. The department's planned program for water pollution control will be defined and revised annually in accordance with section 106 of said federal act. Further, it shall be required that all activities which discharge wastes into waters within the state, or otherwise adversely affect the quality of said waters, be in compliance with the waste treatment and discharge provisions of state or federal law.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-150, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-160 Implementation. (1) **Discharges from municipal, commercial, and industrial operations.** The primary means to be used for controlling municipal, commercial, and industrial waste discharges shall be through the issuance of waste disposal permits, as provided for in RCW 90.48.160, 90.48.162, and 90.48.260.

(2) **Miscellaneous waste discharge or water quality effect sources.** The director shall, through the issuance of regulatory permits, directives, and orders, as are appropriate,

control miscellaneous waste discharges and water quality effect sources not covered by subsection (1) of this section.

(3) **Nonpoint source and storm water pollution.**

(a) Activities which generate nonpoint source pollution shall be conducted so as to comply with the water quality standards. The primary means to be used for requiring compliance with the standards shall be through best management practices required in waste discharge permits, rules, orders, and directives issued by the department for activities which generate nonpoint source pollution.

(b) Best management practices shall be applied so that when all appropriate combinations of individual best management practices are utilized, violation of water quality criteria shall be prevented. If a discharger is applying all best management practices appropriate or required by the department and a violation of water quality criteria occurs, the discharger shall modify existing practices or apply further water pollution control measures, selected or approved by the department, to achieve compliance with water quality criteria. Best management practices established in permits, orders, rules, or directives of the department shall be reviewed and modified, as appropriate, so as to achieve compliance with water quality criteria.

(c) Activities which contribute to nonpoint source pollution shall be conducted utilizing best management practices to prevent violation of water quality criteria. When applicable best management practices are not being implemented, the department may conclude individual activities are causing pollution in violation of RCW 90.48.080. In these situations, the department may pursue orders, directives, permits, or civil or criminal sanctions to gain compliance with the standards.

(d) Activities which cause pollution of storm water shall be conducted so as to comply with the water quality standards. The primary means to be used for requiring compliance with the standards shall be through best management practices required in waste discharge permits, rules, orders, and directives issued by the department for activities which generate storm water pollution. The consideration and control procedures in (b) and (c) of this subsection apply to the control of pollutants in storm water.

(4) **Allowance for compliance schedules.**

(a) Permits, orders, and directives of the department for existing discharges may include a schedule for achieving compliance with water quality criteria contained in this chapter. Such schedules of compliance shall be developed to ensure final compliance with all water quality-based effluent limits in the shortest practicable time. Decisions regarding whether to issue schedules of compliance will be made on a case-by-case basis by the department. Schedules of compliance may not be issued for new discharges. Schedules of compliance may be issued to allow for: (i) construction of necessary treatment capability; (ii) implementation of necessary best management practices; (iii) implementation of additional storm water best management practices for discharges determined not to meet water quality criteria following implementation of an initial set of best management practices; (iv) completion of necessary water quality studies; or (v) resolution of a pending water quality standards' issue through rule-making action.

(b) For the period of time during which compliance with water quality criteria is deferred, interim effluent limitations shall be formally established, based on the best professional judgment of the department. Interim effluent limitations may be numeric or nonnumeric (e.g., construction of necessary facilities by a specified date as contained in an ecology order or permit).

(c) Prior to establishing a schedule of compliance, the department shall require the discharger to evaluate the possibility of achieving water quality criteria via nonconstruction changes (e.g., facility operation, pollution prevention). Schedules of compliance may in no case exceed ten years, and shall generally not exceed the term of any permit.

[Statutory Authority: Chapter 90.48 RCW and 40 CFR 131. 97-23-064 (Order 94-19), § 173-201A-160, filed 11/18/97, effective 12/19/97. Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-160, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-170 Surveillance. A continuing surveillance program, to ascertain whether the regulations, waste disposal permits, orders, and directives promulgated and/or issued by the department are being complied with, will be conducted by the department staff as follows:

(1) Inspecting treatment and control facilities.

(2) Monitoring and reporting waste discharge characteristics.

(3) Monitoring receiving water quality.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-170, filed 11/25/92, effective 12/26/92.]

WAC 173-201A-180 Enforcement. To insure that the provisions of chapter 90.48 RCW, the standards for water quality promulgated herein, the terms of waste disposal permits, and other orders and directives of the department are fully complied with, the following enforcement tools will be relied upon by the department, in cooperation with the attorney general as it deems appropriate:

(1) Issuance of notices of violation and regulatory orders as provided for in RCW 90.48.120.

(2) Initiation of actions requesting injunctive or other appropriate relief in the various courts of the state as provided for in RCW 90.48.037.

(3) Levying of civil penalties as provided for in RCW 90.48.144.

(4) Initiation of a criminal proceeding by the appropriate county prosecutor as provided for in RCW 90.48.140.

(5) Issuance of regulatory orders or directives as provided for in RCW 90.48.240.

[Statutory Authority: Chapter 90.48 RCW. 92-24-037 (Order 92-29), § 173-201A-180, filed 11/25/92, effective 12/26/92.]

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Potential Health and Environmental Effects Linked to Artificial Turf Systems

Final Report

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Assignment report

Potential health and environmental effects linked to artificial turf systems - final report

Brief summary

The Norwegian Building Research Institute (NBI) has carried out a study of potential health and environmental effects linked to artificial turf systems on behalf of the Norwegian Football Association (NFF). The study covers a total of four types of rubber granulate and two types of artificial turf fibre, which are in use in the Nordic region. This report presents the results from three types of rubber granulate made from recycled rubber, one EPDM rubber granulate and two artificial turf fibres.

The rubber granulates and artificial turf fibres were analysed with regard to the total content of arsenic, cadmium, copper, chromium, mercury, nickel, zinc, PCB, PAH, phthalates and phenols. Leachate tests and degassing tests were also carried out. The results are compared with Norwegian and foreign limits for soil and water.

Address of the building			Year of construction
	Method Laboratory study	Keywords Artificial turf, rubber granulate, environmental toxins, risk assessment	File name Report NFF

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1 Introduction

In the winter of 2003, the Norwegian Building Research Institute (NBI) was commissioned to study the potential environmental and health effects linked to the use of artificial turf systems. The client was the Norwegian Football Association, c/o Ole Myhrvold.

There are currently no accepted requirements or test methods for the use of rubber granulate in artificial turf systems. The mechanisms for changes in the rubber granulate's properties and constancy over time when subjected to various environmental stresses have not been studied in detail. Similarly, the potential health-related and environmental influences of rubber granulates on the surroundings have not be studied in any detail.

The aim of this project was to give a satisfactory fingerprint of potentially hazardous substances for soil, air, water and humans, linked to the use of rubber granulate in artificial turf systems. The generation of high quality data was an aim, enabling the data to be included in a more comprehensive risk assessment and used as a basis in any development of a Norwegian, Nordic or European product approval scheme for rubber granulate for use in artificial turf systems.

The study covers laboratory testing and a simplified risk assessment for four types of rubber granulate and two types of artificial turf fibre. Three of the rubber granulates are based on recycled rubber, while the fourth is an EPDM rubber.

2 Test object

Rubber granulate and artificial turf fibre from a number of manufacturers were obtained from suppliers of artificial turf systems; see Table 1.

Table 1. Description of rubber granulates and artificial turf fibre.

Sample no.	Manufacturer	Sample type	Material	Description
1	Genan Business & Development	Rubber granulate	Recycled rubber	Coarse-grained, 2-4 mm
2	Jacobs Rubber	Rubber granulate	Recycled rubber	Fine-grained
5	Jacobs Rubber	Rubber granulate	Recycled rubber	Coarse-grained
6	Saltex Oy	Rubber granulate	EPDM	1-4 mm
3	CABRITA	Artificial turf	Polyethene	Split fibre
4	Desso	Artificial turf	Polyethene /polypropene copolymer	Monofibre

3 Test methods

3.1 Total analysis

To determine the total content of selected elements and organic compounds, see Table 2, rubber granulates and artificial turf fibre were sent to NBI's subcontractor AnalyCen AS for chemical analysis.

Table 2. Total analysis. Test method.

Parameter	Detection limit	Measurement uncertainty	Method based on
Arsenic, As	0.03 mg/kg	± 35 %	NS 4781-1 m
Lead, Pb	0.4 mg/kg	± 20 %	NS-EN ISO 11885
Cadmium, Cd	0.017 mg/kg	± 20 %	NS-EN ISO 11885
Copper, Cu	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Chromium, Cr	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Mercury, Hg	0.5 µg/kg	± 30 %	NS 4781-1 m
Nickel, Ni	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Zinc, Zn	0.2 mg/kg	± 20 %	NS-EN ISO 11885
PCB(7) in artificial turf fibre	0.002 mg/kg	± 25 %	NTR 329 Sintef 1997
PCB(7) in rubber granulate	0.2 mg/kg	± 25 %	SNV report 4697
PAH(16)	0.01 mg/kg	± 25 %	NTR 329 Sintef 1997
Phthalates(8)	0.1-1 mg/kg	± 20 %	
4-t-Octylphenol	5-50 µg/kg	± 10 %	Derivatisation
4-n-Nonylphenol	5-50 µg/kg	± 10 %	Derivatisation
iso-Nonylphenol	5-50 µg/kg	± 10 %	Derivatisation

3.2 Leaching

The leaching procedures were based on pr EN 12457-4 and NT ENVIR 005.

3.2.1 Leaching of elements from artificial turf fibre and rubber granulate

Deionised water and artificial turf fibre or rubber granulate were transferred to a 2-litre rectangular polyethene container. The water to solid material ratio L/S was 10 L/kg. The conductivity, pH and temperature of the deionised water were measured before mixing; see Table 3. The container with water and solid material was rotated at a speed of 10 RPM for 24 hours. Immediately after this process, the temperature, pH and conductivity of the leachate were measured. The leachate was then vacuum-filtered. A Sartorius glass vacuum filter holder with a 0.45 µ Millipore MF membrane filter with nitrocellulose was used for the filtration. The filtrate was acidified using 1% v/v concentrated HNO_3 and stored in a polypropene bottle.

Table 3. Leaching of metals from artificial turf fibre and rubber granulates. Test conditions.

Sample type	Sample no.	Sample weight [g]	Deionised water			
			Volume [ml]	Temp. [°C]	pH	Conduct. [µS/cm]
Granulate	1	100.02	1000	18.5	6.25	1.21
Granulate	2	100.03	1000	18.5	6.25	1.21
Granulate	5	100.03	1000	22.4	5.63	0.75
Granulate	6	100.05	1000	22.4	5.63	0.75
Fibre	3	50.00	500	21.0	5.60	0.82
Fibre	4	50.00	500	21.0	5.60	0.82

The analysis of zinc in the leachate was carried out by NBI using a flame atomic absorption spectrometer. The detection limit was 0.02 mg/L.

The analysis of chromium in the leachate was undertaken by NBI using a graphite furnace atomic absorption spectrometer. The detection limit was 0.6 µg/l.

3.2.2 Leaching of organic compounds from rubber granulate

Deionised water and rubber granulate were transferred to a rectangular 1-litre Duran glass container with a Teflon-coated cork. The water to solid material ratio L/S was 10 L/kg. The conductivity, pH and temperature of the deionised water were measured before mixing; see Table 4. The container with water and solid material was rotated at a speed of 10 RPM for 48 hours. Immediately after this process, the temperature, pH and conductivity of the leachate were measured. The leachate was then filtered at normal pressure. An ash-free paper filter (598[3]) from Schleicher and Schull was used for the filtration. The filtrates were sent to AnalyCen for analysis of organic compounds; see Table 5.

Table 4. Leaching of organic compounds from rubber granulates. Test conditions.

Sample type	Parallel	Sample weight [g]	Deionised water			
			Volume [ml]	Temp. [°C]	pH	Conduct. [μS/cm]
1	1	90.90	910	20.2	5.63	0.81
1	2	90.89	910	20.2	5.63	0.81
1	3	90.86	910	20.2	5.63	0.81
1	4	90.93	910	20.2	5.63	0.81
2	1	90.96	910	21.3	6.35	0.72
2	2	90.93	910	21.3	6.35	0.72
2	3	90.92	910	21.3	6.35	0.72
2	4	90.90	910	21.3	6.35	0.72
5	1	90.92	910	20.7	5.90	0.79
5	2	90.93	910	15.5	6.20	0.64
6	1	90.92	910	15.5	6.20	0.64

Table 5. Analysis of organic compounds in leachate. Test methods.

Parameter	Detection limit	Measurement uncertainty	Method based on
PAH(16)	0.02 μg/L	± 30 %	NS 9815
Phthalates(8)	0.1-1 μg/L	± 20 %	-
4-t-Octylphenol, 4-n-Nonylphenol, iso-Nonylphenol	5-50 ng/L	± 10 %	Derivatisation
Total organic carbon (TOC)	0.1 mg/L	± 10 %	NS-EN 1484
Dissolved organic carbon (DOC)	0.1 mg/L	± 10 %	NS-EN 1484-1
Turbidity	0.05 FTU	± 10 %	NS-ISO 7027-1
Suspended matter	0.6 mg/L	± 20 %	NS 4733-2

3.3 Degassing from rubber granulate

For the degassing test, 2g of rubber granulate was weighed out. This granulate was then heated to 70°C for 30 minutes before the gas mixture was analysed. The degassing test was carried out by NBI's subcontractor AnalyCen AS.

4 Results

4.1 Total analysis

Tables 6 and 7 show the analysis results for total content of selected elements and organic compounds in rubber granulates and artificial turf fibres.

Table 6. Total content of selected elements and organic compounds in rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6	SFT's normative value[1)]	Agriculture Canada [2)]	PNEC[3)]
Arsenic, As	mg/kg	< 3	< 3	< 2	< 2	2	12	
Lead, Pb	mg/kg	20	15	17	8	60	70	
Cadmium, Cd	mg/kg	1	1	2	< 0.5	3	1.4	
Copper, Cu	mg/kg	35	20	70	< 3	100	63	
Chromium, Cr	mg/kg	< 2	< 2	< 2	5200	25	64	
Mercury, Hg	mg/kg	0.04	0.04	< 0.03	< 0.03	1	6.6	
Nickel, Ni	mg/kg	< 2	< 1	< 5	< 5	50	50	
Zinc, Zn	mg/kg	7500	7300	17000	9500	100	200	
Polychlorinated biphenyls (PCB)								
PCB(7)	mg/kg	< 0.175	< 0.175	0.202	< 0.004	0.01	0.5	
PCB 28	mg/kg	< 0.05	< 0.05	0.114	< 0.001			
PCB 52	mg/kg	< 0.05	< 0.05	0.072	< 0.001			
PCB 101	mg/kg	< 0.05	< 0.05	0.002	< 0.001			
PCB 118	mg/kg	< 0.05	< 0.05	0.001	< 0.001			
PCB 153	mg/kg	< 0.05	< 0.05	0.003	< 0.001			
PCB 138	mg/kg	< 0.05	< 0.05	0.008	< 0.001			
PCB 180	mg/kg	< 0.05	< 0.05	0.002	< 0.001			
Polycyclic aromatic hydrocarbons (PAH)								
PAH(16)	mg/kg	51	74	76	1	2		
Naphthalene	mg/kg	0.4	0.32	0.72	0.19	0.8	0.1	
Acenaphthylene	mg/kg	0.6	0.79	1	< 0.08			
Acenaphthene	mg/kg	< 0.2	< 0.2	0.32	< 0.08			
Fluorene	mg/kg	0.4	0.55	0.68	< 0.08	0.6		
Phenanthrene	mg/kg	4.8	5.9	5.8	0.43		0.1	
Anthracene	mg/kg	0.6	0.55	0.76	< 0.08			
Fluoranthene	mg/kg	7.8	11	11	0.12	0.1		
Pyrene	mg/kg	23	37	34	0.16	0.1	0.1	
Benzo(a)anthracene	mg/kg	1.4	1.9	1.8	< 0.08		0.1	
Crysene	mg/kg	2.2	2.2	4.2	< 0.08			
Benzo(b)fluoranthene	mg/kg	2.2	3.5	3.9	< 0.08		0.1	
Benzo(k)fluoranthene	mg/kg	0.4	0.55	1.5	< 0.08		0.1	
Benzo(a)pyrene	mg/kg	2.4	3.1	3	0.12	0.1	0.1	
Indeno(1,2,3,cd)pyrene	mg/kg	0.8	0.95	1.4	< 0.08		0.1	
Dibenzo(a,h)anthracene	mg/kg	< 0.4	< 0.2	0.44	< 0.08		0.1	
Benzo(g,h,i)perylene	mg/kg	3.4	5.8	5.1	< 0.08			
Phthalates								
Dimetylphthalate (DMP)	mg/kg	< 1.0	< 1.0	< 1.0	3.4			
Dietylphthalate (DEP)	mg/kg	< 1.0	< 1.0	< 1.0	1.5			
Dibutylphthalate (DBP)	mg/kg	3.4	2.6	3.9	1.6			2[4)]

Benzylbutylphthalate (BBP)	mg/kg	1.3	2.8	1.9	< 1.0			
Diethylhexylphthalate (DEHP)	mg/kg	21	21	29	3.9			
Di n-octylphthalate (DOP)	mg/kg	< 1.0	< 1.0	< 1.0	3.2			
Diisononylphthalate (DINP)	mg/kg	57	78					30[4]
Diisodecylphthalate (DIDP)	mg/kg	< 1.0	< 1.0					100[4]
Phenols								
4-t-Octylphenol	µg/kg	33700	27800	19600	49.8			
4-n-Nonylphenol	µg/kg	< 5	< 5	< 5	< 5		5700[5]	
iso-Nonylphenol	µg/kg	21200	21600	9120	1120		5700[5]	300[4]

1) Guidance concerning risk assessment of polluted ground. Norwegian Pollution Control Authority guidance 99:01a. 1999.
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration.
4) European Commission, Summary Risk Assessment Reports, 2002 and 2003.
5) The values apply to total nonylphenols.

Table 7. Total content of selected elements and organic compounds in artificial turf fibre.

Parameter	**Unit**	**Sample 3**	**Sample 4**	**SFT's normative value[1]**	**Agriculture Canada[2]**	**PNEC[3]**
Arsenic, As	mg/kg	< 3	< 2	2	12	
Lead, Pb	mg/kg	< 2	< 2	60	70	
Cadmium, Cd	mg/kg	< 0.1	< 0.1	3	1.4	
Copper, Cu	mg/kg	59	68	100	63	
Chromium, Cr	mg/kg	< 2	< 2	25	64	
Mercury, Hg	mg/kg	< 0.03	< 0.03	1	6.6	
Nickel, Ni	mg/kg	< 1	< 1	50	50	
Zinc, Zn	mg/kg	3100	3300	100	200	
Polychlorinated biphenyls (PCB)						
PCB(7)	mg/kg	< 0.007	< 0.007	0.01	0.5	
PCB 28	mg/kg	< 0.02	< 0.02			
PCB 52	mg/kg	< 0.02	< 0.02			
PCB 101	mg/kg	< 0.02	< 0.02			
PCB 118	mg/kg	< 0.02	< 0.02			
PCB 153	mg/kg	< 0.02	< 0.02			
PCB 138	mg/kg	< 0.02	< 0.02			
PCB 180	mg/kg	< 0.02	< 0.02			
Polycyclic aromatic hydrocarbons (PAH)						
PAH(16)	mg/kg	< 1.0	< 2.0	2		
Naphthalene	mg/kg	< 0.05	< 0.1	0.8	0.1	
Acenaphthylene	mg/kg	< 0.05	< 0.1			
Acenaphthene	mg/kg	< 0.05	< 0.1			
Fluorene	mg/kg	< 0.05	< 0.1	0.6		
Phenanthrene	mg/kg	< 0.05	< 0.1		0.1	
Anthracene	mg/kg	< 0.05	< 0.1			
Fluoranthene	mg/kg	< 0.05	< 0.1	0.1		

Pyrene	mg/kg	< 0.05	< 0.1	0.1	0.1	
Benzo(a)anthracene	mg/kg	< 0.05	< 0.1		0.1	
Crysene	mg/kg	< 0.05	< 0.1			
Benzo(b)fluoranthene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(k)fluoranthene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(a)pyrene	mg/kg	< 0.05	< 0.1	0.1	0.1	
Indeno(1,2,3,cd)pyrene	mg/kg	< 0.05	< 0.1		0.1	
Dibenzo(a,h)anthracene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(g,h,i)perylene	mg/kg	< 0.05	< 0.1			
Phthalates						
Dimetylphthalate (DMP)	mg/kg	< 1.0	1.2			
Dietylphthalate (DEP)	mg/kg	< 1.0	< 1.0			
Dibutylphthalate (DBP)	mg/kg	< 1.0	1			2[4]
Benzylbutylphthalate (BBP)	mg/kg	< 1.0	< 1.0			
Diethylhexylphthalate (DEHP)	mg/kg	1.7	8			
Di n-octylphthalate (DOP)	mg/kg	< 1.0	< 1.0			
Diisononylphthalate (DINP)	mg/kg	< 1.0	5.5			30[4]
Diisodecylphthalate (DIDP)	mg/kg	< 1.0	< 1.0			100[4]
Phenols						
4-t-Octylphenol	µg/kg	< 5	36.4			
4-n-Nonylphenol	µg/kg	< 5	< 5		5700[5]	
iso-Nonylphenol	µg/kg	< 50	213		5700[5]	300[4]

1) Guidance concerning risk assessment of polluted ground. SFT guidance 99:01a. 1999.
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration.
4) European Commission, Summary Risk Assessment Reports, 2002 and 2003.
5) The values apply to total nonylphenols.

4.2 Leaching

4.2.1 Leaching of elements from artificial turf fibre and rubber granulate

Table 8 shows the results of the leaching of Zn and Cr from artificial turf fibre and rubber granulates.

Table 8. Leaching of Zn and Cr from artificial turf fibre and rubber granulates.

Sample type	Sample no.	Leachate				
		Temperature [ºC]	pH	Conductivity [µS/cm]	Zn [µg/l]	Cr [µg/l]
Granulate	1	27.0	7.69	77.4	2290	-
Granulate	2	26.0	7.80	34.4	1220	-
Granulate	5	27.8	7.54	35.1	590	-
Granulate	6	27.7	11.36	1276	80	< 2
Fibre	3	27.2	7.12	28.4	1000	-
Fibre	4	27.3	6.95	69.5	860	-

4.2.2 Leaching of organic compounds from rubber granulate

Tables 9 and 10 show the results of the leaching of organic compounds from rubber granulate.

Table 9. Leaching of organic compounds from rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6	Drinking water Norway[1)]	SFT Environmental Quality Class I[2)]	SFT Environmental Quality Class V[2)]
pH		7.7	7.7	7.9	11.6	6.5-9.5	> 6.5	< 5
Conductivity	µS/cm	85.6	38.3	37.6	1390	2500		
Temperature	°C	28.0	28.4	24.6	24.6			
Total organic carbon (TOC)	mg/L	57	35	35	170	5	< 2.5	> 15
Dissolved organic carbon (DOC)	mg/L	56	34	34	170			
Turbidity	FTU	2.1	3.2	2.3	1.0	4	< 0.5	> 5
Suspended matter	mg/L	2.9	2.7	2.7	1.3		< 1.5	> 10

1) Regulation on water supply and drinking water (the Drinking Water Regulation), 2004
2) SFT, Classification of environmental quality in freshwater, guidance 97:04, 1997. Environmental quality class for nutrient salts, organic matter, pH, particles and bacteria. Status class I: Very good. Status class V: Very poor.

Table 10. Leaching of organic compounds from rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Drinking Water Norway[1)]	Freshwater Canada[2)]	PNEC[3)]
Polychlorinated biphenyls (PCB)							
PCB(7)	µg/L			< 0.01		0.0001	
PCB 28	µg/L			< 0.01			
PCB 52	µg/L			< 0.01			
PCB 101	µg/L			< 0.01			
PCB 118	µg/L			< 0.01			
PCB 153	µg/L			< 0.01			
PCB 138	µg/L			< 0.01			
PCB 180	µg/L			< 0.01			
Polycyclic aromatic hydrocarbons (PAH)							
Sum PAH(16)	µg/L	0.87	0.44				
Sum PAH(4)[4)]	µg/L	< 0.01	< 0.01		0.1		
Naphthalene	µg/L	0.15	< 0.01			1.1	
Acenaphthylene	µg/L	0.27	< 0.01				
Acenaphthene	µg/L	0.03	0.02			5.8	
Fluorene	µg/L	0.04	0.04			3.0	
Phenanthrene	µg/L	0.16	0.17			0.4	
Anthracene	µg/L	0.03	0.03			0.012	
Fluoranthene	µg/L	0.06	0.06			0.04	
Pyrene	µg/L	0.13	0.12			0.025	
Benzo(a)anthracene	µg/L	< 0.01	< 0.01			0.018	

Crysene	µg/L	< 0.01	< 0.01		
Benzo(b)fluoranthene	µg/L	< 0.01	< 0.01		
Benzo(k)fluoranthene	µg/L	< 0.01	< 0.01		
Benzo(a)pyrene	µg/L	< 0.01	< 0.01	0.015	
Indeno(1,2,3,cd)pyrene	µg/L	< 0.01	< 0.01		
Dibenzo(a,h)anthracene	µg/L	< 0.01	< 0.01		
Benzo(g,h,i)perylene	µg/L	< 0.01	< 0.01		
Phthalates					
Dimetylphthalate (DMP)	µg/L	0.6	1.6		
Dietylphthalate (DEP)	µg/L	6.6	8.3		
Dibutylphthalate (DBP)	µg/L	3.3	2.1	19	10
Benzylbutylphthalate (BBP)	µg/L	< 0.1	0.3		
Diethylhexylphthalate (DEHP)	µg/L	5.1	5.6	16	
Di n-octylphthalate (DOP)	µg/L	2.9	4.4		
Diisononylphthalate (DINP)	µg/L	2.7	2.2		No effect
Diisodecylphthalate (DIDP)	µg/L	< 1.0	1.0		No effect
Phenols					
4-t-Octylphenol	µg/L	3600	2950		
4-n-Nonylphenol	µg/L	43	< 20	1000[5)]	330[5)]
iso-Nonylphenol	µg/L	1120	568	1000[5)]	330[5)]

1) Regulation on water supply and drinking water (the Drinking Water Regulation), 2004
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration. The values were taken from the European Commission, Summary Risk Assessment Report, 2003 and 2004.
4) Total of the concentrations of benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene and indeno(1,2,3-cd)pyrene.
5) The limit applies to total nonylphenols.
6) Water Quality Criteria for Polychlorinated Biphenyls (PCBs). Technical appendix. Ministry of Environment, Land and Parks Province of British Columbia. Canada. 1992.

4.3 Degassing of volatile organic compounds

The results from the degassing test are shown in Table 11.

Table 11. Degassing test - rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6
Alkylated benzenes					
Toluene	µg/kg	80	56	28	9
Ethylbenzene	µg/kg	18	12	7.8	< 5
Propylbenzene	µg/kg	15	< 0.8	8.8	5
iso-Propylbenzene	µg/kg	0.7	12	< 5	< 5
n-Butylbenzene	µg/kg	31	21	28	< 5
m/p-Xylene	µg/kg	37	28	25	< 5
o-Xylene	µg/kg	35	24	20	< 5
p-Isopropyltoluene	µg/kg	23	8.6	17	< 5
1.2-4-Trimethylbenzene	µg/kg	102	83	100	9.4
1.3.5-Trimethylbenzene	µg/kg	23	18	19	< 5
Chlorinated compounds					

Trichloromethane	µg/kg	8	- < 5 < 5		
cis-1,2-Dichlorethene	µg/kg	< 5	< 5	32	10

5 Assessment

5.1 Total analysis and leaching

A simplified risk assessment was carried out for the rubber granulates and artificial turf fibres. In a simplified risk assessment, the total content of hazardous compounds in the source material is compared with the Norwegian Pollution Control Authority's normative values for 'most sensitive land use'. 'Most sensitive land use' covers areas intended for housing, gardens, nurseries, schools, etc.

The Norwegian Pollution Control Authority's list of normative values for most sensitive land use does not contain any values for phthalates or phenols. Values for phenols taken from the "Canadian Environmental Quality Guidelines - Agricultural Soil" were used instead. PNEC values (Predicted No Effect Concentration) for individual phthalates were taken from the EU's programme for risk assessment.

If the normative value is not exceeded, the source material is considered to have an acceptable concentration of the hazardous compound. If the total content of a compound exceeds normative values for most sensitive land use, an extended assessment is carried out. The extended assessment is based on leaching tests. The assessment of water quality depends on how the water is to be used. The limits for drinking water intended for human consumption can in some cases differ considerably from the limits which are considered acceptable for aquatic organisms. In connection with the assessment of the leaching test, it was decided to compare the concentration of the relevant compound with limits for the concentration of the same compound in both drinking water and freshwater. The limits were taken from the Norwegian Drinking Water Regulation, the Norwegian Pollution Control Authority's Environmental Quality Classes I-V and Canada's limits for hazardous compounds in drinking water and freshwater.

For the leaching tests, the mobility of the compounds was calculated, both as a % mobilised compound and as a K_d value. The mobility of a compound expresses the degree to which the compound is transferred from the granulate or fibre to the leachate. The percentage mobilised compound gives an indication of how much of the total content in the granulate or fibre was dissolved into the water. The K_d factor can be considered as the number of litres of extraction water which contains the same quantity of a compound as is found of the compound in 1 kg of granulate or fibre. A high K_d value indicates a low mobility and vice versa.

5.1.1 Assessment of the artificial turf fibres

The total analysis shows that there is little difference between the two artificial turf fibre types with regard to the content of arsenic, lead, cadmium, copper, chromium, mercury, nickel, zinc, PCB and PAH; see Table 7. Sample 4 contains slightly more phthalates and phenols than sample 3.

Copper and zinc were demonstrated in both the artificial turf fibres. Any concentrations of arsenic, lead, cadmium, chromium, mercury, nickel, PCB or PAH are below the detection limit

for the analysis method. Both the artificial turf fibre types come under the Norwegian Pollution Control Authority's normative values for lead, cadmium, copper, mercury, nickel, PCB and PAH.

Both the artificial turf fibres exceed the Norwegian Pollution Control Authority's normative value for zinc. A leachate test was therefore performed with the aim of determining the degree to which zinc is dissolved out of the artificial turf fibre. The Drinking Water Regulation does not specify a limit for the concentration of zinc in drinking water. The concentration of zinc in the leachate from both fibres is above the Norwegian Pollution Control Authority's limit for zinc in water with Environmental Quality Class V (very strongly polluted), but lower than the permitted zinc concentration in Canadian drinking water (=5 mg/l).

The concentration of arsenic in the artificial turf fibres is less than 3 mg/kg, whilst the Norwegian Pollution Control Authority's normative value for most sensitive land use is 2 mg/kg. The data does not therefore provide a basis for concluding whether the Norwegian Pollution Control Authority's normative value for arsenic has been exceeded, but if it has been exceeded it can only be by a small amount.

4-t-octylphenol and iso-nonylphenol were demonstrated in sample 4. Any concentrations of octylphenol or nonylphenol in sample 3 are below the detection limit of the analysis method. The concentration of nonylphenols in the artificial turf fibres is below the limits specified in the Canadian Environmental Quality Guidelines and the PNEC value. No limits were found for octylphenol.

DEHP was demonstrated in samples 3 and 4. Sample 4 contains four times as much DEHP as sample 3. Sample 4 also contained DMP and DINP. The quantities of DBP, DINP and DIDP in both artificial turf fibres are below the PNEC values for terrestrial life. No limits were found for the remaining phthalates in soil, but it is worth noting that DMP is included in the environmental protection authorities' list of particularly hazardous chemicals because it has properties which are harmful to reproductive health. DEHP also has considerable potential for bioaccumulation and high acute toxicity.

The pH measured in the leachate from the artificial turf fibres is within the range specified in the Drinking Water Regulation (6.5-9.5). The conductivity of the leachate also complies with the corresponding limit in the Drinking Water Regulation (2500 µS/cm).

5.1.2 Assessment of the rubber granulates

5.1.2.1 Rubber granulates based on recycled rubber

Samples 1, 2 and 5 are rubber granulates based on recycled rubber. Samples 2 and 5 are fine-grained and coarse-grained rubber types respectively from the same manufacturer.

Sample 1 and sample 2 are very similar with regard to the total concentration of environmental toxins. Sample 5 contains more than twice as much copper and zinc as samples 1 and 2. In addition, sample 5 contains PCB. PCB was not demonstrated in samples 1 or 2. The differences between sample 2 and sample 5, which are both from the same manufacturer, show that products from a single manufacturer can vary considerably. At the same time, products from two different manufacturers can show great similarity with regard to concentrations of environmental toxins, as is the case for sample 1 compared with sample 2.

Lead, cadmium, copper, zinc, PAH, phthalates and phenols were demonstrated in all the rubber granulates based on recycled rubber. Samples 1 and 2 also contained some mercury, whilst PCB was demonstrated in sample 5.

The recycled rubber granulate types are below the Norwegian Pollution Control Authority's normative values for lead, cadmium, copper, chromium, mercury and nickel. The concentration of arsenic in sample 5 is also below the Norwegian Pollution Control Authority's normative values. The concentrations of arsenic in samples 1 and 2 are below 3 mg/kg, while the Norwegian Pollution Control Authority's normative value for most sensitive land use is 2 mg/kg. The data does not therefore provide an adequate basis on which to decide whether the Norwegian Pollution Control Authority's normative value for arsenic has been exceeded, but if it has been exceeded it can only be by a small amount. Similarly, the total analysis shows that the concentrations of PCB in samples 1 and 2 are below 0.175 mg/kg. The Norwegian Pollution Control Authority's normative value for most sensitive land use is 0.01 mg/kg. It is therefore difficult to decide whether the normative values for PCB are exceeded in samples 1 and 2.

The total concentration of zinc exceeds the Norwegian Pollution Control Authority's normative value for recycled rubber granulates. The leaching test shows that zinc is transferred from the granulate to water. The zinc values are above the Norwegian Pollution Control Authority's limit for zinc in water in Environmental Quality Class V (very strongly polluted), but lower than the zinc concentration permitted in Canadian drinking water (5 mg/l).

The concentration of PCB in sample 5 exceeds the Norwegian Pollution Control Authority's normative values. The leaching test shows that little PCB is transferred to the water phase. PCB is virtually insoluble in water.

The total concentration of PAH exceeds the Norwegian Pollution Control Authority's normative value for all three recycled rubber granulates. The leachate from samples 1 and 2 also contained PAH. No leaching test was carried out on sample 5. A total of < 0.01 µg/L each of benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3,cd)pyrene, benzo(g,h,i)perylene and benzo(a)pyrene was found. The leachate can therefore be said to comply with the requirements in the Drinking Water Regulation, as the Regulation only specifies values for benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3,cd)pyrene, benzo(g,h,i)perylene and benzo(a)pyrene. Neither the Drinking Water Regulation nor the Norwegian Pollution Control Authority's environmental quality classes specify limits for the remaining PAH compounds which were found in the leachate. It was therefore decided to compare the values with the limits for freshwater in Canada. The values for anthracene, fluoranthene and pyrene in the leachate from samples 1 and 2 exceed the limits for freshwater in Canada, while the concentrations of naphthalene, acenaphthene, fluorene and phenanthrene are lower. No limit data was found for acenaphthylene.

DBP, BBP and DEHP were demonstrated in all recycled rubber granulates. DINP was also demonstrated in samples 1 and 2. No analysis for DINP or DIDP was carried out for sample 5. Any concentrations of DMP, DEP, DOP and DIDP are below the detection limit for the analysis method. The Norwegian Pollution Control Authority does not specify any normative values for phthalates in soil. It was therefore decided to compares values with PNEC values where such values are available. The total quantities of DBP and DINP in both the rubber granulates exceed the PNEC values for terrestrial life. The rubber granulates also contain some BBP and DEHP. No limits were found for BBP and DEHP, but both are on the environmental protection authorities' list of particularly hazardous chemicals, because they have properties that are harmful to reproductive health, considerable potential for bioaccumulation and high acute toxicity.

Significant quantities of phthalates were found in the leachate, particularly DEP and DEHP, but DMP, DBP, DOP, DINP and DIDP were also found. The concentrations of DBP and DEHP in the leachate were below the limits for freshwater in Canada. No limits were found for the remaining phthalates in water, but it is worth noting that DMP is included in the environmental protection authorities' list of particularly hazardous chemicals as it has properties that are harmful to reproductive health and that BBP also has considerable potential for bioaccumulation and high acute toxicity. The EU's programme for risk assessment concludes that DINP and DIDP do not have any effect on aqueous life.

The presence of 4-t-octylphenol and iso-nonylphenol was demonstrated in both rubber granulates. The concentration of nonylphenol is above the limits specified in the Canadian Environmental Quality Guidelines. The concentration of nonylphenol in the leachate from sample 1 exceeds both the limits for freshwater in Canada and the PNEC value for water. The concentration of nonylphenol in the leachate from sample 2 exceeds the PNEC value for water. No limits were found for octylphenol in soil or water.

The concentration of total organic carbon (TOC) in the leachate from the rubber granulates exceeds the limit in the Drinking Water Regulation (5 mg/l). With regard to TOC, the leachate comes under the Norwegian Pollution Control Authority's Environmental Quality Class V (very poor). The high concentration of organic carbon is probably due to small particulate waste from the rubber granulates which were not captured by the filter during the filtration.

The turbidity of the leachate from the rubber granulates is below the value specified in the Drinking Water Regulation for water for subscribers (4 FTU), but it corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class IV (poor). The quantity of suspended matter in the leachate corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class II (good). No limit is specified for suspended matter in the Drinking Water Regulation. The pH of the leachate is within the range specified in the Drinking Water Regulation (6.5-9.5). The conductivity of the leachate also complies with the Drinking Water Regulation's limit (2500 µS/cm).

The recycled rubber granulates release a large number of alkylated benzenes in gaseous form. Trichloromethane (sample 1) and cis-1,2-dichlorethene (sample 5) were also found. Some of these compounds are regulated through the "Administrative norms for pollution of the working atmosphere"; see Table 12. These norms specify the highest acceptable average concentration over eight hours.

Relating the results of the degassing test to actual air concentrations above an artificial turf pitch falls outside the scope of the project. It is therefore recommended that measurements of air quality be made above pitches to determine whether the quality is satisfactory.

Table 12. Extract from "Administrative norms for pollution of the working atmosphere". These norms specify the highest acceptable average concentration in the air over an eight-hour period.

Compound	**Air concentration [mg/m^3]**	**Remarks**
	Alkylated benzenes	
Ethylbenzene	20	Absorbed through the skin. Carcinogenic.
Trimethylbenzene (all isomers)	100	
m-Xylene	108	Absorbed through the skin.
p-Xylene	108	Absorbed through the skin.

o-Xylene	108	Absorbed through the skin.
	Chlorinated compounds	
1,2-Dichloroethene (mixture of the cis- and trans-forms)	395	
Trichloromethane	10	Absorbed through the skin. Carcinogenic. Reprotoxic.

5.1.2.2 Mobility of metals and organic compounds in rubber granulates

Table 13 shows the calculated mobility for the compounds in the leaching test. Zinc shows a high mobility, yet only a small proportion of the total zinc content has been leached out. The organic compounds show low mobility. The proportion of the total content of organic compounds which have been leached out is low.

Table 13. Mobilistion of compounds.

Parameter	**Sample 1**		**Sample 2**		**Sample 5**		**Sample 6**	
	% mobilised	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**
Chromium, Cr	-	-	-	-	-	-	< 0.0004	> 2600
Zinc, Zn	0.31	3	0.17	6	0.03	29	0.01	119
Polychlorinated biphenyls (PCB)								
PCB (7)	-	-	-	-	< 0.005	-	-	-
PCB 28	-	-	-	-	< 0.009	-	-	-
PCB 52	-	-	-	-	< 0.014	-	-	-
PCB 101	-	-	-	-	< 0.5	-	-	-
PCB 118	-	-	-	-	< 1	-	-	-
PCB 153	-	-	-	-	< 0.3	-	-	-
PCB 153	-	-	-	-	< 0.1	-	-	-
PCB 138	-	-	-	-	< 0.5	-	-	-
PCB 180	-	-	-	-		-	-	-
Polycyclic aromatic hydrocarbons (PAH)								
PAH (16)	0.002	58621	0.001	168182	-	-	-	-
Naphthalene	0.038	2667	< 0.0031	> 32000	-	-	-	-
Acenaphthylene	0.045	2222	< 0.0013	> 79000	-	-	-	-
Acenaphthene	-	< 6667	-	< 10000	-	-	-	-
Flourene	0.010	10000	0.007	13750	-	-	-	-
Phenanthrene	0.003	30000	0.003	34706	-	-	-	-
Anthracene	0.005	20000	0.005	18333	-	-	-	-
Fluoranthene	0.001	130000	0.001	183333	-	-	-	-
Pyrene	0.001	176923	0.000	308333	-	-	-	-
Benzo(a)anthracene	< 0.0007	> 140000	< 0.0005	> 190000	-	-	-	-
Crysene	< 0.0005	> 220000	< 0.0005	> 220000	-	-	-	-
Benzo(b)fluoranthene	< 0.0005	> 220000	< 0.0003	> 350000	-	-	-	-
Benzo(k)fluoranthene	< 0.0025	> 40000	< 0.0018	> 55000	-	-	-	-
Benzo(a)pyrene	< 0.0004	> 240000	< 0.0003	> 310000	-	-	-	-
Indeno(1,2,3,cd)pyrene	< 0.0013	> 80000	< 0.0011	> 95000	-	-	-	-
Dibenzo(a,h)anthracene	-	-	-	-	-	-	-	-
Benzo(g,h,i)perylene	< 0.0003	> 340000	< 0.0002	> 580000	-	-	-	-
Phthalates								
Dimetylphthalate (DMP)	-	< 1667	-	< 625	-	-	-	-
Dietylphthalate (DEP)	-	< 152	-	< 120	-	-	-	-
Dibutylphthalate (DBP)	0.097	1030	0.081	1238	-	-	-	-
Benzylbutylphthalate					-	-	-	-

(BBP)	< 0.008	> 13000	0.011	9333				
Diethylhexylphthalate (DEHP)	0.024	4118	0.027	3750	-	-	-	-
Di n-octylphthalate (DOP)	-	< 345	-	< 227	-	-	-	-
Diisononylphthalate (DINP)	0.005	21111	0.003	35455	-	-	-	-
Diisodecylphthalate (DIDP)	-	-	-	-	-	-	-	-
			Phenols					
4-t-Octylphenol	0.011	9361	0.011	9424	-	-	-	-
4-n-Nonylphenol		< 116			-	-	-	-
iso-Nonylphenol	0.005	18929	0.003	38028	-	-	-	-

5.1.2.3 Comparison of recycled rubber granulate and EPDM rubber granulate

The EPDM rubber (sample 6) contains more chromium than the recycled rubber types. The zinc concentration in the EPDM rubber is at the same level as in the recycled rubber types, while concentrations of PAH, phthalates and phenols are lower. No PCB was demonstrated in the EPDM rubber.

Concentrations of chromium and zinc in the EPDM rubber exceed the Norwegian Pollution Control Authority's normative values for most sensitive land use. The concentration of zinc in the leachate corresponds to the Norwegian Pollution Control Authority's Leaching Class IV (strongly polluted). The concentration of chromium in the leachate was below the requirements in the Drinking Water Regulation and corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class II (moderately polluted).

The leachate from the EPDM rubber has a considerably higher pH and conductivity than that from the recycled rubber. The pH is higher than the recommended range for drinking water in Norway. The conductivity complies with the limit in the Drinking Water Regulation.

The mobility of zinc is slightly lower than for the recycled rubbers.

The EPDM rubber gives off a smaller quantity of volatile organic compounds than the recycled rubber types.

With the exception of chromium and zinc, the EPDM rubber contains lower concentrations of hazardous substances than the recycled rubber types overall.

5.1.3 Comparison of rubber granulates and artificial turf fibre

Per square metre of artificial turf, there is approximately 0.8 kg of artificial turf fibre and 17-18 kg of rubber granulate. The artificial turf fibre-rubber ratio is therefore approximately 0.05 kg fibre/kg of granulate. As the measured concentration of environmental toxins (with the exception of copper) in the artificial turf fibres is lower than in the rubber granulates, and the artificial turf fibres in any case represent a much smaller proportion of the artificial turf system in terms of mass than the rubber granulate, it is suggested that further investigations concentrate on the rubber granulates.

6 Conclusions

6.1 Artificial turf fibre

The total analysis shows that the artificial turf fibres contain copper, zinc, individual phthalates, 4-t-octylphenol and iso-nonyl-phenol. The concentration of zinc complies with the Norwegian Pollution Control Authority's normative values for most sensitive land use for both fibre types. The two fibre types are very similar.

The total content of copper in the artificial turf fibres is below the Norwegian Pollution Control Authority's normative values for most sensitive land use and probably does not constitute an unacceptable environmental risk in either the short or the long term.

The leachate from the fibres contained zinc. The concentration is higher than the Norwegian Pollution Control Authority's limit for zinc in water with Environmental Quality Class V (very strongly polluted water), but lower than the permitted zinc concentration in Canadian drinking water.

As the measured concentration of environmental toxins (with the exception of copper) in the artificial turf fibres is lower than in the rubber granulates, and the artificial turf fibres in any case constitute a much smaller proportion of the artificial turf system in terms of mass, it is suggested that further investigations concentrate on the rubber granulates.

6.2 Rubber granulate

The total analysis shows that the rubber granulates based on recycled rubber contain lead, cadmium, copper, mercury, zinc, polycyclic aromatic hydrocarbons (PAH), certain phthalates, 4-t-octylphenol and iso-nonylphenol. The chemical composition of products from a single manufacturer can vary considerably for individual parameters. However, products from two different manufacturers can also show great similarity. Stricter controls on rubber granulates by manufacturers, possibly in the form of a product control scheme, could give greater homogeneity and predictability with regard to chemical composition.

The total concentration of lead, cadmium, copper and mercury in the recycled rubber granulates is below the Norwegian Pollution Control Authority's normative values for most sensitive land use and probably does not constitute an unacceptable environmental risk in the short or the long term.

The total concentrations of zinc and PAH in the recycled rubber granulates exceed the Norwegian Pollution Control Authority's normative values for most sensitive land use. The concentrations of dibutylphthalate (DBP) and diisononylphthalate (DINP) exceed the PNEC values for terrestrial life taken from the EU's programme for risk assessment. The concentration of isononylphenol is above the limits specified for cultivated land in the Canadian Environmental Quality Guidelines.

The leachate from the recycled granulates contain zinc, polycyclic aromatic hydrocarbons (PAH), phthalates and phenols. The concentration of zinc indicates that the leachate water is placed in the Norwegian Pollution Control Authority's Environmental Quality Class V (very strongly polluted water), but is lower than the permissible zinc concentration in Canadian drinking water. The concentration of anthracene, fluoranthene, pyrene and nonylphenols exceed the limits for freshwater specified in the Canadian Environmental Quality Guidelines. An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the degree to which the concentrations of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols in the leachate are actually harmful to people and the environment.

The recycled rubber granulates give off a significant number of alkylated benzenes in gaseous form. Trichloromethane (sample 1) and cis-1,2-dichlorethene (sample 5) were also found. It is

recommended that measurements be taken of air quality above pitches to determine whether the air quality is satisfactory. With the exceptions of chromium and zinc, EPDM rubber contains smaller quantities of hazardous substances than the recycled rubber types overall. It also gives off much smaller quantities of volatile organic compounds.

Oslo, 10.09.04
for the Norwegian Building Research Institute

Thale Plesser

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Measurement of Air Pollution in Indoor Artificial Turf Halls

Norwegian Pollution Control Authority
Norwegian Institute for Air Research

Measurement of air pollution in indoor artificial turf halls

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Measurement of air pollution in indoor artificial turf halls

Norwegian Pollution Control Authority/
Norwegian Institute for Air Research
State Programme for Pollution Monitoring

Foreword

In October 2005, the Norwegian Institute for Air Pollution (NILU) was commissioned by the Norwegian Pollution Control Authority (SFT) to measure the concentration of airborne dust and gas phase compounds in indoor air in indoor artificial turf pitches.

The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or Styrene Butadiene Rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall with granulate made from thermoplastic elastomer.

The study will be used as a basis for exposure calculations and the assessment of heath effects.

Many thanks to everyone who has contributed to this project:
Norwegian Football Association; Ole Myhrvold
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Østfoldhallen; Leif Andersen

The report was prepared by NILU.

Kjeller, 30 November 2005

Christian Dye
Project Manager

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Summary

This report describes measurements of air quality for three indoor artificial turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber or Styrene Butadiene Rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer. The parameters which were covered are the concentration and chemical composition of airborne dust and the concentration in indoor air of volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH).

The study will be used as a basis for exposure calculations and the assessment of health effects. There is little data in the literature from corresponding air studies. There are also no specific criteria or guidelines concerning air quality in indoor sports facilities. NILU's own experience of indoor environments over many years, together with guidelines and recommendations that NILU considers to be relevant references, was therefore used in the assessment of the results.

The study is characterised as a random sample study based on a limited number of pitches. The measurement programme was pre-determined.

The results indicate that the use of rubber granulate from ground car tyres (SBR rubber) causes a considerable burden on the indoor environment. Manglerudhallen and Valhall use this type of rubber granulate. Rubbers granulate produced from thermoplastic elastomer generate less pollution from the parameters that were measured compared with rubber granulates made from thermoplastic elastomer. For all three halls, the study shows the presence of organic chemicals which have not been identified or reported.

The report contains a method description, measurement results and some results from laboratory studies of the rubber granulate. The results are discussed and summarised.

The report has been prepared by the Norwegian Institute for Air Research (NILU) on behalf of the Norwegian Pollution Control Authority (SFT). NILU is responsible for the results, assessments and conclusions.

1. Introduction

In October 2005, the Norwegian Institute for Air Research (NILU) was commissioned by the Norwegian Pollution Control Authority (SFT) to measure the concentration of airborne dust and gas phase compounds in indoor artificial turf pitches. The measurement programme is described in Table 1.

Table 1: Measurement programme for indoor artificial turf facilities on behalf of SFT.

Fraction	Parameter
Airborne dust (PM_{10})	Concentration Proportion of rubber Vulcanisation compounds, preservative compounds Phthalates Tar compounds (PAH)
Airborne dust ($PM_{2.5}$)	Concentration Proportion of rubber Vulcanisation compounds, preservative compounds Phthalates
Gas phase	Volatile organic compounds (VOC) Tar compounds (PAH)

The measurements were to be taken in a hall with recently laid rubber granulate (SBR rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year, and a hall with granulate made from thermoplastic elastomer.

There is little data from corresponding air studies in the literature. There are also no criteria or guidelines for air quality in indoor sports facilities. NILU's own experience of indoor environments over many years, together with guidelines and recommendations that NILU considers to be relevant references, was therefore used in the assessment of the results.

2. Materials and methods

2.1 Sampling

Airborne dust was collected on a 47 mm quartz fibre filter with a flow rate of 2.3 m^3/hour. Separate filters were used for the PM_{10} fraction (particulate material with an equivalent aerodynamic diameter < 10 μm) and the $PM_{2.5}$ fraction (particulate material with an equivalent aerodynamic diameter < 2.5 μm). The sampling system was of the Kleinfiltergerät type, with an intake which complies with prEN12341.

The airborne dust (PM_{10}) which was to be analysed for PAH was collected on a 150 mm glass fibre filter with a flow rate of 30 m^3/hours, while the gas phase compounds were collected on polyurethane plugs. The sampling system was a Digital Automatic High Volume Aerosol Sampler (DHA-80) with an intake which complies with prEN12341.

Volatile organic compounds (VOCs) were collected on a Tenax-adsorbent using active sampling in accordance with prEN ISO 16017. The carbonyl compounds with one to three carbon atoms were collected on a silica-adsorbent impregnated with 2,4-dinitrophenylhydrazine, using active sampling (Brombacher et al., 2002).

2.2 Chemical analysis

The chemical analysis of the airborne dust involved extracting part of the filter in a solvent in an ultrasound bath for 30 minutes. This was done twice to optimise the extraction yield, and the extracts were then combined and analysed jointly. No isotope-marked standards are commercially available for many of the analytes which were analysed. The sample preparation was therefore based on careful handling, while calculations were based on an external standard. Validation studies which were carried out at the laboratory show that recovery rates in excess of 90% were achieved for most of the analytes.

The carbon analysis was carried out by heating the filter in accordance with the EGA (evolved gas analysis) principle. All the carbon was converted to CO_2 and then methane. The methane was quantified using a FID (flame ionisation detector) (Birch et al., 1996)

The methodology which was used for PAH in airborne dust and gas phase was based on Thrane et al. (1985). The results were corrected for any loss during extraction and preparation through the setting of an internal standard. The most relevant analytical parameters are shown in Table 2.

Determination of all types of volatile organic compounds was carried out in accordance with prEN ISO 16017.

Table 2: The most relevant analytical parameters.

Parameter	Extraction	Preparation	Quantification	Ionisation technique	Column	Measurement uncertainty
Carbon EC/OC	None	Thermo-optical transmission	Methane - Internal state	None	None	± 10%
Proportion of rubber	Liquid	SPE	LC/MS-TOF	ESI(+)	Atlantis dC18, 3 µm 15 cm * 2.1 mm	± 20%
Vulc. and preservative compounds	Liquid	Centrifuging	LC/MS-TOF	ESI(+), ESI (-)	ACE C18 3 µm 15 cm * 2.1 mm, Atlantis dC18, 3 µm 15 cm*2.1 mm	± 25%
Phthalates	Liquid	Centrifuging	LC/MS-TOF	ESI(+)	Atlantis dC18, 3 µm 15 cm*2.1 mm	± 20%
Tar compounds (PAH)	Soxhlet	Liquid/Liquid, LC	GC/MS	EI	Cp Sil8 25m*0.25 mm	± 30%
Volatile organic compounds (VOC)		Thermodesorption	GC/MS	EI	DB 1701, 1 µm, 30 m,0.5 mm	± 25%
Carbonyl compounds	Liquid	SPE	HPLC/UV		NovaPakC18, 15 cm * 3.9 mm	± 14%

EC means elementary carbon, OC means organic carbon.
EI: Electron impact ionisation.
ESI (-/+): negative/positive electrospray.
GC/MS: Gas chromatography linked to mass spectrometer
LC/MS-TOF: Liquid chromatography linked to a "time-of-flight" mass spectrometer. This gives high resolution mass spectrometry in contrast to an ordinary LC/MS. (Instrument: Waters LCT).
SPE: Solid phase extraction. (OASIS MCX, Waters DNPH-silica).
Thermo-optical transmission: See www.sunlab.com

2.3 Measuring points

Table 3 describes the artificial turf pitches from which samples were taken. We have also enclosed photographs of the halls and the rubber granulate in Appendix 2. Table 4 describes the sample types which were taken.

Table 3: Description of measuring points.

	Manglerudhallen (Oslo)	Manglerudhallen (Oslo)	Valhall (Oslo)	Østfoldhallen (Østfold)
Date	17.10.05	19.10.05	19.10.05	18.10.05
Time	16.20 - 22.35	17.33 - 18.17	16.45 - 21.55	17.05 - 22.40
Temperature start (°C)	18	15	15	17
Temperature stop (°C)	10	15	15	17
Relative air humidity (%)	53	Not measured	42	34
Air pressure (hPa)	Not measured	Not measured	1009	1028
Pitch dimensions (metres)			68X105	68X105
Rubber granulate (type)	Ground car tyres (black and an unknown type (green)	Ground car tyres (black and an unknown type (green)	SBR rubber	Thermoplastic elastomer

Weight/volume of rubber granulate (kg/m^3)	489	489	395	790
Weight per granule with standard deviation (mg)	10 (±2.2) black 15 (±4.1) green	10 (±2.2) black 15 (±4.1) green	13 (±2.8)	7 (±0.7)
Age (number of months at time of sampling)			2	10

Table 4: The samples which were taken.*

Fraction	Location	Typical volume in litres
Airborne dust (PM_{10})	Manglerudhallen, Valhall, Østfoldhallen	12
Airborne dust ($PM_{2.5}$)	Manglerudhallen, Valhall, Østfoldhallen	12
Volatile organic compounds (VOC)	Manglerudhallen, Valhall, Østfoldhallen	5-25
Tar compounds (PAH) in airborne dust and gas phase	Manglerudhallen, Valhall, Østfoldhallen	120 000-170 000
Highly volatile carbonyl compounds	Manglerudhallen, Valhall, Østfoldhallen	600

* Samples of granulate and rubber mats in the body of the pitch were also taken.

3. Results

The results from the measurements are presented in Tables 5 to 7.

Table 5: Concentration of polycyclic aromatic hydrocarbons (PAH) in the gas phase and airborne dust (PM_{10}).

Location **Sample type** **Measurement period** **Unit** **Parameter**	**Manglerudh.** **Gas phase** **16.26-22.31** **ng/m^3**	**Manglerudh.** **PM10** **16.26-22.31** **ng/m^3**	**Valhall** **Gas phase** **16.47-21.55** **ng/m^3**	**Valhall** **PM10** **16.47-21.55** **ng/m^3**	**Østfoldh.** **Gas phase** **17.07-22.37** **ng/m^3**	**Østfoldh.** **PM10** **17.07-22.37** **ng/m^3**
Naphthalene	20.9	0.13	56.4	0.17	11.1	0.04
2-Methylnaphthalene	22.3	0.13	57.7	0.13	24.7	0.06
1-Methylnaphthalene	16.1	0.16	42.5	0.07	16.5	0.10
Biphenyl	16.6	0.08	32.7	0.05	13.4	0.03
Acenaphthylene	32.4	0.19	78.1	0.04	6.24	0.07
Acenaphthene	5.82	0.06	14.2	0.02	4.77	0.02
Dibenzofurane	10.8	0.10	17.0	0.04	10.2	0.05
Fluorene	10.2	0.10	19.2	0.04	7.86	0.06
Dibenzothiophene	1.76	0.03	2.74	0.01	0.88	0.03
Phenanthrene	19.7	0.52	25.0	0.33	14.0	0.44
Anthracene	1.86	0.05	1.33	0.04	0.77	0.04
3-Methylphenanthrene	2.02	0.09	2.82	0.08	1.54	0.09
2-Methylphenanthrene	2.12	0.12	3.03	0.12	1.78	0.12
2-Methylanthracene	0.39	0.02	0.22	0.02	0.12	0.01
9-Methylphenanthrene	1.89	0.10	2.75	0.09	1.37	0.12
1-Methylphenanthrene	1.52	0.09	2.11	0.08	1.08	0.09
Fluoranthene	2.81	0.67	2.20	0.48	1.66	0.62

Pyrene	3.54	0.81	3.09	0.64	1.80	1.17
Benzo(a)fluorene	0.05	0.06	0.12	0.02	0.05	0.05
Rethene	0.67	0.36	0.42	0.12	0.49	0.20
Benzo(b)fluorene	0.11	0.10	0.03	0.08	0.07	0.06
Benzo(ghi)fluoranthene	0.17	0.29	0.11	0.23	0.08	0.28
Cyclopenta(cd)pyrene	0.15	0.58	0.07	0.35	0.07	0.23
Benzo(a)anthracene	0.15	0.56	0.07	0.36	0.05	0.14
Crysene /Triphenylene	0.19	0.76	0.11	0.53	0.10	0.38
Benzo(bjk)fluoranthene	0.04	2.24	0.01	1.23	0.04	0.72
Benzo(a)fluoranthene	0.02	0.44	0.01	0.23	0.03	0.35
Benzo(e)pyrene	0.03	0.78	< 0.01	0.48	0.02	0.39
Benzo(a)pyrene	0.02	1.15	< 0.01	0.56	0.01	0.38
Perylene	0.02	0.20	< 0.01	0.09	0.01	0.08
Indeno(123-cd)pyrene	< 0.02	1.11	< 0.01	0.73	< 0.01	0.42
Dibenzo(ac/ah)anthracene	< 0.02	0.13	< 0.01	0.07	< 0.01	0.06
Benzo(ghi)perylene	< 0.02	1.11	< 0.01	0.84	< 0.01	0.69
Anthanthrene	< 0.02	0.39	< 0.01	0.22	< 0.01	0.21
Coronene	< 0.01	0.61	< 0.01	0.51	< 0.01	0.38
Dibenzo(ae)pyrene	< 0.01	0.06	< 0.01	< 0.01	< 0.01	< 0.01
Dibenzo(ai)pyrene	< 0.01	0.04	< 0.01	< 0.01	< 0.01	< 0.01
Dibenzo(ah)pyrene	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total	174.17	10.84	363.74	6.46	120.64	4.89

Table 6a: Simplified presentation of the concentration of volatile organic compounds (VOC). Typical rubber components are shown. A more detailed list from each sample is presented in Appendix 1.

Measuring location	**Measurement period**	**Benzothiazole µg/m^3**	**Toluene µg/m^3**	**4-methyl-2-pentanone µg/m^3**	**Total VOC µg/m^3**
Manglerudh. A	16.31-18.50	15.7	85.0	12.7	715.5
Manglerudh B	18.55-22.00	8.9	51.2	3.4	233.8
Manglerudh C	20.26-22.06	4.5	30.0	2.0	150.5
Manglerudh D (19.10.05)	17.33-18.17	20.4	39.4	11.5	255.3
Valhall A	16.53-22.00	29.1	15.0	11.3	233.9
Valhall B	19.35-22.00	31.7	15.3	12.7	289.8
Østfoldhallen A	17.15-20.10	3.4	17.2	< 0.9	136.3
Østfoldhallen B	20.13-22.35	3.9	19.4	< 1.2	161.3

Table 6b: Concentration of phthalates in the gas phase. The concentrations are included in TVOC.*

Measuring location	**Measuring period**	**Diethylphthalate (DEP) µg/m^3**	**Diisobutylphthalate (DiBP) µg/m^3**	**Dibutylphthalate (DBP) µg/m^3**
Manglerudh. A	16.31-18.50	0.04	0.07	0.20
Manglerudh. B	18.55-22.00	0.06	0.10	0.20
Manglerudh. C	20.26-22.06	0.03	0.13	0.38
Valhall A	16.53-22.00	0.01	0.02	0.07
Valhall B	19.35-22.00	0.02	0.01	0.07

Østfoldhallen A	17.15-20.10	0.06	0.03	0.06
Østfoldhallen B	20.13-22.35	0.09	0.05	0.18

*Phthalates which are not referred to in the table have gas phase concentrations of < 0.005 µg/m3

Table 7: Results from the physical and chemical analysis of airborne dust.

Location **Sample type**		**Mangl.** **PM_{10}**	**Mangl.** **$PM_{2.5}$**	**Valh.** **PM_{10}**	**Valh.** **$PM_{2,5}$**	**Østf.** **PM_{10}**	**Østf.** **$PM_{2.5}$**
Measuring period		**16.26-22.31**	**16.26-22.31**	**16.47-21.55**	**16.47-21.55**	**17.07-22.37**	**17.07-22.37**
Parameter	**Unit**						
Weight	µg/m^3	40.10	17.32	31.72	18.83	31.26	10.31
Organic carbon (OC)	µg/m^3	14.72	8.24	10.95	9.70	11.41	7.70
Elementary carbon (EC)	µg/m^3	2.73	1.86	3.51	3.40	0.93	0.83
Total carbon (EC+OC)	µg/m^3	17.45	10.10	14.47	13.10	12.33	8.53
Dimethylphthalate (DMP)	ng/m^3	39.1	11.6	50.3	7.6	17.9	5.4
Diethylphthalate (DEP)	ng/m^3	24.4	2.8	10.4	5.7	27.9	19.8
Dibutylphthalate (DBP)	ng/m^3	31.4	15.1	51.7	53.7	45.4	44.0
Diamylphthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Diethylhexylphthalate (DEHP)	ng/m^3	31.3	5.5	17.7	11.6	22.1	13.2
Dioctylphthalate (DOP)	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
bis (2-n-ethoxethyl) phthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzylbutylphthalate (BBP)	ng/m^3	5.2	2.3	4.3	2.5	3.9	2.6
bis (2-n-butoxyethyl) phthalate	ng/m^3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Total phthalates	ng/m^3	131.4	37.3	134.4	81.2	117.1	84.9
Rubber dust*	µg/m^3	9.3	8.8	8.8	6.6	1.0	0.5
Proportion of rubber dust of total PM	%	23.2	50.1	27.7	35.1	3.2	4.9
2-aminobenzothiazole***	pg/m^3	54	51	28	21	< 0.4	< 0.2
2-methylthiobenzothiazole***	pg/m^3	153	145	137	102	< 5	< 3
N-isopropyl-N'-phenyl-p-phenylendiamine***	pg/m^3	887	839	267	201	< 0.08	< 0.04
N-cyclohexyl-2-benzothiazole sulphenamide***	pg/m^3	23	21	3	2	< 0.03	< 0.02
2-(4-morpholinyl)benzothiazole***	pg/m^3	48	45	38	28	< 0.2	< 0.1
2-morpholinothiobenzothiazole***	pg/m^3	171	162	63	47	< 0.3	< 0.2
N-phenyl-1,4-phenylenediamine***	pg/m^3	158	149	150	112	< 0.1	< 0.05
2-mercapto benzothiazyl disulphide***	pg/m^3	22	21	27	20	< 0.2	< 0.1
N-cyclohexyl-2-benzothiazolamine (NCBA)***	pg/m^3	36	35	60	45	< 0.003	< 0.002
2-mercaptobenzothiazole***	pg/m^3	287	272	352	264	< 0.03	< 0.02
2-hydroxybenzothiazole***	pg/m^3	346	328	566	425	< 0.05	< 0.03
Total selected vulcanisation and preservative compounds	pg/m^3	2185	2068	1691	1268		

*: In Manglerudhallen and Valhall, the rubber quantity was determined using NCBA as a trace material (Kumata et al. 2000). In Østfoldhallen, a trace material with a molecular weight of 312 ionised with APCI (Atmospheric Pressure Chemical Ionisation) was used.

***: Calculated using measurements carried out on ground granulate and measured concentrations of rubber in the airborne dust.

4. Assessment

4.1 Limits

The norms prEN12457 and DIN 18035-7 are often used in connection with environmental aspects linked to rubber granulate. These norms were originally designed to study the leaching of chemicals into water and did not concern air. The norms are therefore considered to be of little relevance to this study.

Today, there are no limits which specifically regulate indoor environments in sports facilities. The national recommended norm for indoor climate is the norm which covers this type of indoor environment. Table 8 summarises the norms and limits together with the norms for outdoor air for information purposes.

Table 8: Norms, limits and national targets for relevant parameters.

Parameter	Measurement period	24 hours	Calendar year	Non-specific
PM_{10}	Binding limits for outdoor air	50 µg/m^3 , can be exceeded 35 times a year	40 µg/m^3	
PM_{10}	National target for outdoor air	50 µg/m^3 **A)** can be exceeded 7 times a year		
PM_{10}	National recommended norm for outdoor air	35 µg/m^3		
$PM_{2.5}$	National recommended norm for indoor climate **B)**/outdoor air	20 µg/m^3		
Benzene	National target		2 µg/m^3 **A,C)**	
Benzene	Binding limit for outdoor air		5 µg/m^3	
Benzo(a)pyrene	EU target value for outdoor air[4)]	1 ng/m3 **D)**		
Volatile organic compounds (VOC)	National recommended norm for indoor climate	**B)**		Based on a practical hygienic assessment, unnecessary exposure should be avoided. The presence of particularly irritating/reactive

	substances must be assessed separately.

A): Must be met by 1.1.2010
B): Report from the National Institute for Public Health (1998) Recommended technical norms for indoor climate, ISBN:82-7364133-3
C): Applies to urban background
D): Directive 2004/107/EC of the European Parliament and of the Council, 15 December 2004, Brussels

4.1.1 Experience

NILU's experience of the determination of volatile organic compounds (VOC) in indoor environments shows that in well ventilated domestic environments, individual components with a concentration of over 10 µg/m^3 are rarely encountered. The total concentration of volatile organic compounds (TVOC) in commonly occurring indoor environments is normally below 100 µg/m^3. However, in poorly ventilated single family houses during the winter, levels of 100-150 µg/m^3 will typically be found. Complaints about air quality can be made at concentrations as low as 100 µg/m^3. However, experts no longer focus solely on concentration because no clear link has been demonstrated between concentration and health effects. In poor indoor environments, NILU's experience is that the occurrence of problematic components often has a greater impact than the total level of pollution, and pollutants in the gas phase must be considered together with airborne dust. This is because the airborne dust in itself can cause illness and increased mortality and because fine particulate airborne dust acts as a transporter of semi-volatile organic compounds (SVOC) down into the lungs.

The occurrence of airborne dust in indoor environments is influenced by factors such as level of activity and the characteristics, ventilation and construction materials of the room. It is therefore difficult to present a simple picture of what concentrations of airborne dust should be expected. There are no limits for homes, sports halls or other comparable buildings. In the discussion of the results, reference is therefore made to examples of corresponding measurements (parameters) which have been taken in indoor environments in the Oslo region. A summary of these studies is presented in Table 9.

Table 9: Summary of studies of airborne dust in 14 different indoor environments in Oslo. The study covers schools, nurseries and private homes.

	OC µg C/m^3	EC µg C/m^3	TC µg C/m^3	Weight µg/m^3
PM_{10}				
Arithmetic mean	6.3	0.8	7.1	21.1
Min	1.3	0.3	1.7	3.8
Max	17.6	1.3	18.6	83.5
$PM_{2.5}$				
Arithmetic mean	2.9	0.7	3.5	7.2
Min	1.1	0.2	1.4	0.9
Max	5.8	1.5	7.3	14.9

4.2 Volatile organic compounds (VOC)

The results give an average over the measuring period. The occurrence of volatile organic compounds is created by dynamic processes which are influenced by temperature, air pressure, air humidity, air turnover, concentrations of airborne dust and source strength. For example, the use of scents, spray-painting, washing, miscellaneous use of machinery, etc. could alter the composition from one minute to the next.

4.2.1 Manglerud artificial turf hall, Oslo

Sampling was commenced at 16.31 and concluded at 22.06. The sampling location was chosen as the halfway line off the pitch itself, so as not to hinder planned football activities (see the photograph in Appendix II). After 30 minutes' sampling, 8 roof hatches and 16 windows were opened for ventilation. The outdoor temperature was around 0°C while the temperature inside the hall was 18°C. This created a considerable air flow and by 20.00 the indoor temperature had fallen to 10°C. The sampling was therefore carried out sequentially in order to demonstrate any concentration gradient during the ventilation period. The ventilation was stopped when the sampling equipment was packed away at about 22.15.

The first sample taken at the halfway line (16.31-18.50) shows a TVOC concentration of 716 $\mu g/m^3$ (Table 6a, Appendix I). This is considered to be an extremely high concentration given that there was full ventilation during 80% of the sampling period. Other samples at the halfway line (18.55-22.00) show a TVOC concentration of 234 $\mu g/m^3$. This is also a high concentration, but considerably lower than the first sample. Assessed on the basis of the effectiveness of the ventilation, i.e. the difference between the first and the second sample, it is reasonable to assume that the TVOC was closer to 1000 $\mu g/m^3$ at the start of sampling and down towards 100 $\mu g/m^3$ at the end. Sample 3 with a TVOC of 151 $\mu g/m^3$ was taken at the entrance to the hall (20.26-22.06) and can be characterised as a slightly but not uncommonly high value.

The analyses of the air show a very large number of compounds which experience has shown could contribute to an unpleasant atmosphere. The chemical spectrum shows a good correspondence with NILU's degassing analyses of the rubber granulate from the pitch substrate and the rubber mats (Dye et al., 2005) which are lowermost in the pitch substrate with typical rubber components such as benzothiazole, 4-methyl-2-pentanone, miscellaneous alkylbenzenes (such as styrene) and formaldehyde. The correspondence is so clear that it must be concluded that the rubber granulate is the most important source of the TVOC values measured. The results show that even with good ventilation and low temperatures, values would not fall much below 100 $\mu g/m^3$ with the clear dominance of chemicals from the rubber granulate. This indicates a considerable source strength in the rubber granulate, something which requires a high turnover of air.

The total concentration of PAH in the gas phase was 174 ng/m^3 (Table 5). This corresponds to an outdoor sample from Oslo during the summer (Larssen, 1988)

Inside the halls during the period, we measured a benzene concentration of 2 ug/m^3 (Appendix I). Based on regular outdoor measurements of BTEX (Benzene, Toluene, Ethylbenzene and Xylene) adjacent to the E6 European road at Manglerud, the rolling 12-month average benzene concentration was measured at 1.3 ug/m^3 in October 2005. In the case of Manglerudhallen, there was a significant wind from the background area when the last VOC sample was taken (east, southeast). There was also a period when the road traffic normally decreased significantly. We therefore estimate the outdoor concentration of benzene to have been 0.7 ug/m^3. The net contribution of benzene from indoor sources in Manglerudhallen is therefore estimated to be 1.3 ug/m^{3s}.

Due to the ventilation, a further sample was taken on 19.10.05 during the period 17.33-18.18, two days after the first round. Roof hatches and windows were closed and the temperature in the hall was 15°C. The TVOC concentration measured during this period was 255 µg/m^3 (Table 6a, Appendix I).

4.2.2 Østfoldhallen artificial turf pitch, Fredrikstad

Sampling was carried out during the periods 17.15-20.10 and 20.13-22.35. The samples were taken from the centre of the pitch (see the photograph in Appendix II). Activity levels and operating conditions on the pitch were normal throughout the sampling period. The first sample showed a TVOC concentration of 136 µg/m^3, whilst the second sample showed 161 µg/m^3 (Table 6a, Appendix I). This level indicates that the environment is affected by one or more sources, but the level itself is not unusual in indoor environments. The TVOC level rises slightly with use. This rise can be explained through the mechanical working of the granulate which causes degassing to increase. It is unclear whether the concentrations of benzothiazole largely originate from the rubber mat beneath the artificial turf or whether the rubber granulate is the source. Analyses of the rubber granulate (NILU report) indicate the absence of traditional vulcanisation chemicals which are found in SBR and the presence of benzothiazole. The chemical spectrum in the air also shows the signature of the timber in the hall (α-pinene) and the road traffic from outside the hall (BTEX).

4.2.3 Valhall artificial turf pitch, Oslo

Sampling was carried out during the periods 16.53-22.00 and 19.35-22.00. Activity levels and operating conditions on the pitch were normal throughout the sampling period. A large hall door was opened on two occasions early in the sampling period in order to let two vehicles out. This could have reduced the concentrations slightly. A sampling location was chosen off the pitch so as not to hinder planned football activities (see the photograph in Appendix II). The average TVOC concentration for the entire period was 234 µg/m^3, whilst the corresponding value for the second half of the sampling period was 290 µg/m^3 (Table 6a, Appendix I). This increase can be explained by mechanical working

of the granulate, causing an increase in degassing. The TVOC concentrations are relatively high and the air analyses show good correspondence with NILU's degassing analyses of the rubber granulate from the pitch substrate and the rubber mats (glued rubber granulate) lowermost in the pitch substrate (NILU report), with typical rubber components such as benzothiazole, 4-methyl-2-pentanone, miscellaneous alkylbenzenes (such as styrene) and formaldehyde. The correspondence is so clear that it must be concluded that the rubber granulate is the most important source of the TVOC values measured.

The total concentration of PAH in the gas phase was 363 ng/m^3 (Table 5). This is more than twice the figure for Manglerudhallen. The level could correspond to outdoor air in Oslo on days with severe pollution during the warmer months (Larssen, 1988).

Inside the hall, during this period we measured a benzene concentration of 2.4 ug/m^3 (Appendix I). The dominant outdoor wind direction during the sampling was east-north-east, i.e. parallel to the E6. The sampling was carried out during a period when road traffic is normally quiet. Based on regular outdoor measurements of BTEX in Oslo, we estimate the background level of benzene to have been 1 µg/m^3. The net contribution of benzene from indoor sources is therefore estimated to have been 1.4 µg/m^3.

4.2.4 Laboratory tests

4.2.4.1 Relative source strength

A degassing test was carried out to compare the source strength for the rubber granulates. Rubber granulate samples (2g) from each of the pitches were stored in a 100 ml Pyrex glass bottle for equal periods of time at 23°C. An adsorption tube was placed in each of the bottles to take samples of the degassed compounds. In such a test, each individual volatile compound will act according to its own physical and chemical properties. To obtain a simple overview, benzothiazole was chosen as an indicator component because it is a typical rubber component. The results are shown in Figure 1. The values have been normed in relation to Valhall, which gave the highest values. Manglerudhallen gives off 82% compared with Valhall, while the granulate in Østfoldhallen gives off 27%. The results correspond well with the actual measurements shown in Table 6a.

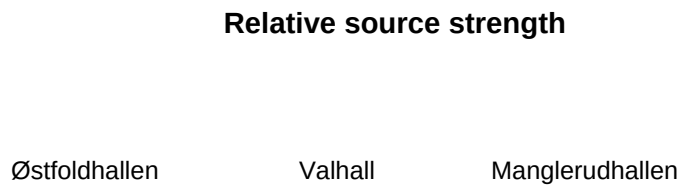


Figure 1: Relative source strength for benzothiazole in the artificial turf granulate.

4.2.4.2 Surface coating on the granulate

The granulate in Valhall was glossier and shinier than that from Manglerudhallen. Examination under a stereo microscope (visual magnification) confirmed that the granulate from Valhall appeared to have a coating or a film on the surface to which particulate material was attached. The granulate from Manglerudhallen appeared to have a drier surface which was also significantly more covered with particles. Against the background of these observations, both the granulates were washed with cyclohexane. The cyclohexane dissolved the coating slightly, indicating lipid (fat- or oil-like) properties. After washing, the surfaces of both granulates were visually identical, and for both granulate types the washing process resulted in considerable quantities of black fine-grained particulate material being left behind in the solvent after decanting. After drying, a further degassing test was carried out.

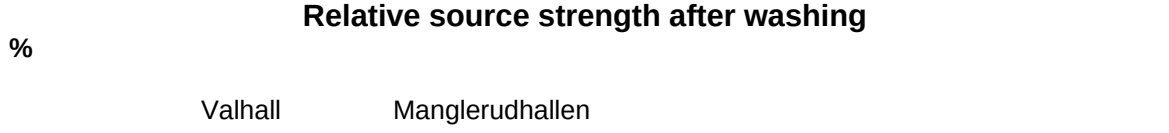


Figure 2: Relative source strength for benzothiazole in the artificial turf granulate after washing with cyclohexane.

The results are shown in Figure 2. These results indicate that the difference in source strength with regard to benzothiazole increased considerably compared with the results in Figure 1 (before washing). A reasonable explanation (hypothesis) of this phenomenon could be that the observed film is saturated with benzothiazole and therefore acts as a diffusion barrier. As the diffusion barrier dries out or is removed mechanically by wear, the source strength will increase. The magnitude of the increase over time (years) is difficult to estimate because the granulate will also be 'emptied' of chemicals. On the basis of this test, there is reason to assume that the TVOC level in Valhall will increase to a maximum after a period of time (years) and then decrease as the granulate is "emptied".

4.2.4.3 Source strength and temperature influence

The ventilation in Manglerudhallen generated a need to know how the temperature affects the source strength. This was tested in headspace studies at 6°C, 20°C, 27°C and 36°C. The results are presented for benzothiazole and 4-methyl-2-pentanone in Figure 3. The figure shows that the source strength for the two components during a temperature reduction from 18°C to 10°C decreased by 50% and 22% for benzothiazole and 4-methyl-2-pentanone respectively. The effect of the source strength reduction is therefore in addition to the replacement of the air in Manglerudhallen. The temperature test in Figure 3 will in principle be of relevance to both Valhall and Østfoldhallen; the values and the increase coefficients of the curves may however be slightly different.



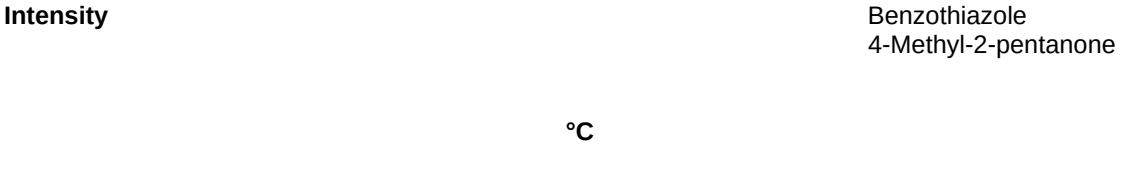


Figure 3: Change in source strength with change in temperature for rubber granulate in Manglerudhallen.

It is assumed that temperatures over 25°C in the granulate are rare indoors, but in no way unrealistic outdoors in direct sunlight.

4.3 Airborne dust

The EC/OC ratio (the ratio between elementary carbon (EC)/carbon black and organic carbon (OC) was determined for the particle samples. The aim in doing this was to determine what proportion of the particles is inorganic and what proportion is organic. The relevance for artificial turf pitches is that rubber from car tyres contains between 26% (Edeskär, 2004) and 33% (Dye et al., 2005) carbon black. Together with trace material measurements, the method can therefore give an indication of the sources of the airborne dust. This makes it easier for example to assess any measures in relation to the sources of the airborne dust.

A general characteristic of airborne dust is that the concentrations of individual organic components can often seem modest compared to what is present in the gas phase. This does not mean that the chemical composition of the airborne dust is of no importance, but the mechanisms of action are complex and will not be considered in this report.

4.3.1 Manglerud artificial turf hall, Oslo

The values measured in the hall represent an average over the measurement period. Due to the ventilation described in section 4.2.1, it must be assumed that the results represent some of the lowest values that can be achieved in the hall. The PM_{10} level was 40 μg/m^3, while the $PM_{2.5}$ level was 17 μg/m^3 (Table 7). Based on the discussion in 4.2.1, it is reasonable to assume that the airborne dust values may have been more than twice as high because the source strength of the airborne dust could hardly have been as strong as it is for volatile organic compounds. It follows from this that the airborne dust levels were probably of the order of twice that of norms and national targets for 24-hour mean values.

The concentrations measured are higher than the arithmetic mean in the Oslo study (Table 9), which showed values of 21 μg/m^3 and 7 μg/m^3. The proportion of carbon is also higher than in the Oslo study, with an EC/PM_{10} ratio of 0.07. In the Oslo study, the arithmetic mean for the EC/PM_{10} ratio was 0.04. The proportion of rubber dust was 23.2% in the PM_{10} fraction and 50.1% in the $PM_{2.5}$ fraction. This indicates a strong contribution from the granulate. The presence of selected vulcanisation and preservative compounds is given in Table 7 and indicates that the granulate contains the same

compounds that are found in car tyres. The air concentration of PAH in the airborne dust is comparable to an outdoor air sample from Oslo during the warm months (Larssen, 1988). Based on chemical analyses of the granulate (Dye et al., 2005) and the measured concentration of rubber in the airborne dust, the granulate is an insignificant source of benzo(a)pyrene in the airborne dust.

4.3.2 Østfoldhallen artificial turf pitch, Fredrikstad

The values measured in the hall represent an average over the measurement period. The PM_{10} level was 31 µg/m^3, while the $PM_{2.5}$ level was 10 µg/m^3 (Table 7). This is higher than the arithmetic mean in the Oslo study, which showed values of 21 µg/m^3 and 7 µg/m^3 respectively (Table 9). The proportion of carbon is also higher in Østfoldhallen with an EC/PM_{10} ratio of 0.03. In the Oslo study, the arithmetic mean of the EC/PM_{10} ratio was 0.04. This indicates a slightly weaker EC source than that indicated by the Oslo study. The rubber granulate in Østfoldhallen does not contain any carbon black. The proportions of rubber in the PM_{10} and $PM_{2.5}$ fractions are 3.2% and 4.9% respectively. These values are not abnormally high, but the rubber which was found originates from the granulate. The granulate does not contain any vulcanisation or preservative compounds which are normally found in car tyres. The air concentration of PAH in the airborne dust is comparable to an outdoor air sample close to a busy road.

4.3.3 Valhall artificial turf pitch, Oslo

The values measured in the hall represent an average over the measurement period. The PM_{10} level was 32 µg/m^3, while the $PM_{2.5}$ level was 19 µg/m^3 (Table 7). The levels are lower than in Manglerudhallen and can be explained by the film on the surface of the granulate acting as a particle trap. This effect is assumed to decrease over time as the film dries out, and the concentration of particulate matter in the air can therefore be expected to increase.

The concentrations of PM_{10} and $PM_{2.5}$ are higher than the arithmetic mean in the Oslo study, which showed values of 21 µg/m^3 and 7 µg/m^3 respectively (Table 9). The proportion of carbon is also higher in Valhall with an EC/PM_{10} ratio of 0.11. In the Oslo study, the EC/PM_{10} ratio was 0.04. This indicates a considerably stronger EC source than that indicated by the Oslo study. The proportion of rubber dust was 27.8% in the PM_{10} fraction and 35.1% in the $PM_{2.5}$ fraction. This indicates a strong contribution from the granulate. The presence of selected vulcanisation and preservative compounds is given in Table 7 and indicates that the granulate contains the same compounds as those found in car tyres. The air concentration of PAH in the airborne dust was 6.5 ng/m^3 and is half of what was found in Manglerudhallen. Based on chemical analyses of the granulate (Dye et al., 2005) and the measured concentration of rubber in the airborne dust, the granulate is an insignificant source of benzo(a)pyrene in the airborne dust.

4.3.4 Occurrence of rubber particles in the airborne dust

In Manglerudhallen, the proportion of rubber dust in the PM_{10} fraction was 23.2%, while the corresponding figure for the $PM_{2.5}$ fraction was 50.1% (Table 7). In Valhall, the proportion of rubber dust was 27.8% in the PM_{10} fraction and 35.1% in the $PM_{2.5}$ fraction. No good references were found in the literature concerning the occurrence of rubber particles in indoor airborne dust. The formation of airborne dust from car tyre wear is however a well known phenomenon outdoors. Concentrations of airborne dust from car tyres and the size distribution of the particles vary with the location of the sampling site relative to the source (road traffic). A general characteristic is that at locations with a high rate of wear (sharp bends), large rubber particles are formed which are not converted into airborne dust, whilst on high speed roads smaller rubber particles are formed which can be found in the airborne dust. A number of studies show a proportion of car rubber particles in the PM_{10} fraction of around 1% (Cadle et al. (1979), Rogge et al (1993) and Fishman et al. (1996)). Along busy roads and urban background areas, Hüglin (2000) found 7.5% and 2% rubber in the PM_{10} fraction respectively. Kumata et al. (1996) found an extremely low contribution of car rubber (0.001 $\mu g/m^3$) in TSP (total quantity of airborne dust) 500 metres from a road in a suburb of Tokyo. Compared with existing literature, both Manglerudhallen and Valhall have unusually high concentrations ($\mu g/m^3$) of particles from car rubber (granulate). The proportion of car rubber (granulate) in the airborne dust is also unusually high in both the PM_{10} and the $PM_{2.5}$ fraction.

Rubber particles have the property that they give off chemicals to the surroundings. This will take place directly to air and liquids with which the particles come into contact. A selection of such chemicals is shown in Table 7. The smaller the particles, the larger the surface area of the particles per unit weight. Smaller particles will have a more effective separation of chemicals per unit weight of rubber than larger particles. In total, larger particles will give off more chemicals, but over a longer period of time and at a slower rate per unit weight.

An average European car tyre consists of 42% rubber. The rubber used consists of 58.3% synthetic rubber and 41.7% natural rubber, Blic (2001). The natural rubber is produced from latex (sap) from the rubber tree, Hevea Brasiliensis. Williams et al. (1995) demonstrated the occurrence of latex allergen from car tyres in airborne dust from Denver in Colorado. Williams concluded that this finding should be taken into account when calculating changes in illness rates and mortality as a result of exposure to particles from car tyres. Latex allergen has also been demonstrated in airborne dust (PM_{10}) along roads in Oslo (Namork (2004)). In the literature, no unambiguous answer is given to the question of whether the latex allergen from car tyre particles airborne dust causes an increase in the occurrence of asthma. It is assumed that variations in the choice of methodology and experimental set-up could contribute to the ambiguity. The concentrations of rubber particles in the indoor air in Manglerudhallen and Valhall are however considerably higher than those reported in these studies. It is therefore recommended that possible problem areas linked to exposure to latex allergens via the air passages be assessed by specialists in the discipline.

It is not uncommon to observe football players sitting on the pitch with their hands in contact with the granulate. Following skin contact with the granulate in Manglerudhallen and Valhall, soot-like remains can be seen on the skin which among other things consists of very small rubber particles. This means that the skin is a possible exposure path for chemicals in the airborne dust, assuming that there is direct skin contact with the rubber granulate. It is recommended that possible problem areas linked to exposure to latex allergens via the air passages be assessed by specialists in the discipline.

4.4 Other factors

4.4.1 Swallowing of granulate

Many users have verbally stated that from time to time they can swallow rubber granulate accidentally. Table 10 presents the weight of each individual rubber ball or granule for the halls in this study. By cross-mirroring the findings in Table 9 with the results in Table 7, one can find answers to potential chemical exposure.

Example calculation:
N-isopropyl-N'-phenyl-p-phenylendiamine occurs in a concentration 887 pg/m^3 in the PM_{10} fraction in Manglerudhallen. This comes from 9.3 µg rubber/m^3. 887 divided by 9.3 gives 95.4 pg chemical/µg rubber. This gives a potential exposure of 954 ng for the black granulate.

Table 10: Weight of the rubber granulates.

	Østfoldhallen	Valhall	Manglerudhallen black	Manglerudhallen green
Average weight of 10 granules (mg)	7	13	10	15
Standard deviation (mg)	0.7	2.8	2.2	4.1
Relative standard deviation (%)	10.6	22.2	21.5	27.3

In general, people who swallow granulates will be exposed in the range 0.1-1000 ng for each chemical depending on the chemical and granulate type. Based on laboratory tests which show that the chemicals are released over a long period of time (until no further chemicals remain), it is reasonable to assume that chemicals will be released throughout the entire digestion period.

The Norwegian Building Research Institute (Plesser et al., 2004) has recently published a report which describes a study of the chemical composition of the rubber granulate. This study largely corresponds with the findings made by NILU in the granulate from Manglerudhallen, Valhall and Østfoldhallen. By comparing the results in Table 10 with the results in the Building Research Institute's report, it will be possible to obtain more answers with regard to potential exposure caused by swallowing.

5. Conclusions

Based on measurements and observations in this study, there are grounds to reach the following conclusions:

Quantity of airborne dust: Østfoldhallen has airborne dust concentrations that one would expect in an indoor environment for both PM_{10} and $PM_{2.5}$ fractions. Manglerudhallen (with full ventilation) and Valhall have elevated levels of the $PM_{2.5}$ fraction and are close to the national recommended norm of 20 $\mu g/m^3$. Manglerudhallen (with full ventilation) and Valhall fall within what one normally finds in an indoor environment for the PM_{10} fraction. Without full ventilation (and with a low outdoor temperature), Manglerudhallen will probably have high values of airborne dust and exceed norms, recommendations and limits for the PM_{10} and $PM_{2.5}$ fractions. Laboratory tests which were carried out indicate that the concentration of airborne dust in Valhall will rise over time (years).

Composition of airborne dust: the airborne dusts in Manglerudhallen and Valhall contain large quantities of rubber from the granulate, whilst in Østfoldhallen the proportion of rubber from the granulate is considerably less. In all three halls, the proportion of organic material is considerable. The airborne dust contains polycyclic aromatic hydrocarbons (PAH), phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines. It also contains organic and inorganic pollutants which are not specified in this study. Possible problem areas linked to latex exposure via the skin and air passages should be assessed by specialists.

Volatile organic compounds (VOC): The total concentration of volatile organic compounds in Manglerudhallen could, without ventilation, reach very high levels. Even with ventilation over a long period of time, the concentration of TVOC could be characterised as higher than normal. The component spectrum has a clear signature from the rubber granulate and contains a considerable number of components which are associated with adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

In Valhall, the concentration of TVOC can be characterised as high, and the level rises slightly over the evening. Laboratory tests indicate that the TVOC level will rise over time (years). The component spectrum has a clear signature from the rubber granulate and contains a large number of components which are associated with adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

In Østfoldhallen, the data indicates that the hall has sources which contribute to slightly elevated TVOC concentrations. The level comes in the upper range of normal levels and rises slightly during use over an evening. The component spectrum has a signature from the pitch substrate together with a number of components which are associated with

adverse effects on health. However, the importance in this particular case must be assessed by specialists in other disciplines.

The measurements taken in this study show that the TVOC concentrations in Manglerudhallen and Valhall are higher than in Østfoldhallen. This means that there are alternative rubber granulates which give lower TVOC levels than SBR rubber. It can therefore be concluded that the national recommended norm for TVOC in indoor climates is not being met in Manglerudhallen and Valhall. In this conclusion, there is however no general recommendation of the granulate which is used in Østfoldhallen as the study was not broad enough to give such a recommendation.

Unclarified factors: The chemical analyses in this study were carried out with regard to chemicals which are known in the literature to be commonly occurring in SBR rubber (car tyres). The chemical composition of the thermoplastic elastomer which is used in Østfoldhallen is very unlike SBR rubber, and there is little information available on this elastomer in the literature. Further studies of thermoplastic elastomers should therefore be carried out to map the occurrence of other components. In all three halls, it can be seen from the chemical analyses of the airborne dust that organic chemicals are present which have not been identified in this study. The levels will probably be of the order of ng/m^3 (for each individual compound) or lower. The identity of these compounds has not been determined. The presence of inorganic compounds was not covered by this study.

Due to the dimensions of a football pitch, inadequate product research before launching a product will lead to a risk of undesirable exposure to chemicals with adverse health effects. An active approach is therefore recommended with respect to future suppliers and manufacturers combined with independent product testing before new pitches are constructed.

6. References

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Appendix I

customer	Manglerudhallen
sample id	pipe 142 16.31-18.50 17 October 2005

Compound	Concentration (µg/m3)
toluene	85.0
butenylbenzene (isomers)	82.5
benzoic acid	81.0
diethenylbenzene (isomers)	41.0
butenylbenzene (isomers)	39.3
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	25.5
diethenylbenzene (isomers)	24.7
ethylbenzaldehyde (isomers)	19.7
benzothiazoles	15.7
1,1'-biphenyl	15.6
acetone	15.3
o-xylene (1,2-dimethylbenzene)	13.1
4-methyl-2-pentanone	12.7
3-phenyl-2-propenal	10.2
ethylbenzaldehyde (isomers)	8.0
pentenyl benzene (isomers)	7.3
pentanedioic acid dimethylester	6.8
ethylbenzaldehyde (isomers)	6.7
ethylbenzene	6.7
styrene (ethenylbenzene)	6.1
hexenylbenzene (isomers)	6.1
ethylcyclohexane	5.6
formaldehyde	5.5
2-butoxyethanol	5.3
unidentified naphthalene derivative	5.0
hexenylbenzene (isomers)	4.8
hexenylbenzene (isomers)	4.6
octane	4.6
undecane	4.6
acetaldehyde	4.3
unidentified naphthalene derivative	4.3
nitromethane	4.1
1-propynylbenzene	4.0
Total concentration of identified compounds	585.6
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**715.5**
number of compounds included in TVOC (conc.> 0.1µg/m3)	218.0

customer	Manglerudhallen
sample id	pipe 4 18.55-22.00 17 October 2005
Compound	Concentration (µg/m3)
toluene	51.2
benzoic acid	20.9
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	17.4
acetone	9.3
benzothiazole	8.9
acetonitrile	8.3
o-xylene (1,2-dimethylbenzene)	7.7
ethylbenzene	4.1
formaldehyde	3.4
4-methyl-2-pentanone	3.4
acetaldehyde	3.2
2-butoxyethanol	3.2
dodecane	3.0
ethylcyclohexane	2.9
octane	2.7
pentanedioic acid dimethylester	2.2
2-methylnaphthalene	2.2
nonane	2.1
decane	2.1
tetrahydrofurane	2.0
cis 1,3-dimethyl cyclohexane	1.9
2-methyloctane	1.9
undecane	1.8
benzene	1.7
benzoic acid ethylester	1.6
heptadecane	1.6
1-ethyl-4-methylbenzene	1.5
3-methyloctane	1.4
TXIB	1.4
junipene (longifolene)	1.4
5-methyltetradecane	1.3
hexanedioic acid dimethylester	1.3
1,2,4-trimethylbenzene	1.2
Total concentration of identified compounds	180.3
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**233.8**
number of compounds included in TVOC (conc.> 0.1µg/m3)	219.0

customer	Manglerudhallen
sample id	pipe 420 20.26-22.06 17 October 2005

Compound	Concentration (µg/m3)
toluene	30.1
acetonitrile	16.8
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	10.1
acetone	6.5
o-xylene (1,2-dimethylbenzene)	4.7
benzothiazole	4.5
tetrahydrofurane	3.6
formaldehyde	3.5
ethylbenzene	2.6
benzene	2.2
acetaldehyde	2.0
4-methyl-2-pentanone	2.0
dodecane	1.9
acetic acid ethylester (ethylacetate)	1.7
undecane	1.6
decane	1.5
ethylcyclohexane	1.5
benzoic acid	1.4
octane	1.3
1-ethyl-4-methylbenzene	1.3
1,2,4-trimethylbenzene	1.2
1-methylnaphthalene	1.2
nonane	1.1
hexandioic acid dimethylester	1.0
cis 1,3-dimethyl cyclohexane	0.9
4-(1-methylethyl)-phenol	0.9
tridecane	0.9
pentanediacid dimethylester	0.9
2-methyloctane	0.9
2-methylnaphthalene	0.8
heptane	0.8
2-butoxyethanol	0.8
Total concentration of identified compounds	113.4
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**150.5**
number of compounds included in TVOC (conc.> 0.1µg/m3)	222.0

customer	Manglerudhallen
sample id	pipe 728 19.10.2005, 17.33-18.17

Compound	Concentration (µg/m3)
toluene	39.4
benzothiazole	20.4
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	17.4
4-methyl-2-pentanone	11.5
o-xylene (1,2-dimethylbenzene)	11.2
dodecane	6.0
pentanedioic acid dimethylester	5.1
ethylbenzene	4.2
undecane	3.7
ethylcyclohexane	3.3
benzoic acid	3.3
octane	3.3
decane	3.1
cyclohexanone	2.9
tridecane	2.8
nonanal	2.7
benzene	2.3
limonene	2.2
2-butanone	2.1
hexanal	2.0
nonane	2.0
2-butoxyethanol	1.9
hexanedioic acid dimethylester	1.8
pentadecane	1.8
decamethyl cyclopentasiloxane	1.8
tetradecane	1.8
junipene (longifolene)	1.7
Texanol B	1.7
butanedioic acid dimethylester	1.6
heptadecane	1.6
Total concentration of identified compounds	166.6
number of identified compounds	30.0
Total concentration of volatile organic compounds (TVOC)	**255.3**
number of compounds included in TVOC (conc.> 0.1µg/m3)	216.0

customer	Valhall
sample id	pipe 722 16.53-22.00 19 October 2005
Compound	Concentration (µg/m3)
benzothiazole	29.1
toluene	15.0
4-methyl-2-pentanone	11.3
acetone	9.5
o-xylene (1,2-dimethylbenzene)	9.5
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	9.2
cyclohexanone	8.4
benzoic acid	8.2
formaldehyde	6.5
junipene (longifolene)	5.8
decane	4.8
dodecane	3.4
1,2,4-trimethylbenzene	3.1
styrene (ethenylbenzene)	3.0
acetaldehyde	2.9
undecane	2.9
ethylbenzene	2.9
naphthalene	2.7
hexanedioic acid dimethylester	2.6
1,2-propanediol	2.6
pentadecane	2.5
acetic acid	2.5
limonene	2.5
2-(2-butoxyethoxy)ethanol	2.4
2-methylnaphthalene	2.1
tridecane	2.1
benzene	2.1
1-methoxy-2-propanol	2.1
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	1.9
butanoic acid butylester	1.9
3-carene	1.8
tetradecane	1.8
1-ethyl-2-methylbenzene	1.7
Total concentration of identified compounds	170.9
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**233.9**
number of compounds included in TVOC (conc.> 0.1µg/m3)	209.0

customer	Valhall
sample id	pipe 700 19.35-22.00 19 October 2005
Compound	Concentration (µg/m3)
benzothiazole	31.7
benzoic acid	19.3
toluene	15.3
4-methyl-2-pentanone	12.7
alpha pinene	10.5
cyclohexanone	9.8
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	9.6
acetone	9.5
junipene (longifolene)	7.2
formaldehyde	6.5
decane	5.0
acetic acid	4.3
dodecane	3.7
ethylbenzene	3.3
1,2,4-trimethylbenzene	3.2
styrene (ethenylbenzene)	3.2
undecane	3.1
acetaldehyde	2.9
limonene	2.6
2-methylnaphthalene	2.5
benzene	2.4
3-carene	2.2
pentadecane	2.2
2,3-dihydro-1,1,3-trimethyl-3-phenyl-1H-indene	2.1
naphthalene	2.1
hexanal	2.0
1,2-propanediol	2.0
1-methoxy-2-propanol	2.0
butanoic acid butylester	1.8
tridecane	1.8
nonanal	1.8
tetradecane	1.8
cyclohexane	1.7
Total concentration of identified compounds	191.7
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**289.8**
number of compounds included in TVOC (conc.> 0.1µg/m3)	245.0

customer	Østfoldhallen
sample id	pipe 704 17.15-20.10 18 October 2005
Compound	Concentration (µg/m3)
toluene	17.2
acetone	8.9
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	6.8
alpha pinene	6.3
formaldehyde	5.1
benzothiazole	3.4
actealdehyde	3.0
decane	2.5
nonanal	2.3
limonene	2.1
2,2,4,6,6-pentamethyl heptane	2.1
undecane	2.0
ethylbenzene	2.0
dodecane	1.9
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	1.9
1,2,4-trimethylbenzene	1.9
benzene	1.8
TXIB	1.8
butanal	1.8
hexadecane	1.7
heptane	1.6
1-ethyl-4-methylbenzene	1.5
2-butanone	1.4
tetradecane	1.3
decamethyl cyclopentasiloxane	1.3
3-carene	1.2
5-Methyl-2-(1-methylethyl)-cyclohexanol	1.1
2-(2-butoxyethoxy)ethanol acetate	1.1
tridecane	1.1
2-ethyl-1-hexanol	1.1
5-methyl-2-isopropyl cyclohexanone	1.0
1-methyl-2-pyrrolidinone	1.0
nonane	0.9
Total concentration of identified compounds	92.0
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**136.3**
number of compounds included in TVOC (conc.> 0.1µg/m3)	209.0

customer	Østfoldhallen
sample id	pipe 709 20.13-22.35
active sampling on Tenax adsorption tubes	18 October 2005

Compound	Concentration (µg/m3)
toluene	19.4
acetone	8.6
p-and m-Xylene (1,4 and 1,3 dimethylbenzene)	7.6
alpha pinene	6.8
formaldehyde	5.1
benzothiazole	3.9
2-hydroxybenzoic acid methylester	3.2
acetaldehyde	3.0
limonene	3.0
cyclohexane	2.9
nonanal	2.8
decane	2.7
2-methylhexane	2.7
2,2,4,6,6-pentamethyl heptane	2.6
2,6-bis-(1,1-dimethylethyl)-4-methylphenol (butylated hydroxytoluene)	2.3
heptane	2.3
undecane	2.3
TXIB	2.2
ethylbenzene	2.2
1,2,4-trimethylbenzene	2.1
dodecane	2.0
benzene	2.0
1-ethyl-4-methylbenzene	2.0
phenol	1.6
hexadecane	1.6
3-carene	1.5
tetradecane	1.5
5-methyl-2-isopropyl cyclohexanone	1.5
decamethyl cyclopentasiloxane	1.4
methylcyclohexane	1.4
acetic acid	1.3
tridecane	1.2
5-Methyl-2-(1-methylethyl)-cyclohexanol	1.2
Total concentration of identified compounds	108.1
number of identified compounds	33.0
Total concentration of volatile organic compounds (TVOC)	**161.1**
number of compounds included in TVOC (conc.> 0.1µg/m3)	230.0

Appendix II

Sampling in Østfoldhallen

Sampling in Valhall

Manglerudhallen with ventilation hatches in the roof

Sampling in Manglerudhallen

Rubber granulate from Valhall

Rubber granulate from Manglerudhallen

Rubber granulate from Østfoldhallen

Norwegian Institute for Air Research (NILU)
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REPORT TYPE ASSIGNMENT REPORT	REPORT NO. NILU OR 03/2006	ISBN 82-425-1716-9 ISSN 0807-7207	
DATE	RESP. SIGN.	NO. PAGES 41	PRICE NOK 150
TITLE Measurement of air pollution in indoor artificial turf halls		PROJECT MANAGER Christian Dye	
		NILU PROJECT NO. O-105133	
AUTHOR(S) C. Dye, A. Bjerke, N. Schmidbauer, S. Manø		AVAILABILITY * A	
		CLIENT'S REF. Marit Kopangen	
CLIENT Norwegian Pollution Control Authority (SFT) Postboks 8100 Dep 0032 Oslo			
KEY WORDS Artificial turf	Airborne dust	Indoor environment	

SUMMARY
This report describes the air quality for three indoor artificial turf pitches. The measurements were taken in a hall with recently laid rubber granulate (SBR rubber), a hall with rubber granulate (SBR rubber) which had been in use for one year and a hall which used granulate made from thermoplastic elastomer. Parameters covered are the quantity and chemical composition of airborne dust and the concentration of volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH). The study will be used as a basis for exposure calculations and the assessment of health effects. The results show that using rubber granulate from ground car tyres (SBR rubber) causes a significant indoor environmental problem.

TITLE
Determination of air pollutants in indoor artificial turf areas

ABSTRACT
In this work the air pollution level has been measured in indoor artificial turf areas. The synthetic turf consisted of SBR rubber and thermoplastic elastomer. The results revealed significant air pollution in the turf areas based on SBR rubber.

** Categories:* *A* *Open - may be ordered from NILU*
B *Limited distribution*
C *May not be distributed*

The State programme for pollution monitoring covers the monitoring of pollution conditions in the air and precipitation, forests, groundwater, watercourses, fjords and maritime areas.

The monitoring programme covers long-term studies of:

- over fertilisation of freshwater and coastal areas
- acidification (acid rain)
- ozone (on the ground and in the stratosphere)
- greenhouse gases
- environmental toxins

The monitoring programme will provide information on the condition and development of the pollution situation and demonstrate any adverse developments at an early stage. The programme will meet the authorities' needs for information concerning pollution conditions, record the effect of measures that have been initiated to reduce the pollution and provide a basis for assessing further measures. The Norwegian Pollution Control Authority is responsible for executing the monitoring programme.

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Artificial Turf Pitches

An Assessment of the Health Risks For Football Players and the Environment - Powerpoint

Dr. Christine Bjørge, Norwegian Institute of Public Health

Norwegian Institute of Public Health

Artificial turf pitches – An assessment of health risks for football players and the environment

Dr. Christine Bjørge
Division of Environmental Medicine
National Institute of Public Health

ISSS Technical meeting 13-14 October 2006

Agenda

- Background information
- Exposure scenarios
- Measurements and calculations
- Hazardous assessment
- Risk assessment - humans and the environment
- Conclusions

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Background - 1

Artificial turf pitches for indoor football

- Artificial turf = artificial turf fibre and rubber granulates
  - Artificial turf fibre (split- and mono fibre)
  - Rubber granulates
    - recycled rubber from car tyres (Styrene-butadiene-rubber, SBR)
    - newly manufactured rubber granulates (ethene-propylene rubber, EPDM)

Background - 2

Artificial turf pitches have many advantages

- Hard wearing
- Easier to maintain than natural grass
- Expand the football season

However, artificial turf often contains rubber granulates from waste tyres which contains several substances with the potential to affect human health and the environment.

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Background – 3

The assessment was based on the following reports

- *Potential health- and environmental effects related to artificial turf pitches, 2004* (SINTEF, Building and Infrastructure initiated by the Norwegian Football Association and the Ministry of Culture and Church Affairs)
- *Measurements of air pollution in indoor artificial turf sports halls* performed by NILU, 2005 (Norwegian Institute of Air Research)
- *The environmental risk assessment of artificial turf performed* by NIVA, 2005 (Norwegian Institute of Water Research)
- *Artificial turf pitches – an assessment of the health risks for football players, 2006* (Norwegian Institute of Pubic Health and the Norwegian Radium Hospital)

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Background -4

- Worst case exposure scenarios identified
- Highest analysis values form recycled rubber granulate (EDPM rubber contains lower levels of hazardous substances, and the leakage to the environment is lower).
- Substance categories considered:
  PCBs, PAHs, metals, phthalates, alkylphenols and VOC (volatile organic hydrocarbons)
- No Observed Adverse Effect Level (NOAEL) for the most relevant biological endpoint:
  cancer, reproductive damage, organ damage

Background - 5

- Exposure duration and frequency were based on information from the managers of the Valhall and Manglerud sports hall in Oslo, Nordlandshallen and Skarpehallen in Tromsø

- Training, matches and cup tournaments (children) were considered

Exposure – 1
General

Exposure scenarios:

- Adults (older than 20 years)
- Juniors (16-19 years)
- Older children (12-15 years)
- Children (7-11 years)

- Inhalation, skin and oral exposure

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Exposure – 2
Inhalation

Worst case exposure scenarios

- Frequency and duration of training
- Volume air inhaled during activity
- Absorption of substances via lungs
- Body weight of the sportsmen

Respiration volumes based on information from the Norwegian University of Sports and Education

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Exposure – 3
Skin

- Dust/particles released from rubber granulate will come in contact with bare skin (legs, thighs, arms and hands).
- Skin uptake levels: 100 % worst case (phthalates: 5 %)
- Quantity of dust/particles deposited on the skin: 1.0 mg/cm^2

  (Skin exposure of children playing with soil: 10 mg/cm^2,
  Skin exposure to soil during Rugby matches: 0.2 – 1.0 mg/cm^2)
- Frequency/duration of training/matches, body surface

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Exposure – 4
Swallowing

- Children may chew rubber granulate in the mouth for chewing, and possibly swallow it during matches/training/cup tournaments.

- **Worst case estimate:**

  1 gram per match/training session swallowed.

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Measurements and calculations -1

- NILU measured the levels of total VOC (volatile organic compounds), airborne dust (PM10 and PM2.5) (Manglerudhallen, Valhall and Østfoldhallen).
- They identified different chemical substances that are hazardous to health in the hall air with artificial turf (PCBs, PAHs, phthalates, alkylphenols).
- However, the level of exposure is important in the calculation of a potential human health risk.

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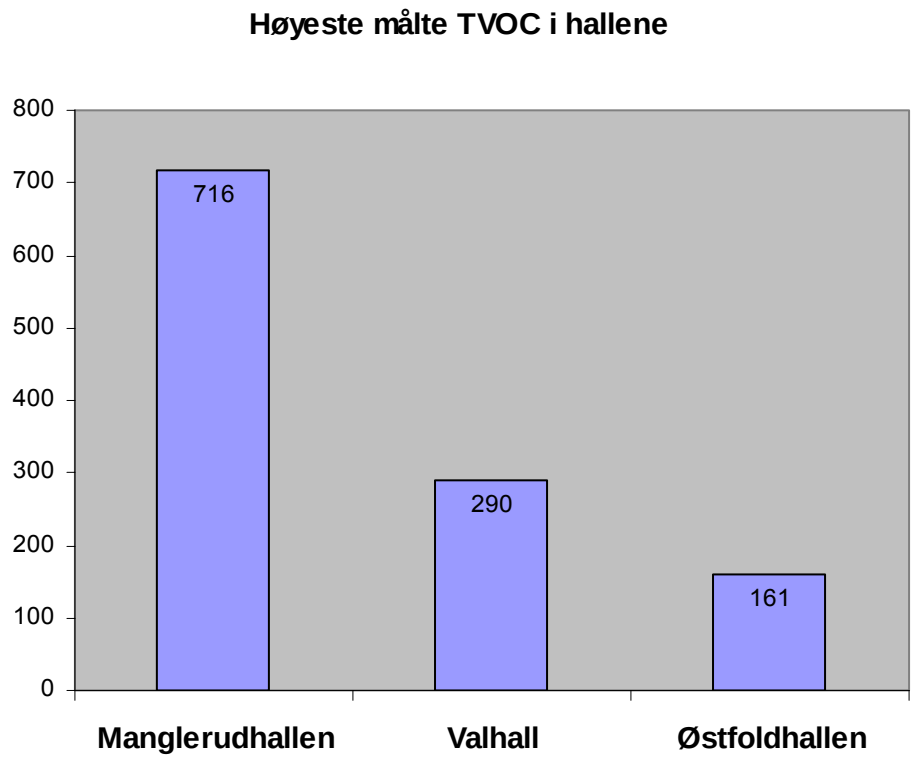
Measurements and calculations - 2

Inhalation - VOC

- Worst case measurements in Manglerudhallen (recycled rubber granulates), 234 different chemicals were found. This gave a total VOC of approx. 716 µg/m^3 (indoor house VOC of 200 µg/m^3)
- For 14 of these compounds the conc. range was from 10-85 µg/m^3 (including acetone, styrene, toluene, xylene and benzene)
- Temperature and ventilation have a great impact on the level of VOC
- The rubber granulates especially from recycled tyres was the main source of the VOCs measured in the halls

Measurements and calculations - 3

Total VOC



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Measurements and calculations - 4

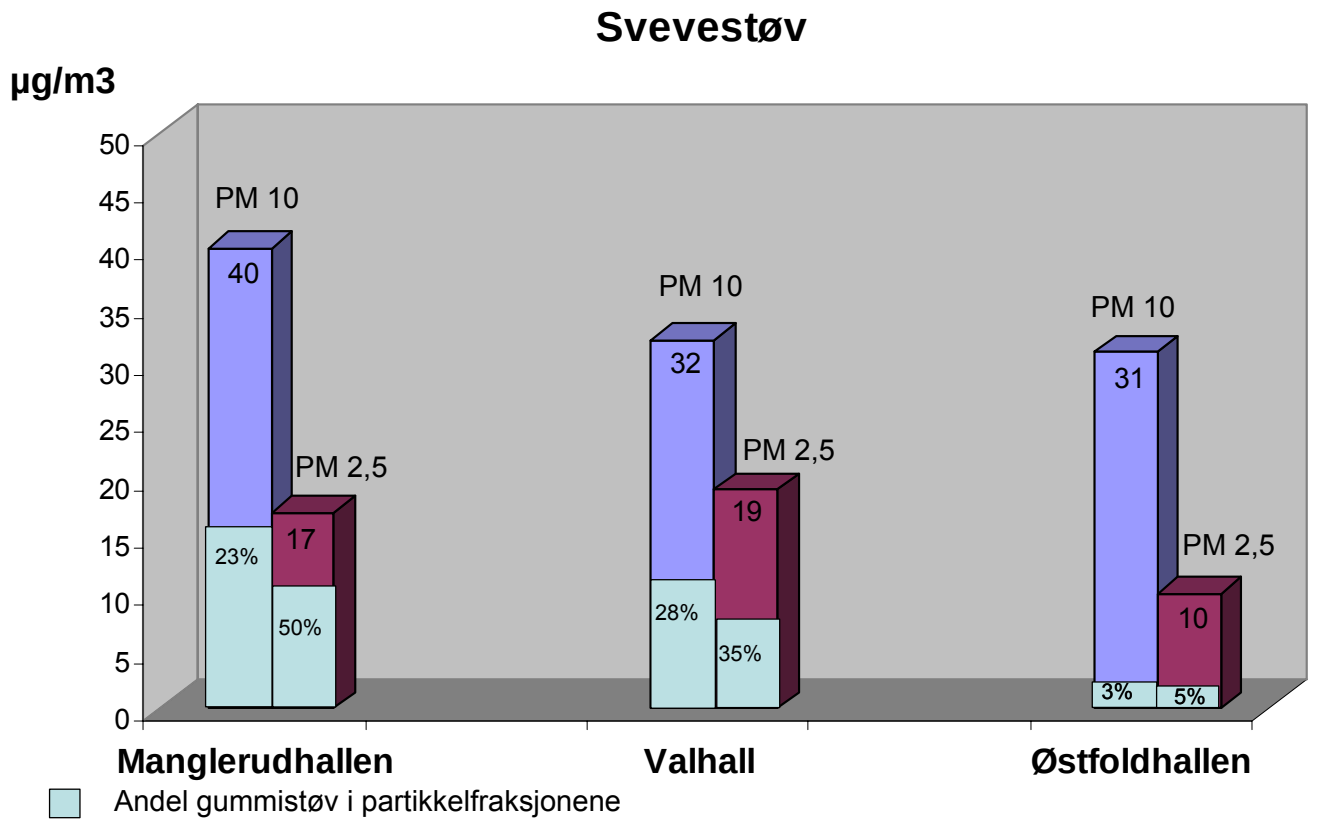
Airborne dust (PM10 and PM2.5)

- The quantity of indoor airborne dust is influenced of exertion, room shape, ventilation and building materials.
- Levels of PM2.5 was close to the Norwegian National norm at 20 µg/m^3.
- In Manglerud hall and Valhall it is assumed that the main source of airborne dust is recycled rubber granulate from tyres (from 23 to 50% of the rubber dust).

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Measurements and calculations - 5

PM10 and PM2.5 in airborne dust ($\mu g/m^3$)



Measurements and calculations - 6

Daily uptake of PAH, PCB, phthalates and alkylphenols from airborne dust

- PAH: 3800 pg/kg bw/day
- PCB: 3 pg/kg bw/day
- Phthalates: 47 000 pg/kg bw/day
- Alkylphenols: 800 pg/kg bw/day

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Measurements and calculations - 7

Skin exposure

- The skin uptake of the chemical is assumed to depend on the same factors which has been found for leaching into water.
- Degree of leaching into water will depend on how the chemical is bound to the rubber granulate and its water solubility (base on data from SINTEF, Building and Infrastructure)
- **Skin uptake for PCB, PAH, phthalates and alkylphenols were shown to be extremely low**

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Measurement and calculations – 8
Oral exposure

- Children may swallow some rubber granulate (1.0 gram) during matches and/ or training sessions.

- **Oral exposure to phthalates and alkylphenols was shown to be very low from this exposure route.**

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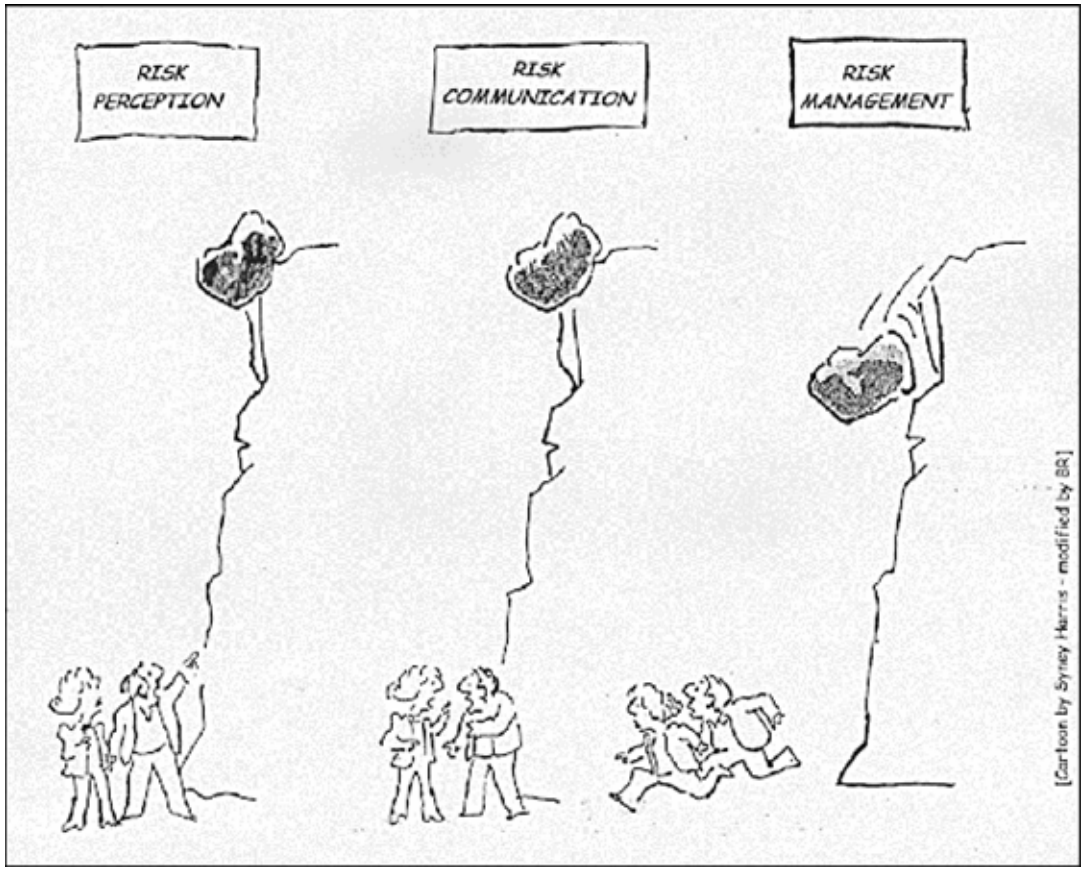
Hazardous assessment

- Total VOC, PCBs, PAHs, Phthalates, Alkylpenols:
  - may induce adverse effects on the reproductive system nervous system, blood forming organs, liver, kidney, genetic material, as well as allergy and cancer.

- However, the exposure has to reach a certain level to induce an adverse health effect

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Risk assessment humans - 1



Risk assessment Humans - 2

Human exposure

↓

Harmful effects (**No A**dverse **E**ffect **L**evel)

↓

Margin of Safety (MOS)

↓

MOS > 100 no concern/ MOS < 100 concern

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Risk assessment Humans– 3
Inhalation

Exposure
- PAH: 3800 pg/kg bw/day
- PCB: 3 pg/kg bw/day
- Phthalates: 47 000 pg/kg bw/day
- Alkylphenols: 800 pg/kg bw/day

NOAEL
- PAH: 40 mg/kg bw/day
- PCB: 0.0005 mg/kg bw/day
- Phthalates: 4.8 mg/kg bw/day
- Alkylphenols: 1.5 mg/kg bw/day

MOS
- PAH: 10 000 000
- PCB: 160 000
- Phthalates: 100 000
- Alkylphenols: 2 000 000

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Risk assessment Humans – 4
Inhalation

Airways allergy/asthma:

- Car tyres contains large quantities of latex. Latex (natural rubber) is a potent allergen, and latex allergy is not unusual. The amount of rubber dust in the airborne dust was 23 to 50 % in halls with recycled rubber granulate (compared to 4% in halls with new rubber granulate).

- Due to the absence of data on concentrations of latex allergens in the rubber dust, the possibility of a risk of developing latex allergy/asthma as a result of regular training on artificial turf pitches cannot be evaluated.

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Risk assessment Humans - 5

Skin contact

- The skin exposure to PCB, PAH, phthalates and alkylphenols were shown to be extremely low.

- No human health risk is assumed from this exposure route.

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Risk assessment Humans - 6

Swallowing:

- Exposure of children to phthalates and alkylphenols from swallowing of rubber granulates is estimated to be very low.

- No human health risk is assumed from this exposure route.

Risk assessment Environment - 1

- Based on the leakage of the hazardous substances in the rubber granulates
- Recycled rubber was the major source of potentially hazardous substances
- An exposure scenario was performed where the run-off of surface water from a football field was drained to a small creek. This scenario showed a positive risk of toxic effect on biota in the water phase and in the sediment.

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Risk assessment Environment – 2

- The environmental risk was attributed to the leakage of **zink , PAH** and **alkylphenols**. For these compounds the environmental concentrations exceeded the No Environmental Effects Concentrations.

- It is expected that the substances will leak from the artificial turf slowly, which indicates that aquatic organisms may be affected for many years.

- The total amount of hazardous substances leaking from a normal sport ground was, however, fairly low which means that any environmental effect are considered to be local.

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Conclusion -1
Human Health

- Rubber granulates used in artificial turf pitches contains many different chemicals which are considered as potentially harmful to human health.
- The amount of these chemicals were much higher in rubber granulates from recycled car tyres compared to newly manufactured rubber granulate.
- The risk assessment was therefore based on the use of recycled rubber granulates in artificial turf.

Conclusion -2
Human Health

- A number of worst case scenarios were identified based on the frequency and duration of matches/training as well as physiological parameters (skin surface, body weight, inhalation volume) and analyses of the chemicals in the hall air.

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Conclusion -3

Human Health

- Based on the exposure and the known harmful health effects of the chemicals in the hall air, it was concluded that the use of artificial turf pitch did not cause any elevated health risk for the football players.
- However, little or no toxicological information is available for many of the volatile organic compounds (VOC) which was present in the hall air.

Conclusion – 4
Human health

- Car tyres contains large amount of latex, and possibly also latex allergen. Latex is a potent airway allergen. Recycled rubber granulates from car tyres may therefore also contain latex allergens.
- As there is no information available regarding the levels of latex in rubber granulates from recycled tyres it was not possible to assess the risk of developing airway allergy/asthma.

Conclusion – 5
Environment

- Artificial turf that contains rubber from recycled tyres may give rise to local environmental risk.

- The environmental risk was attributed to the leakage of **zink, PAH** and **alkylphenols**. For these compounds the environmental concentrations exceeded the No Environmental Effect Concentrations.

Conclusion – 6
Environment

- The total amount of hazardous substances leaking from a normal sport ground was, however, fairly low which means that any environmental effect are considered to be local. The leakage of the substances is expected to be slow, consequently the aquatic organisms may be affected for years.

Norwegian Institute of Public Health

Recommendations

- Artificial turf that contains substances of very high concern should not be used.
- Recycled rubber granulate from car tyres should not be used when rubber granulate is supplemented/replaced.
- More information is needed regarding the amount of latex allergens in hall air, due to its potential to induce of airway allergy/asthma.

Cancer Risk Following Exposure to Polycyclic Aromatic Hydrocarbons (PAHs): a Meta-Analysis

Health and Safety Executive 2003
prepared by London School of Hygiene and Tropical Medicine

HSE
Health & Safety Executive

Cancer risk following exposure to polycyclic aromatic hydrocarbons (PAHs): a meta-analysis

Prepared by the **London School of Hygiene and Tropical Medicine**
for the Health and Safety Executive 2003

RESEARCH REPORT 068

HSE
Health & Safety Executive

Cancer risk following exposure to polycyclic aromatic hydrocarbons (PAHs): a meta-analysis

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We carried out a review and meta-analysis of published reports of occupational epidemiological studies quantitatively informative to the PAH-cancer (lung and bladder) relationship. On average over 39 included cohorts, the estimated unit relative risk (URR) at 100 mg/m 3 years BaP was 1.20 (95%CI: 1.11, 1.29) for lung cancer , and was not sensitive to particular studies or analytic method. However, the URR varied by industry. The estimated mean in coke ovens, gasworks, and aluminium production works were similar (1.15-1.17). Average URRs in other industries were higher but imprecisely estimated, with those for asphalt (17.5; CI:4.21-72.78) and chimney sweeps (16.2; CI: 1.64-160.7) significantly higher than the above three. There was no statistically significant variation of URRs within industry, or in relation to study design (including whether adjusted for smoking), or source of exposure information. Limited information on total dust exposure did not suggest that dust exposure was an important confounder or modified the effect. For bladder cancer (n=27), the average URR was 1.33 (95%CI: 1.17, 1.51), with no statistically significant variation by industry or other putative determinants. However, numbers of cases were small in most studies, and results were highly dependent on two large studies of aluminium production workers.

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EXECUTIVE SUMMARY

Background: Airborne PAHs have long been known to cause cancer in animals and have been widely classified as known human carcinogens. We carried out a review of published reports of occupational epidemiological studies quantitatively informative to this relationship, and a meta-analysis to identify the average and determinants of lung and bladder cancer risk per unit exposure.

Methods: Relevant peer reviewed reports published up to early 2001 were identified systematically using bibliographic databases. We excluded cohorts exposed occupationally to known or suspected carcinogens other than PAH that may have lead to substantial risks (eg foundries, diesel exhaust-exposed, rubber) were excluded. From each study that met the inclusion criteria (n=39), unit relative risk (URR: relative risk at 100 $\mu g/m^3$ BaP years cumulative exposure) was estimated by loglinear Poisson regression from published tables of risk against estimated cumulative exposure. For slightly more than half the studies, this required published data to be supplemented by estimated concentrations and sometimes duration of exposure. This exposure estimation was based on a review of published exposure data carried out by an industrial hygienist. Distribution and determinants of URRs were investigated using standard meta-analytic methods.

Results: On average, URR was 1.20 (95%CI: 1.11, 1.29) for lung cancer , and was not sensitive to particular studies or analytic method. However, the URR varied by industry. The average in coke ovens, coal gasification and aluminium production works were similar (1.17,1.15,1.16 respectively). Average URRs in other industries were higher but imprecisely estimated, with those for asphalt and chimney sweeps significantly higher than the above three. There was no statistically significant variation of URRs within industry, or in relation to study design (including whether adjusted for smoking), or source of exposure information. Limited information on total dust exposure did not suggest that dust exposure was an important confounder or modified the effect.

For bladder cancer, the average URR was 1.33 (95%CI: 1.17, 1.51), with no statistically significant variation by industry or other putative determinants. However, numbers of cases was small in most studies, and results were highly dependent on two large studies of aluminium production workers.

Discussion: Biases in the included studies could bias this meta-analytic synthesis, in particular if consistent across studies in one industry. However, URRs for coke oven, coal gasification, and aluminium production workers were rather consistent. The larger URRs in other industries, in particular asphalt and chimney sweeping, could not be due to chance. It is possible that they may be affected by biases, in particular relating to problems of exposure estimation, but for asphalt evidence is from more than one study, some of which included investigator-reported exposure estimates.

There was no evidence against a single URR for bladder cancer across all industries, but little evidence to positively support this either, with only aluminium smelters showing strongly positive associations. The average URR was slightly higher than for lung cancer but more imprecisely estimated.

1 INTRODUCTION

Airborne PAHs, which are emitted when organic matter is burned, are ubiquitous in the occupational and general environment. It has long been known that several PAHs can produce cancers in experimental animals, and epidemiological studies of exposed workers, especially in coke-ovens and aluminium smelters, have shown clear excesses of lung cancer, and highly suggestive excesses of bladder cancer (IARC 1984; IARC 1985; IARC 1987; Boffetta, Jourenkova et al. 1997; Negri and La Vecchia 2001). The animal experiments have included some using airborne exposure, and have been of mixtures and individual compounds, including in particular benzo(a)pyrene (BaP). Although the existence of a cancer risk is beyond reasonable doubt, there is considerable uncertainty as to the exposure-response relationship, and hence as to the risks posed at today's levels in the workplace and general environment. Information on this relationship is clearly important to inform the setting of occupational and environmental standards.

Estimating exposure-response relationships by extrapolation from animal studies is possible (USEPA 1984; Collins, Brown et al. 1991), but the limitation of this approach, in particular species differences, makes sole reliance on it problematic. A large study of coke-oven workers carried out since the 1960's in the USA (Lloyd 1971, Costantino et al 1995) has been used to estimate risk per unit residential exposure for the USEPA (Nisbet and LaGoy 1992) and the WHO (WHO 1987). However, these two estimates differ widely, and many new studies provide information that has not yet been systematically used to quantitatively assess risk.

The fact that PAHs comprise a mixture, several components of which are animal carcinogens, adds to the complexity of the task. One issue is whether a single index of exposure, such as benzo(a)pyrene (BaP) or total benzene or cyclohexane soluble matter (BSM or CSM) is adequate to determine risk. If such an index is used, risk per unit exposure may differ between studies (and unstudied exposures) because of differences in the ratio of this index to the total carcinogenic potential of the mixture. It is possible that such variation, if present, can be adequately described by classifying exposures in broad categories (for example by source). However, this remains untested.

We report here a review and meta-analysis that aimed to use all relevant published evidence from epidemiological studies to obtain an estimate or estimates of the relationship of PAH exposure with lung and bladder cancer, and to identify sources of variation in this relationship.

2 METHODS

2.1 LITERATURE SEARCH

We sought to include all published, peer reviewed epidemiological studies potentially informative on the PAH–cancer exposure response relationship. The following inclusion and exclusion criteria were employed:

Cancer site

Only studies reporting on *lung* or *bladder* cancer were included. In a review of cancers associated with PAH exposure, Boffetta, Jourenkova et al. 1997 concluded that while some evidence exists for cancer of the larynx, kidney, colon and oesophagus, the evidence is not as conclusive as for lung and bladder. An increase in skin cancer was observed in some studies, but tended to be limited to settings entailing substantial dermal exposure. The restriction to lung and bladder cancer was designed to retain focus on the magnitude of the exposure-response relationship, rather than on whether a causal relationship exists.

Types of study:

Only epidemiological studies of occupational exposure by inhalation were included. Most studies of non-occupational PAH exposure would in any case have been excluded on other criteria (in particular the likelihood of PAH not being the predominant carcinogen).

- Biomarker studies were excluded.
- We made no attempt to access studies published only in the grey literature, although such literature as informed published studies further (e.g. fuller research reports of studies) was sought.
- We excluded studies reporting only proportional cancer analyses.
- Language of publication was restricted to English, for practicality.
- Non-primary research papers (e.g. reviews) were excluded, but such papers were obtained for background information.

Exposures:

- To reduce potential for confounded results, we excluded studies of workplaces in which PAH was considered unlikely to be the predominant lung or bladder carcinogen (i.e. other risks from carcinogenic co-exposures were likely to be substantial). Workplaces excluded by this rule included those in the rubber industry, those involving exposure to diesel exhaust, and foundries. We also excluded studies of steel works on this basis (co-exposure to silica), unless they included separate analyses specifically of coke oven workers.
- We excluded studies for which estimating a quantitative measure of exposure to PAH would be likely to lead to substantial misclassification of exposure. This rule lead us to exclude hospital- and population-based case-control and registry studies.

Duplication

To avoid double counting of information from the same workforce reported in several papers (often from later studies updating earlier ones) we included only the last reported results.

2.2 LITERATURE SEARCH STRATEGY

The search strategy was conducted in three stages:

First stage

Electronic searches were made using the online databases MEDLINE and EMBASE to identify papers relating to epidemiological studies of PAH exposure or PAH associated industries (see search terms in appendix A) and neoplasms. This produced 744 references, with publication dates between

1965 - January 2001 (MEDLINE) and between 1980 and February 2001 (EMBASE). Searches using OLDMEDLINE (papers published between 1958 and 1965), NIOSH and Cancerlit databases identified a further 5 studies. Abstracts and bibliographical information from these studies were imported into a reference manager, Endnote. After exclusion of studies with fields that contained the following terms: hospital based, population based, proportionate cancer, molecular, polymorphism, adduct, reviews, PMR, PCMR, bioassay, assay, biomarker, animal, metabolite, 521 studies remained.

Second stage. First screen on titles and abstracts

Of the 521 studies, 338 could be excluded using the above rules by reading titles and abstracts. To the remaining 183 papers we added a further 31 studies identified from reference lists of reviews or included studies, giving a total of 214 papers.

Third stage: Second screen on further criteria and on full papers

From the full text of the 214 papers, we excluded a further 178, leaving 36 fully meeting our criteria.

Extraction of information

From each included study we systematically extracted general descriptive information, information on potential modifiers of risk associated with PAH, and information from which we estimated unit relative risk increments (see next two sub-sections). Extraction forms were designed to enable standardised extraction of epidemiological information from published studies.

2.3 EXPOSURE ESTIMATION

We distinguished studies according to whether the authors reported:

(a) exposures to PAH indexed as benzo(a)pyrene (N=11).

(b) exposures to PAH indexed by a proxy which we could convert to BaP: Benzene soluble matter (BSM), total PAH, carbon black (N=5).

(c) no measures of exposure (N=20)

For two of the first group, cancer risks were tabulated by total PAH, but the reports gave conversion ratios to BaP:

- Romundstad 2000 (aluminium smelter): Ratio used 50 µg BaP/mg total PAH
- Hansen 1989 (roofers): Ratio used 21.86 µg BaP/mg total PAH (or BaP 0.02% of asphalt condensate)

We converted exposures in the second group to BaP by using a conversion ratio as follows:

(a) BSM:

- Spinelli 1991 (soderberg auminium smelter): Ratio used: 8 µg BaP/mg BSM (Armstrong 1994);
- Costantino 1995, Hurley 1983 (coke ovens): Ratio used: 7.1 µg BaP/mg BSM (WHO 1987);

(b) Total PAH:

- Bye 1998 (Coke oven): Ratio derived from Romundstad 2000, but corrected for Coke oven Vs aluminium smelter ratios of BaP/BSM: 50X7.1/8=44 µg BaP/mg total PAH

(c) Carbon black manufacture:

- Sorahan 2001. Ratio used: 4.8 mg BaP/Kg carbon black (Van Tongeren 2001 – private communication, IARC 1996).

For the group with no exposure measures, with the collaboration of industrialhygienists, we estimated concentration of exposure to PAH for each workgroup for which risk estimates were presented. These estimates drew on the estimates published in the same industries in studies in groups 1 and 2 (Appendix B1), and on a literature review of hygiene surveys of similar workplaces (Appendix B2).

Particularly valuable were a review by Lindstedt and Sollenberg 1982 and the most relevant IARC monograph (IARC 1984). From these sources we derived a job-exposure matrix indicating estimated mean concentrations of exposure to PAH (as BaP) in job groups for which relative risks were published (Appendix B3). Synthesis of data on exposure was by judgement rather than formal statistical summaries of reported concentrations, to allow for data in a wide variety of forms ("hot-spot" measurements, personal and stationary samples, different sampling and analytical technique, very similar and roughly similar workplaces). To reduce bias due to this somewhat subjective process, this was carried out blind with respect to the relative risks found in the epidemiological studies.

- **Scale.** To simplify the task of making estimates for the JEM we made these on the scale: 50,20,10,5,2,1,0.5,0.2, <=0.1, unless there was clear information to lead us to place values between adjacent scale values. (Note for =0.1, we used 0.05)
- **Uncertainty**. We sought to estimate mean exposure in groups of jobs correct to within two points of our scale (i.e. a factor of five), with 95% confidence. Where we did not believe this possible (N=2), we set these studies aside (Ronneberg et al 1988, Martin et al 2000)
- **Time period.** For all included studies, the overwhelming majority of exposure in the likely etiologically relevant period (i.e. with ten or more years latency) occurred before 1970. We thus sought to estimate exposure for this period. In principal we were prepared to separate periods before this if we found clear evidence for changes in exposure, but in practice this never happened. Thus we made just one exposure estimate for each job group.

Most estimates were drawn from the matrix presented in table 1. A full list of exposure estimates made is given in Appendix B3.

2.3.1 Cumulative exposure.

Where risk estimates in categories 1 (BaP measures) and 2 (Proxy measures) were in groups according to cumulative exposure (eg 0, 0.1-9.9,10-99.9,100-199.9,200-) the only further information required was the mean cumulative exposure in each group. For closed groups (0.1-9.9,10-99.9,100-99.9 example above) we took the midpoint of the interval (5,55,150). For upper groups (200- example above) we estimated the mean from the observed distribution over groups by maximum likelihood, under the assumption that the distribution of non-zero cumulative exposures followed a lognormal distribution.

A similar procedure was followed for tables of risk by duration of exposure, except that an upper limit of 40 years was assumed if no upper limit was given for the highest group. Mean durations were then multiplied by the estimated concentration to obtain mean cumulative exposures for each period.

For other studies (for example where risk estimates were by job group, regardless of duration of exposure) estimates of duration of exposure were made using what information was available. In the absence of other information, twenty years was assumed, being a round number representing the average found in studies for which duration was reported.

2.3.2 Dust Exposure

At the inception of this study, we had not planned to seek information on potentially confounding exposures beyond those commented on by the authors. However, there has recently been a sharp increase in interest in the hypothesis that inhaled dust carries a risk of lung cancer regardless of composition. We therefore sought to add what information we could find on total dust exposure. Since very few of the publications reported such estimates, we relied entirely on supplementary data and the judgement of the hygienists on the research team for this. We were aware that this could only be a very rough assessment, so chose a simple scale: LOW (<1 mg/m^3); MODERATE (1-5 mg/m^3); HIGH (5-10 mg/m^3); VERY HIGH (10-25 mg/m^3), and broad job groups or, in some cases, entire industries. Assessments are listed in the final column of table 1. A list of references on which this was based is included in Appendix B4.

2.4 STATISTICAL ANALYSIS

2.4.1 Estimation of unit relative risks (URRs)

A technical description of the estimation of URRs for cancer, and discussion of associated models is given in Appendix C. We present a summary here.

We anticipated that a major determinant of cancer risk due to PAH exposure would be level and duration of exposure. To standardise for these two determinants, and increase the usefulness of our summary, we estimated from published results of each study increments in relative risk per unit cumulative exposure (Smith and Sharp 1985; Smith 1988) to BaP ($\mu g/m^3$ year). Working a normal working year in which the mean shift concentration is 1 $\mu g/m^3$ is defined to comprise 1 $\mu g/m^3$ year cumulative exposure.

For this purpose we fitted two different models for the dependence of relative risk on cumulative exposure:

(a) Loglinear relative risk model: $RR = \exp(b_{loglin} x)$

(b) Linear relative risk model: $RR = 1 + b_{lin} x$

where x is cumulative exposure in $\mu g/m^3$ years; and the b is the slope of the exposure-response relationship. (For both models, RR=1 if x=0.) Thus relative risk represents the risk of lung cancer at a specified exposure (x) relative to that at zero exposure. For example RR=1.30 at x=100 $\mu g/m^3$ BaP years exposure implies that at this exposure, lung cancer risk is 1.3 times that of an unexposed person – a 30% excess.

We used both these models because each has advantages and disadvantages over the other. In summary, the linear model fits the data and most proposed biological mechanisms better (Greenland 1987), but the loglinear model is more reliable in investigating heterogeneity and patterns of URRs over cohorts. Following Greenland (1987) we present main results for the loglinear model for its better statistical properties, but note also those from the linear model.

Estimates of slopes b were made by each method from each study from published tables of risk (usually SMRs or internal RRs) by cumulative exposure, duration of exposure, job group or single group for SMRs. Technical description of this is given in Appendix C. For the thirteen cohorts for which only one SMR was published, these estimates depended on assuming that at zero exposure that cohort would have experienced the same rates as those of the general population (allowing for age and calendar time). For the remainder, rates at zero exposure were inferred from the cohort itself (i.e. exposure-response curves were not constrained to SMR=1 at zero exposure).

To make results more easily interpretable, rather than reporting the slopes b we report results as relative risks predicted by the models at 100 $\mu g/m^3$ BaP years, which is close to the mean of the maximum exposures in included studies. 100 $\mu g/m^3$ BaP years corresponds to a concentration of 2.5 $\mu g/m^3$ BaP over 40 years. We refer to these as unit relative risks (URRs)

2.4.2 Selection of exposure contrasts for estimation of URRs

We referred above to URRs being estimated for **studies**. This was a simplification, for two reasons:

(a) Some publications included separate presentation of risks for quite distinct cohorts. For example, Hurley (1983) presented results (risks by cumulative exposure) for coke-workers from two different companies with distinct exposure estimates (British Steel Corporation workers and National Smokeless Fuels Limited workers). In these cases we considered the two cohorts as separate, and included two separate URR estimates in our meta-analyses.

(b) For just over half cohorts more than one contrast of risk in differently exposed sub-groups was published, each allowing a URR estimate. For example, there were often tables of risk by duration of service (sometimes sub-divided by job-group) and by job group (eg coke-oven top-worker, side worker, and distillation products), as well as on overall SMR.

It would be inappropriate to include URRs estimated from different contrasts from the same cohort as if they were separate studies. Primary analyses used contrasts selected according to the following rules (in order of priority):

i. Internal comparisons were favoured over external (i.e. comparing two SMRs or RRs was preferred over comparing an SMR with an assumed RR of 1.0 at 0 exposure).

ii. Contrasts with high difference in cumulative exposure in highest Vs lowest exposure group were favoured over contrasts with lower difference (e.g. if RRs given for 0 Vs 1-40 years exposure, and for 0, 1-10,10-20,20-30,30-40 years, then the latter is used in preference)

iii. Mortality outcomes were preferred over morbidity outcomes for lung and the reverse for bladder.

iv. Confounder-controlled contrasts were preferred over uncontrolled (eg smoking -adjusted Vs unadjusted)

v. Estimation of URRs from k groups was preferred over estimation of URRs from less than k groups. (i.e. intermediate groups were retained).

vi. To maximise comparability in primary analyses, estimates without latency or lag restrictions were preferred over those with such restrictions.

Rules for assigning preferred contrasts were set up before cancer risks for each contrast were investigated (i.e. the assignation was carried out blind).

2.4.3 Meta-analysis

The distribution of URRs (essentially slopes b) from each cohort were summarised using standard meta-analytic methods (Sutton 2000). Broadly, these methods allow for variation in precision by which URRs are estimated in different studies, but allow also for possible variation between studies that is not due to imprecision in URR estimates ("random effects"). Thus to obtain an average URR weights were implicitly given to each study reflecting these two factors. Further, to identify cohort or exposure characteristics that explained variation in URRs (eg industry, source of exposure information) each was considered as a dependant variable in a meta-regression analysis (Thompson and Sharp 1999) (see table 4 or 6 for examples.)

For URRs estimated from the log-linear model, meta-analyses were carried out on the log scale, in view of their approximately lognormal sampling distribution.

3 RESULTS

3.1 LUNG CANCER

3.1.1 Study characteristics

Of the 34 publications included, five reported two distinct cohorts for which results were presented separately. Thus there were 39 cohorts from which we could estimate URRs and include in the meta-analyses. Characteristics of these 39 cohorts, are shown in table 2 (which also shows estimated URRs - see below). Summaries of selected quantitative study characteristics are given in table 3 and Table 4 in which studies are divided by qualitative characteristics (the table is also used to show URR in these groups, as described below). A full description of the included studies is included in Appendix D.

All were essentially cohort studies, but one (Armstrong 1994) used case-cohort sampling, and three used nested case-control samples from within the cohort. For thirteen of the cohorts only single SMRs were reported; for the remainder there were risk comparisons (contrasts) across two or more (maximum 7) exposure groups. Of these, the contrasts selected according to our criteria were by cumulative exposure (8), duration of exposure (12), and job group (6).

A remarkable feature was the large range of exposures. Table 2 lists the cumulative exposure in the highest exposure group in each study, which ranged across three orders of magnitude, from 0.75 to 805 $\mu g/m^3$ BaP years. This corresponds approximately to concentrations in air of 0.04 $\mu g/m^3$ to 40 $\mu g/m^3$. This large range was the predominant reason for the large range in precisions with which the URR was estimated.

3.1.2 Unit relative risks

Relative risks predicted at 100 $\mu g/m^3$ BaP years from the loglinear model are shown to the right of the cohort characteristics in table 2. They ranged from 0 to over 1000. There was also substantial variation in the precision with which these relative risks were estimated, with standard errors (log scale) ranging from 0.02 to over 1000. Most of the variation in precision was due to variation in the degree of exposure contrast in the studies. Many of the studies at the foot of the table (power and carbon black industries) have low exposures. This limits the range of exposures , which causes imprecision in estimated URRs, shown as wide confidence limits. (This can be understood by reference to fact that the URRs are essentially regression coefficients – a narrow range in the x variable leaves uncertainty in the slope of the line.) Some variation in precision was also due to variation in size of cohort populations and duration of follow-up, which is reflected in the number of cases.

For cohorts without any exposure groups with mean higher than 100 $\mu g/m^3$ BaP, the estimate of relative risk at this value (the URR) is an extrapolation, and this explains the extreme variation of URRs. To give an indication of the actual relative risks found in the cohorts, we also show for each cohort (table 2, last column) the relative risks for the group with the highest exposure in that cohort, as predicted by the (loglinear) model.

Twenty-eight (72%) of the URRs were above zero, with the lower confidence limit above one ($P<0.05$) in 14 of these. The mean (estimated by random effects meta-analysis), overall and in sub-groups, is shown in table 4. A graph of all results loses definition catastrophically in the more precise studies. Limiting the graph to studies with standard errors below 10 (Figure 1a) and 1 (Figure 1b) allows focus on the more precise and consequently influential cohorts.

The overall mean URR was 1.20 and significantly above zero ($p<0.001$). There was no one cohort dominating this estimate, and it was little changed on removal of less precise cohorts. However, there was significant heterogeneity of URRs across cohorts ($p<0.001$).

Meta-regression revealed that much of the heterogeneity was explained by variation in URRs across industries ($p=0.002$); although coke ovens, gasworks, and aluminium smelters, exposed to coal tar

volatiles at similar levels, had similar mean URRs. There was no significant heterogeneity of URRs within industry groups. We therefore examined variation in URRs according to other factors after allowing for the differences across industries by including industry in the meta-regression. After doing so, there was no difference more than could easily be explained by chance ($p>0.20$) when studies were grouped according to source of exposure information, exposure contrast, continent, or whether the outcome of studies was mortality or morbidity, study design, smoking adjustment, or exposure contrast (cumulative exposure, duration, etc). Neither did maximum exposure explain variation. The higher URRs in the three nested case-control studies ($p=0.02$) was related to that in the four smoking-adjusted studies ($p=0.05$), as two of the case-control studies also adjusted for smoking.

3.1.3 Publication bias

There was little evidence that the URR was related to its standard error or to number of cases ($p>0.20$), factors that might relate to publication. Further, neither Egger's test nor Begg's ($p>0.20$) gave evidence for publication bias (Sutton et al 2000). Applying a trim-and-fill analysis (designed to correct for publication bias, if any) made negligible difference to the mean.

3.1.4 Dust

Because our information on dust exposure was for each cohort, or sometimes for broad job group within studies (Table 1), we could not use conventional methods for controlling for confounding (stratification or inclusion of dust in multiple regression analyses). We adopted three ad-hoc approaches to use the data we had to shed what light we could on this issue:

We compared relative risks estimated at 100 µg/m3 BaP years in cohorts in which we had identified substantial dust exposure with those in which there was less. If generic dust were an important cause of lung cancer in these cohorts one would expect greater apparent risks per unit PAH (BaP) where it was accompanied by dust. Results are shown at the bottom of table 4. There was no association between estimated relative risk per unit PAH (BaP) exposure and dust exposure in the industry.. This give some reassurance that dust is not the predominant cause of the association seen in this cohort between PAH and lung cancer.

The above approach assumes that dust exposure is correlated with PAH exposure within studies, at least across the groups used for exposure-response estimation. In general, this appeared to be the case, but for aluminium production there was some important independence between dust exposure and PAH exposure in groups for which we had risk estimates. Specifically, Soderberg potrooms were estimated to have very high dust and PAH exposure, whereas prebake potrooms had only slightly lower dust exposure, but very much lower PAH level. This suggests that the above approach is of limited values for aluminium production, but it also gave us the opportunity to look directly to see whether the dust or the PAH exposure explained risk. Table 8 shows risks by duration of service in prebake and Soderberg potrooms in the two included studies which reported this. For neither cohort was there evidence of a trend in risk by duration of service in prebake potrooms. In Armstrong 1994 there was a significant trend by duration of service in Soderberg potrooms. Thus this pattern of results does not support the hypothesis that the association of PAH with lung cancer in the aluminium industry is due to dust.

Finally, we can reason informally from the comparisons of fitted maximum relative risks on Table 2 (last column). In particular, carbon black workers are assessed as having similar levels of dust exposure as coke oven workers, but much lower PAH exposure. In both industries we expect total dust exposure to be highly correlated with PAH exposure. If dust rather than PAH were the predominant carcinogen, we would expect maximum risk to be similar in the two industries. In fact, maximum risk is considerably higher on average in the coke oven workers. Indeed, it is unclear if there is any excess at all in the carbon black workers.

3.1.5 Sensitivity analysis

By investigating dependence of URRs on study characteristics (section 3.1.2; Table 4) we have already implicitly examined sensitivity of results to these characteristics (study design, smoking

adjustment, exposure information, etc), and found little such sensitivity. Here we examine sensitivity of our results to some statistical modelling assumptions.

Repeating analyses using the linear model, we found very similar rankings of URRs (Spearman's correlation = 0.99); the mean estimated relative risk at 100 μg/m3 BaP years was similar (1.19, compared to 1.20; both highly significant); and the patterns of variation of risk across industries were broadly similar. Fitted relative risks at the maximum exposure found in each plant were also similar. However, there was some variation in URRs of individual cohorts, with those with lower exposures typically lower with the linear model, and those with higher exposures higher. For example, the mean URR for the asphalt industry was 17.50 with the exponential model, but 6.29 with the linear model; relative risks predicted at 10 $\mu g/m^3$ years, however (more typical for asphalt workers) were less different and reversed in order: 1.33 and 1.53 respectively.

We also repeated analyses using alternative criteria for choice of contrast:

- minimum standard error;
- as above, using internal comparisons instead of single SMRs whenever available.

In either case, the mean URR and the basic pattern of URRs between industry changed little, although estimates for individual studies changed, sometimes substantially.

Finally, we investigated dependence of our results on extrapolation of risks from very high exposures, by repeating analyses three times, excluding exposure groups with means more than 80 $\mu g/m^3$ BaP years (40 years at 2 $\mu g/m^3$), 40 $\mu g/m^3$ BaP years (1 $\mu g/m^3$), and 20 $\mu g/m^3$ BaP years (0.5 $\mu g/m^3$). For example Costantino et al (1994), who included 7 groups with means: 0.0, 14.8, 73.7, 162.4, 251.2, 339.9, 805.4, contributed only the first three groups to the first re-estimated URR (means $\leq$ 80), and the first two only to the second and third re-estimated URRs (means $\leq$40 and $\leq$20). Overall mean URRs and mean URRs for coke ovens, gasworks and aluminium smelters are given in Table 5. The mean URR increases substantially on removal of higher exposure groups. This is partly explained by the greater weight given by URRs from industries with lower exposures, which we have seen to have higher URRs. However, looking at the results for coke ovens, gasworks, and aluminium smelters only (last column), we see that even within these industries restricting analyses to groups with lower cumulative exposures led to higher mean URRs, suggestive of an exposure-response curve steeper at the origin than at higher exposures. However, for all these analyses except those excluding all exposures above 20 $\mu g/m^3$ BaP years, which was very imprecise, there was significant heterogeneity between studies. These results should therefore be interpreted with caution.

3.2 BLADDER CANCER

There were 27 cohorts for which risk estimates were published for bladder cancer (Table 6). Mean numbers of cases was much lower than for lung cancer (19 Vs 74), and a much higher proportion (16/27) were simple single-group SMRs. Some large cohorts reporting full lung cancer results reported only partial results for bladder cancer; often only a single group SMR was reported.

Nineteen (70%) unit relative risks were above one, though only one (Tremblay 1995) statistically significantly so. The mean URR was 1.33 (95%CI: 1.16,1.52), and this changed little on excluding less precise URRs (table 7). Neither a general test of heterogeneity ($p>0.20$), nor specific tests for variation in URRs over industries ($p=0.20$) or other potential modifiers ($p>0.20$) showed evidence for variation more than could be easily explained by chance (table 7).

The overall mean was strongly dependent on results for the aluminium production industry, in particular two large studies (Romundstad 2000 and especially Tremblay 1995). Although the URRs from other industries were statistically compatible with those for aluminium, there was little independent evidence for an association of bladder cancer with PAH in coke ovens or in other industries. However, small numbers of cases, especially for mortality studies, limited power.

As with lung cancer, there was no evidence for publication bias, nor did analysis with contrasts chosen by alternative criteria change overall patterns substantially. However, application of the linear

model led to rather different results – there was significant heterogeneity in URRs between studies and the overall mean was no longer statistically significant. We return to this in the discussion section.

4 DISCUSSION

4.1 LUNG CANCER

That our meta-analysis supports the conclusions of previous reviews that lung cancer is associated with PAH exposure is not surprising. The attention in this meta-analysis to quantification of this relationship is novel, though such estimates have been made in a selective review, and by several methods from the Costantino (1994) cohort. We compare our results with these in section 4.1.4.

Our results for coke ovens, gasworks, and aluminium production are relatively well-supported, though biases (4.1.1) should be considered. Our findings of higher URRs for other industries are more tentative, and need careful consideration of potential biases (4.1.1) and possible explanations (4.1.3).

4.1.1 Possible biases

Each of the studies included in this meta-analysis is subject to the usual range of biases in epidemiological studies, in particular confounding and information bias (exposure error).

Our first concern is potential confounding by smoking, which was uncontrolled in most studies. There are two reasons, however, that this seems unlikely to have caused major bias:

(a) Though only four studies controlled for smoking, two of these were large studies with substantial exposure allowing quite precise estimates of URRs. The mean URR in smoking-adjusted studies was statistically compatible with, but somewhat higher than that for the studies uncontrolled for smoking, and statistically significant in its own right.

(b) Several methodological papers (Axelson and Steenland 1988; Blair, Steenland et al. 1988; Siemiatycki, Wacholder et al. 1988) have explored the potential for confounding by smoking mathematically. One common conclusion was that where manual workers are compared with other manual workers, substantial confounding is unlikely because smoking rates are unlikely to differ much in exposed and unexposed.

Confounding by other occupational exposure is also possible, but we have limited potential for this by excluding cohorts in which PAH was judged unlikely to be the predominant carcinogen. An exception to this is total dust, because the hypothesis that dust may cause lung cancer regardless of composition has only recently gained credence (EC Scientific Committee for Toxicity, Ecotoxicity and the Environment http://europa.eu.int/comm/food/fs/sc/sct/out108_en.html), and because dust is a universal co-exposure of PAHs. The analyses that we were able to carry out addressing the possibility of confounding by dust gave no support to the hypothesis that dust played a major confounding role. However, these could not rule out confounding completely, because of the limited information on total dust exposure available to us, and the lack of control for this exposure in the published studies. Further evaluation of this will be possible when assessments are carried out of the "dust" hypothesis in its own right, which was not possible in this study.

Exposure is likely to have been inaccurately estimated in many studies, in particular those for which no exposure data was published in the report of the epidemiological study itself, so we made estimates. Random exposure error tends to bias exposure-response slopes towards the null value (Armstrong 1996). However, if our estimates were systematically too high or too low, exposure response slopes would be under- or over-estimated respectively. We included estimates if we believed them to be within five times the true exposure, so considerable margin for uncertainty remains. It is of some reassurance that the mean URR in those studies for which we estimated exposure was not much different from the mean URR in those studies with author-provided exposure information (Table 4). However, errors in exposure estimation might explain particularly high or low URRs in specific studies or industries. In those industries (tar distillation, chimney sweeping, power) with no studies reporting investigators own exposure estimates, interpretation should be particularly cautious.

4.1.2 Explanations for variation in URRs

URRs may vary between industries and cohorts for three reasons: (a) chance, (b) biases, or (c) because risk per unit BaP really varies. We have established that variation in URRs *between* industries cannot be explained by chance (in particular Coke ovens and Aluminium production Vs asphalt and chimney sweeping), but variation *within* industry can be, so it seems sensible to focus attention on explaining variation between industries. We have discussed biases and confounding above. Biases, in particular from inevitably inaccurate exposure estimation, could explain some variation. Confounding by other occupational exposures, perhaps dust, could also play a part.

There are two reasons that might account for true variation in URRs:

(a) *A factor which modifies the effect is present to varying degrees in different industries.* An example is smoking. Even if the exposed and unexposed groups in each cohort smoke to the same extent (so there is no confounding) a heavily smoking cohort might exhibit greater or lesser effect per unit occupational PAH than a lightly smoking cohort. Unfortunately, we did not have the information to address this. In the main, we can assume that our cohorts were mixed smokers and non-smokers, so the exposure-response relationships are most likely to predict risk well in similarly mixed groups. Other occupational exposures might also modify the effect per unit PAH, by promoting or inhibiting the action of PAH. Such a hypothesis is too general to evaluate without making it more specific. Finally we mention the possibility that *cumulative* exposure is not the right metric. If another metric – say early adult exposure, lagged exposure, or another time-weighted exposure – were the relevant one, modification would arise if the time pattern of exposure differed across cohorts. Information on timing of exposure was insufficiently available for us to evaluate such hypotheses, but we expect that timing of exposure would be in any case too similar across cohorts for very informative results to emerge. A few studies reported risk by lagged cumulative exposure, but these generally differed little from tables of risk by overall cumulative exposure.

(b) *The carcinogenic potency of the PAH mixture varies across industries*. It is known that many PAH aside from BaP are carcinogenic in animals (IARC 1985). BaP is used as an indicator of the total risk, not because it is the sole causal agent but in the hope that it is well-correlated with others. To the extent that the PAH mixtures in different industries have different relative concentrations of the various carcinogenic PAHs (their "profiles"), this could thus explain differences in risk per unit BaP. An approach that derives a risk metric by combining information on PAH profiles with information on relative carcinogenic potency from animal studies has been proposed (Krewski, Thorslund et al. 1989). For us to apply this to this meta-analysis, however, would require estimates of PAH profiles for each study, or at least each industry. We did not have such information, which is not readily available, for this study. However, PAH profiles are slowly being ascertained and some are published (some publications of profiles are listed in appendix B3), so this approach could probably be applied in the future.

Some specific studies with URRs quite different from the mean for their industry deserve specific mention.

- The two cohorts of gasworks workers studies by Doll (1972) have high URRs. The estimate of exposure for retort workers in these plants was 3 $\mu g/m^3$ BaP, heavily influenced by measurements reported in 1965 from mask samples. It may be that these were underestimates.
- The very high URR estimated from the study by Liu (1997) for carbon anode plant workers was based on exposure estimates reported by Liu, but just for one of seven plants, which may not have been representative.
- The low and precisely-estimated URR from the study of several Norwegian aluminium production plants (Romunstad 2000) has no obvious explanation. Exposure estimation was based on substantial hygiene data for most plants. The non-significance of the test for

heterogeneity in URRs among studies of aluminium production workers indicates that the absence of excess risk in this study could have been due to chance, but the result remains noteworthy.

4.1.3 Comparisons with other studies

The most directly comparable study is the brief report of,Gibbs 1997 who estimated lifetime risks of lung cancer per 100,000 from 50 years *continuous* exposure to 1 ng/m^3 BaP from nine studies, using a "linear no-threshold model". Eight of the nine studies were occupational (4 from coke ovens, 2 gasworks, one aluminium production, and one asphalt), and they or updates of them were included in our analysis. The ninth was a study of domestic exposure to "smoky coal" in China. To translate Gibbs' risk lifetime estimates from continuous exposure to relative risk estimates from occupational exposure we used the conversion factors used by Gibbs to do the reverse:

$$URR = 1 + \left[ULR \cdot \left(\frac{1}{50} \right) \cdot \left(\frac{10}{23} \right) \cdot \left(\frac{230}{365} \right) \cdot \left(\frac{1}{0.09} \right) \right] = 1 + \left[ULR \cdot 0.61 \right]$$

where ULR is the lifetime risk per ng/m^3 continuous (23 m^3 /day Vs 10 occupational) exposure (365 days Vs 230 occupational - our assumption) over 50 years, assuming a 9% lifetime risk. Gibbs' finding of ULRs: 0.3,4.2,4.4,5.8,6.6,7.2,7.8,9.5 translates to URRs: 1.02,1.26,1.27,1.35,1.40,1.44,1.48,1.58 – somewhat higher on average than the estimates in this study, but not grossly different.

It is also possible to compare our meta-analytic estimates with those that have been published from the cohort reported by Costantino (1995):

- The USEPA (1984), cited by WHO (1987,2000) estimated a lifetime risk from *continuous* exposure per ng/m^3 BaP of 8.7/100,000, using the linearised multistage model. Following the translation we used for Gibbs' study, this corresponds to a URR (relative risk from 100 µg/m3 BaP years) of about 1.53.
- Moolgavkar, Luebeck et al. 1998 estimated a unit absolute risk from continuous 1 µg/m3 BSM of 15/100,000 using the two-stage clonal expansion model. Roughly re-expressing this as above gives URR=1.13.

The second of these alternative estimates of URR is very similar to our estimate from Costantino (1994) using the exponential model (Table 2: URR=1.15). Our estimate from Costantino (1994) using the linear relative risk model was 1.31.

Our findings of a larger URR in the asphalt industry than in coke-ovens or aluminium smelters was tentative. Recent publication of a very large European study of mortality in the asphalt industry (Boffetta, Burstyn et al. 2001) will add importantly to information on this question. The study was not published in time for formal inclusion in this meta-analysis. It found an association of lung cancer with exposure to bitumen fumes in some but not other analyses. Estimates of exposure to PAH as BaP were made, allowing as far as possible for knowledge of the extent to which coal tar was used as an additive, time trends in exposure levels and type of asphalt paving. In the asphalt industry, PAH exposure originates from bitumen, coal tar (banned in Western Europe) and diesel exhaust. Contribution of diesel exhaust to PAH exposure was not incorporated into quantitative PAH exposure metric, because available data did not permit the investigators to identify groups of asphalt pavers within the cohort with different diesel exhaust exposure. The report includes a table (8.9.4) of lung cancer rate ratios in relation to cumulative exposure to PAH (as BaP), from which it was possible to estimate a URR in the method standard for this meta-analysis. The estimate (44.9; 95% CI: 25.0,64.8) places it similar to the other asphalt worker studies included in this review, adding support to the hypothesis that risk per unit BaP is higher in this industry than in coke ovens or aluminium production. However, analysis of risk by quantitative estimate of PAH exposure was possible only for workers only employed in paving (including mastic paving); it may be that other groups in the study (eg roofers) showed different patterns.

4.1.4 Interpretation for risk assessment

We have used a benchmark of 100 μg/m^3 years exposure to provide a scale for presenting the URR, but risk predictions at other exposures (x) can be made using the formulae:

$$URR_{cum.exp=x} = [URR_{cum.exp=100}]^{(x/100)}$$

For example, relative risk consequent on exposure to 1 μg/m^3 for 40 years (40 μg/m^3 years) according to the mean estimate for coke ovens is $1.17^{(40/100)}$=1.06. (At these moderate-low relative risks, log-linear interpolation is close to linear interpolation.) Risk estimates calculated this way for a range of URRs and exposure concentrations are given in Table 9.

Model choice. We adopted the log-linear model because it was amenable to statistical evaluation – p-values for heterogeneity are unreliable when meta-analysis was conducted on URR_{lin}. However, there is evidence (Appendix C) that the linear model fits the data and arguments on mechanism better. As we noted in the "Sensitivity analyses" section of the Results, risk prediction made from the two differ little if applied within the range of exposures from which they were estimated. Thus for simplicity we work with the loglinear model. This is not ideal. The development of methods to allow better synthesis of linear relative risk models would be useful. Other more elaborate models (eg two-stage, multistage) are possible with much more information on timing of exposure than was available from published studies (effectively original individual data).

Our URRs for coke ovens, gasworks, aluminium production, and the overall mean, are driven by risks observed at levels around 100 μg/m^3 BaP years. Risks estimates are at their most secure at exposure not too far from this (say 20-500 μg/m^3 BaP years). estimating risks for much lower levels inevitably requires model assumptions. We have emphasised the log-linear model, and noted that estimates are similar for the linear model (this includes low exposures). Models with very different assumptions about increments at low exposures (eg threshold models) could predict very different risks at these levels. The sensitivity analysis (Table 5) investigating dependence of results on high exposures is suggestive of an exposure-response curve steeper at lower exposure than at higher.

Overall or industry-specific means? The URRs overall had significant and substantial heterogeneity – there was evidence that risk per unit BaP varied across cohorts. The mean in the presence of this heterogeneity is a rather artificial one, reflecting those industries and cohorts that happen to have been studied. Within industries there was no significant heterogeneity, so that the industry-specific means could be interpreted as representative of each industry. These considerations favour use of industry-specific means. Means for coke ovens, gas works, and aluminium production are consistent and relatively precisely estimated. The combined mean URR for these industries was 1.17 (95%CI:1.12,1.22), and might reasonably be used for all these industries. However, means for other industries are rather imprecise. Risk assessment for these industries will inevitably be very uncertain, whether the imprecise industry-specific mean or the overall mean was used.

Attributable burden of disease The number of cancers caused by occupational exposure to PAH depends on three factors beyond the exposure-response relationship: (a) the number of persons exposed; (b) the levels at which they are exposed, and (c) the background rate of lung cancer, on which relative risks will act. A comprehensive assessment is beyond the scope of this report, but we have made an estimate of cases that would be caused in UK coke oven workers, by PAH exposures continuing at current levels, ignoring probably higher past exposures. There are currently about a thousand coke oven workers in the UK, with mean exposure about 1.5 μg/m^3 BaP (John Unwin, personal communication). General population lifetime risk of lung cancer in UK males, using 1997 rates, is 8% (Office of National Statistics 2000). Using the URR of 1.17 for coke ovens, one year's exposure will therefore lead eventually to a lifetime excess risk of $0.08X(1.17^{(1.5/100)}-1)=1.9X10^{-4}$, which among 1000 workers will lead to 0.2 cases. 40 years of such exposure would lead to 40X0.2=8 cases, almost all of whom will die from this cancer.

4.2 BLADDER CANCER

Results for bladder cancer were more uncertain than for lung cancer, due mainly to the much smaller number of cases in this rarer cancer. Although our results support a PAH-bladder cancer association,

there is less evidence for a PAH–bladder cancer causal association than there is for lung cancer. Only for the aluminium production industry was the evidence for an association strong. On the other hand the data from the other industries were weak rather than negative – and were compatible with a generic PAH risk of the same magnitude per unit BaP across all cohorts.

As we commented in the Introduction, previous reviews have similarly concluded that there is a much stronger weight of evidence that PAH causes lung than that it causes bladder cancer. One recent review (Negri and La Vecchia 2001) noted specifically that the evidence was confined to the aluminium production industry. Other co-exposures, in particular aromatic amines and nitro-PAH (Tremblay 1995) known to be present in small concentrations in aluminium potrooms, have been suggested as alternative causal agents. However, it is unclear why these would not also be present in other PAH-exposed workplaces.

If we do assume a causal association, the absence of significant heterogeneity between studies suggests focusing for quantitative risk estimation on the overall mean URR: 1.33. As for lung cancer, estimates of risk from exposures other than 100 $\mu g/m^3$ BaP years can be calculated from this. This mean URR is slightly larger than that for lung cancer (1.20). However background mortality due to bladder cancer is much lower than that that of lung cancer, so that number of lung cancer deaths attributable to PAH would be much higher than the number of attributable bladder cancer deaths. For example, using the same methods as for lung cancer the expected number of bladder cancers in 1000 coke oven workers following 40 years exposure at 1.5 $\mu g/m^3$ is 3.3 (Vs 8 lung cancers), with about one third expected to die of the cancer.

Most of the caveats discussed for the lung cancer results apply also to bladder cancer. One is stronger: application of the linear model leads to quite different results We have noted that p-values are unreliable for the linear model, so this observation should be taken as a note of caution rather than an invalidation of the loglinear results.

4.3 METHODOLOGICAL ISSUES

Compared to their widespread use in clinical trials, meta-analyses are relatively new to occupational epidemiology, and even more rare in investigations of exposure-response relationships. In entering this poorly charted territory, this study threw up several methodological challenges for which we found ad-hoc solutions. It might be useful to future similar meta-analyses for us to draw attention to the principle ones:

(a) We needed to choose one contrast from each study from which to estimate an exposure-response relationship. To be objective, we chose a simple choice algorithm and explored sensitivity of results to it, but it may be that this could be improved on.

(b) We needed to estimate mean exposure in upper exposure groups for which only a lower limit is published.

(c) A priori considerations and data in the meta-analysis studies suggested use of linear rather than log-linear models, but estimates of URRs from linear models proved intractable in meta-analysis, so we worked with loglinear models. It would be preferable not to have to compromise. One possibility would be to apply a random effects linear relative risk model to semi-aggregated data (see below), but such models have not to our knowledge been discussed in the statistical literature, nor can they be fitted with standard software.

(d) We proceeded in this meta-analysis to estimate first a single effect measure (URR) from each study, then analyse these using standard meta-analytic methods. However, it appears to us that once "semi-aggregated" data has been assembled for cases, exposures, and relative risks in *each exposure-group* in each study (eg Appendix E), it would be possible to use methods developed more multi-level data (multi-level models) more generally.

4.4 CONCLUSIONS

(a) **On average, relative risk predicted for lung cancer at 100 mg/m^3 BaP years (URR) was 1.20 (95%CI:1.11-1.29), but this varied significantly across industries. Coke ovens (1.17; CI:1.12-1.22), gasworks (1.15; CI:1.11-1.20), and aluminium production (1.16; CI:1.05-1.28) were slightly lower than the mean, and asphalt (17.50; CI:4.21-72.78) and chimney sweeping (16.2; CI:1.64-160.7) were much higher but imprecisely estimated.**

(b) These results are subject to several uncertainties, the most important being due to uncertainty in past exposures.

(c) Difference between industries may be due to artifacts, or to real differences in risk associated with one unit BaP in different industries.

(d) Within coke ovens, gasworks, and aluminium smelters, there is no evidence against BaP being an adequate indicator of lung cancer risk from PAHs. In other industries this is less certain.

(e) Linear models fitted better than loglinear though they gave a similar mean URR. We worked with the loglinear model because of its better statistical properties, but this compromise is not ideal.

(f) There was also an association of PAH with bladder cancer (mean URR=1.33; 95%CI: 1.16-1.52, no significant heterogeneity), but this finding was less robust than that for lung cancer, being largely dependent on two studies of aluminium production workers. Bladder cancer is also much less common than lung cancer, especially as a cause of death, so lung cancer is reasonably considered as the lead risk.

(g) The URR represents risk at fairly common exposures historically, but high for today. Risks at other exposures can be estimated from URRs under (loglinear) model assumptions: eg at 1µg/m3 BaP for 40 years, cumulative exposure is 40 µg/m^3 BaP years, and the average lung cancer risk is 1.20(40/100)=1.076.

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TABLES AND FIGURES

Table 1: Main supplementary exposure estimates (BaP; total dust).

Industry	Job group		BaP(ug/m^3)	Dust*
Coke ovens	Top		20	H
	Side		10	M
	Other		0.5	M
	Typical mean		10	H/M
Coal gas production	Retorts		3	M
	By-products		0.5	L
	Typical mean			M/L
Aluminium smelting	Soderberg potroom		15	VH
	Prebake potroom		0.05	H
	Carbon plant		2	H
	Typical mean	Sod	3	H
	Typical mean	Pre	0.5	H/M
Carbon anode plants	-		1	H
Asphalt	-		0.5	M
Tar distillation	-		0.5	M
Chimney sweep	-		1	VH
Thermo-electric Power	-		0.05	L
Carbon black	-		0.05	H

*Dust classification: LOW (<1 mg/m^3); MODERATE (1-5 mg/m^3); HIGH (5-10 mg/m^3); VERY HIGH (10-25 mg/m^3)

Table 2 Cohort characteristics and unit relative risk estimates: Lung cancer

Cohort Characteristics											RR at 100 µg/m^3 BaP years				RR at
Author-year	Industry	Country	design	author exposure inform.	Contrast	Outcome	Smok adj	n of cases	n of exp. gps	max exp	estimate	(95%CI)		standard error	max exp.
Bye et85	coke_ovens	Norway	cohort	Proxy	cum. exp.	Morb	N	7	4	10.0	>1000	0.01	>1000	11.43	6.10
Chau, 93	coke_ovens	France	cohort	None	job group	Mort	Y	24	5	294.4	1.00	0.68	1.46	0.20	0.99
Costan95	coke_ovens	USA&Canada	cohort	Proxy	cum. exp.	Mort	N	458	7	805.4	1.15	1.10	1.21	0.02	3.18
Franco93	coke_ovens	Italy	cohort	None	single SMR	Mort	N	19	1	186.0	1.41	1.07	1.79	0.17	1.90
Hurley83	coke_ovens	UK	cohort	Proxy	cum. exp.	Mort	N	182	4	252.9	1.36	1.04	1.79	0.14	2.19
Hurley83	coke_ovens	UK	cohort	Proxy	cum. exp.	Mort	N	59	4	262.9	1.19	0.77	1.85	0.22	1.60
Reid a56	coke_ovens	UK	cohort	None	job group	Mort	N	21	3	400.0	0.94	0.64	1.39	0.20	0.79
Sakabe75	coke_ovens	Japan	cohort	None	single SMR	Mort	N	15	1	200.0	1.13	0.85	1.45	0.18	1.28
Swaen,91	coke_ovens	Holland	cohort	None	job group	Mort	N	273	3	200.0	1.19	0.97	1.45	0.10	1.41
Xu et 96	coke_ovens	China	nested_cc	BaP	duration	Morb	Y	194	3	453.8	1.33	1.14	1.56	0.08	3.65
Berger92	gasworks	Germany	cohort	BaP	single SMR	Mort	N	78	1	747.6	1.15	1.12	1.19	0.02	2.88
Doll e72	gasworks	UK	cohort	None	job group	Mort	N	79	3	60.0	4.01	1.16	13.87	0.63	2.30
Doll e72	gasworks	UK	cohort	None	job group	Mort	N	110	2	60.0	5.82	1.06	32.00	0.87	2.88
Gustav90	gasworks	Sweden	cohort	BaP	single SMR	Mort	N	0	1	28.7	0.00	0.00	66.56	1450	0.00
Armstr94	aluminium	Canada	case-coh	BaP	cum. exp.	Mort	Y	338	5	413.1	1.22	1.09	1.37	0.06	2.30
Milham79	aluminium	USA	cohort	None	duration	Mort	N	35	6	99.2	0.19	0.00	>1000	6.15	0.19
Moulin00	aluminium	France	cohort	None	duration	Mort	N	19	5	200.0	1.11	0.46	2.66	0.45	1.23
Mur, J87	aluminium	France	cohort	None	duration	Mort	N	17	3	248.2	0.69	0.31	1.54	0.41	0.40
Rocket83	aluminium	USA	cohort	None	duration	Mort	N	64	5	116.1	1.85	0.53	6.53	0.64	2.05
Rocket83	aluminium	USA	cohort	None	duration	Mort	N	133	5	15.4	0.06	0.00	9.58	2.59	0.65
Romund00	aluminium	Norway	cohort	BaP	cum. exp.	Morb	N	189	4	222.4	0.99	0.79	1.22	0.11	0.97
Spinel91	aluminium	Canada	cohort	Proxy	cum. exp.	Morb	N	37	5	251.1	1.31	0.72	2.39	0.30	1.99
Donato00	carbon	Italy	cohort	None	duration	Mort	N	34	3	36.4	0.18	0.01	5.61	1.75	0.54
Liu97	carbon	China	cohort	BaP	job group	Mort	N	50	4	17.3	53.07	3.44	819	1.40	1.99
Moulin89	carbon	France	nested_cc	BaP	duration	Morb	Y	7	4	94.9	2.82	0.20	40.59	1.36	2.67
Moulin89	carbon	France	nested_cc	BaP	duration	Mort	N	13	4	5.8	0.00	0.00	>1000	24.21	0.41
Hammon76	asphalt	USA	cohort	BaP	duration	Mort	N	121	4	66.8	5.63	0.89	35.53	0.94	3.17
Hansen91	asphalt	Denmark	cohort	BaP	single SMR	Mort	N	25	1	20.3	189.59	22.19	>1000	1.35	2.90
Swaen,97	asphalt	Holland	cohort	None	single SMR	Mort	N	39	1	10.0	15.23	0.50	347	2.19	1.31
Hansen89	tar_distil.	Denmark	cohort	None	single SMR	Mort	N	16	1	10.0	35.76	0.13	>1000	3.42	1.43
Maclar87	tar_distil.	UK	cohort	None	single SMR	Mort	N	12	1	6.0	>1000	0.04	>1000	6.58	1.60
Swaen,97	tar_distil.	Holland	cohort	None	single SMR	Mort	N	48	1	10.0	5.32	0.25	89.38	1.97	1.18
Evanof93	chim_sweep	Sweden	cohort	None	duration	Mort	N	53	4	40.0	9.88	0.60	162	1.43	2.50
Hansen83	chim_sweep	Denmark	cohort	None	single SMR	Mort	N	5	1	30.0	44.63	1.02	752	2.04	3.13
Cammar86	power	Italy	cohort	None	single SMR	Mort	N	5	1	1.0	>1000	0.00	>1000	61.16	1.77
Forast89	power	Italy	cohort	None	duration	Mort	N	8	3	1.5	0.02	0.00	>1000	110.37	0.94
Petrel89	power	Italy	cohort	None	single SMR	Mort	N	6	1	1.0	>1000	0.00	>1000	55.83	1.36
Robers96	carbon_bla	USA	cohort	None	single SMR	Mort	N	34	1	1.0	0.00	0.00	>1000	23.45	0.84
Soraha01	carbon_bla	UK	cohort	Proxy	cum. exp.	Mort	N	64	4	0.8	>1000	0.00	>1000	58.15	1.48

Table 3: Summaries of cohort characteristics (lung cancer)

Variable	n of studies with information	mean	min	max
Year:				
of publication	39	1988	1956	2001
of first exposure	28	1923	1893	1964
of last exposure	4	1981	1968	1989
of start of follow up	39	1958	1935	1987
of end of follow-up	39	1983	1954	1996
Duration (years)				
of follow-up (maximum)	39	25.3	5	59
of latency (maximum)	28	53.8	24	87
Number				
of lung cancer cases	39	74.2	0	458
of exposure groups	39	3.1	1 (13 studies)	7
Cumulative exposure in highest exposure group (ug/m^3 years)	39	154.9	0.75	805.4

Table 4 Distribution and determinants of unit relative risks for lung cancer

Group	n of studies	mean URR*(95%CI)	Significance tests**
All	39	1.20(1.11,1.29)	p(het)=0.007
Studies with SE<10	31	1.20(1.11,1.30)	p(het)=0.002
Studies with SE<1	19	1.18(1.12,1.23)	p(het)=0.19
By Industry			p=0.002
- coke_ovens	10	1.17(1.12, 1.22)	
gasworks	4	1.15(1.11, 1.20)	
aluminium	8	1.16(1.05, 1.28)	
[above 3 combined	22	1.17(1.12, 1.22)	p(het)>0.20]
carbon	4	4.30(0.81, 22.79)	
asphalt	3	17.50(4.21, 72.78)	
tar_distillery	3	12.28(0.48, 314.4)	
chimney_sweep	2	16.24(1.64, 160.7)	
power	3	>1000(0 , >1000)	
carbon_black	2	0 (0 , >1000)	
By exposure information from authors*			p>0.20
BaP	10	1.29(1.11, 1.49)	
Proxy	6	1.16(1.11, 1.21)	
None	23	1.17(1.03, 1.33)	
By contrast*			p>0.20
cum. exp.	8	1.16(1.11, 1.22)	
duration	12	1.27(1.10, 1.48)	
job group	6	1.16(0.99, 1.36)	
single SMR	13	1.20(0.95, 1.51)	
By study design*			p=0.10
cohort	36	1.16(1.11, 1.21)	
nested cc	3	1.33(1.14, 1.55)	
By smoking adjustment*			p=0.05
N	35	1.16(1.11, 1.21)	
Y	4	1.31(1.16, 1.48)	
By continent*			p>0.20
Asia	3	1.30(1.13, 1.50)	
Europe	28	1.13(1.02, 1.26)	
N.America	8	1.16(1.11, 1.22)	
By outcome			p>0.20
Mortal	34	1.17(1.12, 1.22)	
Morbid	5	1.21(1.06, 1.38)	
By dust exposure for industry			p=0.12
low	3	>1000(0,>1000)	
moderate	10	1.16(1.11,1.21)	
high	24	1.17(1.13,1.22)	
very high	2	16.24(1.64,14.8)	

* URR: Unit relative risk (RR at 100 μg/m3 BaP years). Adjusted for differences across industries by including industry indicator in a meta-regression. Means are scaled to show fitted values for coke ovens, though ratios would apply to any industry.

** Generally, the Wald test for significance of variation in mean URRs across the groups indicated; "p(het)" indicates the test for heterogeneity across all studies.

Table 5 Investigating the dependence of Mean URR on high exposures

Excluding groups with exposures:	All studies			Coke, gas, aluminium		
	N*	URR(95%CI)	p(het)	N*	URR(95%CI)	p(het)
No exclusions	39	1.20(1.11,1.29)	<0.001	22	1.17(1.12, 1.22)	>0.20
>80 ug/m^3	34	3.46(2.03,5.90)	<0.001	17	1.88(1.22,2.91)	0.02
>40 ug/m^3	30	6.49(1.99,21.12)	<0.001	14	2.42(0.56,10.40)	0.01
>20 ug/m^3	21	4.54(1.26,16.30)	>0.20	7	1.87(0.24,14.22)	>0.20

* remaining number of studies from which URRs could be estimated
p(het): test for heterogeneity between URRs.

Table 6 Cohort characteristics and unit relative risk estimates bladder cancer

Cohort Characteristics											Unit Relative Risk Increment				RR at max exp.
Author-year	Industry	Country	design	author exposure inform.	Contrast	Outcome	Smok adj	n of cases	n of exp. gps	max exp	estimate	(95%CI)		standard error	
Bye et85	coke_ovens	Norway	cohort	Proxy	cum. exp.	Morb	N	5	4	10.0	0.00	0.00	>1000	107.38	0.01
Chau, 93	coke_ovens	France	cohort	None	single SMR	Mort	N	1	1	97.4	0.69	0.01	4.04	1.76	0.70
Costan95	coke_ovens	USA&Canada	cohort	Proxy	single SMR	Mort	N	16	1	217.0	1.06	0.82	1.33	0.20	1.14
Hurley83	coke_ovens	UK	cohort	Proxy	single SMR	Mort	N	8	1	143.8	0.91	0.51	1.47	0.42	0.88
Hurley83	coke_ovens	UK	cohort	Proxy	single SMR	Mort	N	16	1	143.8	1.08	0.73	1.51	0.30	1.11
Swaen,91	coke_ovens	Holland	cohort	None	job group	Mort	N	38	3	200.0	1.02	0.50	2.07	0.36	1.04
Doll e72	gasworks	UK	cohort	None	job group	Mort	N	5	3	60.0	8.23	0.01	>1000	3.22	3.54
Doll e72	gasworks	UK	cohort	None	job group	Mort	N	11	2	60.0	9.56	0.01	>1000	3.59	3.88
Milham79	aluminium	USA	cohort	None	single SMR	Mort	N	1	1	60.0	0.00	0.00	3.64	17.14	0.00
Moulin00	aluminium	France	cohort	None	duration	Mort	N	7	5	200.0	1.66	0.32	8.59	0.84	2.75
Rocket83	aluminium	USA	cohort	None	job group	Mort	N	19	3	100.0	2.46	0.33	18.06	1.02	2.46
Romund00	aluminium	Norway	cohort	BaP	cum. exp.	Morb	N	130	4	222.4	1.19	0.88	1.61	0.16	1.47
Spinel91	aluminium	Canada	cohort	Proxy	cum. exp.	Morb	N	16	4	131.7	4.47	0.94	21.26	0.80	7.19
Trembl95	aluminium	Canada	nested_cc	BaP	cum. exp.	Morb	Y	138	5	413.1	1.48	1.24	1.76	0.09	5.04
Donato00	carbon	Italy	cohort	None	duration	Mort	N	7	3	37.2	0.10	0.00	>1000	4.78	0.43
Moulin89	carbon	France	cohort	BaP	single SMR	Mort	N	3	1	2.0	>1000	0.00	>1000	48.30	1.94
Moulin89	carbon	France	cohort	BaP	single SMR	Morb	Y	0	1	37.4	0.00	0.00	3.30	6081.8	0.00
Hammon76	asphalt	USA	cohort	BaP	single SMR	Mort	N	15	1	28.6	3.94	0.52	22.65	1.55	1.48
Hansen89	asphalt	Denmark	cohort	BaP	single SMR	Morb	N	5	1	20.3	8.66	0.03	563.1	3.78	1.55
Swaen,97	asphalt	Holland	cohort	None	single SMR	Mort	N	3	1	10.0	3.94	0.00	>1000	9.89	1.15
Hansen89	tar_distil.	Denmark	cohort	None	single SMR	Mort	N	5	1	10.0	>1000	0.74	>1000	7.66	3.01
Maclar87	tar_distil.	UK	cohort	None	single SMR	Mort	N	3	1	6.0	>1000	0.08	>1000	16.49	4.29
Swaen,97	tar_distil.	Holland	cohort	None	single SMR	Mort	N	2	1	10.0	0.00	0.00	953.4	12.12	0.55
Evanof93	chim_sweep	Sweden	cohort	None	duration	Morb	N	37	4	40.0	0.16	0.00	14.61	2.30	0.48
Cammar86	power	Italy	cohort	None	single SMR	Mort	N	2	1	1.0	>1000	0.00	>1000	121.17	7.41
Forast89	power	Italy	cohort	None	single SMR	Mort	N	2	1	1.0	>1000	0.00	>1000	121.17	1.74
Soraha01	carbon_bla	UK	cohort	Proxy	single SMR	Mort	N	6	1	0.3	>1000	0.00	>1000	246.33	1.73

Table 7 Distribution and determinants of unit relative risks for bladder cancer

Group	n of studies	mean URR*	(95%CI)	Significance tests*
All	27	1.33	(1.17, 1.51)	p(het)>0.2
Studies with SE<10	18	1.33	(1.17, 1.51)	p(het)>0.2
Studies with SE<1	8	1.30	(1.12, 1.51)	p(het)>0.2
By Industry				p=0.20
coke_ovens	6	1.04	(0.79, 1.37)	
gasworks	2	8.80	(0.08, 967.68)	
aluminium	6	1.42	(1.23, 1.65)	
[above 3 combined	14	1.32	(1.16, 1.51)	p(het)>0.20]
carbon	3	0.14	(0.00, >1000)	
asphalt	3	4.40	(0.27, 70.67)	
tar_distillery	3	>1000	(0.04, >1000)	
chimney_sweep	1	0.16	(0.00, 14.61)	
power	2	>1000	(0.00, >1000)	
carbon_black	1	>1000	(0.00, >1000)	
By exposure information from authors				p>0.2
BaP	6	1.41	(1.21, 1.64)	
Proxy	6	1.10	(0.82, 1.48)	
None	15	1.18	(0.65, 2.14)	
By contrast				p>0.2
cum. exp	4	1.42	(1.22, 1.65)	
duration	3	1.18	(0.26, 5.42)	
job group	4	1.17	(0.61, 2.27)	
single SMR	16	1.06	(0.79, 1.43)	
By study design				p>0.2
cohort	26	1.15	(0.95, 1.41)	
nested_cc	1	1.48	(1.24, 1.76)	
By smoking adjustment				p>0.2
unadjusted	25	1.15	(0.95, 1.37)	
adjusted	2	1.48	(1.24, 1.76)	
By continent				p>0.2
Europe	21	1.13	(0.89, 1.44)	
N.America	6	1.42	(1.22, 1.67)	
-				
By outcome				p>0.2
Mortal	20	1.09	(0.83, 1.42)	
Morbid	7	1.41	(1.22, 1.64)	

* URR: Unit relative risk (RR at 100 μg/m3 BaP years).
** Generally, the Wald test for significance of variation in mean URRs across the groups indicated; “p(het)” indicates the test for heterogeneity across all studies.

Table 8 Special investigation of prebake aluminium potrooms to inform on potential confounding by dust.

Cohort/contrast	Group	Prebake potrooms		Soderberg potrooms	
		n. cases	RR*	n. cases	RR*
Armstr94	<1yr	88	1.00	88	1.00
	1-9yrs	32	1.22(0.68-2.02)	65	1.32(0.91-1.92)
	10-19yrs	70	1.15(0.55-2.42)	35	1.37(0.87-2.16)
	20+yrs	7	1.25(0.40-3.89)	74	2.00(1.38-2.90)
Rocket83	<10yrs	51	1.14(0.85,1.49)	13	0.66(0.35,1.13)
	10-15yrs	6	0.60(0.22,1.34)	10	1.40(0.67,2.57)
	15-20yrs	11	1.03(0.51,1.81)	12	1.15(0.59,2.01)
	20-25yrs	10	1.41(0.68,2.60)	2	0.32(0.04,1.16)
	25+yrs	9	0.73(0.33,1.38)	5	2.06(0.66,4.81)

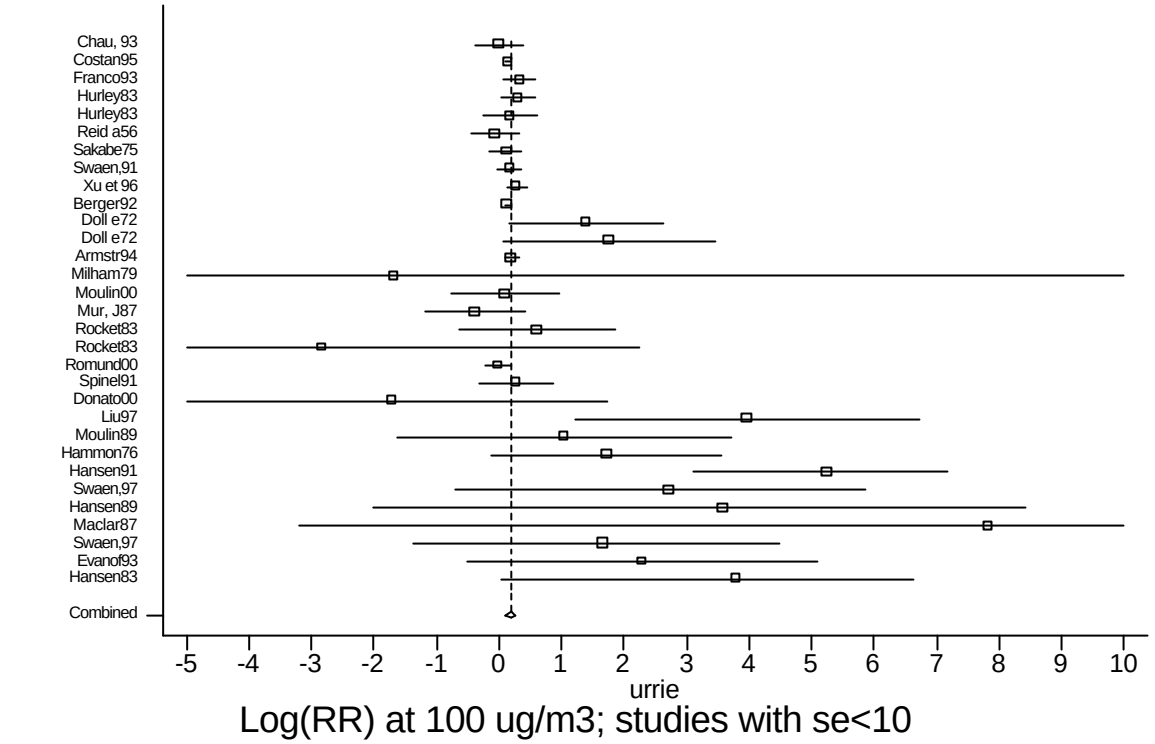
* RR; For Armstrong 1994: internally estimated rate ratio adjusting for smoking and years worked in Soderberg potrooms; for Rockette 1983: SMR.

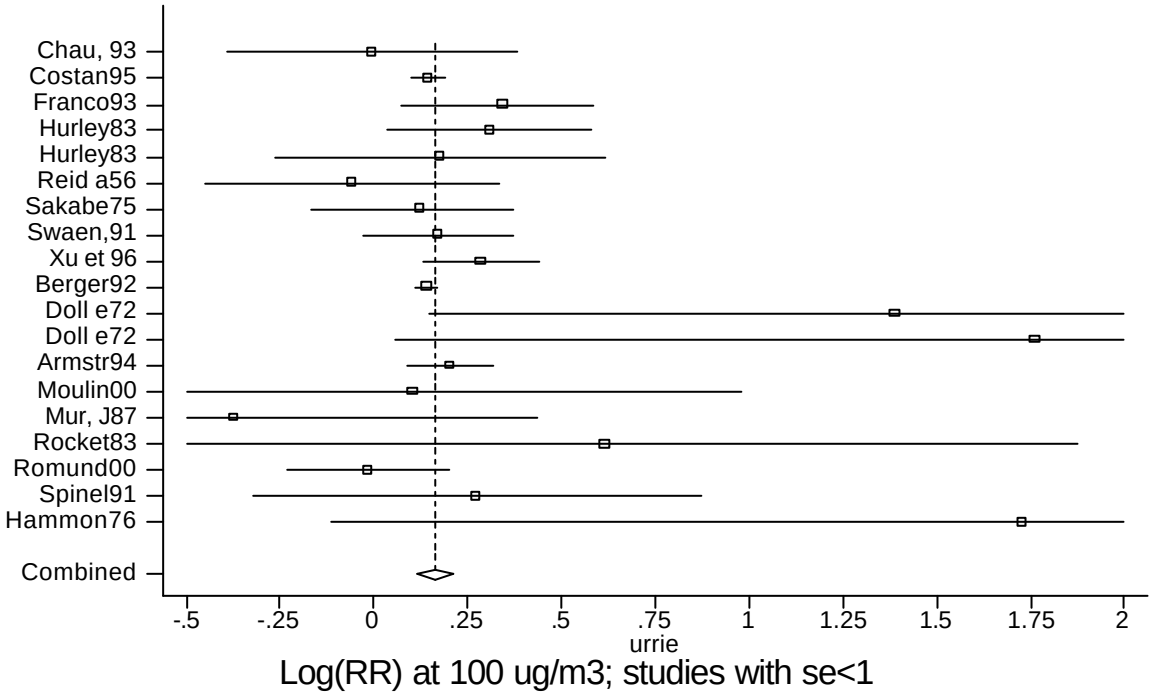
Table 9. Relative risks for contracting cancer estimated to follow from 40 years occupational exposure

	Exposure to BaP in μg/m^3 for a working life of 40 years			
	0.1	0.2	0.5	1
Overall mean URR(1.20)				
Lung cancer	1.007	1.015	1.035	1.076
Bladder cancer	1.011	1.023	1.059	1.121
Mean URR for Coke ovens, aluminium smelters, and gasworks (1.16)				
Lung* cancer	1.006	1.012	1.030	1.061
Mean URR for asphalt (17.5)				
Lung* cancer	1.12	1.26	1.78	3.14

* no evidence for variation in bladder cancer risk across industries

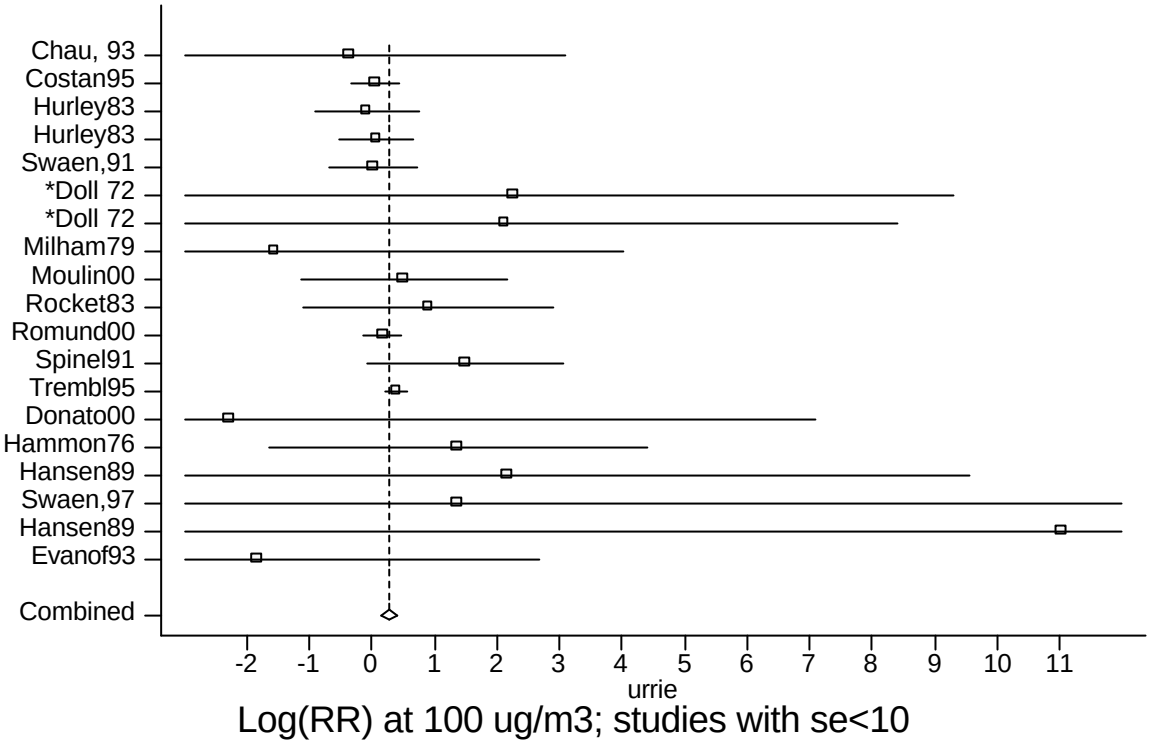
Figure 1: Relative risk at 100 mg/m^3 years (URR) for lung cancer.





Figures 1a and 1b show estimated URRs (squares) and 95% confidence intervals (lines) for each cohort. These are presented as (natural) logarithms, thus a log(RR) of 1 is equivalent to a RR of 2.3. Confidence intervals are truncated at the edges of the graph. Diamonds at the bottom of each show the overall mean and its CI. The top figure shows all studies with standard errors (SEs) below 10. To show the detail of more precise studies, the lower figure shows studies with SEs below 1. Very imprecise studies (SE >10) are not graphed.

Figure 2: Relative risk at 100 µg/m^3 years (URR) for bladder cancer



APPENDICES

Appendix A. Specific search terms used to identify studies.

	Search terms for electronic databases		
	Neoplasm (MESH term)		
And	(epidemiolog* or occupational*)	Not	Molecular
		Not	adduct*
And	Polycyclic aromatic hydrocarbon (MESH term)	Not	Polymorphism*
Or	Smoky coal	Not	Bioassay
Or	Unvented coal smoke	Not	Assay
Or	Carbon black*	Not	review*
Or	Carborundum	Not	PMR
Or	silicon carbide	Not	PCMR
Or	Bitumen	Not	Proportionate cancer
Or	Coal tar*	Not	Population based
Or	Creosote*	Not	hospital based
Or	Mineral oil*	Not	registry data
Or	shale oil*	Not	Biomarker*
Or	Soot*	Not	animal*
Or	Aluminium	Not	Metabolite*
Or	Anode baking		
Or	Coke		
Or	coal gasification		
Or	Iron foundry		
Or	Steel foundry		
Or	Tar distillation		
Or	Roofers		
Or	asphalt workers		
Or	Carbon electrode*		
Or	graphite electrode*		
Or	Chimney sweeps		
Or	Calcium carbide production		
Or	Wood treatment		
Or	gas worker*		

Mesh terms:

Mesh headings were used in searches of electronic databases, in order to broaden the scope of the search. These headings are mapped to the following terms:

Polycyclic Aromatic Hydrocarbon

used for

- Arene
- Aromatic Hydrocarbon,Polycyclic
- Hydrocarbon,Polycyclic Aromatic
- Pah
- Polyaromatic Hydrocarbon
- Polycyclic Hydrocarbons, Aromatic
- Polycyclic Aromatic Hydrocarbon

Polycyclic Aromatic Hydrocarbon (7680)
[Associated Terms]

- Benz[A]Anthracene (645)
- Benz[A]Anthracene Derivative (81)
- Benzo[A]Pyrene (6232)
- Benzo[A]Pyrene Derivative (376)
- Benzo[E]Pyrene (195)
- Benzo[Ghi]Perylene (111)
- Benzo[K]Fluoranthene (149)
- Chrysene (479)
- Chrysene Derivative (143)
- Dibenz[A,C]Anthracene (60)
- Dibenz[A,H]Anthracene (237)
- Dibenzo[A,L]Pyrene (30)
- 7,12 Dimethylbenz[A]Anthracene (2486)
- Dimethylbenz[A]Anthracene (1635)
- Fluoranthene (663)
- 3 Methylcholanthrene (4312)
- Naphthacene Derivative (25)
- Perylene (213)
- Polycyclic Aromatic Hydrocarbon Derivative (957)
- Pyrene (1263)
- Pyrene Derivative (357)

BLADDER CANCER

- Urinary Bladder Cancer
- Urine Bladder Cancer
- Vesical Cancer

LUNG CANCER

- Bronchus Cancer
- Cancer,Lung
- Pulmonary Cancer
- Schneeberg Disease

CANCER

- Cancer Morphology
- Cancer Pattern
- Primary Cancer

Appendix B1: Summary of information on PAH exposure (as BaP) in published epidemiological studies.

Industry	Cohort	Sub-groups (if any)				Mean	Comment
Coke ovens		top	side	other			
	Constantino 95	22.4	6.2			3.5	total includes about 60% zero exp.
	Hurley 1983	14.3	6.4	3.5		7.2	
	Berger 1992					28	
	Bye 1998					0.07	includes many unexposed
	Gustavsonn 1990					2.4	
	Xu 1996	50?	15?	5?		16.5	some guessing from JEM supplied by Xu
Aluminium smelters		potroom-sod	potroom-prebake	Carbon plant	other		
	Armstrong 1994	15	0.03	1		2.3	
	Spinelli 1991					2.2	
	Romunstad2000	3 to 20	0 to 5	1 to 10		3.5	
carbon plant		"high"	"med"	"low"	"none"		
	Moulin 1989					2.2	16+4 4 hr personal samples from 2 plants: Hot spots?
	Liu 1997	1.2	0.3	0.1	0	0.8	
Asphalt							
	Hansen 1989&91					1	
	Hammond 1976					17	Probably mostly CTP

Note: this information was used only to inform exposure estimates for studies for which none were provided (Appendix B3); exposure-response relationships for the studies referenced on this table were estimated directly from published tables of risk by exposure (typically cumulative exposure).

Appendix B2: Review of PAH exposure information pertaining to studies for which this was not provided by the authors

(John Unwin)

Units are in μg/m^3 unless stated.

A: Studies for which a conversion from a proxy measures of exposure was sought.

Study: Ronneberg et al 1988
Subject: Exposure to oil mist in cable manufacturing (1916 - 1983).
Unable to find any data on this subject. Suggest exposures are < 0.1 or less due to the low aerosol exposures involved, low temperatures for volatilisation of BaP and the use of refined oils after 1972.

Study : Spinelli 2001.
LSH to use own BaP/BSM conversion ratio.

Study: Sorahan T et al - 2001

Subject: Proportion of BaP in Carbon Black (1947 - 1996).
Source: IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 2, Carbon Blacks, Mineral Oils and Some Nitroarines, Vol 33, IARC,Lyon, France, April 1984, p45.
Results:
(1) in toluene extracts of 5 furnace blacks 0.55, 1.64, 1.5, 5.06 and 3.15 μg/mg. Mean value = 2.38 μg/mg (Taylor et al 1980). Typical exposures from Sorahan range from 0.5 - 30 mg/m^{-3} equivalent to 1.19 - 71.4.
((2) in benzene extracts of furnace blacks 2 - 40 μg/mg (as total benzopyrenes)).
3) Gabor et al (1969) (in the criteria for a recommended standard Occupational exposure to carbon black. US Department of health, Education and Welfare. N IOSH, September 1978) described the respiratory system of workers who produced furnace, thermal, or channel blacks in Rumania. The 6 hour concentrations of 3,4-benzp yrene were 260 - 510 during thermal black production. During furnace black production, 6 hour concentration was 52.
Analysis of thermal black for BaP revealed 345 μγ/γ. Furnace black contained 68 μγ/γ. No PAHs were detected in channel black.

B: Studies for which no exposure information was not provided by the authors

Study: Moulin J J et al 2000
Subject: Exposure in various tasks during Al smelting (1910 - 1994).
Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification , Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
One estimate in workshops/pot room/electrode manufacture/LEV operations/pot lining/maintenance.
i) Soderberg: 36.0 - 38.0 .
(Adamiak-Zie mba J A et al (1977) The evaluation of exposure to harmful substances emitted in the process of the production of aluminium using selfbaking anodes (Pol). Med. Pr., 28, 481-489).
ii) Prebake potroom: 0.03 - 0.1
(Shuler P J and and Bierbaum P J (1974), Environmental surveys of aluminium reduction plants (HEW/NIOSH) Publ. no 74-101) Cincinatti, OH, National Institute for Occupational Safety and Health (USA).
iia) Pre bake potroom 0.02-0.05
(Bjorseth et al. (1978) Polycyc ic aromatic hydrocarbons in the work atmosphere. I. Determination in an aluminium reduction plant. Scand. J. Work Environ. Health, 4, 212-223, (Norway).

(PAH profile data given in IARC)

Source: Holliday M and Engelhardt F R. Occupational health aspects of exposure to coal tar pitch volatiles (CTPV) in Ontario. CA: Ontario. Ministry of Labour
Ottawa, 1983.
Results:
i) Soderberg 0.6 - 56 (8 - 23 mg/m3 CTPV).
ii) Prebake - zero.

Source: Angerer et al. Occupational exposure to polycyclic aromatic hydrocarbons in a graphite electrode producing plant: biological monitoring of 1-hydroxypyrene and monohydroxy lated metabolites of phenanthrene. Int Arch Occup Environ Health (1997) 69:323-331.
Results:
(i) Baking (n=6) mean = 1.06 (range 0.22 - 1.96),
(ii) Impregnation (n=2) mean 0.44 (range 0.07 - 0.8),
(3) Graphitisation (n=4) mean 0.11 (range 0.01 - 0.33).

Source: Tjoe Ny E et al. The relationship between polycyclic aromatic hydrocarbons in air and urine of workers in a Soderberg potroom. Am Ind Hyg Assoc J. 54(6):277 - 284 (1993).
Results: means of 2.7, 14 and 48 for people continuously employed in potroom.

Study:Mur J M et al 1987.
Subject: Al production 1910 - 1976.
Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification , Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results: Three estimates in pot rooms.
i) Soder berg: pot operator during pot processing 17.9 - 29.4 (ref Konstantinov 1971 USSR).
Soderberg potroom: 0.02 - 53.0 (ref Shuler and Bierbaum 1974, USA).
Soderberg potroom: 3.4, 116.3, 53.7 (ref Bjorseth et al 1978, Norway).
ii) Prebake potroom: 0.03 - 0.1 (ref Shuler and Bierbaum 1974, USA).
Prebake potroom 0.02-0.05 (ref Bjorseth et al 1978, Norway).
Prebake potroom not detected (ref Konstantino v 1971 USSR).
iii) Soderberg and prebake together ?

Source:Bjorseth A et al. Polycyclic aromatic hydrocarbons in the work atmosphere. Determination of area-specific concentrations and job-specific exposure in a vertical pin Soderberg aluminium plant . Scand J Work Environ Health, (1981), 7, 223-232.
i) PAH profile given.

Source:In Lindstedt G and Sollenberg J. Polycyclic aromatic hydrocarbons in the occupational environment. With special reference to benzo(a)pyrene measurements in Swedish industry. Scand J Work Environ Health, 8 , 1-19.
i) prebake potrooms:0.01 - 0.2 (1966 197 USSR)
ii) Soderberg potrooms: 1.8 - 51 (1968 - 1978 Sweden)

Source: Tremblay and Armstrong . American Journal of of Industrial Medicine 27:335 - 348 (1995).
Results:
i) Soderber g potroom (1930 - 1970) 0.3 - 35.5 see table
ii) Prebake (1930 - 1970) 0.02 - 0.1 see table.

Study: Hansen 1989
Subject : Asphalt plants (1970 - 1980)

Source:In Lindstedt G and Sollenberg J. Polycyclic aromatic hydrocarbons in the occupational environment. With special reference to benzo(a)pyrene measurements in Swedish industry. Scand J Work Environ Health (1982), 8, 1-19.
i) < 0.05 (Adamiak- Ziemba et al , Polish 1972).

Source: Hicks JB. Asphalt industry cross-sectional exposure assessment study. Applied occupational and environmental hygiene. Oc t 1995, vol 10, no 10,840 - 848
Results:
i) Asphalt refinery/terminals 0.16.
ii) roofing felt manufacture 0.16.

Source: Puzinauskas VP and Corbett LW. Report on emissions from asphalt hot mixes. Asphalt institute, College Park, Maryland, Report no RR751A (1975).
Results:
Asphalt hot mix plants
i) 0.003 - 0.02.
ii) 0.014 - 0.022.

Study: Robertson et al 1980
Subject:: Carbon black exposure (1935 - 1974).

Source: Rivin D. Effect of carbon black on worker health in the rubber industry. Dangerous properties of industrial materials report. Jan/Feb. 1985 vol 5, no 1, 2 - 11.
Results:
Data is given for BAP content of Carbon blacks of 5, 6.5 and 8 ppm. Mean = 6.5 ppm.
Exposures in **US Tyre Factories** of 0.2 - 5.8 mg/m3. Therefore extrapolated BAP exposure = 0.001 - 0.04.

Study: Donato et al - 2000
Subject: Carbon Electrode manufacture (1945 -1971).
Source: Companion paper Monarc et al 1982.
Results:
i)BaP exposure from petroleum pitch/coke at site A - extrapolated from mean total suspended particulate exposure of 0.66 mg/m^3 in pilot plant. Concentration of BaP in airborne particulate determined to be 908 $\mu\gamma/\gamma$. Therefore BaP concentration = 0.6.

Source: Greife A. In National Inst for Occupational Safety and Health, Cincinnati, OH Div of Surveillance, Hazard Evaluations and Field Studies. Walk-Through Survey at Airco Carbon, St Mary's, Pennsylvania. Govt-Reports- Announcements-Index, Issue 22, 1988 - data collected 1983.
Results:
ii) BaP exposure from electrode manufacture - 12 results from various activities 1.59, 2.5 and 2.26 remaining samples not detected (limit of detection 0.52 / sample).
PAH profile data given.

Source: Moulin J J et al. Risk of lung, larynx, pharynx and buccal cavity cancers among carbon electrode manufacturing workers. Scan J Work Health 1989;15:30 - 37.
Results:
i) Plant A : mean 2.7 (range 0.59 - 6.2).
ii) Plant B: mean 0.17 (range 0.015 - 0.57).

Source: Petry T et al. Airborne exposure to polycyclic aromatic hydrocarbons and urinary excretion of 1-hydroxypyrene of carbon plant anode workers. Ann Occup Hyg, Vol 40, no 3, 345 - 357. (1996)
Results: All anode plant workers.

Exposure range: 0.16 - 4.88.

Source: H M Van Delft et al. (1998) Monitoring of occupational exposure to polycyclic aromatic hydrocarbond in a carbon-electrode manufacturing plant. Ann occup Hyg, Vol 42, no 2,105 - 114.
Results:
i) intermediate exposure (n = 12, 0.09 - 5.0) 0.37.
ii) high exposure (n = 18, 0.43 - 3.2) 1.2.

Source: Salisbury SA. Health hazard evaluation determination report No HHE7591489. Alcoa Aluminium Company Warwick operations, Newberg. Hazard evaluations and technical assistance branch, NIOSH, Cincinnati, Ohio (1978)
Results:
Exposure range for several jobs 0.3 - 5.9.

Study: Evanoff 1993
Subject:: Exposure in chimney sweeps (1906 - 1980).
Source: In Lindstedt G and Sollenberg J. Polycyclic aromatic hydrocarbons in the occupational environment. With special reference to benzo(a)pyrene measurements in Swedish industry. (ref Bagchi NJ and Zimmerman RE. An industrial hygiene evaluation of chimney sweeping. Am Ind Hyg Assoc J. 41, 1980, 297 - 299.)
Results:
During cleaning from the top of the chimney they found a CTPV value of 14.53 mg/m3 and a BAP content of 40 in the breathing zone of the worker (0.275% BAP in CTPV). Cleaning from the hearth was less exposed CTPV= 2.16 mg/m3 by analogy with the given above result you could expect a BAP level of 5.9.

Source: Knech U et al. Atmospheric concentrations of polycyclic aromatic hydrocarbons during chimney sweeping. Br J Ind Med 1989;46:479 - 482.
Results:
TWA shift mean concentrations of 0.02 - 0.21 obtained on 11 days.

Study Chau et al 1993
Subject: Coke oven Plant workers (1939 - 1982)
Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification , Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
i) constantly employed on coke ovens (coke oven operators) 0.16 - 33 (ref Blome1981, FRG).
ii) near coke oven and intermittently exposed to ovens. coke-oven conveyor-belt side 0.49 - 0.55. (ref Tanimura, 1968, Japan).
iib) sorting 0.25 - 1.4. (Source: Hemminki K et al. Aromatic DNA adducts in white blood cells of coke workers. Int Arch Occup Envron Health (1990)).
iii) repair/maintenance workshops ?
iv) byproducts in oven gas treatment sector 1.06 - 9.2 (ref Masek 1971, Czechoslovakia).
v) Underground work in coal mines. ?
(PAH profile in IARC)

Study: Franco et al 1993.
Subject: Coke oven 1947- 1985.
Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
i)Coke oven plant - constantly employed on coke ovens (coke oven operators) 0.16 - 33 (ref Blome1981, FRG).

Source; Davies G M. Measurement and analysis of airborne emissions from coke ovens with particular reference to worker exposure. Commission of the European Communities, Office for Official Publications, 5 rue du Commerce, l-2985 Luxembourg, 1981, 75 - 95.
Results:
i) coke oven plants: means of several UK plants 1.4 - 11.0.

Source: Masek V. The use of silver membrane filters in sampling for coal tar pitch volatiles in coke oven plants. (1970) Am Ind Hyg J. Vol 31, 641 - 644.
Results: Pitch coke oven battery 9.9 (not personal sampling).

Study: Sakabe et al 1975
Subject: Coke ovens (1939 - 1973)

Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
i) Iron and steel works - 1.3 - 159 (ref Masek 1971, Czechoslovakia).
ii) Byproduct workers - 1.06 - 9.2 (ref Masek 1971, Czechoslovakia).
iii) Coke manufacturing - 0.5 - 135 (ref Bjorseth 1978, Norway).

Study: Swaen et al 1991
Subject: Coke plant (1918 - 1984)

Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
i) coke oven workers - 0.16 - 33 (ref Blome 1981, FRG).
ii) byproduct workers - 0.19 - 296 (ref Masek 1971, Cze choslovakia).
iii) Tar distillery: 1.06 - 9.2 (ref Masek 1971, Czechoslovakia).
iv) Top oven workers - 8 - 135 (ref Bjorseth 1978, Norway), 20 - 383 (av. 112, ref Braszczynska et al 1978), 5 - 15 (ref Eisenhut et al 1982, FRG), 9.4 - 13.5 (ref Lindstedt et al, 1982, Sweden, 1.27 - 27.4 (ref Yanysheva et al, 1962, USSR).
v) Side oven workers: 0.04 - 3.3 (ref Eisenhut et al 1982, FRG).

Source: Hemminki K et al. Aromatic DNA adducts in white blood cells of coke workers. Int Arch Occup Envron Health (1990).
Results;
i) coke oven workers top side 9.4 - 90, coke-side, 0.54 - 13.6.
ii) byproduct workers (distillation) 3 plants each 0.6.
iii) tar distillery as above 0.6.
iv) top side 9.4 - 90,
v) coke-side, 0.54 - 13.6.

Study: Mclaren et al 1987
Subject: Tar distillation workers (1955 - 1976)

Source: From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
i) 1.06 - 9.2 (ref Masek 1971, Czechoslovakia).

Source: Masek V. The use of silver membrane filters in sampling for coal tar pitch volatiles in coke oven plants. (1970) Am Ind Hyg J. Vol 31, 641 - 644.
Results:
ii) Tar distillation plant 4.6 (not personal sampling).

Source: Hemminki K et al. Aromatic DNA adducts in white blood cells of coke workers. Int Arch Occup Envron Health (1990).
Results:
ii) Results: Tar distillation at 3 coke plants 0.6.

Study: Swaen 1997
Subject: Tar Distillery and Roofers (1947 - 1988)

Source:Malaiyandi M et al. Measurement of potentially hazardous polynuclear aromatic hydrocarbons from occupational exposure during roofing and paving operations. Polynuclear aromatic hydrocarbons : Physical and biological chemistry, Cooke,M., A J Dennis, and G L Fisher, Editors;Springer-Verlag, New York, p 471 - 489. (1982)
Results:
Coal tar pitch roofing
i) site 1, 0.01, 0.4, 4.22, site 2, 0.08, 1.22, 0.62, site 3, 0.02, 0.93, 11.3.

Source:Herbert R et al. A pilot study of detection of DNA adducts in white blood cells of roofers by 32P-postlabelling.
Results:
Coal tar pitch
i) day 1, 0.53 - 1.78.
ii) day 2, 0.6 - 1.39.

Source:Herbert R et al. Detection of adducts of DNA in white blood cells of roofer by 32P-postlabelling. Scand J Work Environ Health 1990: 16:135-43.
Results:
Coal tar pitch exposure.
i) 0.53 - 2.03.

[From HSE survey (1997). Tar distillation (high temperature) mean exposure 0.3. Tar distillation (low temperature) not found.]

See McLaren study above for exposure in tar distillery workers.

Study: Doll et al 1972
Subject: Exposure in gas workers 1948 - 1965.
Source**:** From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results:
Three estimates of exposure;-
i) Heavy exposure in coal carbonisation plant: 200. (ref Lawther et al 1965)
ii) In other gas producing plants: 2 and 7.3 (ref Kreyberg 1959), mean concentration of 4.8 (horizontal retort) and 1.4 and 2.7 in two different verticle retort houses. (ref Lawther et al 1965)
iii) no such expsure/byproducts ?
(PAH profile available in IARC)

Source: In Lindstedt G and Sollenberg J. Polycyclic aromatic hydrocarbons in the occupational environment. With special reference to benzo(a)pyrene measurements in Swedish industry. Scand J Work Environ Health, 8 , 1-19.
Results:
i) Heavy exposure - top of oven men of 134 1-h samples 4.3 (max 33, data from 1964), 13.5 and 9.4 (1980), 25 (range 8 - 78, Thielen 1979)
ii) 25 m from ovens 0.15 (344 samples)
iii) Pitch battery (byproducts ?) up to 40 (Masek 1971).

Study: Kawai et al 1967
Subject Exposure in gas generator workers 1933 - 1953.
Source**:** From IARC Monographs on theEvaluation of the Carcinogenic Risk of Chemicals to Humans. Polynuclear Aromatic Compounds, Part 3, Industrial Exposures in Aluminium Production, Coal Gasification, Coke Production and Iron and Steel Founding, Vol 34, IARC,Lyon, France.
Results: Using data from Lawther (1965) and Kreyberg (1959) range 1.4 - 7.3 (4.4).

Appendix B3: Supplementary estimates of PAH(BaP), for studies in which these were not provided by the authors.

Author	Year	Industry	Grouping	Group	Area and Country	BaP exposure	Comment
Chau, N., et al.	1993	Coke oven	Job type	(1) constantly employed on coke ovens	Lorraine, France	20	
				(2) in those near the ovens and intermittently exposed to ovens		10	
				(3) employed in repair and maintenance workshop		1	Uncertain
				(4) exposed to byproducts in the oven gas treatment centre		0.5	Uncertain
				(5) underground work in coalmines		0.05	
Franco, F., et al.	1993	Coke oven	Coke workers	Coke oven plant workers (excluding administrative staff)	Carrara, Italy	10	
Reid and Buck	1956	Coke ovens	3 groups	(1) Oven workers (top?)		20	
				(2) Maintenance		1	uncertain
				(3) By-product workers		0.5	
Sakabe H et al	1975	Coke oven	Coke workers by type of plant	(1) iron and steel works	Japan	10	
				(2) city gas companies		5	
				(3) coke manufacturing companies		10	

Swaen, G. M., et al.	1991	Coke plant.	Job type	(1) all coke oven workers	3 coke plants in The Netherlands	10	
				(2) byproduct workers,		0.5	Uncertain
				(3) tar distillery workers		0.5	Uncertain
				(4) top oven coke workers		20	
				(5) side oven coke workers		10	
Kawai M et al	1967	Gas workers (in a steel plant)	All gas workers	Gas generator workers in this steel plant	Itakyushu, Japan	??	Discarded
Doll et al	1972	Gas workers.	Heavy, medium, low	(1) heavy exposure in coal carbonisation plants	8 area gas boards in England	3	
				(2) with intermittent exposure in coal carbonisation plants or to conditions in other gas producing plants		1.5	Uncertain
				(3) no such exposure or exposure only to byproducts		0.5	Uncertain
Milham	1979	Aluminium production	all	Prebake plant - all workers	WA USA	0.5	
Moulin, J. J., et al.	2000	Aluminium production.	Job type (BaP exposure likely)	All workshops where PAH exposure is likely (potroom, electrode manufacture department, exhaust ventilation operations, pot lining and maintenance)	France	5	

Mur, J. M., et al.	1987	Aluminium production.	Job type	Potrooms for prebake processes		0.05	
				Potrooms for Soderberg processes		15	
				Potrooms for prebake and Soderberg processes together*	France	11.7	
Rockette and Arena	1983	Aluminium production	3 groups	(1) Soderberg potrooms	USA	15	
				(2) Prebake potrooms		0.05	
				(3) Carbon plant		2	
				(4) Soberberg plants -average*		4	
				(5) prebake plants-average*		0.5	
Donato, F., et al.	2000	Carbon electrodes.	All workers	Carbon electrode manufacute workers	Umbria, Central Italy	1	
Hansen ES	1989	Asphalt industry (asphalt plants, roofing felt plants, tar plant)	All workers	Asphalt workers	Denmark	0.5	Uncertain
Maclaren, W. M. and J. F. Hurley.	1987	Tar distillery workers.	All workers	Tar distillation plant workers	4 plants in England and Wales	0.5	Uncertain

Swaen, G. M. and J. M. Slangen.	1997	Tar distillery and roofers	Job type	(1) tar distillery workers (2) roofers	The Netherlands	0.5	Uncertain
Evanoff, B. A., et al.	1993	Chimney sweeps.	All workers	Chimney sweeps	Sweden	1	
Hansen	1983	Chimney sweeps			Denmark	1	
Martin, J. C., et al.	2000	Elecricity and gas.		Semi- BaPitative index - found impossible tp convert to BaP within desired accuracy	France	??	Discarded
Cammarano, G., et al.	1986	thermoelectric power plant .	All workers	Thermoelectric power plants	Milan, Italy	0.05	Very uncertain
Forastiere, F., et al.	1989	thermoelectric power plants.	All workers	Thermoelectric power plants	Latium, Italy	0.05	Very uncertain
Roberstson J	1996	Carbon black	All workers	Carbon black workers	USA. 4 plants	0.05	

* Derived as weighted mean of other estimates.

See text for methods and scale of assessment.

Appendix B4: Total dust exposure in included industries: a review

INDUSTRY	SUB-GROUP	DUST EXPOSURE (mg/m^3)		REFERENCES
		TOTAL PARTICULATE	RESPERABLE	
Aluminium	Potroom Soderberg	15.1 (6.5-20), 4.7 (2-7.4), 12.1 (1-38.2), 2.9 (1.8-4.5).		Environmental surveys of aluminium reduction plants. P J Schuler and PJ Bierbaum.PB232 776/5WJ, National technical information service, Virginia USA, p33, 1974. (data means of means).
	Potroom Prebake	6.2 (3.9–11.6), 4.6 (3.9 –7.2).		
	Carbon electrode plant	3.8 (1.5-5.4), 2.9 (1.1-5.7).		
		-		
	Other			
	Potroom Soderberg	8.6 (1-26)		Data fro 1979. Occupational health control technology for the primary aluminium industry. J W Sheehy. US Dept of health and human services, CDC, NIOSH,1983.
	Potroom Prebake	2.8 (1.7-3.5)		
	Potroom Soderberg	1.5 (0.346-6.52)		Mean of 3 potrooms. Polycyclic aromatic hydrocarbons in the work atmosphere. A Bjorseth et al. Scan. J. Work Environ. Health 7 (1881) 223-232. 1981.
	Carbon electrode plant	10.28 and 4.11		
ASPHALT (coal	Roofers	0.34.	0.14.	Hazard Review - Health effects of occupational exposure to Asphalt. US Dept of Health and Human services, NIOSH,December

Tar)	Manufacture	0.6.	0.08.	2000. Table 4.8 p35 adapted from Exxon 1997. (GMs)
	Roofers	1.3 (0.2-1.9)		Health hazard evaluation determination reportNo HHE75-194-324, Western roofing company….Hervin RL and Emmett EA. Hazard evaluation services branch, NIOSH**.** (1976)
	Roofers	0.77	0.18	Asphalt industry cross-sectional exposure assessment study. Appl. Occup. Environ. Hyg 10(10) 840-848, 1995. (means)
	Manufacture	2.6	0.29	
	Roofers	5.9 (2.1, 2.5, 4, 3.2, 10.3, 13.1)		Mean of 6 values. V Behrens and G Liss, Hazard evaluations and technical assistance branch, NIOSH, U S Dept of Health and human services, Report no HETA-84-062-1552, 1983
	Roofers	3.6 (2.6, 6.2, 3.6, 1.8, 3.9)	0.67 and 1.7	Tharr D. Health hazards evauation reports No HETA-81-432-1105, Roofing sites, Rochester and Buffalo, New York, NIOSH 1982
	Roofers	1.9 (1.67, 2.84, 2.2, 1.5, 2.2, 0.76)		Mean of 6 values. Reed L, Health hazard evaluation report No HETA-83-380-1671, Roofing sites Dayton, Ohio
Coal gasworks	Retorts	0.93-1.1		IARC Vol 34 (Year 1984) - cited Lawther (1965)
	Other (by-products)			
Carbon electrode plant	All	1.6 (0.21 – 8.78)		US Dept of health, education and welfare, CDC, HIOSH. Health hazard evaluation determination Report No 75-91-489. ALCOA aluminium company. (data 1975 and 1976)
Coke oven	Top	Plant A 0.83-7.76	0.21-1.1	Range of averages. Evaluation of coke oven emissions. WM Smith. J.Occ. Med. 1971.
		Plant B 0.84-5.43	0.28-2.07	
		Plant C 0.8-3.0	0.24-1.13	
Coke oven	Top	4.0 – 6.3.		Measurement and analysis of airborne emissions from coke ovens… Davies G M. Commission of the European Communities, Office for

	Side	1.9 - 4.0.		Official Publications, 1981, p75-95. (data 1971)
	Other (by-product)	3.8.		
Coke oven	Top	12.8		Experience in controlling airborne pollutant exposure of operatives at a coke oven. A T Gillies ,Ann. Occup., Hyg Vol 27. No 2, pp 221-222, 1983.
	Side	4.0		
	Other(coke side assistant)	9.7		
Carbon black manu		1950-1959 = 8		Sorahan et al 2001. Means of factories 1 and 4 over time periods shown
		1960-1964 = 7.1		
		1665-1969 = 6.0		
		1970-1974 = 5.4		
Carbon black manu		0.44-1.45	0.13-0.35	Geometric means. Occupational exposure to carbon black: aparticulate study. R G Smith and D C Musch. Am. Ind. Hyg Assoc. J 43(12) 925-930 (1982)
Carbon black manu		0.66-1.72		Geometric means. A cross-sectional study of pulmonary function in carbon black workers in the US. J M Robertson et al. . Am. Ind. Hyg Assoc. J. 49(4): 161-166 (1988)
Chimney sweeps				
Thermoelectric power plants				

Appendix C. Estimating unit relative risk increments

Model choice

We fitted two different models for the dependence of relative risk on cumulative exposure:

- Loglinear relative risk model: RR =exp(b_{loglin}x)
- Linear relative risk model: RR=1+b_{lin}x

where x is cumulative exposure in $\mu g/m^3$ years; and the slope b is the unit relative risk increment (URR). (For both models, RR=1 if x=0)

Advantages and disadvantages of each.

In favour of the linear model:

- Arguments from mechanism give more support to the linear than log-linear form (Greenland 1987).
- Plotting results from some of the large studies (Armstrong 1994, Constantino 1996) suggested linear rather than log-linear forms
- Exploratory analysis confirmed that in included studies with several exposure groups, the linear form fitted significantly better, for both lung and bladder cancer. for lung cancer, overall deviance was 85.1 (54 dfs) when linear models were fit to each study, compared to 101.7 (54 dfs) with loglinear models. (Bladder: 38.9 Vs 51.2 on 18 df) The addition of a quadratic term was significant in a single-slope loglinear model (p=0.006), but not in a single-slope linear model (p>0.20).

In favour of the loglinear model.

- Estimates of b_{loglin} have symmetric sampling distributions, but those of b_{lin} do not. This makes blin much harder to treat statistically. We calculated confidence intervals using the likelihood profile method (Mason and Prentice). However standard meta-analysis methods (see below) assume symmetrical (normal) sampling distributions - evaluating significance of patterns, for example differences between industries, may be compromised. We proceeded by estimating standard errors as a quarter of the width of the likelihood profile confidence interval (an approximation to 1/(2X1.96)).

Model estimation

Typical data from a study is in the form of the first two rows of Table C1. Where expected cases are not given, these were calculated as R_k/O_k. [In a few cases where O_k=0 and expected numbers were not given, they were estimated from numbers of all deaths in that group by assuming the proportion of expected deaths that were due to lung or bladder cancer was the same in that group as overall.] Mean cumulative exposures C_k for each group were estimated as described in the "estimating exposures" section.

Assembling the data in this way allowed us to use standard Poisson regression software to estimate the slope b of the loglinear (STATA) or linear (EPICURE) relative risk model. Because the sampling distribution of b_{lin} is known to be skewed in small samples (Prentice & Mason, 1986) we estimated confidence intervals using the profile likelihood.

This method is standard where the relative risks are SMRs, and would seem to be well suited to RRs estimated by Poisson regression. However, for ORs estimated from the three nested case control studies, with few controls per case, they would be expected to underestimate uncertainty. However, comparing our estimates in one study with a method not requiring approximation by a Poisson distribution (Greenland and Longnecker 1992), we found little difference.

Table C1 Data layout for estimation of URRs

	Group			
	1	2	…	K
Observed cases	O_1	O_2		O_K
Relative Risk*	R_1	R_2		R_K
Expected cases	E_1	E_2		E_K
Cumulative exposure	C_1	C_2		C_K

* SMR, RR estimated from Poisson regression, or OR.

For studies presenting only a single SMR in a group with mean cumulative exposure C we estimated

$$URR_{lin} = 1 + (SMR-1)/(C/100);\ SE(URR_{lin}) = SE(SMR)/(C/100) = \sqrt{O}/(E.C/100).$$

$$URR_{loglin} = SMR^{(100/C)}l;\ GSE(URR_{loglin}) = \exp(1/O)$$

Where O=0, we estimated $SE = \sqrt{E}/(E.C/100) = 1/(\sqrt{E}.C/100)$ and $GSE(URR_{loglin}) = \exp(1/E)$; 95% confidence limits for the SMR and hence b_{lin} and b_{loglin} were estimated using Poisson exact limits for the mean underlying O.

Method to estimate bin means

Introduction

To make estimates of exposure-response relationships from published data, it was necessary to have a mean (for linear models) exposure for each exposure group (bin).

Assume the data is in the form:

Group	Lower bound	Upper bound	Py or freq in controls*	mean
1	$y1_1$	$y2_1$	f_1	?
2	$y1_2$	$y2_2$	f_2	?
…				
k	$y1_k$	$y2_k$	f_k	?

* or expected cases

Mean exposures for groups with both lower and upper limits (all except the highest) were estimated by the mid point [(y2-y1)/2] of the interval. The upper bin is problematic.

Strategy

Fit a log-normal distribution to the distribution observed, then calculate bin means. For this we require a proportion of subjects falling in each bin. This is provided by the number of expected cases in each bin (E=O/RR). Exploratory analyses on data for which we knew the true bin means suggested that this was improved by excluding the first bin (often zero exposure); leaving a truncated lognormal distribution.

In stata, this strategy is effected by carrying out interval regression to estimate parameters of a log-normal distribution best fitting the observed proportions, then predicting the mean for the bins from the fitted distribution.

Example Armstrong (1994):

Obs cases	Range	RR
138	<10	1.00
94	10-99	1.48
41	100-199	2.06
46	200-299	2.06
19	>=300	1.85

Exp. Cases – obs cases/RR.

This gives:. (Excluding first group):

```
           y1        y2      probs    relfreq      means  truemeans
  1.       10       100   .3953748    .547451   58.18076      40.92
  2.      100       200   .3427276    .171552   140.0813     147.18
  3.      200       300   .1398394    .192473   241.0813     250.48
  4.      300         .   .1215088    .088524    438.102     413.14
* probs = probabilities predicted by lognormal fit
** relfreq = observed relative frequencies of expected numbers
```

Appendix D: Description of individual studies (by industry)

Coke and coal gas workers

Twelve papers were identified reporting on lung and or bladder cancer risks in coke workers, representing 14 studies, when sub-studies were considered.

Of the two papers reporting on coke workers in Asia, Sakabe et al (1975) reported on lung cancer mortality in coke workers in Japan who had retired between 1949 and 1973 from 11 plants including manufacturing, gasworks and iron and steel plants. 2,178 retirerees were identified, with a maximum 34 years reported duration of employment. This suggests that earliest exposure among the cohort was in 1915. SMRs were generated using national lung cancer rates for comparison. Results were reported by type of plant, a significant increase in risk was only obtained for gas company workers. Xu et al (1996) reported on lung cancer morbidity in a case cohort study among workers and retired employees who had worked for at least 10 years in the coke works of an iron and steel plant in China. 610 incident cases, aged between 30 and 70 were identified between 1987 and 1993 and compared to 959 randomly selected controls. Use of exposure information provided by correspondence with the author and reported smoking adjusted ORs by duration of exposure produced a URR greater than 1, which was statistically significant.

Only one study was conducted in North America. Costantino et al (1995) followed up lung and bladder cancer mortality over a 30 year period in a cohort of 15,818 workers in steel plants in the USA and Canada, selected either from workers employed from 1951 to 1955 in 10 of the plants, or from 1953 7 of the plants. Cancer risks were reported in relation to frequency matched non-oven steel workers. Significant increased risk for lung cancer by cumulative exposure to BSM was reported, but risks reported for bladder cancer in relation to exposure to BSM were not significant.

The remaining 9 papers reported on 11 cohort studies, 9 investigating mortality and 2 morbidity from lung and/or bladder cancer conducted in Europe. All the studies used national mortality or morbidity rates as reference populations, with the exception of one of the 3 UK studies, Reid and Buck (1956), which used rates among other industrial workers and a Swedish study (Gustavsson & Reuterwall 1990) which used local mortality rates in occupationally active men.

Bye et al (1998) reported on a cohort of 888 workers with at least one year of employment during the operational period of a plant in Norway which was from 1964 to 1988. Follow up was from 1962 (some men were employed during the construction period from 1962) to 1993. Risks for lung and bladder cancer morbidity by cumulative exposure to PAH resulted in non-significant greater than 1 (lung) and non significant less than 1 (bladder) URR estimates, based on 7 and 5 cases respectively.

Chau et al (1993) re-examined mortality a cohort of 536 retired workers who had retired from one of two plants in France between 1963 and 1982, extending follow up a further 5 years from 1963 to 1987. The plants started production in 1911 and 1955, with the 1911 plant receiving regeneration in 1963, and thus occupational exposure conditions improving beyond that of the 1955 plant. The year of birth among the cohort ranged from 1902 and 1935, with mean age of death of 64.8. 13.1% of retirees had worked in the old generation of plant A. Workers were classified by job group, with total duration of exposure ranging from 18-24 years. Although a significant increased risk for lung cancer was reported for the whole cohort (2.38, $p<0.001$), risks for lung cancer by job group gave rise to a null estimate for the URR of 1.00 (0.68, 1.46) adjusted for smoking. Due to the small number of observed cases for bladder cancer (1), the risk reported for the whole group was utilised, resulting in non-significant estimate of the URR which was below 1.

Franco et al (1993) investigated mortality in a cohort of 538 workers who had been employed for at least one year between 1960 and 1985 ion a plant in Italy, with follow up from 1960 to 1990, resulting in 10,665 person years with an average of 20 years. The plant was operational from 1947 to 1989, and also from 1943-44. The mean age of entry into the cohort was 37 years, and average length of employment was 18.6 years. A significant increase in risk for lung cancer was observed, applying estimated generic exposures to these data, a URR of 1.41 (1.07, 1.79) was estimated.

Swaen et al (1991) reported on a cohort of 5,639 workers who had worked for at least 6 months between 1945 and 1969 at one of three plants in The Netherlands, had Dutch citizenship and were resident in the Netherlands. Coke production started in 1918 - 1929 and ended in 1968. The cohort were followed up for mortality from 1945 to 1984, during which time 273 deaths from lung cancer and 38 from bladder cancer were identified. Using risks reported by job group and relevant estimated generic exposures, URRs greater than 1 were estimated for both lung and bladder cancer, but neither achieved statistical significance.

Berger and Manz (1992) investigated cancer mortality in a cohort of 4,908 men who had worked in a gasworks in Hamburg, Germany for at least 10 years between 1900 and 1989. 789 of these men had worked in the ovens, their mean duration of exposure was 26.7, mean age at entry was 32, and average age at death was 68. 70% were smokers. As national mortality data was unavailable prior to 1952, a subset of workers was followed up from 1952 to 1989. A highly significant increased risk of lung cancer (SMR 2.88, 2.28, 3.59) was reported for this group. Using data on BaP exposure reported in the paper, a significant URR of 1.15 (1.12, 1.19) was estimated.

Gustavsson and Reuterwall (1990) investigated mortality and incidence of cancer in a cohort of 295 men who had worked for at least one year between 1965 and 1972 in a Swedish gas plant. The plant started operation in 1893 and coal gas was produced in coke ovens from 1918 to 1972. Prior to 1918, gas was produced in retorts, and since 1972 from cracking of petroleum products. Follow up was from 1966 until 1986 for mortality and 1983 for morbidity, using rates for local occupationally active men for mortality, and national rates for morbidity. Lung cancer mortality was reported by job group; 66 men worked in the coke oven department, the only job for which exposure information to BaP was reported, mean length of exposure was 11.9 years. No cases of lung cancer were observed, giving rise to a non-significant URR less than 1.

The earliest of the 3 UK studies was reported by Reid and Buck (1956). All men who had died during the period 1949-1954 and were registered on the books of NCB (National Coal Board) coking plants were investigated. About 8000 men were employed in NCB coking plants during this time. Mortality risks for lung cancer mortality, in comparison to rates from other industrial workers, were reported according to job group. Combining these with estimated generic exposures, a non-significant URR below 1 was estimated.

Doll et al (1972) reported on mortality in two cohorts of workers at gas boards; termed "original" and "additional". Follow up for the original cohort (1953-1961) was extended a further 4 years to 1965. The cohort included men who were employed by or were in receipt of a pension from one of 4 area gas boards in 1953, were aged 40 - 65 and had been employed for more than 5 years. 2,449 men working as coal carbonising processors and 579 by-product workers were identified. The additional cohort was identified from 4 additional gas boards, and included men employed or retired in 1957 (3 boards) or 1959 (1 board) with follow up to 1965. 1,176 carbonising plant workers, 1,430 men with intermittent exposure (maintenance in gas plants and processors in gas producing plants other than retort houses) and 2,081 men with minimal or no exposure were identified. Using exposure information based on measurements made by Lawther et al (1965), reported lung and bladder cancer mortality risks by job group gave rise to statistically significant increased risks (URRs >1) for lung cancer in both cohorts, but increased risks (URRs >1) for bladder cancer did not reach statistical significance.

A more recent study of mortality among BSC (British Steel Corporation) and NSF (National Smokeless Fuels Ltd - a subsidiary of the National Coal Board) cohorts was reported by Hurley (et al 1983). The BSC cohort comprised all male manual workers employed between 1966 to mid 1967, and the NSF cohort comprised all workers employed at the beginning of 1967. A total of 6,767 workers were identified from 14 BSC works and 13 NSF works. A more in depth (unpublished) research report on the study with additional follow up to 1987 was made available to us by the author (Hurley, approx date 1988?). Using data from this report, which included exposure information to BSM, reported lung cancer risks by cumulative exposure gave rise to significant increased risks for the NSF cohort but not for the BSC cohort. Bladder cancer risks were reported for the whole group for each

cohort: a URR below 1 was estimated for the BSC cohort, and above 1 for the NSF, neither result was significant.

Aluminium

Eight studies were identified; 6 of which were cohort studies and 2 case-cohort. Of 5 studies conducted in North America, 3 reported risks according to cumulative exposure to BaP or proxies to BaP. Armstrong et al (1994) studied lung cancer mortality during the period 1950 to 1988 in men who had worked for at least one year between 1950 and 1979 at a plant in Quebec, Canada. 338 lung cancer deaths were observed and compared to a random sample (sub-cohort) of 1, 138 drawn from the 16,297 aluminium workers eligible for inclusion. Based on reported risks by cumulative exposure to BaP, a statistically significant URR of 1.22 (1.09, 1.37) was estimated. Tremblay et al (1995), using the same cohort, investigated bladder cancer morbidity - 138 cases of bladder cancer were identified and compared to three matched controls drawn mainly from the same sub-cohort. Using risks (rate ratios) reported by cumulative exposure to BaP, a significant URR was estimated (1.48 (1.24, 1.76)) for bladder cancer morbidity. Spinelli et al (1991 reported morbidity risks for both lung and bladder cancer by cumulative exposure to coal tar pitch volatiles (CTPV, measured as BSM) in a cohort of 4,213 men who had worked for at least 5 years at a Soderberg plant in British Columbia, Canada between 1954 and 1985. A total of 60,590 person years were observed, with 2.9% accounted for by 204 men with over 20 BSM years exposure. Risks were compared to regional rates, with a 3 year lag period and follow up from 1959 to 1985. A URR greater than 1 was derived for both cancers, but did not reach statistical significance for either cancer.

Mortality was investigated in a cohort of 2,103 men who had worked at least 3 years, with at least one year between 1946 and 1962, at a pre-bake aluminium plant in Washington State in the United States by Milham (1979). The cohort was followed up for 30 years from 1946 to 1976. Number of cases of lung cancer were reported by duration of exposure, in 5 year bands from 3-4 years exposure to over 25 years, and compared to that expected from national rates. Using these results, and applying estimated generic exposures, a URR of less than 1 was estimated, but did not reach statistical significance. An SMR of less than one was reported for bladder cancer mortality, but this result was not significant, and was based on only 1 case in a non-exposed worker.

Rockette and Arena (1983) reported on a cohort of 21,829 workers with five or more years employment in 14 plants in the US between 1946 and 1977, which were also followed up from 1946 to 1977. The earliest start up date was 1903. Seven of the plants were prebake only, 6 Soderberg and the remaining two mixed. Results were reported by duration of exposure and according to the type of plant for lung cancer mortality, these were utilised to generate sub-group specific URRs: 1.85 (0.53, 6.53) for Soderberg plants and 0.06 (0.00, 9.58) for prebake plants. The number of bladder cancer deaths were reported according to job group and compared to national rates, a non-significant URR (>1) was derived.

The three remaining cohort studies were conducted in Europe and only one reported exposure information (Romundstad et al 2000). Moulin et al (2000) reported on mortality among 2,133 male workers who had been employed in a plant in France for at least 1 year between 1950 and 1994. The cohort was followed up for an average of 16.5 years for mortality from 1968 to 1994, giving a total of 35,145 person years. Lung and bladder cancer risks were reported by duration of exposure, and were based on comparison with regional rates. Non-significant URRs were derived for both cancers. Both prebake and Soderberg anodes were used in this plant, although only prebake has been used since 1982. Mur et al (1987) also reported on mortality in workers in plants in France. A cohort of 6,455 workers who had worked for at least one year in one of 11 plants between 1950 and 1976 was followed up for mortality also from1950 to 1976, giving a total of 113,671 person years. The earliest date of exposure was 1907, and the majority of plants used both prebake and Soderberg processes. The majority of workers, about two thirds, had been employed for over 10 years, and a third for over 20 years. Numbers of deaths from lung cancer for all plants collectively were reported by duration of exposure and compared to national rates, resulting in a non-significant URR below 1. Romunstad et al (2000) updated results from 6 previous cohort studies in Norway. Cancer incidence was investigated

among 11,103 men employed for more than 3 years between 1953 and 1996, with follow up also from 1950 to 1996, giving 272,554 person years. The earliest start up date of the 6 plants was 1914. Lung and bladder cancer incidence in relation to national rates were reported by cumulative exposure to PAH. No increase in lung cancer risk (rate ratio) was observed. Although a weakly significant increased risk was reported for bladder cancer incidence with increasing PAH exposure, URR estimates in relation to BaP concentration based on these data did not reach significance (1.19 (0.88, 1.61).

Carbon workers

Three papers reported on 4 studies (3 cohort and one case control) in carbon workers, one paper from China and two from Europe, only one of which produced a significant URR estimate. Liu et al (1997) investigated cancer mortality among a cohort of 6,635 male carbon workers who had been employed for more than 15 years in seven factories including one aluminium plant. The cohort was followed up from the cohort entry date, 1st Jan 1971 to 1985, resulting in 95,847 person years. 89 were lost to follow up, of the remaining 6,546, 56.2% were smokers. Measurements of BaP were taken at the Shanghai carbon plant in 1986-7, using glass fibre filters with analysis by high performance liquid chromatography (HPLC). Mortality risks were reported in relation to those of 11,470 other steel workers employed in rough rolling mills. 222 of the total 390 deaths (all cause) were among non-smokers. Using results reported by 4 exposure levels (including non-exposed), a statistically significant URR greater than 1 was estimated for lung cancer mortality. A significantly positive relationship was also found for lung cancer mortality for the overall group (SMR= 2.16, $p<0.01$). Results (SMRs) were also reported for lung cancer risks among non-smokers for exposed and highly exposed workers of 3.00 ($p<0.01$) and 5.34 ($p<0.01$) respectively.

Donato et al (2000) reported on cancer mortality among a cohort of 1,006 workers who had been employed for at least one year between 1945 and 1996 in a carbon (graphite) electrode plant in Umbria, Italy, which has been in production since 1901. From 1945-1971, petroleum derived coke, coal tar pitch and petroleum pitch were all used as raw materials; petroleum coke was used as a basis, and pitches as binding materials. Follow up was carried out from 1955 to 1996, (mean 39.5 years), giving 34,248 person years. Lung and bladder cancer mortality risks were reported according to duration of employment in relation to national mortality rates. Applying relevant generic exposure estimates to these results non-significant URRs below 1 were estimated for both lung and bladder cancer

Moulin et al (1989) reported results from two studies: morbidity and mortality from selected cancers among carbon electrode workers were investigated in two plants (A and B respectively) in south eastern France. Personal and area exposure measurements were taken in both plants in 1983-84 using glass fibre filters and analysed for PAHs including BaP by HPLC. Within each cohort, a case-referent study was conducted, as results by duration of exposure were reported for lung cancer in the case-referent studies, these results were utilised in the lung cancer meta-analysis.

Cancer morbidity was reported among a cohort of 1,302 men who were employed at one plant (Plant A) on 1st January 1975, with 11 years of follow up to 1985. 153 men (11.8%) were lost to follow up. This plant began operation in 1895, but graphite electrode manufacture was only initiated in 1950. The earliest exposure among cancer cases was 1934. Lung cancer incidence risks were reported by duration of exposure in comparison to randomly chosen referents from within the cohort matched for smoking (3 per case). Applying reported personal exposure measurements (2.7 $\mu g/m^3$ BaP) to these results a non-significant URR greater than 1 was estimated. Lung cancer risk (SIR) reported from the cohort study was also non-significant, but less than 1. Smoking adjusted risks for bladder cancer incidence were reported, in relation to local rates from a nearby district, for the overall cohort group. Applying reported exposure data to these results, a non-significant URR of less than 1 was derived.

Cancer mortality was investigated among a cohort of 1,115 men in Plant B who were employed on 1st January 1957, with 28 years of follow up to 1984. The vital status was unknown for 150 workers (13.5%) who were born abroad. Plant B was set up in 1897, and the earliest exposure among cancer

cases was 1911.. Smoking data was not available for this plant. Again, lung cancer risks were reported according to duration of exposure from the case-referent study (3 referents per case), however, risks were not adjusted for smoking in this plant. Applying reported exposure measurements for this plant (0.17 µg/m^3 BaP) to these results, a URR of less than 1 was also estimated for lung cancer mortality. Lung cancer risk (SMR) from the cohort study was greater than 1, but did not achieve statistical significance. Risks for bladder cancer mortality were reported, using national mortality rates as the reference population, for the overall cohort group. Applying reported exposure data to these results, a non-significant, very imprecise URR (> 1) was estimated.

Asphalt

This category included those workers who use asphalt (such as roofers, waterproofers, pavers) rather than those who are involved in the production (distillation) process. Asphalt is composed of stone and/or sand and a binder. Results are complicated by the change in composition of asphalt over time and in its definition between countries. In Europe asphalt refers to the stone and binder, while in North America, asphalt refers to the binder only. Binders were historically composed of coal tars or tar, while bitumen is now more commonly used in paving applications, although coal tars are still used in some roofing applications. Modern asphalts (bitumens) are manufactured by non-destructive vacuum distillation of crude petroleum oils, whereas coal tars are products of the destructive distillation of coal and coal tar pitches are residues from the distillation of coal tars. IARC (1984) considered that there was sufficient evidence of carcinogenicity only for extracts of steam refined or air refined bitumens, based on animal data.

Four studies were identified, all of which were cohort studies and three of which reported exposure data.

An increased risk 1.55 (95% CI 0.5-3.61) for bladder cancer incidence was reported by Hansen (1989) in a cohort of 679 Danish mastic asphalt workers identified from 1959 to 1980, with follow up to 1985. A risk (SIR) was also reported for lung cancer morbidity, (SIR) of 3.44 (95% CI 2.27-5.01), however as the same cohort was later evaluated for lung cancer mortality, with follow up extended to 1986 (Hansen 1991), applying our inclusion criteria, we used results from this paper to feed in to the meta-analysis. 25 cases were observed in the later study with an SMR of 2.9 (95% CI 1.88-4.29).

Hammond et al (1976) reported on a cohort of 5,939 men currently or previously employed as roofers and waterproofers in the USA who had been in the union for at least 9 years. 121 cases of lung cancer and 15 of bladder cancer were observed and compared to national population rates, giving rise to URRs of 5.63 (0.89, 35.53) and 3.94 (0.52, 22.65) respectively. The study which did not report exposure data, was the only study to report non-significant increased risk for lung cancer: Swaen and Slangen al (1997) reported on a cohort of 866 roofers who were employed for at least 6 months between 1947 and 1988 in The Netherlands and were followed up until 1988, no exposure data were reported. Increased risks for lung and bladder cancer were observed, although the SMRs were not statistically significant for either.

Tar distillery

Three cohort studies were identified, none of which contained data on exposure. Hansen (1989) followed up 1320 workers employed in the asphalt industry for 10 years and compared their lung and bladder cancer mortality rates to unexposed workers in Denmark. Non-significant increases were observed for both cancers. Swaen and Slangen (1997) also reported on a cohort 907 tar distillery workers, in which elevated risks of lung cancer (48 cases), and a reduced risk of bladder cancer (2 cases) were observed, although the SMRs were again not statistically significant. MacClaren and Hurley (1987) followed up 255 British tar distillery workers employed on 1 January 1967 from 1967 to 1983, non-significant increases in both lung and bladder cancer deaths were observed.

Chimney sweeps

Two cohort studies without exposure information were identified. Evanoff et al (1993) investigated mortality and morbidity in a cohort of 5,542 Swedish chimney sweeps employed through their national trade union at any time between 1918 and 1980, with follow up to 1987 for incidence and 1990 for mortality. Mean duration of exposure was estimated at 12 years. URRs derived from risks reported for duration of exposure suggested a non-significant increase in risk for lung cancer and a non-significant decrease in risk for bladder cancer. Hansen (1983) followed up mortality in a cohort of 713 Danish chimney sweeps from 1970 to 1975 and compared this to mortality in the national working male population. The mean length of exposure of those who died was 30 years, employing an estimated generic exposure for chimney sweeps of 1 $\mu g/m^3$ BaP per year, estimates based on this study also resulted in a significant URR greater then 1 for lung cancer mortality.

Thermoelectric power (Code 10)

Three cohort studies, all investigating lung or bladder cancer mortality, based in Italy and reporting no exposure information were identified. Cammarano et al (1986) followed up mortality for 25 years, until 1985, in all workers employed between 1960 and 1969 who had at least 10 years employment at a plant in Milan established in 1928. Based on mortality rates compared to those in the male regional population, non-significant URRs greater than 1 were estimated for both lung and bladder cancer. Petrelli et al (1989) reported on lung cancer mortality only in a cohort of 1,307 workers employed at two power plants (which used coal since 1968) near Venice between 1968 and 1980. The cohort were followed up until 1984, giving 12,581 person years at risk, of which 28% were attributable to workers who had had more than 10 years exposure. Using the male Italian population mortality rates as a reference, a non-significant increase in risk - SMR of 1.3 was reported. Forastiere et al (1989) reported on a cohort 406 workers employed between 1968 and 1970 at two plants near Latium, one of which started operation in 1953 as a coal-fired plant, but changed to oil in 1962. The second plant started operation in 1964, using oil. The cohort was followed up from 1968 to 1986, comparison to national male mortality rates produced a non-significant increase in risk (SMR = 1.74, (0.3, 5.5)) for bladder cancer. Results were reported by duration of employment for lung cancer, giving rise to a non-significant URR of (-0.00, >1000).

Carbon black

Two studies of carbon black workers were identified, one from the USA and one from the UK. Robertson and Inman (1996) reported on an update of an earlier mortality cohort study among male workers aged 15 or more who were employed for at least one year between 1935 and 1994 at one of 4 USA carbon black producing companies. Follow up was from 1935 and extended an additional 20 years to 1994 to give 54,784 person years. Retired workers contributed 20% of the additional person years of follow up. For one of the companies, data from 1975 to 1994 only was included. Using reported results for lung cancer risk (compared to state specific rates) for the whole group and applying appropriate generic estimates for exposure to BaP, a non-significant URR lass than 1 was estimated.

Sorahan et al (2001) investigated mortality among a cohort of 1,147 male workers from five UK factories manufacturing carbon black who had worked for at least one year variously between 1950 to 1971 and 1974, according to the factory from which they were drawn. Entry cohorts were also used - all workers employed on 1 January 1968, 1956 and 1967. By definition, no subject was employed at any time before 1947. Inhalable and respiratory dust measurements were taken at 19 European factories, including two included in this study during the period 1987 to 1995. These were combined with data on job histories to construct exposure estimates for these factories for the late 1980s, job-exposure matrices were then constructed for inhalable dust exposure and combined with changes in the site histories to construct mean exposure levels for each of the 12 job categories for all the earlier periods. These were then used to produce individual estimates of cumulative carbon black exposure. The cohort was followed up for mortality from 1951 to 1996. Results for lung cancer risk, using

national rates as a comparison, were reported by cumulative exposure to carbon black (mg/m3yr). 64 cases were reported among workers aged 30 - 84 years. Using conversion factors to derive cumulative exposure to BaP, a non-significant and very imprecisely estimated URR of greater than 1 was derived. This was in contrast to lung cancer risks reported for the whole group, which were highly significant with an SMR of 1.73 (1.32, 2.22). Bladder cancer risks were reported for the whole group, leading to a non-significant, extremely imprecise estimate for URR

Appendix E: meta-data on exposure-response (lung cancer preferred contrasts)

cname	grp num	cum_exp	cases	exp. cases	Rel. risk
Berger92	1	747.6	78	27.10	2.88
Bye et85	1	0.0	4	5.56	0.72
Bye et85	2	1.1	0	1.40	0.00
Bye et85	3	4.4	0	0.70	0.00
Bye et85	4	10.0	3	0.83	3.60
Chau, 93	1	0.0	6	2.63	2.28
Chau, 93	2	0.3	1	1.35	0.74
Chau, 93	3	21.9	6	1.39	4.33
Chau, 93	4	24.0	2	0.84	2.37
Chau, 93	5	230.0	8	3.17	2.52
Chau, 93	6	454.0	2	1.14	1.75
Costan95	1	0.0	203	203.00	1.00
Costan95	2	14.8	34	27.42	1.24
Costan95	3	73.7	43	27.56	1.56
Costan95	4	162.4	56	28.72	1.95
Costan95	5	251.2	39	19.31	2.02
Costan95	6	339.9	27	10.04	2.69
Costan95	7	805.4	56	17.89	3.13
Doll e72a	2	10.0	11	14.67	0.75
Doll e72a	1	60.0	99	54.70	1.81
Doll e72b	1	0.0	16	30.19	0.53
Doll e72b	2	30.0	40	23.26	1.72
Doll e72b	3	60.0	23	17.16	1.34
Franco93	1	186.0	19	10.00	1.90
Gustav90	1	28.7	0	0.90	0.00
Hurley83a	1	0.0	28	28.00	1.00
Hurley83a	2	23.8	11	18.64	0.59
Hurley83a	3	71.4	11	22.45	0.49
Hurley83a	4	262.9	9	5.92	1.52
Hurley83b	1	0.0	100	100.00	1.00
Hurley83b	2	23.8	33	37.93	0.87
Hurley83b	3	71.4	32	24.24	1.32
Hurley83b	4	252.9	17	8.17	2.08
Reid a56	1	10.0	3	3.00	1.00
Reid a56	2	20.0	14	14.00	1.00
Reid a56	3	400.0	4	5.00	0.80
Sakabe75	1	200.0	15	11.72	1.28
Swaen,91	1	0.0	107	122.99	0.87
Swaen,91	2	10.0	104	104.00	1.00
Swaen,91	3	200.0	62	48.06	1.29
Xu et 96	1	0.0	172	172.00	1.00
Xu et 96	2	123.8	8	2.05	3.90
Xu et 96	3	453.8	14	4.12	3.40
Armstr94	1	2.3	138	138.00	1.00
Armstr94	2	40.9	94	63.51	1.48
Armstr94	3	147.2	41	18.39	2.23
Armstr94	4	250.5	46	21.90	2.10
Armstr94	5	413.1	19	10.16	1.87
Milham79	1	10.5	4	3.85	1.04
Milham79	2	22.5	4	5.71	0.70
Milham79	3	37.5	9	5.73	1.57
Milham79	4	52.5	14	7.57	1.85
Milham79	5	67.5	4	5.19	0.77
Milham79	6	99.2	0	1.63	0.00
Moulin00	1	0.0	4	8.51	0.47
Moulin00	2	25.0	5	7.25	0.69
Moulin00	3	70.0	4	4.76	0.84
Moulin00	4	120.0	3	5.36	0.56
Moulin00	5	200.0	3	4.29	0.70
Mur, J87	1	58.5	8	4.12	1.94
Mur, J87	2	175.6	3	4.29	0.70
Mur, J87	3	248.2	6	5.56	1.08
Rocket83a	1	20.0	6	12.68	0.47
Rocket83a	2	50.0	15	15.03	1.00
Rocket83a	3	70.0	24	23.60	1.02
Rocket83a	4	90.0	11	17.11	0.64
Rocket83a	5	116.1	8	5.41	1.48
Rocket83b	1	2.5	28	21.96	1.27
Rocket83b	2	6.3	23	22.07	1.04
Rocket83b	3	8.8	19	29.83	0.64
Rocket83b	4	11.3	26	23.51	1.11
Rocket83b	5	15.4	37	45.40	0.81
Romund00	1	0.0	66	66.00	1.00
Romund00	2	10.6	36	32.73	1.10
Romund00	3	58.7	42	38.18	1.10
Romund00	4	222.4	45	45.00	1.00
Spinel91	1	4.0	11	15.28	0.72
Spinel91	2	24.0	9	8.82	1.02
Spinel91	3	60.0	7	6.14	1.14
Spinel91	4	120.0	7	5.65	1.24
Spinel91	5	251.1	3	2.10	1.43
Donato00	1	4.5	10	10.00	1.00
Donato00	2	14.0	12	13.33	0.90
Donato00	3	36.4	12	20.34	0.59
Liu97	4	0.0	13	8.72	1.49
Liu97	3	1.2	6	5.04	1.19
Liu97	2	4.5	5	3.29	1.52
Liu97	1	17.3	26	6.05	4.30
Moulin89	1	0.0	1	1.00	1.00
Moulin89	2	14.9	2	0.69	2.90
Moulin89	3	41.8	2	0.69	2.91
Moulin89	4	94.9	2	0.49	4.07
Moulin89	1	0.0	7	7.00	1.00
Moulin89	2	0.9	3	7.89	0.38
Moulin89	3	2.6	2	2.27	0.88
Moulin89	4	5.8	1	3.13	0.32
Hammon76	1	23.4	22	23.91	0.92
Hammon76	2	40.9	66	43.42	1.52
Hammon76	3	57.6	21	14.00	1.50
Hammon76	4	66.8	12	4.86	2.47
Hansen91	1	20.3	25	8.62	2.90
Swaen,97	1	10.0	39	29.70	1.31
Hansen89	1	10.0	16	11.19	1.43
Maclar87	1	6.0	12	7.50	1.60
Swaen,97	1	10.0	48	40.61	1.18
Evanof93	1	4.5	4	5.19	0.77
Evanof93	2	14.0	17	8.06	2.11
Evanof93	3	24.0	13	5.78	2.25
Evanof93	4	40.0	19	6.74	2.82
Hansen93	1	30.0	5	1.60	3.13
Cammar86	1	1.0	5	2.83	1.77
Forast89	1	0.3	1	0.69	1.45
Forast89	2	0.8	5	2.56	1.95
Forast89	3	1.5	2	1.25	1.60
Petrel89	1	1.0	6	4.41	1.36
Robers96	1	1.0	34	40.48	0.84
Soraha01	1	0.0	16	16.00	1.00
Soraha01	2	0.2	11	14.10	0.78
Soraha01	3	0.4	17	9.19	1.85
Soraha01	4	0.8	20	15.15	1.3

Rel risk: Risk relative to baseline, or SMR (See Table 2)

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A Survey of Microbial Populations in Infilled Synthetic Turf Fields

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A Survey of Microbial Populations in Infilled Synthetic Turf Fields

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INTRODUCTION

Staphylococcus aureus is a bacterium that is a common inhabitant of human skin and can cause various types of skin or soft tissue infections (Marples, et al, 1990). *S. aureus* has also been implicated in certain types of food poisoning (Bennet and Lancette, 1998) and in serious medical problems such as toxic shock syndrome. Strains of *S. aureus* that are resistant to common antibiotics are becoming more common, particularly in medical settings. There have been reports recently of methicillin-resistant S. aureus causing infection in athletes (Begier, et al, 2004). With the increase in athlete infections, there is growing concern regarding the role of infilled turf systems (Seppa, 2005). While there is some indication that the source of these bacteria may be more closely associated with locker room activity than with the infill system (Begier, et al, 2004; Kazakova, et al, 2005), conclusive evidence is not currently available.

The objective of this survey was to determine the microbial population of several infilled synthetic turf systems as well as natural turfgrass fields. In addition, other surfaces from public areas and from an athletic training facility were also sampled. Colonies suspected to be *S. aureus* were positively or negatively identified.

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Materials & Methods

Sample Collection

All samples in this study were collected between June 15 and June 30, 2006. Infilled synthetic turf systems were located at facilities in Pennsylvania and were in use by all levels of play ranging from elementary to professional athletes. Infill material samples were collected from both a 'high use' and a 'low use' area of each field. A 'high use' area typically was a goal mouth or, for a football only field, an area between the 30- and 40-yard lines between the hash marks. A 'low use' area was typically an area toward the edge of the field (but within the field of play) or an end zone. Approximately 2–3 ml of infill material were removed from each area of the field using a sterile test tube inserted directly into the infill. Pile fiber samples were also collected from many fields by clipping several fibers from the backing and transferring the fibers to a sterile test tube. Samples were stored in a cooler and processed as soon after collection as possible.

Sample Processing

Approximately 0.075 g of infill material was transferred to a test tube containing 10 ml sterile 0.1% peptone broth. The sample was agitated for 30 seconds Serial dilutions of each sample were plated up to 10-3 on both R2A agar for total organism populations and Baird-Parker agar, a selective media for *Staphylococcus* (Bennet and Lancette, 1998). Duplicate platings were made for each media and each dilution. Petri plates were parafilmed and incubated at room temperature and colony counts were made 72 hours after processing. Samples on Baird-Parker agar were also observed again after 5 days. Calculations were then made to determine the number of colony forming units (CFU) per gram of infill material.

For comparison purposes, soil samples were also collected from a native soil and a sand based natural turfgrass athletic field. Samples were processed in the same manner as the infill material samples with 0.2 grams of soil being used for processing.

Sampling of Other Surfaces

Samples were collected from common surfaces in public areas as well as from various surfaces in an athletic training area. Samples were collected by swabbing surfaces with sterile cotton swabs. Random individuals were also tested by swabbing hands and/ or face. Both R2A and Baird-Parker agar plates were wiped with the sterile swabs. Plates were incubated at room temperature and colony counts were conducted after 72 hours for R2A agar and again at 5 days for Baird-Parker media.

Identification of *Staphylococcus aureus* colonies

Gram stains and latex agglutination tests (Essers and Radebold, 1980) were performed on colonies suspected of being S. aureus. Several potential *S. aureus* colonies isolated from hand and facial swabs were also included in the testing.

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Results

Field Samples

The results of total microbial populations are shown in Table 1. While microbes exist in the infill media the number was low compared to natural turfgrass field soils. It should be remembered that microbes tend to be present on most surfaces humans come in contact with and the simple presence of microbes should not be cause for concern. In fact, many products on the market claim to boost the microbial populations of natural turfgrass soils with higher microbial populations considered to be beneficial.

Table 1. Colony forming units (CFU) detected on R2A media per gram of crumb rubber.

Field ID#[1]	Product	CFU/g crumb rubber
1H	100% crumb rubber	20200
1L	100% crumb rubber	32667
2H	Crumb rubber - Sand mix	3533
2L	Crumb rubber - Sand mix	133
3H	Crumb rubber - Sand mix	3467
3L	Crumb rubber - Sand mix	13133
4H	100% crumb rubber	9467
4L	100% crumb rubber	30267
5H	Crumb rubber - Sand mix	18867
5L	Crumb rubber - Sand mix	8333
6H	Crumb rubber - Sand mix	267
6L	Crumb rubber - Sand mix	28333
7H	Crumb rubber - Sand mix	4800
7L	Crumb rubber - Sand mix	55333
8H	Crumb rubber - Sand mix	4867
8L	Crumb rubber - Sand mix	24133
9H	100% crumb rubber	9800
9L	100% crumb rubber	17867
10H*	Crumb rubber - Sand mix	0
10L*	Crumb rubber - Sand mix	67
11H	Crumb rubber - Sand mix	33200
11L	Crumb rubber - Sand mix	28000
12H	100% crumb rubber	333
12L	100% crumb rubber	800

13H	100% crumb rubber	267
13L	100% crumb rubber	67
14H	100% crumb rubber	8267
15H	Crumb rubber - Sand mix	8600
15L	Crumb rubber - Sand mix	3867
16H*	Crumb rubber - Sand mix	200
16L*	Crumb rubber - Sand mix	0
17H	Crumb rubber - Sand mix	0
17L	Crumb rubber - Sand mix	7267
18H	100% crumb rubber	5000
18L	100% crumb rubber	5533
19H	Crumb rubber - Sand mix	53067
19L	Crumb rubber - Sand mix	80000
20H	Crumb rubber - Sand mix	54333
20L	Crumb rubber - Sand mix	8867
Native soil (silt loam)		259500
Sand based soil		309500

[1] H = sample collected from higher use area of field
L = sample collected from lower use area of field
* = sample collected from indoor field

Pile fiber samples were also collected from several fields. CFUs for fiber samples range from 200-2933 CFUs per fiber sample (2 fibers approximately 1 cm long) indicating that the fibers alone generally exhibited lower microbial populations compared to the infill.

Microbial colonies isolated from field samples generally included both fungi and bacteria. Some fields had predominantly one organism type while other fields contained a variety of organisms. In order to positively identify the presence of *S. aureus*, three procedures were used. No colonies isolated from any crumb rubber or fiber samples tested positive for *S. aureus* via selective media, gram stain or latex agglutination tests.

Other Surfaces

Surfaces other than athletic playing surfaces were tested for the presence of microbes and S. aureus. These surfaces are not granulated and thus the results are listed in Table 2 as total colony number as opposed to CFU per gram of granulated material.

Table 2. Number of colonies per swab detected on R2A media from various sources in public spaces and an athletic training facility.

Source	Colony number
Public areas	
Computer mouse	>600
Elavator button	155
Outside door handle	80
Computer keyboard	33
Athletic training facility	
Cold pool	24
Blocking pads*	130
Sauna	536
Football*	142
Weight equipment 1*	62
Weight equipment 2*	414

Towel hamper	103
Stretching table	14
Used towels*	29
Trash can for drink cups	205
*Sampled immediately after use	

Table 3. Surfaces that tested positive (+) for *S. aureus* colonies per swab detected.

Source	Colony number
Public areas	
Human hands	+
Human faces	+
Computer mouse	-
Elavator button	-
Outside door handle	-
Computer keyboard	-
Athletic training facility	
Natural turfgrass playing field	-
Synthetic turf playing field	-
Cold pool	-
Blocking pads*	+
Sauna	-
Football*	-
Weight equipment 1*	+
Weight equipment 2*	+
Towel hamper	-
Stretching table	+
Used towels*	+
Trash can for drink cups	-
*Sampled immediately after use	

Microbial colonies isolated from surfaces included a mixture of fungi and bacteria. Colonies from the trash can were predominantly fungi. While not specifically identified, all colonies from the sauna swab appeared to be the same. *S. aureus* was positively identified from several samples including towels, blocking pads, weight equipment, and the stretching table. In addition, *S. aureus* was positively identified from every facial and hand swabs tested.

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Discussion

Considering the data in Table 1, the number of total colonies detected varied considerably between sites. In most cases, the number of total microbes at a given site was similar for both high use and low use areas of the field. In general, indoor fields tended to have lower overall microbial populations (0–7267 CFU) than outdoor fields. At one facility where indoor and outdoor fields were sampled on the same day, the indoor fields contained 0–67 CFU/g crumb rubber, while the outdoor field contained $2.8–3.3\times10^4$ CFU/g crumb rubber. While indoor fields represent only 20% of the fields sampled in this study a consistent trend is apparent.

Total microbial populations for the two natural turf athletic fields were an order of magnitude higher than populations for the infill systems with the highest numbers. Also, observationally, there appeared to be a greater diversity in the types of organisms isolated from soil samples than crumb rubber samples. However, no specific determinations of any cultures were made other than to positively or negatively identify *S. aureus*.

One factor that may influence total microbial populations of infill surfaces is use. Of the 11 fields with at least one subsample having greater than 1×10^4 CFU/g crumb rubber, one of those fields had been heavily used within 7 days of sampling and two fields had been used within 24 hours of sampling. Tracking microbial population fluctuations of a field over time may be of interest.

It is perhaps not surprising that no S. aureus colonies were found on any fields, given that the temperature range for growth of *S. aureus* is 7–48°C, with the optimal temperature for growth being 37°C (Baird-Parker, 1990). Surface temperatures of infill surfaces outdoors often exceed the temperature range of *S. aureus* (McNitt, 2005). However, high surface temperatures do not explain the relatively low numbers of total microbes on indoor playing surfaces. These low numbers may, in part, be explained by the permanently very low moisture content of indoor infilled surfaces.

In conclusion, there are generally lower numbers of total microbes present in the infill or fibers of the synthetic turf systems tested compared to natural turfgrass rootzones and *Staphylococcus aureus* bacterium were not found on any of the playing surfaces. *Staphylococcus aureus* bacterium were found on towels and other devices used by athletes.

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

Determining Staphylococcus aureus Survival in Synthetic Turf Infill Systems

A.S. McNitt, Ph.D. and D.M. Petrunak, M.S. Plant Pathology
The Pennsylvania State University

Determining *Staphylococcus aureus* Survival in Synthetic Turf Infill Systems

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SUMMARY

The study entitled "A Survey for the Presence of *Staphylococcus aureus* in the Infill Media of Synthetic Turf" has been accepted for publication in the ISHS journal. I presented this paper in July, 2007 at the ISHS conference in Beijing, China. It should be in print by November, 2007. The study indicated that infill synthetic turf systems are not a 'breeding ground' for microbes such as staph. The study did find staph on inanimate objects such as weight equipment and blocking pads. Certainly, we believe that live staph can be deposited onto infilled synthetic turf systems and survive for a limited period of time. The question is: 'How long can they survive?" and "Does antimicrobial impregnated fiber significantly reduce this survival time?" Our null hypothesis is that staph can live only a short time on an infill system and especially in outdoor situations, this survival time will not be significantly reduced by antimicrobial impregnated fibers since the survival time is suspected to be very limited.

INTRODUCTION

Staphylococcus aureus is a common skin inhabiting bacterium than can cause numerous types soft tissue infections. Once limited to medical settings, strains of *S. aureus* that are resistant to commonly used antibiotics are becoming more common in community settings. There have recently been reports of methicillin-resistant *S. aureus* (MRSA) infection in athletes ranging from high school to professional levels (Begier et al, 2004; Kazakova et al, 2005). While direct person-to-person contact is thought to be the major mode of transmission of MRSA infections (Rihn et al, 2005), there is growing concern regarding the role of infilled turf systems (Seppa, 2005). There are conflicting reports regarding the role of various surfaces in the transmission of MRSA infections. Kazakova et al (2005) suggested that locker room surfaces and hygiene practices of athletes were involved in the spread of MRSA. However, other studies have found that sharing of equipment and towels were not directly associated with infection (Barlett et al, 1982, Rihn et al, 2005).

It is unknown how long *S. aureus* is able to survive on an infilled synthetic turf system. Neely and Maley (2000) found that MRSA and methicillin-sensitive *S. aureus* are capable of surviving for relatively long periods of time on swatches of polyethylene hospital plastic that were maintained at conditions conducive to growth of *S. aureus*. However, McNitt et al (2007) surveyed twenty synthetic athletic fields to determine microbial populations and no *S. aureus* was found in any of the samples. Because *S. aureus* cannot survive temperatures above 48^{o}C (Baird-Parker, 1990), it seems unlikely that *S. aureus* can survive for long periods on outdoor infill systems because these fields

often exceed that critical temperature (McNitt, 2005). It is currently unknown how long *S. aureus* is capable of surviving if introduced onto an infilled synthetic turf system.

The objective of this study is to determine the length of time *S. aureus* is capable of surviving when introduced onto infilled turf systems in both indoor and outdoor environments.

PROCEDURES

S. aureus will be cultured on R2A agar plates to gain sufficient bacterial populations for use. To obtain inoculum, R2A plates will be washed with sterile 0.1% peptone solution. The concentration of the bacterial solution will be adjusted appropriately and will be applied to a small section of infilled synthetic turf which will be contained indoors at room temperature and standard indoor fluorescent light. Fibers and infill media will be sampled at 1 hour intervals for 8 hours by collecting infill media and clipping fibers from the turf and placing them onto Baird-Parker media for identification of *S. aureus* (Bennet and Lancette, 1998). Samples will then be collected 24 hours after inoculation and at subsequent 24 hour intervals for 7 days. Baird-Parker plates containing the fiber samples will be incubated at room temperature for 3-5 days. Colonies suspected of being *S. aureus* will be confirmed using a latex agglutination test (Essers and Radebold, 1980). If *S. aureus* is positively identified on infill system fibers after 7 days, a similar experiment will be conducted with sampling of fibers beginning 7 days after inoculation and continuing until 28 days after inoculation. A similar experiment will be conducted on several infill systems that are installed outdoors in natural conditions. One will be a system without antimicrobial materials in the fiber and one will be a system with antimicrobial fibers.

Grant In Aid Requested - $15,000

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

Overview of the Latest Attacks Against Artificial Turf

Overview of the Latest Attacks Against Artificial Turf

The success of artificial turf sports fields has had an impact on the suppliers of natural grass fields. As growth of artificial turf increases dramatically on a global scale it now represents a considerable threat to this established industry.

According to Turfgrass Producers International, natural grass generates over $40 billion in grass and maintenance sales each year in the US.



Artificial turf has also had an impact on the local communities where such fields are installed. The installation of any new artificial turf field means kids can now play on it day and night - without fear of destroying the grass or creating mud baths in bad weather. As a result, many installations are often followed by lights, increased usage during the day and night and the subsequent crowds that such activity brings.

Concessions, traffic and other inconveniences have affected the homeowners nearby. The local community usually feels threatened by new construction as, unfortunately, most local residents have limited input in such decisions. Unless the homeowners have children who use the facilities, their reaction is usually based on protecting the peace and quiet of their lives and the value of their property, which they fear will be affected.

In past they have been unable to stop progress. But now the natural grass industry and those who have issue with artificial grass (or anything artificial) are using the local residents to put forward their own agenda to try to stop the installation of new artificial turf fields. There is nothing like an environmental or health scare to put the brakes on any new construction. And we believe it is the natural grass industry lobby that have been feeding local communities, their town halls and the local media with these scare tactics. And in some regions it's working.



So much study has already been done on this subject. Hundreds of reports and tests have created thousands of documents of very detailed medical reports. Making sense of this complex literature and making it available and understandable to the general public is a far more difficult task.

Everyone understands the truth, but hysteria and wild claims of imminent danger are a lot easier to make headlines with - and so such tactics continue to be effective. In the lobby against artificial turf in particular, there have been many such claims.

Overview of the Latest Attacks Against Artificial Turf

First it was ***Silicosis***, with threats that playing on artificial turf with sand in the infill meant inhaling silica, which cause silicosis. This proved to be a ridiculous assumption, since the size of our smallest particle of silica sand is many times larger than the particle size the lung is able to ingest. In any case, it required locating many of the countless studies published to prove that it was in fact an empty threat.



Then it was ***Heat***. This threat purported dangers of kids dying on hot artificial grass fields, fuelled by a few tragic incidents where young athletes dies of heat exhaustion and related conditions. These horrible events actually took place on natural grass, not on artificial turf.

Next was the ***Staph*** scare, where artificial turf was blamed for serious infections that were making headlines. As it turned out, this was completely false when it turned out that such infections were caused by bad hygiene, the transfer of germs from open wounds and germs on surfaces inside the sports facility training and locker rooms.

Then it was ***Global Warming***, blaming artificial turf for increasing temperatures on earth. A scientific review of global warming contributions from shopping center parking spaces alone, made such claims microscopic in comparison.

The Carbon Footprint assumes that as artificial turf replaces natural grass we are removing the oxygen from the environment and replacing it with CO2.



And now it is ***SBR***, that is the latest scare. The dangers of cancer-causing materials found in the crumb rubber from used tires has created a lot of noise and controversy - but has been proven to be as overstated just like the rest of these scares.

The scare starts with PAHs or Polynuclear Aromatic Hydrocarbons. In the making of salt, two extremely dangerous substances to humans (Sodium and Chlorine) are combined to create salt, a harmless substance consumed daily by every human. The manufacture of rubber tires also combines and creates some dangerous particles during the vulcanization process. While such substances are being phased out of production worldwide, these dangerous substances cannot be extracted from the tire product, unless extreme solvents and processes are utilized. If a child was to eat a handful of crumb rubber, the particles, which may contain dangerous materials, will pass right through the body untouched. The human digestive system is unable to break down these compounds. In the same way, the rubber cannot be absorbed by the lungs or the skin and therefore, like salt, potentially dangerous substances have no effect on human safety.

The following pages look at these claims and some of the facts that have not been reported, or have been conveniently omitted where it serves another agenda.

Overview of the Latest Attacks Against Artificial Turf

SBR - The Claim:

SBR, the crumb rubber used as infill in artificial turf fields, is toxic



SBR - THE FACTS:

Over 46 billion tires have been ground up on our highways and city streets. And more are being shredded by trucks, buses, cars and planes every single day.

If SBR is truly dangerous then we should put the concern where it belongs

- on the automotive and transportation industries and the cars we drive
- not on artificial turf fields which represent .0000075 of the SBR that is part of the atmosphere and the air we breathe every day.

Here's another interesting point to consider - the claims of PAHs in SBR should be balanced with the fact that burning fossil fuels, including heating and cooking are in fact the #1 causes of PAHs in our atmosphere.

O^2 - The Claim:

The amount of O2 in the atmosphere is being reduced, as artificial turf replaces natural grass

O^2 THE FACTS:

Only growing forests produce a net gain of oxygen as they store carbon. A mature forest is in a steady state, where growth and decay are equal. Decay releases the same number of molecules of CO^2 that the tree stored during its life and growth. Peat bogs retain CO^2 as well.



Most rainforests are the perfect example of this steady state, with rapid growth and rapid decay being essentially equal. Managed forests, with healthy growth and long-term storage of the harvested wood, produce oxygen.

Natural grass playing fields do not produce oxygen because the grass clippings all decay.

As for the worry that natural grass is being lost to artificial turf, consider this: Americans spend $11 billion a year on water, pesticides, fertilizers and gas to keep 30 million acres of lawn green and tidy, making grass America's largest irrigated crop.

Artificial turf fields represent .0002487% of this green space in the US.

Overview of the Latest Attacks Against Artificial Turf

Global Warming - The Claim:

The reduction of natural grass contributes to global warming

Global Warming - THE FACTS:

When considering the heat generated by artificial turf fields consider that the total of all artificial turf fields in the US represents .006172% of the asphalt urban jungle - not including the massive area of glass wall buildings which deflect and generate heat in every city in America.



To get a proper perspective on this, consider that just the area of black asphalt parking spaces in US shopping malls alone is currently the equivalent of more than 50 times all of the artificial turf fields in the US. Over 900 new shopping malls were constructed in 2006. If just a few of the new shopping centers built each year installed multi-level parking, rather than the vast sea of asphalt normally provided, the net heat reduction would exceed any heat generated from artificial turf installations.

Infection - The Claim:

That staphylococcus (staph) infections are caused by parasitic bacterium present on the playing surface of artificial turf fields

Infection - THE FACTS:

Some makers of antiseptic sprays have tried to promote the dangers of infection to enhance their business. However, no staph infections have been found in artificial turf fields, although they have been found in almost every other part of the athletic environment, including; benches, clothing, towels, tubs, showers, tables and dressing room floors.



If spraying antiseptic really solved this problem of staph infections, then it would be commonly used in every hospital around the world - which it is not.

In fact, tests executed to evaluate the potential of an artificial grass field retaining bacteria, involved the placement of living organisms into the turf. All of these living organisms passed right through the turf system and each was recovered in the drainage system of the field.

Overview of the Latest Attacks Against Artificial Turf

Silicosis - The Claim:

That the sand used in artificial turf fields can cause silicosis

Silicosis - THE FACTS:

Diseases from sand are caused by respirable crystalline silica. As you might surmise you can't get silicosis from going to the beach or working your way around sand traps because of the sizes of the sand involved. If the sand particles you breathe are too large they never get down into the lungs. If they are too small they pass right through the lungs and do not cause harm.



Respirable crystalline silica is around the 10 micron size, which is so small as to be invisible to the naked eye, and is caused by activities involved in sand blasting or in mining where the forces involved are actually fracturing the sand. Diseases associated with this require exposures to the harmful sizes for years and / or fewer but massive amounts of exposure. Cases of silicosis in this country have been declining markedly over the past 80 years. It is completely preventable now and recent court decisions have found that the silicosis issues of today are generated by plaintiffs' lawyers out to make money rather than by any true incidence of silicosis as a health concern today.

Health and Safety - The Claim:

The materials used in artificial turf fields can affect the health of the athletes who play on it

Health and Safety - THE FACTS:

Not a single injury has been ever been reported where an athlete or anyone else has fallen sick or was injured as a result of inhaling, having skin contact with or ingestion of artificial turf infill materials.

Given this fact, perhaps we should be more aware of the real issues and put the emphasis where it belongs - like preventing real and present everyday dangers.



According to the Sports Concussion Institute, more than 750,000 Americans report injuries sustained during recreational sports each year, with 82,000 involving brain injuries. 10% of all contact sport athletes sustain concussions yearly. Up to 86% of athletes that suffer a concussion will experience Post-Traumatic Migraine or some other type of headache pain. Brain injuries cause more deaths than any other sports injury. In football, brain injuries account for 65% to 95% of all fatalities. Football injuries associated with the brain occur at the rate of one in every 5.5 games. In any given season, 10% of all college players and 20% of all high school players sustain brain injuries.

A five year study comparing artificial turf to natural grass has shown that artificial turf resulted in 55% fewer Neural injuries, 47% fewer Cranial Cervical Injuries, 45% less time lost to injury (22+ days), 38% fewer 3rd degree injuries and 35% less time lost to injury (1-2 days).

Overview of the Latest Attacks Against Artificial Turf

Environmental Concerns - The Claim:

That artificial turf is dangerous to the environment

Environmental Concerns - THE FACTS:

Burning of fossil fuels remains the #1 global concern. Getting fixated on the unproven potential of a possible miniscule contribution by artificial turf requires some common sense and balance, considering the injury prevention and health and safety benefits provided each day to those who play on artificial turf.



The environmental benefits of artificial turf include the recycling of old tires, the elimination of thousands of tons of pesticides, chemicals and fertilizers from our environment as well as the reduction of the heat generated and fuel required to just to maintain natural grass playing fields.

And don't forget about all the chlorine, bleach and soap required to wash natural grass stains off millions of tops, shorts and players' uniforms each day.

Maintenance - The Claim:

That maintaining an artificial turf field is difficult and costly

Maintenance - THE FACTS:

The savings achieved in the reduction of equipment, fuel, pesticides, chemicals and fertilizers is considerable. An average natural grass playing field costs $50,000 to properly maintain each year. An artificial grass field costs $5,000 to maintain.

City and Parks Administrations, Sports Facility and Stadium Managers, Athletic Directors, Coaches and Field Maintenance Staff in schools and colleges from coast to coast consistently prove that the savings and economic benefits of artificial turf are a fact.

Over a ten year period, the average cost per hour of use of an artificial turf field is less than 25% the cost of use of a natural grass field.

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SYNTHETIC TURF
INFILL RESEARCH SOURCES

Independ§nt Testing, Studies and Reports on the Subject of SBR and Any Potential Health and Environmental Impact

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

Hundreds of studies have been completed and thousands of pages compiled which detail the exhaustive research readily available on the subject of SBR and the other components of artificial turf infill materials.

Unfortunately, although this is indeed a "fact rich" environment, many have simply jumped on the "scare tactic" bandwagon, reacting and bending to misleading headlines deliberately presented by those with their own agenda to promote.

Those with their own agenda include the manufacturers of alternative infill granulate material and others who provide chemical sprays and treatments. However, the strongest lobby group by far, is the natural grass producers who have been severely impacted by the success of artificial turf.



This natural grass lobby is trying to maintain some $40+ billion in grass sod, seed, fertilizers, pesticides and equipment sold each year in the US alone. In desperation, however, they have reverted to familiar but deceptive PR tactics, ignoring the facts and creating myths, scares and dangerous headlines to try and reverse the trend toward artificial turf.

In looking for the truth, just look to the research and the reports. The following is a sampling of just some of the conclusions reached by the independent experts who have completed the studies.

What The Experts Say

"Tyre waste has no toxic influence on fauna and micro-aquatic organisms."



"In the event of ingestion of crumb particles, although it is highly improbably, the particles do not present any toxicity, as the digestive system is not powerful enough to extract the chemical components from the rubber."

"Inhaling is practically negligible because crumb rubber does not give off volatile products."

"Direct contact with the skin does not present any real danger, even from the point of view of allergy."

"Biological tests have shown the absence of genotoxicity."

Laboratoire de Recherches et de Controle du Caoutchouc et des Plastiques - End of Life tyre Crumb Rubber in Sports Floors - Environmental Consequences, 2006 Update

(We have intentionally avoided using documents that could be thought to be too heavily loaded towards one technical opinion. Some bodies (suppliers, rubber industry trade associations, ecological associations, etc.) could be considered biased, and could be tempted to present arguments either for or against lacking in objectivity.)

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"Epidemiological studies conducted by the Health Effects Institute, The World Health Organisation and other investigators do not implicate tyre wear particles in ambient air as contributing to human health effects (respiratory and cardiovascular diseases)."

FIFA - potential cancer risk from certain granulate infills from artificial turf - July 2006

"The available body of research does not substantiate the assumption that cancer resulting from exposure to SBR granulate infills in artificial turf could potentially occur."

Danish Ministry of the Environment



"Because tyre rubber is designed to be strong, durable and substantially impermeable, it is unlikely that any losses could occur to air or water in concentrations that would pose serious human or environmental risk. This opinion is supported by the reports and academic studies reviewed, which have shown insignificant effects of such chemicals or release of volatiles and particulates into the atmosphere."

The Use of Recycled Rubber in Sports Surfaces - Sports and Play Construction Association - 2006



"No test was clearly genotoxic. No tests performed without microsomal activation demonstrated genotoxic activity. Seven test tests were marginal after activation but did not meet the criteria for genotoxicity and are considered negative."

"In all instances except one, the PEEP index was determined to be less than 3, which is considered acceptable by Environment Canada. In the case of the schoolyard material, which was freshly installed and kept in place for three months, the PEEP index was only marginally greater than 3 (3.2). With further aging in place or treatment before installation, this value should drop below 3."

Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds - Birkholz, Belton and Guidotti - July 2003

"All heavy metal levels are in compliance with the standards applicable to toy manufacturing and the risk of harmful effects on sportsmen and women is therefore negligible."

"Indoor and outdoor use of rubber infill poses absolutely no risk to sportsmen/sportswomen or other parties concerned through inhalation."

Study from ISA Sport test institute, the NOC/NSF and the KNVB

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

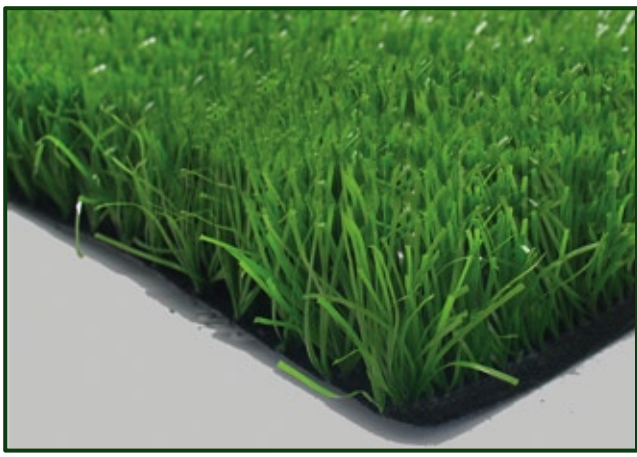
Conclusions - What The Experts Say

"De Telegraaf, once again reported a number of factual inaccuracies on the use of SBR rubber in artificial grass fields. The information in the report does not substantiate any of the statements reported in the intended article."

Incorrect Reporting in De Telegraaf on Research Report on Infill Used in Artificial Grass - May 2006

"Using the most severe extraction methodology, the nitrosamines found were only slightly above the detection level. These low levels of NDMA and N-MOR represent a worst-case scenario with regard to the product."

Tun Abdul Razak Research Centre - 2006



"The RIVM has reached the conclusion that PAHs can in fact be released, to a small degree, from rubber granule particles in artificial turf fields, but on the basis of the available data, this does not seem to entail any health risk."

Ministry of Social Housing, Regional Planning and Environmental Administration, The Hague - 2007

"Since there is no risk for PAHs, as the most harmful component of PAHs, it seems unlikely that this would be the case for other substances."

"PAHs are absorbed in the matrix of the rubber granules and do not leach."

Dutch National Institute for Public Health & the Environment
Answers to Questions on Harmful Substances in Artificial Turf Fields
Public Health, Social Welfare & Sport

"The concentration of 0.03 ppb means a level of about one million times below the limit recommended in the TUV report. I consider such a margin safe enough."

Answers to Questions on Harmful Substances in Artificial Turf Fields
Public Health, Social Welfare & Sport - Dr. J.M. Roels - Head of Substances Expertise Centre

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"A wide range of PAHs, including the carcinogenic ones, is found in the air -especially in urban air. They originate from various combustion sources (eg; power generation, vehicular traffic, space heating, etc.). Given their widespread availability, human exposure to PAHs cannot be avoided. Some exposure scenarios are:

– inhalation of smoke particles

– ingestion of smoked, charred or char grilled foodstuffs

– skin contact with soot



Exposure does not stop at risks from smokes and chars. As any particulate pollutant once released into the air can be transferred to other materials or media the PAHs carried on smoke can settle on the ground (or vegetation) or be washed into ground waters.

That means that if you go hunting for PAHs (yes, even the carcinogenic ones) you will find them."

PAHs & Other Organics in Tires - Origins and Potential For Release - June 2006

"The health risk on children's playgrounds that contained both worn tyres and granulate rubber was insignificant."

Danish Ministry of the Environment



"Regarding the potential for Zinc leaching, away from trench, Zn levels rapidly decay to background levels."

"Tire shreds placed above or below water table have a negligible impact on water quality."

Rubber – Its Implications to Environmental Health (Hydrocarbon Rubbers) - Brian G Willoughby

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"N-Nitrosamines figure prominently in concerns over cancer risks from rubber, although they have the potential to be formed whenever protein-containing material is roasted in a current of air."



"Beer, whisky and bacon contain carcinogenic N-nitrosamines. Unlike the carcinogenic PAHs, N-nitrosamines are volatile. They can be formed during vulcanisation and released from the rubber (12 different ones are regulated for the German rubber industry)."

"Over the last twenty years, the tyre industry has responded to worldwide concerns and effected large reductions in N-nitrosamine levels. Quite possibly they are now completely undetectable."

"That may be the case for tyres – but is it so for EPDM? N-Nitrosamines can be particularly difficult to eradicate from EPDM."

PAHs & Other Organics in Tires - Origins and Potential For Release - June 2006

"From an ecotoxicological viewpoint, the results obtained show that the nature of the percolates likely to infiltrate into the ground underlying the artificial turf sports surface proves to be without impact on the aquatic environment."

Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007

"It can be concluded that rubber tires contain PAHs originating from certain oils used in tire manufacturing, but there is clear scientific evidence that any release into the environment is negligible relative to other PAH sources."

The European Commission's Scientific Committee on Toxicity, Ecotoxicity and the Environment



"One of the earliest studies of airborne PAH in tyre factories (started in 1973) quickly found that the results made little sense without comparative measurements on the outside air. Studies, over the remainder of that decade, in both the UK and USA, found that:

– no carcinogenic PAH was present in tyre factories in excess over ambient air levels."

PAHs & Other Organics in Tires - Origins and Potential For Release - June 2006

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"The effects of motorway runoff on the water quality, sediment quality, and biota of small streams were investigated over a 12-month period. Downstream of motorway runoff discharges there was an increase in the sediment concentrations of total hydrocarbons, aromatic hydrocarbons, and heavy metals and an increase in the water concentrations of heavy metals and selected anions. Hydrocarbon contamination of sediments was positively correlated with potential contaminant loading (i.e., length of road drained/stream size).

The dominant PAHs in contaminated sediment at this site were phenanthrene, pyrene, and fluoranthene, whereas the dominant metals were zinc, cadmium, chromium, and lead. Differences between the station upstream and downstream of discharges in the diversity and composition of the macro invertebrate assemblages were detected in four out of the seven streams surveyed.



However, there was no evidence of an effect on either the diversity or abundance of epilithic algae. The diversity of the aquatic hyphomycete assemblage was only affected at the most impacted site. Reductions in the macroinvertebrate diversity were associated with reductions in the processing of leaf litter and a change from an assemblage based on benthic algae and coarse particulate organic matter to one dependent upon fine particulate organic matter."

The Effects of Motorway Runoff on Freshwater Ecosystems
Cranfield Centre for Ecochemistry - Cranfield University

"A reduction of the concentration of PAHs in tyres will insignificantly reduce the overall concentration of PAHs in the environment."

The European Commission's Scientific Committee on Toxicity, Ecotoxicity and the Environment

"It also has been demonstrated that the risk of rubber workers developing skin cancer from exposure to highly aromatic oils contained in rubber is non-existent."

Environmental Health and Safety Report - Goodyear Tire and Rubber

"Polycyclic aromatic hydrocarbons (PAHs) are formed during incomplete combustion. Domestic wood burning and road traffic are the major sources of PAHs in Sweden."

Cancer Risk Assessment, Indicators & Guidelines for Polycyclic Aromatic Hydrocarbons in the Ambient Air

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"The rubber granulate meets the Building Materials Decree requirements regarding chemical composition and the leaching out of substances."

"The rubber granulate meets the standards set for heavy metals and the Toys Decree."

"No health risks are posed by breathing in or brief skin contact."

"No studies showing that rubber granulate poses a risk to health and the environment were unearthed."

"The use of rubber granulate in playgrounds forms no relevant risk to children or the environment."



"Prolonged daily skin contact with rubber tyres does not pose any relevant health risk."

RUBBER GRANULATE FROM RECYCLED CAR TYRES IS SAFE FOR PEOPLE AND THE ENVIRONMENT - VACO - June 2006

Danish Technology Institute 2005, Commissioned by the Danish Ministry of the Environment



"Serious Blunder With Artificial Turf - Scattered rubber granules safe for sports after all."

"Poisonous nitrosamine vapours floating above artificial turf pitches have probably never existed. According to the State Institute for Public Health (RIVM), artificial turf pitches sprinkled with rubber granules are in fact not damaging for health, as had been previously assumed."

by Jouke Schaafsma, ARNHEM - 2007

"There is no risk for the health playing on artificial grass fields that are filled with rubber particles."

"The environment aspects have also been examined. Representatives of the Ministries of VROM and Health, Welfare and Sport, the association Dutch municipalities, ISA sport and the player trade union VVCS also participated in the advisory commission beside the constituents."

*KNVB and combined Netherlands Olympic Committee and Dutch Sports Federation NOC*NSF - March 2007*

Tire Crumb Rubber Used in Artificial Turf Fields - March 2007

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"PAHs can in fact be released to a limited extent from rubber granule particles, but based on the available data, this does not lead to a health risk. There is no health risk for DEHP from oral exposure either."

Dutch National Institute for Public Health & the Environment - Answers to Questions on Harmful Substances in Artificial Turf Fields
Public Health, Social Welfare & Sport

"It is accepted that the vast majority of PAHs in the environment derive from the incomplete combustion of fossil fuels in particular diesel exhausts from truck and car emissions."



The University of Dortmund Institute for Environmental Research

"The aliphatic oils used in EPDM and other rubbers are a more prolific source of volatiles from hot rubber."

PAHs & Other Organics in Tires - Origins and Potential For Release - June 2006



"Epidemiological studies conducted by the Health Effects Institute, The World Health Organisation and other investigators do not implicate tyre wear particles in ambient air as contributing to human health effects (respiratory and cardiovascular diseases).

Tyre debris is found in diffuse roadside soils, but the published studies present no evidence for ecotoxic effects in or from roadside soil.

In general tyre abradate is a much finer particulate than are the granules used as infill materials in Football Turf. The finer the particulates the greater the surface area and higher potential for chemicals to leach out of the rubber. The majority of the studies have been on these higher surface area particles and have concluded they are currently acceptable.

The larger granules used in Football Turf will therefore have even less potential for emissions.

A study undertaken by the Danish Ministry of the Environment concluded that the health risk on children's playgrounds that contained both worn tyres and granulate rubber was insignificant."

FQC - Infill Health Statement 2007
Evaluation of the environmental impact on water:

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"All of the physicochemical results (42 parameters analyzed) obtained on the percolates from the 32.5-m2 pilots leads to the observation of a release kinetic for potentially polluting substances comparable to the course of time irrespective of the type of granulate used (7 percolate samples analyzed at one year).

The artificial turf pilot without filling granulates used as a control also displayed release rates fairly close to those of the 3 pilots. The concentrations recorded were low for the majority of the compounds and elements searched for. While certain elements displayed slightly higher concentrations at the start of experimentation, these fell very rapidly, thereby indicating a very rapid reduction effect in terms of release rates.

In situ on the football pitch the concentrations and release kinetics are fairly comparable to those observed on the pilots. The chlorides, fluorides and sulphates are even in lower concentrations than in the percolates collected on the pilots, a finding to be linked with the difference in chemical composition of the water that has percolated through the sports surfaces (rain water in situ and drinking water on the pilots)."

Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007



"Waste waters in tyre manufacturing plants have been the subject of study, where evidence of some of the lower molecular weight PAHs (non carcinogenic) PAHs can be found. Studies in the field are inevitably confounded by the presence of PAHs from other sources - ie; washed out of the atmosphere."

PAHs & Other Organics in Tires - Origins and Potential For Release - June 2006

"The studies to date have concluded that PAHs are not released or at most negligibly released from tyre abradate."

The University of Dortmund Institute for Environmental Research

*"*A Health Risk Evaluation (HRE) conducted by the Institut National de l'Environnement Industriel et des Risques (France) was based on the values of the concentrations of 112 substances identified in the emission chambers and their comparison to the international toxicological reference values (RTV). According to the HRE methodology, a "worst-case scenario" was modeled "small."

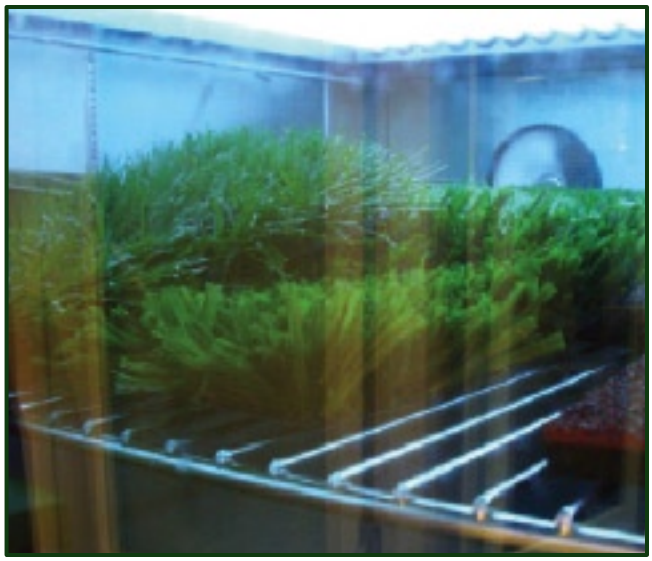
Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

"On the basis of a comparison with the French and European limit values currently in force, the concentrations of organic compounds, metals and anions from the percolates are without impact on water resources.

Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007



"Emissions tests of Volatile Organic Compounds and aldehydes by elastomer granulate-based sports surfaces conducted by the CSTB (Centre Scientifique et Technique du Bâtiment - France) using the standards in force for the characterization of the emissions in indoor air of construction products (emission chamber) show that:

- Emissions from the artificial turf containing used tyre granulates are relatively low.
- Emissions from the artificial turf containing the EPDM granulates are the most significant."

Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007



Zinc
"With all surface types, Zinc was found in concentrations of 0.009 to 0.003 mg/l. In rainwater, which was also investigated, a concentration of 0.02 mg/l was found."

Polycyclic Aromatic Hydrocarbons
"None of the surface systems including the surfaces with recycled granules showed any noticeable PAH concentration. PAHs are ubiquitous substances in the environment and in water. They are present in any street sewage and also in purified sewage from communal sewage purification plants as well as sewage sludge in partly much higher concentrations."

"Due to the results of the pre-test it is expected that the DOC concentration will decrease in the course of time."

Swiss Federal Authority of Health July 6, 2006

Conclusions - What The Experts Say

"This authority was challenged to provide a statement regarding health risk caused by PAH in artificial turf. The issue refers to recycled rubber granules i.e. SBR granules from car tires.

It is considered the question of abraded particles being inhaled as dust and being washed out and ending up in waters and in the subsoil. PAHs can be substances added to softeners of tires, but are also generated by burning processes, from traffic exhaust fumes and heating systems; they also come from tobacco smoking and chimneys.

The estimatable PAH stress is low even in worst case scenarios compared with stress from other sources. The health risk for players and spectators is classified low. Thus, from the health point of view no urgent need of action is seen."

Investigation and Assessment of Synthetic Sports Surfaces in Switzerland Including Athletic and Soccer Facilities - Hans J. Kolitzus, IST Switzerland

"Initiated in 2005, this study was conducted with the scientific aim of getting as close as possible to the pitch usage conditions. The results of the evaluation of the environmental impact on the water and of the health risk evaluation (gaseous emissions) on the population groups show:

- comparable behaviour irrespective of the type of filling granulate (virgin TPE and EPDM, used tyre granulates)
- an absence of impact of this type of work on water resources
- no effect worthy of concern on the health associated with the inhalation of VOC and aldehydes emitted by artificial surfaces."



Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as infill in third-generation artificial turf - General conclusions - Dr Robert Moretto ADEME / ALIAPUR 2007

"Recycled rubber granulate contains many chemical substances which are potentially harmful to health. The concentrations of these substances are however extremely low, they are only leached from the rubber granulate in very small quantities and they are only present in low concentrations in the hall air."

"The quantities of this type of substance are consistently lower than in the other types of rubber granulate which are used."

Artificial turf pitches – an assessment of the health risks for football players
Norwegian Institute of Public Health and the Radium Hospital - Oslo, January 2006

INDEPENDANT TESTING, STUDIES AND REPORTS ON THE SUBJECT OF SBR AND ANY POTENTIAL HEALTH AND ENVIRONMENTAL IMPACT

Conclusions - What The Experts Say

Norwegian Institute for Water Research (2005) carried leachate tests on granulate found:

– only two-to-four-ring (non carcinogenic) PAHs in leachate.

Log Kow values:

– ca. 3-4 for three-ring

– ca. 4-5 for four-ring

– ca. 6 for five-ring

So five-ring (carcinogenic) PAH is ca. 10 6 times more likely to partition in an organic phase rather than in water

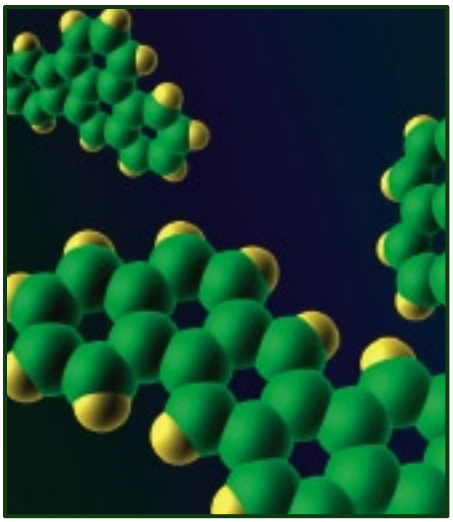
Five-ring PAHs will stay in the vulcanised rubber



Rubber – Its Implications to Environmental Health (Hydrocarbon Rubbers)
- Brian G Willoughby

"On the basis of estimated exposure values and the doses / concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults."

Artificial turf pitches – an assessment of the health risks for football players
Norwegian Institute of Public Health and the Radium Hospital - Oslo, January 2006



"As regards allergies, it is concluded that exposure to the low concentrations which were measured does not constitute any elevated risk with respect to the development of contact allergies.

Worst case calculations based on air measurements carried out by NILU and exposure values from the Norwegian Institute of Public Health indicate that training in sports halls does not cause any increased risk of leukemia as a result of benzene exposure or any elevated risk as a result of exposure to polycyclic aromatic hydrocarbons."

Artificial turf pitches – an assessment of the health risks for football players
Norwegian Institute of Public Health and the Radium Hospital - Oslo, January 2006

Conclusions - What The Experts Say

BRMA survey of airborne benzo[a]pyrenein ten UK tyre factories found:

– concentrations from zero to 28 ng/m3

– no correlation with process or factory area

– strong correlation with seasons and weather

Nutt (1984) repeated this with simultaneous measurements of inside (tyre factory) and outside air found:

- no excess of B[a]Pin factory air

Willoughby (1994) analyzed PAHs from laboratory vulcanizations at up to 200ºC found

– only two-to-four ring (non carcinogenic) PAHs in volatiles

Rubber – Its Implications to Environmental Health (Hydrocarbon Rubbers)
- Brian G Willoughby

"On the basis of the exposures which have been calculated in connection with the use of indoor halls with artificial turf in which recycled rubber granulate is used, there is no evidence to indicate that the use of such halls causes an elevated health risk."

Artificial turf pitches – an assessment of the health risks for football players
Norwegian Institute of Public Health and the Radium Hospital - Oslo, January 2006



"PAHs are already in the environment from combustion processes, transport, power generation, cigarettes, etc.

PAHs are:

– routinely monitored in ambient air

– carried on soot particles and washed out of air by rain

– passed into rivers and lakes - and then into sediments

Nilsson et al (2005) studied PAHs in sand in a children's playground with used tyre components and found:

- distribution of PAHs did not reflect that in tyre rubber
- that the PAHs arose from deposition from the air
- additional risks from PAHs in tyre granulate judged insignificant"

Rubber – Its Implications to Environmental Health (Hydrocarbon Rubbers)
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Conclusions - What The Experts Say

"The air studied at the artificial turf football field does not exceed any maximum value established in the European legislation of air environment

- results obtained in the analysis of HAPs and VOCs picked up in the realized samples are similar to the emission generated by traffic in the zone of influence
- no sulphurated hydrogen detected in the air sampled in the installation"

IBV - Instituto De Biomechanica De Valencia- Applus Medico Ambiente - 2007

