A REVIEW OF THE POTENTIAL HEALTH AND SAFETY RISKS FROM SYNTHETIC TURF FIELDS CONTAINING CRUMB RUBBER INFILL

Prepared for

New York City Department of Health
and Mental Hygiene
New York, NY

Prepared by

TRC
Windsor, Connecticut

May 2008

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May 2008

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LIST OF ACRONYMS

°C = degrees Celsius
°F = degrees Fahrenheit
ASTM = American Society for Testing and Materials
BTEX = Benzene, toluene, ethyl benzene, xylene
CalEPA = California Environmental Protection Agency
COPC = Chemical of potential concern
CVAA = Cold vapor atomic absorption
DOHMH = NYC Department of Health and Mental Hygiene
DPR = NYC Department of Parks and Recreation
dw = Dry weight
EPA = United States Environmental Protection Agency, also *USEPA*
EPDM = Ethylene propylene diene monomer
FID = Flame ionization detection
GC/MS = Gas chromatography-mass spectrometry
GI = Gastrointestinal
HA = Highly aromatic
HPLC = High performance liquid chromatography
ICP-AES = Inductively coupled plasma atomic emission spectrometry
ICP-MS = Inductively coupled plasma mass spectrometry
LOAEL = Lowest observed adverse effect level
MEK = Methyl ethyl ketone
MIBK = Methyl isobutyl ketone
MRL = Minimal risk level
MRSA = Methicillin-resistant *Staphylococcus Aureus*
MSDS = Material Safety Data Sheet
NA = Not available
NILU = Norwegian Institute of Air Pollution
NIOSH = National Institute for Occupational Safety and Health
NOAEL = No observed adverse effect level
NR = Naphthalene rubber
NYC = New York City
PAH = Polycyclic aromatic hydrocarbon
PCB = Polychlorinated biphenyl
PM = Particulate matter
PUF = Polyurethane foam
SBR = Styrene butadiene rubber
SCO = Soil cleanup objective
SIM = Selective ion monitoring
SPME = Solid phase microextraction
SVOC = Semi-volatile organic compound
TBBS = N-*tert*-butyl benzothiazole sulfonamide
ToxNet = Toxicology Data Network
TPE = Thermoplastic elastomer
TPH = Total petroleum hydrocarbons
US = United States
UV = Ultraviolet
VOC = Volatile organic compound
ww = Wet weight

EXECUTIVE SUMMARY

1. Background and Purpose of Review

Synthetic turf fields have been installed in many athletic and playing fields throughout New York City (NYC), the United States and the world. The NYC Department of Parks and Recreation (DPR) began installing synthetic turf playing fields in 1997 with a total of 94 installations completed at the time of this report (87 crumb rubber infill fields and 7 carpet-style fields). An additional 68 synthetic turf fields are either planned or under construction around the five boroughs. Of these planned fields, 32 will have crumb rubber infill for use in high impact areas and the other 36 will be carpet-style turf. The carpet-style synthetic fields are part of the PlaNYC effort to address the increased demand for playing space by converting existing asphalt fields into multi-purpose use fields.

Synthetic turf fields are used in NYC parks because they:

- Provide even playing surfaces.
- Have padding that helps prevent injuries.
- Need no watering or mowing.
- Use no fertilizers or pesticides.
- Can be used year-round and in most weather.
- Do not need to be closed to protect or re-sod grass.
- Last a long time with little maintenance.

This report focuses primarily on synthetic turf fields with crumb rubber infill. The infill-type synthetic turf fields in NYC parks contain several layers, including:

- A bottom layer composed of geotextile.
- Middle layers composed of broken stone with plastic perforated pipe for drainage and rubber padding for shock absorbance.
- A top layer composed of carpet with soft, flexible plastic grass.
- Crumb rubber infill made from recycled tires added to the 'grass' layer to provide extra padding, serve as a ballast to hold the carpet down, and keep the grass upright. Sand is sometimes mixed with the crumb rubber.

Recent concern about the potential for exposure to chemicals found in crumb rubber, also known as ground rubber, prompted NYC DPR to request assistance from the NYC Department of Health and Mental Hygiene (DOHMH). In response to this request, and with a grant awarded by the New York Community Trust, the DOHMH contracted a private consultant, TRC, to lead an intensive literature review focusing on the potential exposures and health effects related to synthetic turf fields and to identify gaps in what is known.

This report includes an assessment of the currently available literature and is meant to assist athletic field installers and operators in making decisions related to the selection and use of synthetic turf fields. The report is organized into six chapters. The Executive Summary provides a brief overview of the findings of this report. Chapter 1 provides the background and scope of work. Chapter 2 covers the chemical composition of the crumb rubber infill and develops a list of chemicals of potential concern (COPCs). Chapter 3 covers the potential for exposure to and human health effects from the COPCs. Chapter 4 is a review of the physical health effects associated with synthetic turf systems, including the risks for physical injury, heat-related illness, burns and infections with Methicillin-Resistant *Staphylococcus Aureus* (MRSA). Chapter 5 lists benefits associated with using synthetic turf fields. Chapter 6 provides recommendations for the crumb rubber industry and synthetic turf field operators. A summary of the reviewed articles is included as an appendix under the relevant section headings.

2. General Findings

Components of Crumb Rubber

The crumb rubber used in synthetic turf systems is made primarily from recycled waste tires. The tires themselves contain several COPCs, and undergo minimal processing to become crumb rubber. Direct and indirect methods have been used in studies to determine the presence of these COPCs in the crumb rubber. These studies have found polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), benzothiazole, and certain metals. Studies have also identified phthalates, alkylphenols and benzene, which likely become bonded to tires during their use. Direct analyses confirming the presence of these COPCs in crumb rubber have used vigorous extraction methods. Some COPCs have been identified through indirect methods including analysis of leachate in the environment near where recycled tire products were used or in controlled laboratory studies. Because crumb rubber is a recycled material, the presence and concentrations of COPCs is expected to vary between products and even among batches from the same manufacturer.

Potential Health and Safety Risks Associated with Synthetic Turf Fields

For the COPCs in the crumb rubber to be a health concern for users of the fields, users would have to be exposed to high enough concentrations to increase the risk for health effects. The three possible routes of exposure for COPCs from crumb rubber are inhalation, ingestion, and dermal absorption. Crumb rubber, or the dust generated from crumb rubber, may be accidentally ingested by placing fingers in the mouth or not washing hands before eating and after playing on the fields. Young children on the fields may eat the crumb rubber itself. Dust may be breathed in from playing on the field, or vapors that volatilize from the turf may also be inhaled. Some COPCs may also be absorbed through the skin by direct contact.

To date, eleven human health risk assessments were identified that evaluated exposure to the constituents in crumb rubber. Although each risk assessment was conducted using distinct assumptions and evaluated different concentrations of COPCs in crumb rubber, all had a similar conclusion: exposure to COPCs from the crumb rubber may occur, however the degree of exposure is likely to be too small through ingestion, dermal or inhalation to increase the risk for any health effect. These risk assessments have been conducted primarily by state agencies, consultants and industry groups. They are based upon quantitative measurement of the chemicals from various forms of tires (scrap tire, shreds, tire crumb rubber, recycled tire flooring, etc) with levels derived from leachate studies or ambient air testing. Risk assessments evaluating oral and dermal exposures used these surrogate concentrations for exposure and a number of assumptions pertaining to ingestion rates, dermal contact rates, bioavailability, etc. Thus, these evaluations are theoretical estimates of exposure and risk. However, the highest available concentrations combined with scenarios which overestimated the duration of the exposure make these risk assessments conservative. Similar to the oral and dermal risk assessments, each of the inhalation risk assessments used conservative estimates of exposure and maximum concentrations of indoor air contaminants.

Children, especially very young children, have many characteristics which make them uniquely vulnerable to environmental exposures. Children breathe more air per pound of body weight than adults in the same environment and physical activity adds an additional factor to exposure through inhalation. Children also engage in hand-to-mouth behavior and very young children may eat nonfood items, such as rubber crumbs while on the fields. The protective keratinized layer of the skin is not as well developed in children and increases dermal absorption of COPCs as well as increasing evaporative loss of water on hot days. Children also have many more years to develop diseases with long latency periods after exposure. Risk assessments looking at inhalation, ingestion, dermal absorption and the risk for heat stress would have to combine these considerations to be as conservative as possible. It appears that these considerations were addressed by the reviewed health risk assessments. However, uncertainties exist in the magnitude of factors to account for children's increased susceptibility. As our understanding of the impact of low-level environmental exposures during childhood increases, the inclusion of new data in future risk assessments may be warranted.

Due to the distinct physical characteristics of synthetic turf systems, there has also been concern over potential adverse health effects not related to chemical exposure. The potential physical health effects associated with synthetic turf systems include heat-related illnesses, burns, injuries and infections.

> Heat-Related Illness - Synthetic turf fields with crumb rubber have heat-absorbing properties and can retain elevated temperatures at their surface. This increase in temperature of the turf system may increase the risk of heat-related illness among field users.
>
> Physical Injuries - Concerns over the potential for increased injuries associated with the use of synthetic turf systems have led to a number of studies among athletes to evaluate any differences in injury rates, injury types, and lost time between synthetic and natural turf materials. These studies have shown either no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by men or women, or that injury rates are similar but that the type of injury varies between the two surfaces.
>
> Bacterial Infections - Concerns have been raised over the potential for bacterial infections, such as MRSA infections, to occur in athletes playing on synthetic turf. Studies among school and professional athletes have shown that although synthetic turf abrasions provide a means of access for infections, transmission of infection occurs via physical contact, sharing of equipment, and poor sanitary practices. Another study found that synthetic turf systems are not a hospitable environment for microbial activity. However, an increased number of abrasion injuries could increase the risk of various infections if other safeguards aren't maintained.

3. Data Gaps and Recommendations

Certain knowledge gaps associated with exposure to synthetic turf fields have been identified. Highlighted gaps, and recommendations to address them, are listed below:

> Gap: Consistent test methods for determining the chemicals in crumb rubber made from different source materials and from different processing techniques.
> Recommendation: The crumb rubber industry should provide information on the COPC content of products and documentation on the testing methods and criteria used to identify COPCs. Consistent and validated testing methods should be established through an objective process and complied with by the industry. This information, along with the heat absorption and injury properties of synthetic turf, should be provided to prospective buyers.

Gap: Outdoor air concentrations of COPCs on both newly installed and older synthetic turf fields. Most of the data generated have been from indoor synthetic turf facilities.
Recommendation: Field operators should measure air concentrations of COPCs and particulate matter above outdoor fields to give more representative data related to use of playing fields in urban parks. Measurements taken on a hot, calm (no wind) day would represent a worst case scenario.

Gap: Background air concentrations of COPCs in New York City. Many of the COPCs found in crumb rubber are also present in the urban environment, but there is little available data on background levels of these COPCs.
Recommendation: When conducting air studies over fields with crumb rubber, air measurements should also be taken simultaneously at nearby off-field sites, as well as on natural and/or asphalt fields, to provide comparative data on exposures related to urban environments.

Additional Recommendations:

Heat: The primary health concern with the use of synthetic turf fields is the potential for causing physical health effects associated with heat stress and dehydration. It is recommended that field operators assess the feasibility of adding shaded areas and easy access to drinking water near playing fields. It is also recommended that field operators educate field management staff, coaches and athletic staff, field users, and parents on the potential for heat-related illnesses, and how to recognize and prevent heat-related symptoms and illness.

Purchasing Protocol: Field operators should adopt protocols for selecting and purchasing synthetic turf and crumb rubber products. Such protocols should include requirements for suppliers and manufacturers to provide available information on: chemical content of products, potential COPC emissions from products over time, heat absorbency characteristics, injury factors and other relevant health and safety information. In addition, protocols should provide for the continuous evaluation of new technologies, health and safety factors, and best practices for use and maintenance of synthetic turf fields.

4. Conclusions

This comprehensive review of the available literature on the potential health effects of crumb rubber infill from synthetic turf fields has demonstrated that the major health concern from these fields is related to heat. COPC concentrations from the crumb rubber vary depending on the type of crumb rubber, the method of extraction used for analysis, and the media measured (crumb rubber, air, leachate). Eleven different risk assessments applied various available concentrations of COPCs and none identified an increased risk for human health effects as a result of ingestion, dermal or inhalation exposure to crumb rubber. However, additional air studies at synthetic turf fields as well as background air measurements would provide more representative data for potential exposures related to synthetic field use in NYC, particularly among younger field users.

1.0 INTRODUCTION

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People may theoretically be exposed to COPCs from the crumb rubber infill in several possible ways. Crumb rubber, or the dust generated from crumb rubber, can be accidentally ingested by placing fingers in the mouth or not washing hands before eating and after playing on the fields. Dust can be breathed in from playing on the field, or vapors given off by the turf can also be inhaled. Some COPCs may potentially also be absorbed through the skin by direct contact. Therefore, these three routes of exposure were considered in determining the potential for exposure.

Children, especially very young children, have many characteristics which make them uniquely vulnerable to environmental exposures. Children breathe more air per pound of body weight than adults in the same environment and physical activity adds an additional factor to exposure through inhalation. Children also engage in hand to mouth behavior and very young children may eat nonfood items, such as rubber crumbs while on the fields. The protective keratinized layer of their skin is not as well developed in children and increases dermal absorption of COPCs as well as increasing evaporative loss of water on hot days. Children also have many more years to develop diseases with long latency periods after exposure. Risk assessments looking at inhalation, ingestion, dermal absorption and the risk for heat stress would have to combine these considerations to be as conservative as possible. It appears that these considerations were addressed by the reviewed health risk assessments. However, uncertainties exist in the magnitude of factors to account for children's increased susceptibility. As our understanding of the impact of low-level environmental exposures during childhood increases, the inclusion of new data in future risk assessments may be warranted.

1.2 Scope of Work

1.2.1 Literature Search

An extensive literature search was conducted for information regarding synthetic turf fields and the crumb rubber that makes up the infill material. Internet search engines were utilized for finding information regarding the chemical composition of crumb rubber. Because they were the primary available sources, industry documents, technical specifications, technical presentations, research studies by European agencies and on-line publications were evaluated. Literature searches for potential health effects, both due to chemical exposure and physical effects were conducted on the National Library of Medicine's MedLine database and the Toxicology Data Network (ToxNet). Relevant articles were obtained from local universities.

1.2.2 Key Questions

The project was designed to address the following:

1. Characterize the components of the material used to make synthetic turf fields in NYC and other relevant locations.
2. Identify COPCs in materials used in synthetic turf, COPC concentrations in crumb rubber used as infill, and variability of chemical composition among different batches of the synthetic materials; other environmental sources and background levels of identified COPCs in NYC.
3. Cite laboratory methods that have been used to characterize/extract crumb rubber to determine chemical composition.
4. Research impact of environmental factors such as ultraviolet (UV) rays, temperature/humidity, rain, air pollution, and usage on synthetic turf material over time.
5. Identify potential pathways of exposure for people using synthetic turf fields.
6. Describe child and adult usage patterns on synthetic turf fields, especially type(s) of activities, estimated duration and frequency of the activities.
7. Describe potential biomarkers indicative of exposure to specific substances.

8. Identify guidance levels to evaluate COPC levels in crumb rubber; identify limitations or adjustments of existing soil guidelines.
9. Characterize the impact of temperature on synthetic turf fields; compare to other types of playing surfaces used in NYC parks, such as asphalt and grass.
10. Describe potential health effects, such as heat-related illness and dermal injury, on users of synthetic turf fields; provide recommendations to address these potential health effects.
11. Identify techniques for measuring heat effects from synthetic turf fields.
12. Describe benefits of using synthetic turf fields, including increased access to playing fields.

2.0 DESCRIPTION OF CRUMB RUBBER INFILL USED IN SYNTHETIC TURF

Modern synthetic turf fields are structured in layers: a bottom layer composed of geotextile, middle drainage layers and padding, and a top layer of synthetic grass. The top layer contains cushioning infill material of crumb rubber produced from recycled tires. The crumb rubber material, which has been processed to the size of coarse sand, is spread two to three inches thick over the base turf material and raked down in between the plastic fibers which simulate grass. The crumb rubber helps support the blades of fiber, and also provides a surface with some give, so that it feels more like the soil under a natural grass surface.

The crumb rubber used in many synthetic turf systems is made of styrene butadiene rubber (SBR) primarily from recycled tires and is used as infill in the top grass layer of the synthetic turf. Other infill material may be made from ethylene propylene diene monomer (EPDM) and thermoplastic elastomers (TPEs) which are produced specifically for field turf applications. SBR crumb rubber is produced through either mechanical grinding or cryogenic reduction (freezing process to reduce rubber to granules). This report focuses mainly on the characteristics of SBR crumb rubber.

In general, SBR crumb rubber is manufactured from automotive and/or truck scrap tires. Tires contain many different substances but approximately 40% is rubber. Rubber consists of elastic polymers that are obtained directly from plants (natural rubber) or manufactured from petroleum (synthetic rubber). Natural rubber, obtained from the latex of rubber trees, accounts for about 23% of all rubber consumed in the United States. The balance is synthetic rubber. Of the synthetic rubbers, SBR and polybutadiene rubber are most utilized, accounting for 71% of synthetic rubber production. A variety of specialty synthetic rubbers, such as butyl, EPDM rubber, polychloroprene, nitrile, and silicone, account for the balance of synthetic rubber production. A comparison of two tire manufacturers showed similarities in tire components between the various types of tires produced (Firestone and Dow Chemical Company Technical Specifications).

Due to the manufacturing processes of crumb rubber, various amounts of the components used in the original production of the tire, besides rubber, occur in the crumb rubber. Vulcanizing agents, accelerators, activators, antiozonants, antioxidants, retarders, plasticizers and extenders are used in the original tire manufacturing process. In addition, studies have shown that various chemicals such as benzene, phthalates and alkylphenols may become bonded to tires during use (Willoughby 2006a, b). However, as seen in Cocheo et al. (1983), phthalates, alkylphenols, and benzene can also off-gas during tire manufacturing. All of these chemicals have been detected in direct analyses of crumb rubber using vigorous extraction methods (see Table 2-1). It is difficult to discern the original source of the chemicals found in crumb rubber. They may be present as a result of the manufacturing of the tires, or due to environmental sources present while the tires are in use. Studies have been conducted to identify chemicals or particulates released by tires or tire shreds, chips or crumb in the field or laboratory setting. Tables 2-2 and 2-3 summarize the results of these studies and are organized by chemical group.

2.1 Manufacturing Processes of Rubber

Initially, rubber was manufactured from natural plant sources using a vulcanization process that was discovered in 1893. In 1912, carbon was added to the process to strengthen rubber. Synthetic rubber took over as the major source of rubber in the United States (US) during the 1950s, and by the 1990s, natural rubber had only 30% of the US market (SBR Tire Facts 2007).

The process of manufacturing tires begins with the selection of the type of rubber. The choice of the rubber to be used depends on cost and performance requirements. The specialty rubbers often impart superior performance properties but do so at a higher product cost. Many rubber products contain less than 50% by weight of rubber. The balance is a selection of fillers, extenders, and processing or protective coatings. Aromatic process oils are excellent plasticizers/softeners for tire rubbers. They are created by the extraction of lubricating oils from highly aromatic (HA) oils to remove the aromatics. As noted in Firestone and Dow Chemical Company technical specifications, Willoughby (2006a, b), and the material safety data sheets (MSDSs) for the rubber infill materials from select parks in NYC, these oils are a significant component of the major type of rubber (SBR) used in the manufacturing of crumb rubber. Additional studies (KEMI 2006, Crain and Zhang 2006 and 2007, RAMP 2007, NILU 2006, and NBI 2004) show the presence of polycyclic aromatic hydrocarbons (PAHs) in rubber granulates, leachate, indoor air and in particulate matter. The composition of these oils is therefore critical to understanding COPCs in crumb rubber since the PAHs noted as detected in the listed studies may very likely be due to these oils. These oils are rich in PAHs (approximately 20-30%), including the carcinogenic PAHs. Typically the boiling point range of these oils is 250-680°C. The PAH content of the treated distillate aromatic extracts, also used in the rubber manufacturing process as summarized in Section 2.2, is approximately 1.8-13.9%. A table summarizing the components of HA oil can be found in Appendix B-1 (Table B-2).

2.2 Manufacture of Rubber Tires

Rubber tires are manufactured by compounding, mixing and forming the ingredients used to make the specific rubber, then tire components are formed and the tire is built from those components. Reinforcing cords, also known as steel belts, are added at this stage. Vulcanization is the last step that converts the essentially plastic, raw rubber mixture to an elastic state. The process of manufacturing tires requires the use of many types of chemicals, including vulcanizing agents, accelerators, activators, antiozonants, antioxidants, retarders, plasticizers and extenders. These chemicals are therefore potentially found in the tires used to make crumb rubber (Cocheo et. al. 1983).

Tires contain many different substances but approximately 40% is rubber. Rubber consists of elastic polymers that are obtained directly from plants (natural rubber) or manufactured from petroleum (synthetic rubber).

Natural rubber, obtained from the latex of rubber trees, accounts for about 23% of all rubber consumed in the United States. The balance is synthetic rubber. Of the synthetic rubbers, SBR and polybutadiene rubber are most utilized, accounting for 71% of synthetic rubber production (Mechanical-Engineering-Archives 2006, IISRP 2007). A variety of specialty synthetic rubbers, such as butyl, EPDM rubber, polychloroprene, nitrile, and silicone, account for the balance of synthetic rubber production.

A typical scrapped automobile tire weighs 9.1 kg (20 lb). Roughly 5.4 kg (12 lb) to 5.9 kg (13 lb) consists of recoverable rubber, composed of 35% natural rubber and 65% synthetic rubber. Steel-belted radial tires are the predominant type of tire currently produced in the United States. A typical truck tire weighs 18.2 kg (40 lb) and also contains from 60 to 70% recoverable rubber. Truck tires typically contain 65% natural rubber and 35% synthetic rubber (SBR Tire Facts 2007). Although the majority of truck tires are steel-belted radials, there are still a number of bias ply truck tires, which contain either nylon or polyester belt material.

The components of Firestone's and Dow Chemical Company's rubber are summarized in technical specification documents. Although they are only two of many different rubber manufacturers, a similarity between the two vendors is readily apparent, even between three different types of rubber, solution-SBR, cold polymerized emulsion SBR, and high cis-polybutadiene rubber. In general, the following similarities were observed between the two manufacturers for the compounds used to produce the rubber:

- The polymer used to produce solution-SBR contained approximately 18-40% bound styrene.
- The oil content in the polymer ranged from 27.3-32.5% in solution-SBR and cold polymerized emulsion SBR. Oils used include aromatic oil, high viscosity naphthenic oil, and treated distillate aromatic extract oil.
- Besides the polymer used, the other components of the rubber were similar between manufacturers and the relative proportions (parts by weight) of these other components ranged as follows:
  - Carbon black: 50.00 – 68.75
  - Zinc oxide: 3.00
  - Stearic acid: 1.00 – 2.00
  - Sulfur: 1.5 – 1.75
  - N-tert-butyl benzothiazole sulfonamide (TBBS): 0.9 – 1.50
  - Naphthenic or aromatic oil: 5.00 – 15.0

The components summarized above are the principal components of the major type of rubber (SBR) used for the manufacturing of crumb rubber and therefore have the potential to have a significant presence in crumb rubber. As discussed in subsequent sections of this report, some of these components have been found to be prevalent in crumb rubber, including zinc (from the zinc oxide), benzothiazole compounds (from TBBS), and PAHs (possibly from the oils used). These compounds may be attributed to the SBR used in the manufacturing of crumb rubber.

Further discussions on the manufacture of tires and their components can be found in Appendix B-1. Appendix B-1 also contains summaries of pertinent articles reviewed for this chapter.

2.3 Chemicals Identified in Recycled Tires

The 2007 California Environmental Protection Agency (CalEPA) report provides a discussion on the chemicals released by recycled tires and where in the tire production process the given substance most likely originated. The discussion focuses on metals (zinc, iron, manganese, barium, lead, and chromium), volatile organic compounds (VOCs) (methyl isobutyl ketone [MIBK], naphthalene, acetone, toluene, total petroleum hydrocarbons [TPH], methyl ethyl ketone [MEK]), and semi-volatile organic compounds (SVOCs) (benzothiazoles, aniline, phenol, diphenylnitrosoamine and dimethylnitrosoamine). The results from the CalEPA (2007) report on chemicals found in recycled tires are presented below.

Metals:

- Zinc, iron, and manganese were the metals detected most frequently. Iron and manganese are components of the steel belts and beads while zinc oxide is used as an activator in the vulcanization process. Since the production of crumb rubber removes approximately 99% of the steel belting and bead material, this should reduce the release of iron and manganese from the recycled tire material.
- Barium was also detected in several instances which could be a result of its use to catalyze the synthesis of polybutadiene rubber.
- The presence of lead in several instances may be due to its former use as an activator in the vulcanization process, in the form of lead oxide.
- The presence of chromium in several instances may be due to its use in steel production; however, removal of the steel wire during the production of crumb rubber should reduce the release of chromium.

VOCs:

- MIBK and naphthalene were the VOCs detected at the highest concentrations. MIBK may result from its use in the production of rubber antioxidants and naphthalene can originate from carbon black.
- Other VOCs detected may result from the use of petroleum oils and coal tar fractions in tire production: acetone, toluene, ethyl benzene, TPH, PAHs, and MEK.
- Conclusions could not be drawn about the release of VOCs from surfaces using crumb rubber due to the lack of data.

SVOCs:

- Five different benzothiazoles were detected; these compounds have been proposed as environmental markers for tire-derived material. Benzothiazoles are used in tire production to accelerate the vulcanization process, as antioxidants, and to help bond the metal wire and metal belts to the tire rubber.
- Aniline was detected and could be due to its addition to tires to inhibit rubber degradation.
- Phenols detected may be due to use of petroleum oils and/or coal tar fractions as softeners and extenders in tire production. Also, steel cords and fabrics comprising the belts were treated with phenol/formaldehyde to improve their adhesion to rubber.
- The detection of two nitrosamines (diphenyl and dimethyl) 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.

2.4 Different Types of Crumb Rubber and Manufacturing Processes

In general, crumb rubber is manufactured from automotive and/or truck scrap tires. Crumb rubber can be differentiated by the type of raw material used as well as the type of processing used. During the manufacturing process, the steel and polyester/nylon fiber is removed from the tire, leaving the tire rubber with a granular consistency. Continued processing with mechanical grinding, possibly with the aid of cryogenics, further reduces the size of the particles. Various size reduction techniques can be used to obtain a wide range of particle sizes. The particles are sized and classified based on different criteria:

(1) color
(2) magnetically separated
(3) removal of polyester/nylon fiber
(4) mesh size of granulates

There are essentially four types of crumb rubber infill materials as discussed below (Melos GmbH 2004):

SBR Infill Granules

SBR infill granules are the most cost-effective infill granules since these come from recycled materials. The material has a high rubber content that gives it high elasticity, and carbon black gives it resistance to UV and the weather. Since this product is manufactured from recycled materials (principally old car tires), some variation in quality is expected. As the supply of granules may come from different sources, the quality of this material is typically not traceable. Impurities like stones and metals may be present in the granules. Depending on the length of time the original material was used, it may become brittle after a relatively short time. This material has high heat absorption, but it cannot be flameproofed. Studies note that the PAH and zinc content of SBR material is highly variable (Melos GmbH 2007).

Coated SBR Infill Granules

Coated SBR granules combine the elasticity of SBR materials with a free choice of colors. The cost is somewhere between SBR and EPDM infill granules, which makes coated SBR the logical alternative where colored (green or brown) granules are to be used. It is not possible to flameproof this material. When the coating is degraded or destroyed, the material exhibits similar characteristics of uncoated SBR infill granules.

EPDM Infill Granules

EPDM infill granules are produced especially for playing fields and so the material can be tailored to individual requirements so it is possible to supply flame retardants and foamed granules in any desired color. No impurities like stones or metals will be present. The heat absorption is lower than in SBR infill material. EPDM granules are naturally non-fading and have good UV and weather resistance. The use of suitable pigments prolongs colors, and choosing appropriate cross-linking chemicals produces a material with excellent ecotoxicological properties and PAH values under 1 mg/kg (Melos GmbH 2007). Supplies and formulations of these granules are traceable. EPDM granules are more expensive than SBR infill granules.

TPE Infill Granules

TPE is the latest development in the field of infill granules. It can be made flame-retardant and to a specified elasticity. This infill material has low wear and high elasticity, and its thermoplastic properties enable it to be recycled. These granules have relatively weak heat resistance and may stick together at normal summer temperatures. This material also has relatively weak UV and weathering resistance and requires stabilizers to improve this. If the material is stabilized, it can be very expensive.

EPDM and TPE do not contain impurities, and EPDM is considered to be resistant to heat and UV weathering while TPE has a low heat resistance and requires stabilizers at additional cost to improve resistance.

2.5 Chemicals of Potential Concern (COPCs) in Crumb Rubber

The SBR crumb rubber has been shown to contain several COPCs. Extraction studies have found that crumb rubber contains polycyclic aromatic hydrocarbons (PAHs), including carcinogenic PAHs (benzo[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene and and indeno(1,2,3-cd)anthracene). Airborne PAHs were also identified in PM_{10} and $PM_{2.5}$ samples collected from indoor sports halls.

SVOCs such as amines and benzothiazole compounds have also been identified in crumb rubber. Benzothiazole has been identified as a constituent of rubber and leachate from rubber and benzothiazole compounds have been proposed as environmental markers for tire-derived material.

VOCs have been found in crumb rubber, especially from indoor air off-gassing. VOCs, including aromatic hydrocarbons, ketones and carbon disulfide have been detected in crumb rubber samples. VOCs were also detected in indoor air samples collected from an indoor sports hall. Aromatic hydrocarbons, including toluene and xylene isomers, along with benzoic acid, cyclohexanone and aldehydes such as formaldehyde and ethylbenzene aldehyde isomers were among the chemicals detected at the highest concentrations. Leachate samples also had detectable VOCs.

Metals have also been detected at significant levels in leachate studies, including barium, chromium, copper, iron, lead, manganese, and zinc. Zinc has been found at concentrations that are orders of magnitude above other metals in samples from one study. These metals along with aluminum have also been identified in leachate from crumb rubber.

All of these chemicals have been detected in direct analyses of crumb rubber if vigorous extraction methods are used (see Table 2-1). Phthalates, alkylphenols, and benzene have been found to off-gas during tire manufacturing (Cocheo et. al. 1983). In addition, studies have also shown that various chemicals such as phthalates, alkylphenols, and benzene may become bonded to tires during use (Willoughby 2006a, b). Since these chemicals are used during the tire manufacturing process, or are present in the environment while the tires are in use, their presence in the crumb rubber would be expected. It should also be noted that there are a number of uncertainties associated with using these COPCs to assess potential exposures. These are discussed at length in Chapter 3.

In addition, crumb rubber includes some amount of dusts and small particles, which may be further increased by mechanical abrasion and wear that comes with use of the fields. The Norwegian Institute of Air Pollution (NILU 2006) conducted a study to measure indoor air quality in sports halls that use synthetic turf in order to generate data for use in exposure studies. The range of PM_{10} detected in the halls was 31 to 40 ug/m^3, while the measured concentrations of $PM_{2.5}$ were 10 to 19 ug/m^3. In the two halls with SBR rubber granulate, it was calculated that 23 to 28% of the PM_{10} consisted of rubber, while 35% to 50% of the $PM_{2.5}$ was associated with the rubber particulate. Results of the airborne dust showed the presence of PAHs, phthalates, other SVOCs, benzothiazoles, and aromatic amines.

Relative concentrations of chemicals detected were noted to be higher in infill material produced with recycled SBR granulates as opposed to EPDM rubber granulates. The one exception to this is that chromium concentrations were significantly higher in infill material produced with EPDM rubber granulates. Infill materials produced with EPDM rubber granulates are considerably more expensive than materials produced with recycled SBR granulates.

Studies have identified concentrations of COPCs in crumb rubber. As discussed in Chapter 3, little is known about the release and bioavailability of these materials from a crumb rubber matrix. Studies have identified concentrations of these chemicals and the maximum levels identified are shown below:

- Total PAHs: 76 mg/kg
- VOCs: methyl isobutyl ketone: 11.4 mg/kg
- Benzothiazole: 171 mg/kg
- Alkylphenols: 4-t-octylphenol: 33,700 mg/kg
- Metals: zinc: 17,000 mg/kg, chromium: 5200 mg/kg, depending on source of rubber granulate
- Bis(2-ethylhexyl)phthalate: 203 mg/kg

Tables 2-1 through 2-3 provide detailed lists of COPCs identified in crumb rubber or in environmental media impacted by crumb rubber. A table on COPCs identified in the tire manufacturing process can also be found in Appendix B-1 (Table B-8).

2.6 Analytic Methods for Identifying COPCs in Crumb Rubber

Based on the studies reviewed, direct measurement of crumb rubber for extractable organic compounds could be performed using rigorous extraction procedures (i.e, soxhlet or pressurized fluid extraction) followed by gas chromatography-mass spectrometry (GC/MS) analysis. Measurements of crumb rubber for metals could be performed using rigorous acid or microwave digestion procedures followed by inductively coupled plasma atomic emission spectrometry (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS), or cold vapor atomic absorption (CVAA) analysis, depending on the metal of interest. It is important to note that extraction only provides information on the content of the material, not bioavailability. Further testing may focus on the major COPCs identified in Table 2-1 and how these COPCs differ in crumb rubber manufactured using mechanical grinding versus cryogenic processing, and in crumb rubber produced from different sources (i.e. SBR granules versus EPDM granules versus TPE granules).

2.7 Material Safety Data Sheets for Crumb Rubber

MSDSs for Rubber Infill Materials were provided by the NYC DPR and can be found in Appendix A. The MSDSs provided were from two different synthetic turf manufacturers (Aturf and Forever Green Athletic Fields), representing three different manufacturers of the rubber infill material (Recycling Technologies Int'l, LLC, Re-Tek, Inc and SJM group of New York). The compositions of the different materials were, in general, very similar and are summarized in Table 2-4.

In general, the following similarities were observed between the rubber infill materials:

- The three main components of each were the rubber material, carbon black, and the process oils.
- The carbon black content was similar and ranged from 27-35%.
- Zinc oxide or zinc compounds exhibited similar proportions (1-5%).
- Sulfur and stearic acid were noted as being present in two of the three materials between 1 and 5%.

As discussed previously and in subsequent sections, the process oils and the zinc oxide observed in all of these materials can be significant contributors to COPCs in crumb rubber.

2.8 Impact of Environmental Factors on Synthetic Turf Material over Time

Environmental factors such as temperature, humidity, rain, air pollution, UV radiation and usage may all impact synthetic turf material over time. Studies pertaining to the effect of temperature, humidity, rain, and air pollution on the synthetic turf material were not identified and represent a data gap as to the material's durability. As discussed in Chapter 3, the surface temperature of synthetic turf systems has been measured as high as 174 degrees Fahrenheit (˚F) (Williams and Pulley 2002); however, no studies measuring the effect of temperature on the turf material itself have been located.

Verschoor (2007) evaluated the leaching of zinc from new, 1-year old and 3-year old turf, where two different types of aged samples were evaluated: 1) aged samples that were produced by laboratory exposure to UV equivalent to 1 or 3 years sunlight exposure in accordance with ISO 4892-3 and 2) aged samples that were taken from synthetic turf fields of different ages (1 and 3 years of use). The data from the study showed that zinc concentrations in leachate from rubber crumbs of car and truck tires aged in the laboratory increase with aging; whereas in samples aged under field conditions, zinc concentration increases with age for the car tire crumbs but not for truck tire crumbs. The study notes that trends of field emissions are more difficult to interpret because the variety in field samples is high. Kolitzus (2007) notes that current synthetic turf fields should last for 10 to 15 years and UV radiation is not considered to be an issue as pile fibers are being produced by reliable manufacturers. The author notes that a test method to determine the resistance of synthetic turf to UV radiation has not been developed on the international level.

McNitt and Petrunak (2007b) evaluated the effect of high usage on the synthetic turf fields. Simulated foot traffic was applied to the turf fields using a “Brinkman Traffic Simulator”. The traffic simulator was pulled with a tractor. Two passes of the traffic simulator produces the equivalent number of cleat dents created between the hash marks at the 40-yard line during one National Football Game. Thus, 24 passes per week are equivalent to the cleat dents sustained from 12 games per week. Surface hardness and impact attenuation were conducted in accordance with American Society for Testing and Materials (ASTM) methods on “no wear” turf and “wear” turf which simulated turf after having up to 96 games played on it. It is clear from the results that even after wear simulating 96 games, the hardness index remained well below the maximum Gmax rating of 200.

2.9 Background Levels of COPCs in the Environment

Most of the chemicals found in crumb rubber are common in an urban environment. Possible exposure sources for a variety of these chemicals are listed in Table 2-5. A significant outdoor source for PAHs, for instance, is vehicular exhaust. Worn tires also contribute to a small percentage of urban respirable dust. Breathing air containing PAHs from cigarette smoke and eating grilled or charred meats are the major contributors to an individual’s PAH exposure. Table 2-6 lists PAH levels in a variety of foods. Diet is an important source not only of PAHs but also numerous other chemicals.

In general, there is limited data on environmental background levels of the various PAHs that have been found in crumb rubber. *The Statewide Rural Surface Soil Survey*, a background study that collected 269 rural soil samples throughout New York State and analyzed 179 analytes, including some PAHs, provides some background soil levels (6NYCRR Part 375 Appendix D). These rural background levels, however, may not be representative of background levels in an urban setting like NYC. Menzie (1992) estimated that PAH concentrations in rural soil ranged between 0.01 to 1.01 mg/kg (dry weight) whereas in urban settings the soil might contain from 0.06 to 5.8 mg/kg of PAHs. The ‘soil’ of NYC has been moved, contaminated, replaced with other soil, and augmented with clean soil multiple times in the past 400 years. As in most urban areas, there are places where concentrations of any given chemical are much higher or lower than in others.

2.10 Potential Data Gaps

Potential data gaps include the lack of consistent test methods for determining the chemicals in crumb rubber made from different source materials and from different processing techniques. Consistent and validated testing methods should be established through an objective process and complied with by the crumb rubber industry to determine the variability of infill material, including:

- Analyses of crumb rubber that is manufactured using mechanical grinding versus cryogenic processing.
- Analyses of crumb rubber produced from different sources (i.e. SBR granules versus EPDM granules versus thermoplastic elastomer [TPE] granules).

The crumb rubber industry should provide information on the COPC content of products and documentation on the testing methods and criteria used to identify COPCs. This information should be provided to prospective buyers.

TABLE 2-1: CHEMICALS OF POTENTIAL CONCERN
MATRIX: CRUMB RUBBER
BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED

Analyte Group Detected	Individual Analytes Detected	Maximum or Range of Concentrations Detected	Matrix Analyzed	Reference
Amines	aniline	0.000742 mg/g tire	Tires, tire shreds, chips, or crumb	CalEPA 2007*
	n-nitrosodiphenylamine	7.03 mg/kg	Crumb rubber	RAMP 2007
Aromatic hydrocarbons	benzene toluene ethylbenzene	0.000218 mg/g tire 0.0168 mg/kg 0.337 mg/kg	Tires, tire shreds, chips, or crumb rubber	CalEPA 2007*; RAMP 2007
	xylenes	0.134 mg/kg	Crumb rubber	RAMP 2007
Benzothiazole compounds	benzothiazole 2-hydroxybenzothiazole 2-(4-morpholino) benzothiazole	171 mg/kg 80.9 mg/kg 3.76 mg/kg	Crumb rubber	Reddy and Quinn 1997
Ketones	acetone methyl isobutyl ketone	1.45 mg/kg 11.4 mg/kg	Tires, tire shreds, chips, or crumb rubber	CalEPA 2007*; RAMP 2007
	methyl ethyl ketone	0.000017 mg/g tire	Tires, tire shreds, chips, or crumb	CalEPA 2007*
Metals	barium chromium iron lead manganese zinc	0.001700 mg/g tire 0.000500 mg/g tire 1.100000 mg/g tire 0.000920 mg/g tire 0.005800 mg/g tire 2.320000 mg/g tire	Tires, tire shreds, chips, or crumb	CalEPA 2007*
	cobalt arsenic lead manganese zinc	141 mg/kg 1.01mg/kg 67.2 mg/kg 7.5 mg/kg 17,000 mg/kg	Crumb rubber	RAMP 2007
	cadmium chromium copper lead zinc	<0.5 – 2 mg/kg <2 – 5200 mg/kg <3 – 70 mg/kg 8-20 mg/kg 7300-17,000 mg/kg	Crumb rubber	Plesser and Lund 2004
PAHs	naphthalene chrysene fluoranthene pyrene	0.000100 mg/g tire 3.82 mg/kg 15.9 mg/kg 28.3 mg/kg	Tires, tire shreds, chips, or crumb	CalEPA 2007*; RAMP, 2007
	3-6 carcinogenic PAHs	0.06 – 8.58 mg/kg	Rubber granules from synthetic turf samples	Crain and Zhang 2006, 2007

TABLE 2-1: CHEMICALS OF POTENTIAL CONCERN
MATRIX: CRUMB RUBBER
BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED

Analyte Group Detected	Individual Analytes Detected	Maximum or Range of Concentrations Detected	Matrix Analyzed	Reference
	naphthalene through benzo(g,h,i)perylene	Total PAHs: 1 – 76 mg/kg Phenanthrene: 0.43 – 5.9 mg/kg Fluoranthene: 0.12 – 11 mg/kg Pyrene: 0.16 – 37 mg/kg Benzo(a)pyrene: 0.12 – 3.1 mg/kg Benzo(b)fluoranthene: <0.08 – 3.9 mg/kg	Crumb rubber	Plesser and Lund 2004
Phenols	4-t-octylphenol iso-nonylphenol	49.8 – 33,700 mg/kg 1120 – 21,600 mg/kg	Crumb rubber (recycled rubber)	Plesser and Lund 2004
Phthalates	bis(2-ethylhexyl)phthalate diethylphthalate	203 mg/kg 3.1 mg/kg	Crumb rubber	RAMP 2007
	di-n-butylphthalate diisononylphthalate bis(2-ethylhexyl)phthalate	1.6 – 3.9 mg/kg 57 – 78 mg/kg 3.9 – 29 mg/kg	Crumb rubber (recycled rubber)	Plesser and Lund 2004
Other	carbon disulfide chloroform methylene chloride tetrachloroethene	0.525 mg/kg 0.732 mg/kg 0.286 mg/kg 0.280 mg/kg	Crumb rubber	RAMP 2007

*CalEPA 2007: all concentrations reported by this study based on leachate studies and are in units of ng released/g tire

TABLE 2-2: CHEMICALS OF POTENTIAL CONCERN
MATRIX: AIR
BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED

Analyte Group Detected	Individual Analytes Detected	Matrix Analyzed	Reference
Alcohols	2-butoxyethanol 1,2-propanediol 1-methixy-2-propanol	Indoor air with synthetic turf including rubber granulates	NIPH 2006
Aldehydes	ethylbenzene aldehyde isomers 3-phenyl-2-propenal formaldehyde acetaldehyde hexanal	Indoor air with synthetic turf including rubber granulates	NIPH 2006
Straight-chain Alkanes	n-C7 through n-C22	Indoor air in tire-retreading factory	Cocheo et al. 1983
	n-C8 through n-C15	Indoor air with synthetic turf including rubber granulates	NIPH 2006
	n-hexadecane	Crumb rubber headspace	Mattina et al. 2007
Cycloalkanes	methylcyclohexane trans-1-isopropyl-4-methylcyclohexane cis-1-isopropyl-4-methylcyclohexane 1-isopropyl-3-methylcyclohexane indane	Indoor air in tire-retreading factory	Cocheo et al. 1983
	ethylcyclohexane	Indoor air with synthetic turf including rubber granulates	NIPH 2006
Cycloalkenes	styrene 1-isopropyl-4-methyl-1,4-cyclohexadiene 1-methyl-3-(1-methylvinyl)cyclohexene 5-methyl-3-(1-methylvinyl)cyclohexene 1-methyl-4-(1-methylvinyl)cyclohexene dimethylstyrene cyclodecatriene p-ter-butylstyrene 4-vinylcyclohexene	Indoor air in tire-retreading factory	Cocheo et al. 1983
	styrene alpha-pinene limonene 3-carene 2,3-dihydro-1,1,3-trimethyl-3-phenyl-1H-indene	Indoor air with synthetic turf including rubber granulates	NIPH 2006
Aromatic amines	n-isopropyl-n’-phenyl-p-phenylendiamine n-cyclohexyl-2-benzothiazole sulphenamide n-phenyl-1,4-phenylenediamine n-cyclohexyl-2-benzothiazolamine	Airborne dust from indoor air with synthetic turf and SBR granulates	NILU 2006
Aromatic Hydrocarbons	benzene toluene ethylbenzene xylenes alkylated benzenes	Indoor air in tire-retreading factory	Cocheo et al. 1983

TABLE 2-2: CHEMICALS OF POTENTIAL CONCERN
MATRIX: AIR
BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED

Analyte Group Detected	Individual Analytes Detected	Matrix Analyzed	Reference
	benzene toluene ethylbenzene xylenes alkylated benzenes 1,1'-biphenyl 2-methylnaphthalene	Indoor air with synthetic turf including rubber granulates	NIPH 2006
	toluene	Indoor air with synthetic turf and SBR granulates	NILU 2006
	alkylated benzenes	Crumb rubber headspace	Plesser and Lund 2004
Benzothiazole compounds	benzothiazole	Indoor air with synthetic turf including rubber granulates	NIPH 2006
	benzothiazole	Indoor air with synthetic turf and SBR granulates	NILU 2006
	2-aminobenzothiazole 2-methylthiobenzothiazole 2-(4-morpholinyl)benzothiazole 2-morpholinothiobenzothiazole 2-mercaptobenzothiazole 2-hydroxybenzothiazole	Airborne dust from indoor air with synthetic turf and SBR granulates	NILU 2006
	benzothiazole	Crumb rubber headspace	Mattina et al. 2007
Esters	pentanedioic acid dimethyl ester	Indoor air with synthetic turf including rubber granulates	NIPH 2006
Ketones	acetone 4-methyl-2-pentanone (MIBK) cyclohexanone	Indoor air with synthetic turf including rubber granulates	NIPH 2006
	4-methyl-2-pentanone (MIBK)	Indoor air with synthetic turf and SBR granulates	NILU 2006
Organic acids	benzoic acid acetic acid	Indoor air with synthetic turf including rubber granulates	NIPH 2006
PAHs	30 PAHs (naphthalene through perylene)	Indoor air with synthetic turf and SBR granulates	NILU 2006
Phenols	2-isopropyl-6-methylphenol 2,6-di-ter-butyl-4-ethylphenol	Indoor air in tire-retreading factory	Cocheo et al. 1983
	4-t-octylphenol	Crumb rubber headspace	Mattina et al. 2007
Phthalates	diethylphthalate diisobutylphthalate di-n-butylphthalate bis(2-ethylhexyl)phthalate	Indoor air in tire-retreading factory	Cocheo et al. 1983
	diethylphthalate diisobutylphthalate di-n-butylphthalate	Indoor air with synthetic turf and SBR granulates	NILU 2006

TABLE 2-2: CHEMICALS OF POTENTIAL CONCERN MATRIX: AIR BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED			
Analyte Group Detected	**Individual Analytes Detected**	**Matrix Analyzed**	**Reference**
	dimethylphthalate diethylphthalate di-n-butylphthalate bis(2-ethylhexyl)phthalate butylbenzylphthalate	Airborne dust from indoor air with synthetic turf and SBR granulates	NILU 2006
Others	triisobutylene tetraisobutylene 2,6-di-ter-butyl-p-quinone	Indoor air in tire-retreading factory	Cocheo et al. 1983
	nitromethane junipene	Indoor air with synthetic turf including rubber granulates	NIPH 2006
	butylated hydroxyanisole	Crumb rubber headspace	Mattina et al. 2007
	trichloromethane cis-1,2-dichloroethene	Crumb rubber headspace	Plesser and Lund 2004

TABLE 2-3: CHEMICALS OF POTENTIAL CONCERN MATRIX: CRUMB RUBBER LEACHATE BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED

Analyte Group Detected	Individual Analytes Detected	Matrix Analyzed	Reference
Straight Chain Alkanes	n-hexadeane	Crumb rubber leachate	Mattina et al. 2007
Amines	aniline nitrosodimethylamine n-nitrosodiphenylamine	Tire shred leachate	CalEPA 2007
Benzothiazole compounds	benzothiazole 2-hydroxybenzothiazole 2-(4-morpholino)benzothiazole	Crumb rubber leachate	Reddy and Quinn 1997
	benzothiazole	Crumb rubber leachate	Mattina et al. 2007
	morpholino-thio-benzothiazole 2-(4-morpholinyl)-benzothiazole	Tire shred and whole tire leachates	CalEPA 2007
Metals	aluminum cadmium chromium copper iron magnesium manganese molybdenum selenium zinc	Crumb rubber leachate	Chalker-Scott 2007
	cadmium lead selenium zinc	Crumb rubber leachate	Mattina et al. 2007
Other	butylated hydroxyanisole	Crumb rubber leachate	Mattina et al. 2007
	sulfur	Crumb rubber leachate	Chalker-Scott 2007

TABLE 2-4: RUBBER INFILL COMPONENTS FROM SYNTHETIC TURF IN SELECT PARKS IN NYC TABLE PREPARED USING DATA FROM: MSDS FOR RUBBER INFILL MATERIALS PROVIDED BY NEW YORK CITY PARKS DEPARTMENT (NYC DEPARTMENT OF PARKS AND RECREATION)				
Crumb Rubber Manufacturer	**Source of Information**	**Constituents Noted on MSDS**	**CAS #**	**Weight %**
RTI Ground Rubber	MSDS from DPR(dated April 2002)	Naphthenic/aromatic oil	64742-01-4	<25%
		Carbon black	1333-86-4	<35%
		Talc, Respirable Dust	14807-96-6	<5%
		Zinc compounds	1314-13-2	<3%
Cured Black SBR Rubber (Re-Tek, Inc.)	MSDS from DPR (received by NYC on 4/9/07)	NR (reprocessed rubber)	9003-31-0	44%
		CIS-Polybutadiene	NA	11%
		HAF Black (carbon black)	NA	33%
		Oil (Softener)	NA	5.5%
		Stearic Acid	00057-11-4	1.1%
		Wax	NA	1.1%
		Zinc Oxide	01314-13-2	1.7%
		Sulfur	07704-34-9	1.1%
		NOBS	NA	0.4%
		ANTIOZ	NA	1.1%
Reprocessed Ground Rubber (SJM Group of New York)	MSDS from DPR (received by NYC in July 2006)	Reprocessed rubber NR SBR	 9003-31-0 9003-55-8	40-55%
		Carbon black	1333-86-4	27-33%
		Process oil	64742-04-7	10-20%
		Zinc oxide	01314-13-2	1-5%
		Sulfur	07704-34-9	1-5%
		Stearic Acid	00057-11-4	1-5%
RTI = Recycling Technologies Int'l, LLC NA = Not available NOBS = n-oxydiethylent-2-benzothiazole sulfonamide ANTIOZ = antiozonants				

TABLE 2-5: CHEMICALS OF POTENTIAL CONCERN AND THEIR PRESENCE IN THE ENVIRONMENT		
Chemical or chemical class	**Where found and/or major uses**	**Principal exposure sources for New Yorkers**
Benzothiazoles	Used for vulcanization and as preservatives in tires; as starting compounds in pharmaceutical manufacture; occur naturally in cocoa, asparagus, whisky and mango; as a flavoring agent (e.g. in caramel, coffee, garlic, tomato, potato, meat, and other products)	Food and medications
Polycyclic Aromatic Hydrocarbons (PAHs)	Formed during combustion or burning processes, including fires, burning of fuel, and natural events such as volcano eruptions; rarely produced intentionally	Tobacco smoke, vehicular exhaust, food (especially shellfish, fish, and charbroiled or grilled meats)
Volatile organic compounds (VOCs)	VOCs are carbon-containing compounds with high vapor pressures and low water solubility. They are used in diverse products and may evaporate into the air while you are using them or when they are stored. Although many VOCs are now synthetically produced, many of these chemicals occur in nature.	Fuel (including gasoline and oil) paints, varnishes, waxes, lacquers, paint strippers and other solvents, cleaning products, air fresheners, pesticides, building materials, copiers, printers, correction fluids, carbonless copy paper, adhesives, permanent markers, photographic solutions, dry-cleaned clothing, trees, etc.
Iron*	Essential trace element that is common in the environment; main component of steel and other alloys; iron compounds are used widely as catalysts, pigments, pharmaceuticals, dietary supplements, in agriculture and leather tanning	Ambient air, food and drinking water, and contact with consumer products containing iron compounds; people who work as ironworkers or do demolition and scrap metal recycling generally have greater exposure
Zinc*	Essential trace element that is common in the environment--present in air, water, soil and food; used widely for commercial and industrial applications, such as pennies, dry cell batteries, pharmaceuticals, anti-perspirants/deodorants, anti-dandruff shampoos, sun block; paint, galvanized metals, wood preservatives, etc.	Meat, poultry, fish, leafy greens; dietary supplements
Lead*	Construction, storage batteries; ammunition; nuclear and x-ray shielding devices; cable covering; ceramics; crystallware; solders; noise control materials; bearing and casting metals; alloys; piping; petroleum refining; pigments; plastics and electronic devices	Lead paint; herbal remedies and cosmetics containing lead; imported products (including condiments, spices and other foods); people who work with lead directly have increased exposure
Talc	Used in cosmetics (including talcum powder), ceramics, pharmaceuticals, paints, synthetic rubber, plaster, crayons, and as dusting powder in various industries	Use of products containing talc or from food packaging (which may contain talc)
Carbon black*	Used in tires and other rubber products; as a pigment for eye cosmetics, inks, dyes, and paints; as a UV light absorber; has many industrial applications	Particulate matter from worn tires; contact with products containing carbon; workers in certain industries have increased exposure levels
Sulfur*	Essential element present in proteins and other foods; utilized in the manufacture of agricultural chemicals and petroleum refining in particular, but has numerous other uses	Protein-rich foods, ambient air, water
Aromatic amines	Used in the manufacture of azo dyes, plastics, rubber, isocyanates, inks, resins, varnishes, perfumes, artificial sweeteners, leather, biocides, polymers; in research settings and closed processes; vulcanizing agent	Tobacco smoke, occupational exposure to these compounds
Barium*	Pigments; in manufacture of rubber, photographic paper, x-ray contrast material,	Ambient air, food, water, contact with barium-containing products;

TABLE 2-5: CHEMICALS OF POTENTIAL CONCERN AND THEIR PRESENCE IN THE ENVIRONMENT		
Chemical or chemical class	**Where found and/or major uses**	**Principal exposure sources for New Yorkers**
	ceramics/bricks; also used with metals, oil, glass, plastic, pyrotechnics	medical diagnostic procedures involving a barium enema
Chromium*	Used widely in metal alloys and metalplating; as catalysts; in the textile industry; in tanning leather; pigments, varnishes, inks, paints, glazes; chemical synthesis, photography	Ambient air, food, water, contact with chromium-containing products; occupational exposures are likely to be higher
Stearic acid	Used in soaps, lubricants, baked and confectionary products, vulcanization of tires, plastics, rubber production, pharmaceuticals, candles, cosmetics, organophilic/antistatic coatings, ointments, paper production, paints	Ambient air, tobacco smoke, food and beverages, use of products containing stearic acid
Phthalates	Used to make plastics more flexible; extensive industrial and commercial uses	Ambient air, food and beverages, contact with products containing phthalates
Alkyl phenols	Used in petroleum refining, as surfactants, antioxidants in plastics and rubber, biocides, dyes, pharmaceuticals, adhesives,	Contact with products containing alkyl phenols

*Naturally present in the earth's crust

Sources: Hazardous Substances Data Bank at http:// toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB
and Agency for Toxic Substances and Disease Registry at http://www.atsdr.cdc.gov/toxpro2.html#bookmark05.

TABLE 2-6: PAH LEVELS IN FOODS		
Food	**Concentration of total PAHs (dry weight unless specified)**	**Reference**
Vegetables	4.2 µg/kg (wet weight, ww)	Tateno 1990
Fruit	0.716 µg/kg (ww)	Falcó 2003
Wheat grain	4.0 µg/kg	Jones 1989
Wheat flour	1.5 µg/kg	Dennis 1991
Bran	5.5 µg/kg	Dennis 1991
Raw coffee beans	15.22-20.61 µg/kg	Houessou 2007
Roasted coffee beans	19.81-117.33 µg/kg	Houessou 2007
Brewed coffee	0.12-1.74 µg/L	Houessou 2007
Olive oil	26.3 µg/kg (ww)	Moret 2000
Oysters	1972.0 µg/kg	Sanders 1995
Smoked fish	784.5 µg/kg	Akpan 1994
BBQ beef	42.5 µg/kg	Lodovici 1995
Grilled frankfurters	790.4 µg/kg	Larsson 1983
Lamb sausage	45.43 µg/kg	Mottier 2000

3.0 POTENTIAL HEALTH EFFECTS RELATED TO COPCS IN CRUMB RUBBER

In the previous chapter, chemicals were identified as COPCs based on presence in crumb rubber and the potential for human health effects. These COPCs include PAHs, VOCs, and metals. In laboratory studies, PAHs have caused organ damage and cancer in animals. Some PAHs may also be a cancer risk for people who are exposed over a long period of time (ATSDR 1995). VOCs are a mixture of chemicals that can cause eye, nose, throat and skin irritation, headaches, loss of coordination, and nausea. At high exposure levels, some VOCs can also cause organ damage (USEPA 2007). Metals can cause eye, nose, throat and skin irritation, nervous system effects, and organ damage (ATSDR 2004b, ATSDR 2005b, USEPA 2008). The potential for these chemicals to cause health effects is dependent on several factors including: the amount of exposure to the chemical, the frequency and duration of exposure, the amount of the chemical absorbed into the body and the capacity of the chemical to cause an effect. The risk for health effects may be characterized as acute, sub-chronic or chronic. Acute health effects are those which result from a single or short-term exposure (less than two weeks). Intermediate or subchronic health effects result from an exposure lasting more than two weeks but less than one year. Chronic effects are those which result from a long-term exposure (usually more than one year). In general, duration is inversely proportional to the magnitude of exposure, i.e., the amount of chemical needed to cause an acute health effect is larger than that required to cause a chronic effect, with the necessary dose for an intermediate health effect falling in between.

As discussed in Chapter 2, crumb rubber contains a number of chemicals which can vary depending on the type of tire, the manufacturing process, and the potential for additional bonding during the tire's use. COPCs for crumb rubber exposure include benzothiazoles, VOCs, PAHs, phthalates and metals. The concentration of these COPCs varies depending on the crumb rubber, the method of analysis and the media measured (crumb rubber, air, leachate). Tables 2-1 through 2-3 in Chapter 2 summarize the concentrations of chemicals found in these media. The question is what is the potential for exposure to these COPCs during the use of synthetic turf fields? Potential exposure to the chemicals in crumb rubber used in outdoor synthetic turf fields could occur through inadvertent ingestion of the crumb rubber, ingestion of crumb rubber dust through hand-to-mouth contact, dermal contact with the crumb rubber or dust, inhalation of particulates/fugitive dusts and possibly to inhalation of VOCs off-gassing from the rubber.

Screening risk assessments are well accepted by the USEPA. These types of risk assessments use default assumptions that are selected to overestimate risks. If the screening level exposures to either a particular toxic agent or combination of agents are sufficiently below exposure levels for toxicity, then a full risk assessment is generally not warranted (USEPA 2005c). Eleven human health risk assessments evaluating exposure to the constituents in crumb rubber were reviewed in this report. These risk assessments were conducted primarily by State Agencies, consultants and industry groups. Health risk assessments have been conducted evaluating ingestion (Johns 2008, CalEPA 2007, NIPH 2006, Hofstra 2007, NJDEP 2007), dermal contact (Johns 2008, CalEPA 2007, NIPH 2006, NJDEP 2007, DTI 2005) and inhalation (Johns 2008, NIPH 2006, Hofstra 2007, Broderick 2007a,b, IBV 2006, Morretto 2007 and NILU 2006). Although each risk assessment was conducted using distinct assumptions and evaluated different concentrations of COPCs in crumb rubber, all had a similar conclusion: although exposure to COPCs from the crumb rubber may occur, the degree of exposure is likely to be too small through ingestion, dermal or inhalation to increase the risk for any health effect.

The reviewed risk assessments are based upon quantitative measurement of the chemicals in various forms of tires (scrap tire, shreds, tire crumb rubber, recycled tire flooring, etc) from either leachate studies (from the literature or laboratory studies) or ambient air testing. Risk assessments evaluating oral and dermal exposures used these surrogate concentrations for exposure and a number of assumptions pertaining to ingestion rates, dermal contact rates, bioavailability, etc. Thus, these evaluations are theoretical estimates of exposure and risk. However, the highest available concentrations combined with scenarios which overestimated the duration of the exposure make these risk assessments conservative. Similar to the oral and dermal risk assessments, each of the inhalation risk assessments used conservative estimates of exposure and maximum concentrations of indoor air contaminants and showed no risk to human health (Johns 2008, NIPH 2006, Hofstra 2007, Broderick 2007a,b, IBV 2006, Morretto 2007 and NILU 2006).

Although COPCs have been found in crumb rubber, one should keep in mind that there are a number of uncertainties associated with using the levels found to assess potential exposures. Various assumptions made in the studies may in fact have overestimated potential exposures. The concentrations found in these media are highly dependent on the type of chemical analysis used in the evaluation. The highest detected concentrations are found in those studies which used vigorous and destructive methods. For instance, Crain and Zhang (2006, 2007) quantified carcinogenic PAHs in crumb rubber by using soxhlet extraction, a vigorous lab extraction method which entails the use of solvents such as acetone/hexane or methylene chloride/acetone extraction fluids over a long period of time (16 – 24 hours). Crain and Zhang also quantified metals in crumb rubber by using a microwave digestion of the crumb rubber with nitric acid (Crain and Zhang 2006). These types of studies are conservative because they are only useful to determine the constituents that are present in crumb rubber; they provide no information as to what would happen to crumb rubber under actual physiological conditions if ingested.

Various leachate experiments on different forms of tire rubber (whole, shredded, crumb) have been documented by CalEPA (2007). The laboratory studies CalEPA 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; however, these laboratory conditions do not replicate the predicted routes of child exposure to recycled tire rubber in playground surfaces (CalEPA 2007). This compilation served as 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) and provided some estimate of the magnitude of exposure. It should be noted that these studies were not designed to mimic the physiologic digestion of the tire materials.

To date, only CalEPA (2007) has been identified as conducting a study designed to mimic the digestion of crumb rubber material by the human gastrointestinal system. The gastric digestion study 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 ocyanobenzoic 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 study (CalEPA 2007). Even this study that attempted quantifying gastric digestion using an extraction method to mimic the GI tract has a number of limitations. The study uses a leaching solvent designed to mimic gastrointestinal fluid, held at 37^{o} C for 20 hours and then the fluid analyzed for constituents from the rubber. The holding times of these studies are much longer than the emptying times of the stomach and small intestine. The stomach empties in one to three hours, while the small intestine empties in four to six hours.

Several of these studies that assessed exposure via ingestion assumed a bioavailability of 100%. It is important to note that health effects are not related to the total concentration of a contaminant in the crumb rubber material. Organisms, including humans, only respond to the fraction that is biologically available, therefore the assumption of 100% bioavailability in the risk assessments would tend to overestimate risk. A study by Hansen et al (2007) demonstrated bioavailability of PAHs in three different soil samples ranging from 14% to 40% using an in vitro bioavailability model that simulates gastric digestion (Versantvoort et al 2005). In addition, the Massachusetts DEP uses a relative absorption fraction of 28% for PAHs (MADEP, 2008) in its risk assessment program, however, each of the screening risk assessments reviewed for crumb rubber toxicity used a bioavailability of 100% for the evaluation of risk from ingestion of crumb rubber.

Of all the risk assessments evaluated, only CalEPA (2007) reported a slight increase in exposure risk from the poured in place rubber playground material from exposure to zinc and chrysene. However, there were a number of uncertainties and assumptions that tended to overestimate risk. CalEPA (2007) evaluated two ingestion pathway scenarios, a one-time ingestion of 10 grams of crumb rubber by a 3 year old child and chronic hand-to-mouth activity by children aged 1 to 12 years old. The 10 g ingestion rate is based upon the ingestion rate for a child with pica (CalEPA 2000; USEPA 2002). Pica is a behavior characterized by ingestion of non-food items. Using leachate data for the acute study (from the literature and the GI simulation test), CalEPA showed that with the exception of zinc, all the detected compounds with screening levels were below a level of concern. The dose calculated for the maximum detected zinc concentration was 5-fold higher than the subchronic minimum risk level. However, it should be noted that CalEPA chose to evaluate the maximum detected concentrations in the leachate studies and the concentration chosen for zinc was 2.6- to 2,300-fold higher than other zinc measurements found in their literature search and 18-fold higher than the value measured in the gastric digestion simulation experiment. Thus, using most zinc leaching values other than the maximum value would result in an estimated dose that was below the subchronic screening level for zinc. Even at these high estimates, a child is not likely to experience acute health effects from the zinc in a single ingestion of crumb rubber. In addition, these studies assumed 100% bioavailability of the constituents upon ingestion, which as discussed earlier is not necessarily representative of the amount absorbed by humans.

CalEPA evaluated chronic hand-to mouth activity from contact with poured in place rubber playground surfaces which consist of a SBR base with an EPDM rubber topcoat and showed that calculated exposures were below levels associated with potential adverse health effects. However, cancer risk was calculated to be 2.9E-06, above the cancer risk threshold of 1E-06 (i.e., one in one million), but lower than CalEPA's Proposition 65 No Significant Risk Level of 1E-05 (i.e., one in one hundred thousand). CalEPA's Proposition 65 requires warning labels on materials that are known to the State of California to be a carcinogen or reproductive toxin. Although some of the individual COPCs are on the Proposition 65 list, neither crumb rubber nor tire rubber are on the list which means that these materials do not need health warning labels on them (CalEPA 2008). Within the CalEPA document, the author's present a list of uncertainties that may increase exposure or decrease exposure for this scenario. Taken as a whole, these uncertainties may increase or decrease the total risk from hand-to mouth contact.

Uncertainties that may increase exposure and thus underestimate risk include:

- use of play areas by children in the crawling stage would have greater hand exposure than a child in a walking stage,
- use of playground beyond the age of 12, therefore extending the duration of exposure,
- toxicants loaded onto the hands would be available after the child left the playground, until hands washed, and
- mouthing of objects that contact the play surface.

Uncertainties that may decrease exposure and thus overestimate risk include:

- Risk evaluation uses same hand to floor and hand to mouth contact rate for a three year old as a six to twelve year old. Hand to mouth activity decreases with age,
- Decreases in hand transfer efficiency with increasing number of hand to surface contacts,
- Hand usually not "fully loaded" for every hand to mouth contact as assumed in this evaluation,
- Some toxicant may transfer to child's clothes or equipment, decreasing amount on hand,
- Bioavailability is assumed to be 100%, and
- Assumption of full two hour play time occurs on the rubberized surface, when may be a fraction of the time.

In addition to the uncertainties noted by the authors, the primary uncertainty with the results of this study is that it evaluated hand-to-mouth activity with a poured in place rubber play surface. The study did not evaluate a crumb rubber surface.

The slight increase in cancer risk due to hand-to-mouth exposure to the poured in place rubber play surface noted by CalEPA (2007) was due to chrysene exposure. Chrysene is classified as one of the carcinogenic PAHs. It should be noted, however, that there are considerable uncertainties associated with the chrysene measurement in this study. Two of the three wipe samples had chrysene levels that were similar to background (non-detect), while the third had a concentration that was only 2.5 times higher than the detection limit. No information is provided as to the location of the playground that these samples were obtained from. Chrysene is a product of combustion, and is present in the exhaust from gasoline and diesel engines, as well as in barbecued foods. CalEPA was 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. Field control surfaces were obtained from nearby concrete sidewalks. Since the surfaces are so dissimilar, it is not known whether it is easier to remove substances from the rubber surface than from the concrete sidewalk. Together these uncertainties would tend to overestimate risk.

Despite these uncertainties that may have resulted in some overestimates in risk, none of the risk assessments showed concentrations of contaminants that would be at a level of concern for exposure via ingestion, inhalation or dermal contact even under conservative assumptions. As discussed, a number of assumptions were used in these risk assessments, and although they were conservative, they represent a data gap in the knowledge of oral, dermal and inhalation exposure to COPCs in crumb rubber. Potential data gaps are summarized below:

- As specific information regarding ingestion rates of crumb rubber have not been evaluated, these studies have used ingestion rates ranging from 0.2-10 g/day, some of which may in fact overestimate potential exposures. The NJDEP (2007) and Johns (2008) risk assessments base their ingestion rates upon standard State or USEPA soil ingestion rates. CalEPA (2007) based the ingestion rate on the ingestion rate for a child with pica. Pica is relatively uncommon among the major users of these fields, school age children and adults, and thus this is a very conservative surrogate for crumb rubber ingestion. The ingestion of crumb rubber will more likely be due to hand-to-mouth activity ingestion of crumb rubber dust material adhering to the skin and not the ingestion of rubber itself. For this reason, the use of the USEPA standard soil ingestion factors appears to be a reasonable surrogate for the ingestion of crumb rubber.

- The reviewed oral and dermal risk assessments all assumed a very conservative 100% bioavailability, which under the conditions of the risk assessment did not tend to increase risk. Should evaluations of bioavailability be pursued, a method like the one used by Versantvoort et al (2005) can be employed to simulate the effect of the full gastrointestinal tract including the mouth/esophagus, stomach and small intestine, to evaluate the bioavailability of the polycyclic aromatic hydrocarbons (PAH) in soils. Use of this method may provide data on the bioavailability of the constituents in crumb rubber after ingestion. The DTI (2005) study used an in vitro sweat migration test to evaluate the solubility of PAHs and aromatic amines in a simulated sweat solution. A similar test with crumb rubber and a full evaluation for the presence of the COPCs of crumb rubber in the simulated sweat solution can be conducted to add to what is known. Although the study won't provide information on bioavailability, it will provide information on which compounds would be of concern from leaching into sweat.

- There is little information regarding dermal exposure to crumb rubber. Risk assessments have used conservative estimates of exposure to model risk. Additional studies can be conducted on the sensitization potential of crumb rubber to corroborate the CalEPA (2007) study. More realistic evaluations of the dermal adherence of the chemicals to the skin upon contact could also be conducted.

- There is little information regarding the outdoor air concentrations of COPCs on both newly installed and older synthetic turf fields. The majority of the data have been generated from indoor synthetic turf halls. Each of the inhalation risk assessments found during this review used conservative estimates of exposure and maximum concentrations of indoor air contaminants generated from indoor synthetic turf halls and showed no risk to human health. Though indoor air concentrations would typically be higher and provide a conservative estimate during risk assessments, research measuring constituent concentrations at breathing zone levels for children, youths and adults using the outdoor fields could be conducted to give more representative data for park use related exposures in NYC. Air monitoring targets should include PAHs, VOCs, and particulate matter, and should occur when the fields are hottest and during calm weather conditions for worst case scenarios.

- There is little available information on the background concentrations of the COPCs in New York City air and soils. In order to interpret any findings related to COPCs in crumb rubber, it would be important to characterize these background concentrations as many of the COPCs present in crumb rubber are also present in urban air and soils. This information would provide some context to the measured concentrations of COPCs from crumb rubber. This may also provide some insight into the source of the dust in crumb rubber which may either derive from the deterioration of the crumb or from deposition of urban ambient particulates onto the fields.

3.1 Exposure to COPCs Through Ingestion

The potential for exposure to contaminants in the crumb rubber is greater for children than adults because of the mouthing of their hands or objects. Thus, there is potential for some exposure via the oral route to children who play on synthetic turf fields. Older children and adults using facilities with crumb rubber can reasonably be expected to get some inadvertent/unintentional oral exposure to crumb rubber from dusts generated in routine use of these facilities, however to what extent is not known. Based on the information reviewed none of the risk assessments showed concentrations of contaminants that would be at a level of concern, even under conservative assumptions and thus it does not appear that the ingestion of tire crumb would pose a significant health risk for children or adults. Neither the CalEPA (2007) study, the NIPH study (2006) nor the Johns study (2008) showed significant levels of risk after exposure to crumb rubber, at exposure levels ranging from acute to chronic scenarios.

As discussed, a number of assumptions were used in these risk assessments, and although they were conservative, there is a data gap in the knowledge of oral exposure to COPCs in crumb rubber. A better understanding of the bioavailability of the chemicals in the crumb rubber matrix would enhance our understanding of exposures. However, the studies reviewed assumed a bioavailability of 100%, which most likely overestimates estimated doses. For instance, in studies of PAH bioavailability in a soil matrix, the degree of PAHs that enter the body is not 100%. A study by Hansen et al (2007) demonstrated bioavailability of PAHs in three different soil samples ranging from 14% to 40%. The Massachusetts DEP uses an oral absorption factor of 28% in its risk assessments. These values are well below the 100% bioavailability assumed in the studies reviewed. It is not known whether crumb rubber's bioavailability is similar to soil and further analysis is recommended. Hansen et al (2007) used a method by Versantvoort et al (2005) which is a published test method simulating the effect of the full gastrointestinal tract including the mouth/esophagus, stomach and small intestine, to evaluate the bioavailability of the polycyclic aromatic hydrocarbons (PAH): benzo(a)pyrene and dibenz(a,h)anthracene from soil with detection limits of 0.005–0.01 mg/kg. Use of this method may provide data on the bioavailability of the constituents in crumb rubber after ingestion.

As specific information regarding ingestion rates of crumb rubber have not been evaluated, these studies have used ingestion rates ranging from 0.2-10 g/day, some of which may in fact overestimate potential exposures. The NJDEP (2007) and Johns (2008) risk assessments base their ingestion rates upon standard State or USEPA soil ingestion rates. CalEPA (2007) based their ingestion rate on the ingestion rate for a child with pica. Although this rate is uncommon it is a very conservative surrogate for crumb rubber ingestion. The ingestion of crumb rubber will more likely be due to hand-to-mouth activity ingestion of crumb rubber dust material adhering to the skin and not the ingestion of rubber itself. For this reason, the use of the USEPA standard soil ingestion factors appears to be a reasonable estimate for the ingestion of crumb rubber. A model which can form the basis of a risk estimate would take into account the amount of time a child spends on the field. Since the risk for acute health effects is unlikely, subchronic and chronic health endpoints, such as cancer, would be an appropriate focus for these assessments.

Finally, background soil COPC levels, particularly urban levels of these COPCs, are poorly understood. Urban environments are known to contain many of these COPCs in soil and air but an evaluation of concentrations has not been carried out. The application of this information would be to better understand the risk comparisons of using synthetic turf versus natural grass or dirt fields. Background soil sampling would provide a better understanding of levels of COPCs in the environment.

3.1.1 Study Methods and Findings on COPC Exposures in Crumb Rubber Via Ingestion

No studies have been conducted directly to evaluate the toxicity of crumb rubber via the ingestion pathway in animal or human models. Therefore, the only available method to evaluate the potential toxicity of crumb rubber exposure is through human health risk assessments, which rely on conservative estimates of exposure concentrations, exposure rates and frequency. In the literature, exposure evaluations using screening risk assessment techniques are the primary methods of evaluating this pathway (CalEPA 2007, NIPH 2006, Hofstra 2007, NJDEP 2007, Johns 2008). These screening risk assessments have looked at an acute ingestion scenario for a child with pica ingesting 10 grams (g) of crumb rubber (CalEPA 2007), a chronic hand-to-mouth ingestion scenario (CalEPA 2007), acute and chronic ingestion scenarios for children playing football (rugby) on indoor synthetic turf fields (NIPH 2006), chronic ingestion exposure scenarios during outdoor "play" scenarios conducted for the Bainbridge Island Metro Parks and Recreation District and the Bainbridge Island School District in Washington State (Johns 2008). The NJDEP (2007) provided a generic evaluation of crumb rubber risk, stating that the accidental ingestion of up to 50 to 200 mg/day (the mass of dirt assumed to be ingested in the standard exposure scenario for contaminated sites) of crumb rubber would not be the cause of adverse health effects. The Hofstra (2007) study provides qualitative assessments of risk for adult football (soccer) players, based upon determined chemical levels in the crumb rubber compared against the European Toy Directive which is the comprehensive legislation addressing toy safety of the European Union (EU), (Council Directive 88/378/EEC). This directive is a list of requirements that toys must comply with, and is interpreted in the laws of each member state of the EU in their respective Toy Safety Regulations (e.g.: the UK's *Toys (Safety) Regulations 1995 (Statutory Instrument 1995 No. 204)*). Although not directly applicable to synthetic turf fields, the chemical levels of the Toy Directive have been developed to be protective of children's health, therefore using the Toy Directive chemical levels to evaluate adult exposure would expected to be a conservative estimate of risk.

Of these studies, only CalEPA (2007), Johns (2008) and NIPH (2006) attempt to model actual exposure scenarios of children at play on these fields. The CalEPA evaluates data obtained from the literature (leaching studies) and their own laboratory data (GI digestion simulation test) for the acute ingestion scenarios as well as field data (wipe sampling) for the chronic hand-to-mouth exposure scenario, NIPH evaluates data obtained from tire crumb analysis and the Johns evaluation is conducted on the maximum detected concentrations of constituents obtained from NIPH (2006), Plesser and Lund (2004) and CalEPA (2007). Neither the Johns (2008) study, nor the NIPH (2006) study showed any increased risk to human health from the use of synthetic fields in risk assessments modeling actual field use. Both studies used conservative (i.e., health protective) estimates of exposure (maximum detected concentrations, 100% bioavailability and ingestion rates that were either high end assumptions (1 gram/match; NIPH 2006) or based upon USEPA's soil ingestion rates for children and juveniles (0.1 g/day to 0.2 g/day; Johns 2008).

The CalEPA (2007) evaluated two ingestion pathway scenarios, a one- time ingestion of 10 grams of crumb rubber by a 3 year old child and chronic hand-to-mouth activity by children aged 1 to 12 years old playing on poured in place rubber playground surfaces. The 10 g ingestion rate is based upon the ingestion rate for a child with pica (CalEPA 2000; USEPA 2002). Using leachate data for the acute study (from the literature and the GI simulation test), CalEPA showed that with the exception of zinc, all the detected compounds with screening levels were below a level of concern. The dose calculated for the maximum detected zinc concentration was 5 fold higher than the subchronic minimum risk level. However, it should be noted that CalEPA chose to evaluate the maximum detected concentrations in the leachate studies and the concentration chosen for zinc was 2.6- to 2,300-fold higher than other zinc measurements found in their literature search and 18-fold higher than the value measured in the gastric digestion simulation experiment. Thus, using most zinc leaching values other than the maximum value would result in an estimated dose that was below the subchronic screening level for zinc. In addition, it was also shown that the ingestion of these chemicals based upon the leachate data would not pose a carcinogenic risk under these assumptions. The major assumption of this evaluation is the use of an acute exposure scenario of a one-time ingestion of 10 grams of crumb rubber by a three year old and the evaluation of maximum detected concentrations of chemicals analyzed in leachate that showed variability among various samples. For these, the maximum concentration detected was used for the assessment. In addition, these studies assumed 100% bioavailability of the constituents upon ingestion. When calculating the acute risk, many of the constituents of concern did not have acute toxicity criteria and thus a subchronic or chronic value was used in the evaluation. This would tend to overestimate risk as the subchronic and chronic toxicity criteria are usually orders of magnitude less than acute toxicity criteria, thus making the inappropriate comparison of an acute exposure dose against a comparatively low chronic dose. Finally, the method used in the CalEPA report provides no information regarding chronic exposure.

The evaluation of chronic hand-to-mouth activity showed that calculated exposures were below levels associated with potential adverse health effects. However, cancer risk was calculated to be 2.9E-06, above the cancer risk threshold of 1E-06 (i.e., one in one million), but lower than CalEPA's Proposition 65 No Significant Risk Level of 1E-05 (i.e., one in one hundred thousand). CalEPA's Proposition 65 requires warning labels on materials that are known to the State of California to be a carcinogen or reproductive toxin. Although some of the individual COPCs are on the Proposition 65 list, neither crumb rubber nor tire rubber are on the list which means that these materials do not need health warning labels on them (CalEPA 2008). Within the CalEPA document, the authors present a list of uncertainties that may increase exposure or decrease exposure for this scenario. Taken as a whole, these uncertainties may increase or decrease the total risk from hand-to mouth contact.

Uncertainties that may increase exposure and thus underestimate risk include:

- use of play areas by children in the crawling stage would have greater hand exposure than a child in a walking stage,
- use of playground beyond the age of 12, therefore extending duration of exposure.

- toxicants loaded onto the hands would be available after the child left the playground, until hands washed, and
- mouthing of objects that contact the play surface.

Uncertainties that may decrease exposure and thus overestimate risk include:

- Risk evaluation uses same hand to floor and hand to mouth contact rate for a three year old as a six to twelve year old. Hand to mouth activity decreases with age,
- Decreases in hand transfer efficiency with increasing number of hand to surface contacts,
- Hand usually not "fully loaded" for every hand to mouth contact as assumed in this evaluation,
- Some toxicant may transfer to child's clothes or equipment, decreasing amount on hand,
- Bioavailability is assumed to be 100%, and
- Assumption of full two hour play time occurs on the rubberized surface, when may be a fraction of the time.

CalEPA (2007) also showed a slight increase in cancer risk due to chrysene exposure. Chrysene is classified as one of the carcinogenic PAHs. This was based on wipe samples collected on poured in place playground surfaces made of EPDM rubber. It should be noted, however, that there are considerable uncertainties associated with the chrysene measurement in this study. Two of the three wipe samples had chrysene levels that were similar to background (non-detect), while the third had a concentration that was only 2.5 times higher than the detection limit. No information is provided as to the location of the playground that these samples were obtained from. Chrysene is a product of combustion, and is present in the exhaust from gasoline and diesel engines, as well as on barbecued foods. CalEPA was 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. Field control surfaces were obtained from nearby concrete sidewalks and were non-detect for chrysene. Since the surfaces are so dissimilar, it is not known whether it is easier to remove substances from the rubber surface than from the concrete sidewalk.

3.1.2 Laboratory Analytical Methods Used to Simulate Gastro-Intestinal Digestion of Crumb Rubber

One study has been found that used a gastro-intestinal simulation extraction method to extract chemicals from recycled tires. The CalEPA 2007 study conducted a gastric digestion simulation test on three different shredded tire samples from three recyclers. The simulated gastric fluid was prepared in accordance with Guyton and Hall (2000) and Semple et al. (2001) and is shown in the table below:

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	

(CalEPA 2007)

The gastric digestion study 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 ocyanobenzoic 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 (CalEPA 2007). Zinc was the only metal found to have an estimated dose above the "screening level." It was 5.1–fold higher than the subchronic minimal risk level (MRL). This makes adverse health effects possible, but unlikely since the MRL for zinc has a 3-fold protective factor built into to account for intrahuman variability and it is based on a daily oral exposure for up to one year. Although this study attempts to mimic gastric digestion of the crumb rubber, there are still some uncertainties associated with it. The study used a leaching solvent designed to mimic gastrointestinal fluid, held at 37^{o} C for 20 hours and then the fluid was analyzed for constituents from the rubber. The holding times of these studies are at least 2-fold longer than the combined emptying times of the stomach (one to three hours) and small intestine (three to six hours), thus possibly overestimating the amount of material that can potentially leach out of the crumb rubber during digestion.

This study, although it uses a fluid meant to simulate gastric fluid, does not simulate full digestion by the GI tract. A method by Versantvoort et al (2005) provides a method which was developed to mimic the physiology of digestion. It assumes a three chamber model, starting with saliva, followed by gastric digestion, and then followed by digestion by the small intestine. Each step is characterized by using simulated fluids appropriate for each digestion period, e.g. saliva, gastric juice, duodenal juice and bile juice. As the procedure continues, the "food" and juice mixture is kept at 37°C, at the proper physiological pH for each segment and constantly rotated to simulate the mixing of the material through the gastrointestinal system. At the end of the digestion the fluid is centrifuged yielding the supernatant and the digested pellet which can then be analyzed. Hansen et al (2007) used this method to evaluate the bioavailability of the polycyclic aromatic hydrocarbons (PAH): benzo(a)pyrene and dibenz(a,h)anthracene in soil, with detection limits of 0.005–0.01 mg/kg.

3.1.3 Estimating Quantity of Ingested Crumb Rubber During Use of a Synthetic Turf Field

There are no data regarding the quantity of synthetic turf pellet material that may be ingested by adults or children during routine use of a synthetic turf field. The risk assessments that have been conducted have used various ingestion rates of pellet material for the evaluation. These are summarized in Table 3-1 below:

TABLE 3-1. COMPILED INGESTION RATES

Study	Ingestion Rate		Source of Ingestion Rate
	Adult	Child	
CalEPA 2007	NA	10 g	Ingestion rate for a child with pica (CalEPA 2000; USEPA 2002)
NIPH 2006	NA	1 g	Authors estimated 0.5 – 1 g material ingested per tournament, training session or match
NJDEP 2007	0.05 g/d	0.2 g/d	Soil ingestion rate used for calculation of NJDEP soil clean-up standards
Johns 2008	0.1 g/d (teenager)	0.2 g/d	Default USEPA soil ingestion rates (USEPA 2002)

The NJDEP (2007) and Johns (2008) studies base their ingestion rates upon standard State or USEPA soil ingestion rates. CalEPA (2007) based the ingestion rate on the ingestion rate for a child with pica. This is relatively uncommon among the typical users of these fields, school age children and adults, and thus this is a very conservative surrogate for crumb rubber ingestion. The ingestion of crumb rubber will more likely be due to hand-to-mouth activity ingestion of crumb rubber dust material adhering to the skin and not the ingestion of rubber itself. For this reason, the use of the USEPA standard soil ingestion factors appears to be a reasonable surrogate for the ingestion of crumb rubber. The ingestion rates used in these risk assessments are either consistent with or more conservative than the values recommended for use by USEPA's Child-Specific Exposure Factors Handbook (USEPA 2002). The Child-Specific

Exposure Factors Handbook recommends an average chronic soil ingestion rate of 0.1 g/day for a child 1 to 6 years old and a pica soil ingestion rate of 10 grams.

3.1.4 Models Assessing Ingestion Exposure

There is no information regarding the absorption, distribution, metabolism and excretion (toxicokinetics) of the chemical components of crumb rubber after ingestion. The toxicokinetics of the individual constituents detected in crumb rubber have been characterized in animal models and in some cases, through human exposure. With the exception of the effect of the rubber matrix on the bioavailability of these materials, it is not anticipated that there would be much difference in the toxicokinetics upon ingestion of crumb rubber. However, it is unclear what effect the mixture of chemicals would have on the toxicokinetic profile. This is not unique to crumb rubber. There is little work done addressing the effects of mixtures, because there is no way to standardize the mixtures. Exposures to contaminated soils also have this uncertainty. As a standard methodology in risk assessment, it is assumed that each constituent acts individually, and the risk from each constituent is summed to obtain total risk.

3.1.5 Summary of Studies Evaluating Ingestion Exposure

Table 3-2 provides a summary of the studies evaluating exposure to contaminants in synthetic turf material via ingestion/non-dietary ingestion. A more detailed summary of each article can be found in Appendix B-2.

TABLE 3-2. SUMMARY OF INGESTION STUDIES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
CalEPA 2007	• Evaluated chronic hand-to-mouth activity by 1-12 yr olds playing on poured in place rubber playground padding by using maximum detected concentrations from three different surfaces • Evaluated one time ingestion of 10 g crumb rubber by 3 yr olds by using literature derived maximum detected concentrations from leachate studies.	• The evaluation of chronic hand-to-mouth activity showed that exposures were below potential non-cancer adverse health effect levels. • Cancer risk was calculated to be 2.9E-06, above the generally accepted cancer risk threshold of 1E-06 (i.e., one in one million). A number of factors (as discussed in the text) possibly resulted in an overestimated risk. • Using leachate data for the acute study, CalEPA showed that with the exception of zinc, all the detected compounds with screening levels were below a level of concern.	• Did not evaluate relevant scenarios, evaluated chronic-hand – to-mouth for playground surfaces, but only acute ingestion for crumb rubber. • Unable to determine if Chrysene (risk driver) was actually from rubber or environment. • The maximum detected concentration of a chemical in the leachate (obtained from the literature) was used for the evaluation, without regard to the form of the tire sample (whole tire, shredded tire, crumb rubber, etc), the composition of the leachate or the holding times for the leachate experiment. • Variability of zinc data • Lack of data on the actual leaching of chemicals from crumb rubber in the gastro-intestinal tract and assumption of 100% bioavailability. • Used overly conservative estimates of chronic/subchronic risk to evaluate acute risk
Hofstra 2007	• Qualitative risk assessment comparing chemical levels against the European Toy Directive	• Heavy metal concentrations in rubber infill material did not exceed the European Toy Directive levels, heavy metals and phthalates would not result in adverse health effects to football players. • Considered the ingestion of organics not to be a relevant exposure.	• No supporting documentation is provided that supports study conclusions. • Study data, analytical methods and citation list are not presented in this document. • Applicability of using European Toy Directive standards as a means of determining potential adverse health effects from exposure to infill material is not evaluated. It is assumed that it is a conservative assessment since the European Toy Directive standards were developed to protect chronic exposure to children.
Johns 2008	• Exposure model • Evaluated chronic “play” scenarios for users of outdoor synthetic turf • Evaluated exposure pathways: dermal, ingestion, inhalation of VOCs • Assumed play 3 hrs/day, 5 times/wk for 3 or 7 years	• Cancer risks were all several orders of magnitude below the EPA risk threshold level of 1E-06 and non-cancer risks were below 1. • Risks from the inhalation pathway are well below the risk threshold for all chemicals except benzene and carcinogenic PAHs, however a major uncertainty is the use of indoor air data as a surrogate for outdoor air concentrations.	• The inhalation scenario used indoor VOC levels which overestimates the likely risks associated with inhalation of VOCs in outdoor environments.

TABLE 3-2. SUMMARY OF INGESTION STUDIES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
NIPH 2006	• Evaluated acute and chronic ingestion for child rugby players	• The study concluded that there was no elevated health risks associated with oral exposure to chemicals in recycled rubber granulates.	• Authors estimated 0.5 – 1 g material ingested per tournament, training session or match. No justification provided.
NJDEP 2006	• Used soil ingestion rates included in calculations for determining NJDEP soil clean-up standards	• Concluded ingestion of up to 200 mg/day synthetic rubber material is not associated with adverse health effects	• Conclusion based upon “available” data, no data or reference provided

3.2 Exposure to COPCs Through Dermal Contact

All users of outdoor synthetic fields are expected to have dermal contact with the crumb rubber. Users of the fields relate that crumb rubber adheres to their socks and clothing and gets into their shoes. It would also be expected that any dust released by the crumb rubber would adhere to the skin, especially if the users are sweaty. Concerns addressed in the literature and raised in the risk assessments are related to direct skin reactions to the components of the crumb rubber and dermal absorption of COPCs. The presence of natural latex rubber and synthetic rubber in tires as well as potentially other allergy-inducing compounds introduces the potential for sensitivity type reactions to occur in sensitized individuals. Latex allergen was evaluated using a guinea pig model and did not show sensitization after exposure (CalEPA 2007). The risk assessments looking at dermal absorption did not show concentrations of contaminants that would be absorbed in significant amounts, even under conservative assumptions. From this review of the most current information to date, dermal contact with tire crumb would not pose a significant health risk.

In the literature, exposure evaluations using quantitative data from leaching tests along with screening risk assessment techniques are the primary methods of evaluating this pathway (Johns 2008, CalEPA 2007, NIPH 2006, DTI 2005, Hofstra 2007). The CalEPA (2007) does not consider the dermal pathway to be a significant pathway of exposure due to the insignificant rates of dermal absorption calculated for the exposure scenario. The NIPH (2006) study did not show significant levels of risk to children playing football (rugby) on indoor synthetic turf fields, at exposure levels ranging from acute to chronic scenarios. Johns (2008) conducted a dermal risk assessment, using concentration data from published sources and exposure scenarios specific to children playing on outdoor synthetic turf fields. Similar to the NIPH (2006) study, Johns did not find a risk to human health from exposure to crumb rubber. Hofstra (2007) evaluated the dermal absorption and excretion of PAHs after exposure to tire crumb rubber by measuring PAH metabolites in the urine of adult football players. Urine samples of the players were collected during the days before and after the training and analyzed for 1-hydroxypyrene, a metabolite of pyrene, and a sensitive marker of absorbed PAHs. Despite an exposure scenario with relative intense skin contact with rubber infill no additional PAH exposure was detected. It was concluded that additional dermal uptake, if it takes place at all, is limited and within the range of PAH-exposure from other sources in the environment and food. The Danish Technical Institute (DTI 2005) conducted in vitro migration tests to evaluate the leaching of chemicals from tire samples into synthetic sweat, which they then incorporated into a quantitative health assessment. DTI evaluated the risk of exposure to toddlers and children, exposed for an hour a day to the chemicals leached out of the tires in the sweat migration study and concluded that the health risk was insignificant.

Each of the risk assessments assumed 100% absorption and bioavailability of the chemicals from crumb rubber, which would overestimate the potential exposure and risk. Research measuring dermal absorption of the chemicals in the crumb rubber matrix could be conducted as well as additional studies on the sensitization potential of the crumb rubber to corroborate the CalEPA study. More realistic evaluations of the dermal adherence of the chemicals to the skin upon contact could also be conducted as well as dermal absorption of the chemicals from the crumb rubber. In addition, background soil sampling would improve our understanding since the majority of the compounds observed as coming from the crumb rubber are also contained in vehicular exhaust and other sources which would deposit onto surrounding surfaces, including the synthetic turf fields.

3.2.1 Study Methods and Findings on COPC Exposures in Crumb Rubber Via Dermal Contact

No studies have been conducted evaluating the toxicity of crumb rubber via the dermal pathway in human or animal models. In the literature, exposure evaluations using quantitative data from leaching tests along with conservative screening risk assessment techniques are the primary methods of evaluating of this pathway (Johns 2008, CalEPA 2007, NIPH 2006, DTI 2005; Hofstra 2007). The CalEPA (2007) does not consider the dermal pathway to be a significant pathway of exposure due to the insignificant rates of dermal absorption calculated for a dermal exposure scenario as compared to what would be ingested though hand-to-mouth contact. A dermal sensitization test conducted on behalf of CalEPA showed no dermal sensitization in a guinea pig model from exposure to crumb rubber. The NIPH (2006) study did not show significant levels of risk to children playing football (rugby) on indoor synthetic turf fields, at exposure levels ranging from acute to chronic scenario. Maximum detected concentrations from leaching data of PCBs, PAHs, total alkyl phenols and total phthalates were evaluated in the NIPH study. Johns conducted a dermal risk assessment, using maximum concentration data from published sources and exposure scenarios specific to children playing on outdoor synthetic turf fields. Similar to the NIPH (2006) study, Johns did not find a risk to human health from exposure to crumb rubber via the dermal route.

In general, these studies were conducted in a conservative manner, utilizing maximum detected concentrations of COPCs and conservative estimates of exposure. None of the studies calculated risk from exposure to COPCs in crumb rubber through dermal contact. Assumptions were made as to absorption rates of the chemicals and loading rate of the dust to the skin. However, in all cases, these assumptions were either conservative (100% absorption) or based upon standard EPA default factors (dust loading on the skin) and thus would be biased towards being health protective.

As discussed, a number of assumptions were used in these risk assessments, and although they were conservative, they represent a data gap in the knowledge of dermal exposure to COPCs in crumb rubber. Research measuring dermal absorption of the chemicals in the crumb rubber matrix could be conducted as well as additional studies on the sensitization potential of the crumb rubber to corroborate the CalEPA study. More realistic evaluations of the dermal adherence of the chemicals to the skin upon contact could also be conducted. In addition, background soil sampling would improve our understanding since the majority of the compounds observed as coming from the crumb rubber are also contained in vehicular exhaust and other sources which would deposit onto surrounding surfaces, including the synthetic turf fields. This may also improve our understanding of the source of the dust in crumb rubber which may be the rubber itself or deposition of ambient particulates.

3.2.2 Transfer of COPCs from Crumb Rubber to Skin, Absorption Through Skin, and Local Effects to Exposed Skin

It would be expected that any dust released by the crumb rubber would adhere to the skin, especially if the users are sweaty. The skin is not very permeable and acts as a relatively good barrier to prevent chemical absorption into the body through the skin. The rate limiting step of absorption of a chemical through the skin is diffusion through the stratum corneum, a dead cell layer, which is the uppermost layer of the epidermis. All chemicals move across the stratum corneum by passive diffusion (Rozman and Klaassen 1996). Chemicals that are more water soluble would tend to be more easily absorbed into the skin. Young children have a less developed stratum corneum and thus have increased absorption potential.

No studies have been conducted that quantitatively evaluates dermal contact rates for synthetic turf pellet material for adults or children during routine use of a synthetic turf field. In addition, there is no direct evidence in the literature that crumb rubber produces local effects such as sensitization or irritation. CalEPA (2007) conducted an in vivo sensitization test in guinea pigs and showed no dermal sensitization from rubber flooring materials. NJ DEP (2007) conducted a qualitative assessment and concluded that there was a potential for sensitization to crumb rubber to occur. However, this was based upon an assumption that the population that is sensitive to latex rubber would be sensitive to the latex rubber in tires. Although rubber has been measured in particulate matter from crumb rubber (NILU, 2006) and latex is a component of urban particulate air pollution that is attributable to rubber dust from tires (Williams 1995), it is not known whether the latex in crumb rubber would cause sensitization reactions. Speculation in the scientific community that asthma rates are higher closer to busy roadways is to a degree due to the latex in tire dust are to this date are poorly understood.

3.2.3 Models Assessing Dermal Exposure

There is little information regarding the absorption, distribution, metabolism and excretion (toxicokinetics) of the chemical components of crumb rubber after dermal contact with the crumb rubber. Hofstra (2007) evaluated the dermal absorption and excretion of PAHs after dermal exposure to tire crumb rubber by measuring PAH metabolites in the urine of adult football players. As part of the evaluation of human health and environmental effects conducted by Hofstra, a field study was conducted among football players to determine the presence of PAH metabolites in the urine after they had intensive skin contact with rubber crumb on a synthetic field pitch (Hofstra, 2007). All urine samples of the players were collected during the days before and after the training. The urine samples were analyzed for 1-hydroxypyrene, a metabolite of pyrene, and a biomarker for PAH exposure. Although a low level of exposure to PAHs was evident, it could not be attributed specifically to the crumb rubber and could possibly be attributed to background exposures such as food. Considering food can be an important source for individuals, this is a significant limitation.

The toxicokinetics of the individual constituents detected in crumb rubber have been characterized in animal models and in some cases, through human exposure. With the exception of the effect of the rubber matrix on the bioavailability of these materials, it is not anticipated that there would be much difference in the toxicokinetics upon dermal exposure to crumb rubber.

However, it is unclear what effect the mixture of chemicals would have on the toxicokinetic profile. This is not unique to crumb rubber. There is little work done addressing the effects of mixtures, because there is no way to standardize the mixtures. Exposures to contaminated soils also have this uncertainty. As a standard methodology in risk assessment, it is assumed that each constituent acts individually, and the risk from each constituent is summed to obtain total risk.

Dermal Absorption Simulation

The Danish Technical Institute (DTI 2005) conducted in vitro migration tests to evaluate the leaching of chemicals from tire samples into synthetic sweat, which they then incorporated into a quantitative health assessment. Measurable concentrations of fluoranthene, pyrene, N-(1, 3-dimethylbutyl)-N′-phenyl-p-phenylendiamine (6PPD), and N-isopropyl-N′-phenyl-p-phenylendiamine (IPPD) were detected in the synthetic sweat. 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. The authors conclude that this finding is not only due to a higher amount of amines in the tires, but also due to the higher solubility of the aromatic amines in water (DTI 2005).

Using the results of the synthetic sweat migration study, the investigators evaluated a scenario where toddlers and children were exposed by skin contact. They assumed that parts of the child’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. Calculated doses were compared with the available lowest no observed adverse effect (NOAEL) values for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). The authors concluded that there was no health risk from dermal contact to these chemicals (DTI 2005). The findings of this study were limited to amines and PAHs, however constituents such as metals, VOCs, phthalates and benzothiazoles have been detected in environmental leachate and in vitro gastrointestinal simulation studies. Further studies such as this could be conducted on crumb rubber material and analyzed for crumb rubber COPCs to provide information on the water soluble constituents in crumb rubber.

3.2.4 Summary of Studies Evaluating Dermal Exposure

Table 3-3 provides a summary of the studies evaluating exposure to contaminants in synthetic turf material via dermal contact. A more detailed summary of each article can be found in Appendix B-2.

TABLE 3-3. SUMMARY OF DERMAL EXPOSURE STUDIES			
Reference	**Type of Evaluation**	**Major Conclusions**	**Major Limitations**
CalEPA 2007	• Dermal exposure was evaluated by determining dermal absorption rates for tire-related chemicals. • These rates were compared to the chemical transfer rate determined for dislodged chemical residue as a result of hand-to-mouth activity by children playing on hard rubber playground surfaces. • The potential for allergic reaction from contact with rubber surfaces was evaluated in an *in vivo* guinea pig test.	• Literature values for dermal absorption resulted in a significantly lower mass of chemical entering a child's body than the mass ingested due to hand-to-mouth activity. Therefore, the authors concluded that dermal contact was an insignificant route of exposure as compared to ingestion associated with hand-to-mouth activity. • No sensitization induced by the test materials was observed based on the test conducted. • The authors also concluded that these surfaces would not cause skin reactions in children already sensitized to latex.	• The applicability of this study to dermal exposure to rubber infill material is low considering that the study evaluated hard rubber playground surfaces as the exposure medium. • No corroborating studies were presented as to the presence of latex allergens in the rubber material used in the studies.
DTI 2005	• Conducted in vitro migration tests to evaluate the leaching of chemicals from tire samples into artificial sweat, which they then incorporated into a quantitative health assessment. • Using the results of the artificial sweat migration study, the investigators evaluated a scenario where toddlers and children were exposed by skin contact.	• The results reveal that a significant higher migration of the more water soluble amines takes place in comparison with the PAHs. The authors conclude that this finding is not only due to a higher amount of amines in the tires, but also due to the higher solubility of the aromatic amines in water. • Calculated doses were compared with the available lowest no observed adverse effect (NOAEL) values for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). The authors concluded that there was no health risk from dermal contact to these chemicals.	• The study's focus was primarily on whole tires used in playgrounds, thus the samples were taken from whole tires and did not include crumb rubber; • Exact methodology for application of the artificial sweat was not defined; • Analyses were limited to PAHs and aromatic amines.
Johns 2008	• Evaluated the potential risk to children and youths playing on outdoor synthetic fields by dermal contact. Constructed an exposure scenario for both a child ("child sport play scenario") and a teenager ("teenager sport play scenario") that actively participates in team sport play on a turf field.	• Despite the use of a highly conservative exposure model (assuming that children and teenagers playing on a sport team will use the turf fields 5 times a week for either 3 or 7 years), cancer risks resulting from dermal contact and through incidental ingestion of tire crumb were all several orders of magnitudes below the EPA risk threshold level of 1 in 1,000,000 and non-cancer risks were all less than the EPA threshold of 1.0.	• Used data available in the literature for chemical concentrations including the use of indoor air concentrations as a surrogate for outdoor air, however, this is a conservative assumption, i.e. more health protective. • Johns used standard USEPA default ingestion rates to estimate oral exposure.

TABLE 3-3. SUMMARY OF DERMAL EXPOSURE STUDIES			
Reference	**Type of Evaluation**	**Major Conclusions**	**Major Limitations**
NIPH 2006	• Risk assessment evaluating potential exposure by adult, youths and older child football (rugby) players to synthetic turf materials in indoor sports halls assumed a high-end adherence factor of 1.0 mg/cm^2 as representative of a default value.	• The resulting chemical doses available for skin uptake (by chemical class) ranged from 0.7 ng/kg/day for PCBs to 26.1 ng/kg/day for phthalates. These doses were deemed too low to result in any adverse health effect (NIPH 2006).	• The adherence value is higher than either the geometric mean value of 0.1 or the 95th percentile value of 0.6 mg/cm^2 recommended by the USEPA (2004), however, no reference or supporting documentation was provided for this value (NIPH 2006). According to USEPA (2004) for the dermal exposure route, the soil adherence factor term is a very sensitive parameter. This does not adversely impact the results as the use of 1.0 mg/cm2 is highly conservative (i.e. more health protective).
NJDEP 2006	• Qualitative risk assessment to determine the potential for sensitive sub-populations to be allergic to crumb rubber.	• The author concluded that exposure to crumb rubber infill material has a high potential to cause allergic contact dermatitis in the 6% to 12% of the population that is allergic to rubber in some form. The author considered this risk to be highest in children rather than adults as they participate in activities more than adults do where dermal exposure is likely to occur. However, the author noted the lack of studies in this area.	• No data provided to support conclusions. Conclusion based only upon presence of natural latex in rubber and the percentage of the population that is allergic to latex.

3.3 Exposure to COPCs Through Inhalation

Users of synthetic turf fields may be potentially exposed to COPCs through the inhalation of particulates/fugitive dusts and possibly to volatiles off-gassing from the rubber. Due to the increased exertion level and inhalation rate of users of the synthetic turf field, the inhalation route of exposure could potentially be an important route of exposure if significant levels of chemicals and particulates are emitted.

In the literature, exposure evaluations using quantitative data along with screening risk assessment techniques were the primary methods used to evaluate this pathway (Johns 2008, CalEPA 2007, NIPH 2006, IBV 2006, Morretto 2007, Hofstra 2007 and NILU 2006). Two studies in New York State have shown that there are no detectable levels of PAHs in ambient air on and near synthetic turf playing fields (Broderick 2007a, b). In addition, the IBV (2006) study provides similar information, by showing levels of VOCs and PAHs detected in and around an synthetic turf field that are low enough to be attributable to background vehicular traffic. It should be noted that in vitro studies and ambient air studies in indoor facilities have indicated that there is volatilization from crumb rubber, however, health assessments indicate that the levels are below a level of concern in most cases (NILU 2006, NIPH 2006, Morretto 2007).

Based upon a review of the available literature, risk assessments using conservative estimates of exposure and maximum concentrations of indoor air contaminants have shown no risk to human health. Indoor contaminant levels are generally assumed to be higher than outdoor levels because outdoor levels are readily diluted by the ambient air mass and wind conditions. Additional research measuring COPCs at the breathing zone levels of users on both newly installed and older synthetic turf fields containing crumb rubber should be conducted to give more representative data on exposures related to urban field use. Air monitoring targets should include PAHs, VOCs, and particulate matter, and should occur during hot weather and calm wind conditions to approximate worst case exposure scenarios. In addition, background air sampling should be conducted at nearby off-field sites simultaneously, as well as natural and/or asphalt fields, in order to provide comparative data on exposures related to urban environments.

3.3.1 Study Methods and Findings on COPC Exposures in Crumb Rubber Via Inhalation

There is limited information regarding the potential for inhalation exposures from the use of outdoor synthetic turf fields due to the lack of air concentration data. Two recent studies were conducted in New York State, measuring levels of PAHs in the air above and around two high school football fields with synthetic turf (Broderick 2007a, 2007b) and one Spanish study measured VOCs and PAHs at an outdoor field (IBV 2006). Measurements at the two high school fields did not detect any PAHs in the ambient air (Broderick 2007a, 2007b), while the Spanish study detected low levels of PAHs and VOCs at levels that would be comparable to concentrations due to automobile traffic (IBV 2006).

In a joint study, NILU (2006) measured indoor air concentrations of constituents of concern from synthetic turf at three indoor turf halls, including VOCs and PAHs, and NIPH (2006) conducted a risk assessment on the data. The NIPH risk assessment focused on multiple scenarios for usage of the indoor turf halls. These scenarios were based upon actual usage and number of hours spent in the halls during training, match play and cup tournaments. Using the highest detected concentrations of VOCs and particulates in their assessment, along with the estimates of exposure times, the NIPH determined that there would be no adverse health impacts from use of the indoor turf halls. By using the maximum detected concentrations for their risk calculations, NIPH presents a conservative estimate of risk. For particulates, PAH concentrations were determined to be within the range of background and were concluded not to be attributable to rubber granulates (NIPH 2006).

Using a controlled emission chamber, Moretto (2007) measured VOC emissions in accordance with standard protocols for evaluating emissions from construction materials. Three turfs were evaluated, one using tire granules, one using TPE granules and the third using EPDM granules. Total VOCs were detected at 134 ug/m^3 at 28 days for the synthetic turf containing used tire granules; 118 ug/m^3 for synthetic turf containing TPE granules; and 490 ug/m^3 for synthetic turf containing EPDM granules. The author concludes that the indoor air quality for sports halls with synthetic turf using any of the three rubber infill material types is "approximately the same magnitude" as ambient air quality, but notes that small sports halls with poor ventilation should be adequately ventilated when workers are installing synthetic turf.

Although the Broderick (2007a,b) and IBV (2006) studies monitored outdoor air above synthetic turf fields, both studies had data gaps. The Broderick studies (2007a, b) were only conducted for PAH measurement. Although the studies used rigorous analytical methods, no information was recorded regarding air temperature, field temperature, sky conditions (sunny, cloudy), wind direction, etc., all of which would impact air measurements. Similarly, the IBV study conducted outdoor air testing, however, no information was given regarding sampling and analysis methodology. The NILU (2006) study adequately addresses indoor air quality of indoor turf halls with rubber granulates and the Moretto (2007) study provides a conservative means of estimating indoor air concentrations in an enclosed chamber. However, neither are appropriate for estimating exposures to outdoor air as they would likely overestimate risk.

3.3.2 Characteristics of Particulate Matter Generated During Use of Synthetic Fields

In addition to the potential for inhalation of volatiles during the use of synthetic fields, there is also the potential for inhalation exposure to particulate matter generated during use of synthetic fields. There is no data available regarding particulate generation during the use of outdoor synthetic fields. The majority of information regarding ambient air concentrations (volatiles and particulates) of contaminants is from indoor turf halls (NILU 2007). NILU (2007) measured PM_{10} and $PM_{2.5}$ (respirable particulates) in the air of three indoor turf halls. Of the three sports halls selected, one had a recently laid turf system with styrene butadiene rubber (SBR) granulate, one had a turf system with SBR granulate which had been in use for one year, and one had a turf system with granulate made from TPE. NIPH conducted a risk assessment on indoor air concentrations of contaminants obtained by NILU from three different indoor turf halls. The range of PM_{10} detected in the halls was 31 to 40 ug/m^3, while the measured concentrations of $PM_{2.5}$ were 10 to 19 ug/m^3. In the two halls with SBR rubber granulate, it was calculated that 23 to 28% of the PM_{10} consisted of rubber, while 35% to 50% of the $PM_{2.5}$ was associated with the rubber particulate.

Results of chemical characterization of the airborne dust showed the presence of PAHs, phthalates, other SVOCs, benzothiazoles, and aromatic amines. Higher levels were seen in the SBR rubber air measurements than in the thermoplastic elastomer air measurements. The maximum total SVOC concentration, including PAHs, was approximately 11 ng/m^3. The maximum total phthalates concentration was approximately 134 ng/m^3. The maximum total concentration of other selected vulcanization and tire preservative compound, including benzothiazoles and aromatic amines, was approximately 2.2 ng/m^3.

Concern has also been raised about the presence of latex allergens in the crumb rubber. No studies have been located to evaluate whether latex is present in air-borne particulates from synthetic turf fields. In a study not related to turf fields, Williams et al. (1995) evaluated whether respirable particles in urban air samples, which may be airborne tire fragments, contain natural latex. The study concludes that latex antigens are extractable from rubber tire fragments, which are abundant in urban air samples, and suggests that airborne particles could contribute to the increase in both latex sensitization and asthma. NILU (2007) collected particulate samples but did not evaluate them for latex content. As shown in the Williams paper, extractable latex is present in urban air particulate samples. Of concern would be whether inhalable particulates would contain latex and whether that latex was biologically active, resulting in possible asthmatic attacks in latex-sensitive individuals. Synthetic turf is not likely to be a significant contributor to latex exposure since the majority of exposure comes from roadways and other sources such as house paint. However, the literature on airborne latex as a contributor to asthma and allergies in the urban environment is limited at this time.

The NILU (2007) study represents characterization of indoor air of three turf halls with rubber granulates of varying age and type. However, since they are indoor air measurements, they would overestimate outdoor air concentrations of the particulates and their constituents. Outdoor particulate sampling could be conducted while the synthetic turf fields are in use to give more representative data for NYC parks use related exposures. Total particulates, PM_{10}, $PM_{2.5}$ and concentrations of COPCs bound to the particulate should be measured. In addition, measurement of extractable latex concentrations of the particulates should be considered to determine if inhalation of airborne particulates could contribute significantly to airborne concentration of latex. Concurrent background sampling should occur in order to determine the actual effect of the synthetic turf fields on outdoor air quality above the fields. Further research is needed to better understand the link between airborne latex particles and the risk for latex sensitization and asthma.

3.3.3 Models Assessing Inhalation Exposure

There is no information regarding the absorption, distribution, metabolism and excretion (toxicokinetics) of the chemical components of crumb rubber after inhalation. The toxicokinetics of the individual constituents detected in crumb rubber have been characterized in animal models and in some cases, through human exposure. With the exception of the effect of the rubber matrix on the release of these materials, it is not anticipated that there would be much difference in the toxicokinetics upon inhalation of the chemicals from crumb rubber. However, it is unclear what effect the mixture of chemicals would have on the toxicokinetic profile. This is not unique to crumb rubber. There is little work done addressing the effects of mixtures, because there is no way to standardize the mixtures. Exposures to volatiles from contaminated soils also have this uncertainty. As a standard methodology in risk assessment, it is assumed that each constituent acts individually, and the risk from each constituent is summed to obtain total risk.

3.3.4 Summary of Studies Evaluating Inhalation Exposure

Table 3-4 provides a summary of the studies evaluating the exposure to contaminants in synthetic turf material via inhalation. A more detailed summary of each article can be found in Appendix B-2.

TABLE 3-4. SUMMARY OF INHALATION STUDIES

Reference	Type of Evaluation	Major Conclusions	Major Limitations
Broderick 2007a, 2007b	• Conducted ambient air sampling at two outdoor high school football fields.	• Neither study detected the presence of PAHs in ambient air above or around the football fields.	• Sampling protocol was not defined, there was no information in the report providing length of sampling, or weather conditions at the time of sampling
Hofstra 2007	• This study conducted a literature review and limited experiments to evaluate human health via inhalation exposure	• This study concluded that emissions of hazardous substances from rubber infill material do not pose a risk, based on a review of available literature. They supported this conclusion with their own analysis of the rubber infill, which identified only very limited amounts of volatile chemicals.	• No supporting documentation provided. • The summary does not provide any information on the basis for determining that the inhalation exposure pathway does not pose an adverse health risk.
IBV 2006	• Air samples were collected at an outdoor synthetic turf field and were analyzed PAHs, VOCs and hydrogen sulfide. Samples were obtained from each of the four corners of the field and at the center of the field.	• The study concludes that the VOCs and PAHs picked up in the samples are similar to the emissions generated by traffic in the zone of influence and the values do not exceed any maximum value established by European legislation.	• No information provided as to analytical methods used, sampling times, etc.
Moretto 2007	• Emissions from three different types of rubber granules were evaluated in controlled emission test chambers at an ambient temperature of 23 ± 2^{o}C and relative humidity of 50 ± 5%. • A risk assessment was performed on the results which assumed athletes and workers installing the floors were exposed to these emissions in an indoor gymnasium.	• The paper did not present hazard index or cancer risk estimates, rather qualitatively discussed the VOC results in the context of background air quality. The paper concludes that the indoor air quality for sports halls with synthetic turf using any of the three rubber infill material types is "approximately the same magnitude" as ambient air quality, but notes that small sports halls with poor ventilation should be adequately ventilated when workers are installing synthetic turf.	• Indoor sports hall air quality was evaluated. This represents a highly conservative assessment of outdoor air quality. • No air concentration results for chemical constituents were provided in the study. • No risk calculations were conducted.

TABLE 3-4. SUMMARY OF INHALATION STUDIES

Reference	Type of Evaluation	Major Conclusions	Major Limitations
NILU 2006	• A study was conducted to measure indoor air quality in sports halls that use synthetic turf system in order to generate data to be used in exposure studies.	• The study concludes that the use of rubber granulate from ground car tires adversely affects indoor air quality, even with ventilation. Rubber granulates produced from thermoplastic elastomer generated less pollution. Also, the study shows the presence of organic chemicals which were not previously reported. The study recommends further research into adverse affects associated with latex exposure via the skin and air passages. • Results of the airborne dust showed the presence of PM_{10} and $PM_{2.5}$.	• The study evaluated indoor sport hall air quality at three specific sports halls in Norway. The applicability of the air quality to outdoor applications is low.
NIPH 2006	• This study evaluated the health risks to football players from exposure to synthetic turf fields using the data reported in the NILU 2006 study. As part of the evaluation, the study evaluated inhalation exposure by adults, youths as well as older and younger children who play, train or play cup tournaments at indoor sports halls in Norway.	• Exposure by football players to volatile organic compounds did not result in elevated health risks. Concentrations of polynuclear aromatic hydrocarbons were found to be within the range of background and were not attributed to rubber granules.	• This study evaluates indoor air quality in sports halls, and as such, would represent highly conservative estimates of potential adverse health effects associated with outdoor air exposure at parks where synthetic turf with rubber infill material is used.
Williams et al. 1995	• This study evaluated whether respirable particles in urban air samples, which may be airborne tire fragments, contain natural latex.	• The study concludes that latex antigens are extractable from rubber tire fragments, which are abundant in urban air samples, and suggests that airborne particles could contribute to the increase in both latex sensitization and asthma.	• The applicability of this study to particulates generated from rubber infill material is unknown. • The study does indicate the potential for particulates generated from rubber tires to contain latex, a known allergen.

3.4 Child and Adult Usage Patterns on Synthetic Turf Fields

More sports than ever before are being played generating a greater need for field space in NYC. Not only are the two major field sports of baseball and football played on DPR's fields, but soccer has also become extremely popular. In addition, there are several cricket leagues in the parks, as well as rugby, Ultimate Frisbee, and lacrosse. These sports also tend to be high impact games. With the possible exception of cricket, these sports create a great deal of wear-and-tear on field surfaces. As such, soccer and multi-use fields are prioritized for synthetic turf installation over baseball fields because soccer is much more damaging to lawns than baseball or softball (Benepe 2007). Due to the high demand for field space, DPR athletic fields may only be used for organized sports and school league play with a permit, no practice play is allowed on the fields (NYC DPR 2008).

The DPR issued 66,000 hours of permitted field time in 1999 and in 2007 they issued 137,000 hours of permitted field use. In Brooklyn, the athletic field permits office estimates that synthetic turf fields can be permitted for 1,248 hours per year, which is 28% more than 972 hours per year for natural grass fields (Benepe, 2007). In San Francisco, the Recreation and Park Department has found that with the addition of two new synthetic turf soccer fields the amount of play possible on the fields has increased 50% to 100% (Morrison 2005). The DPR does not keep statistics on the usage patterns on their synthetic fields. Based on the types of sporting activities held on the synthetic turf fields, a game/match can last anywhere from an hour (lacrosse) to two hours (soccer, rugby).

Because there are no detailed data on actual use of synthetic turf fields, studies have made assumptions about the amount of time that certain age groups spend engaged in particular activities. Table 3-5 summarizes the exposure assumptions, including frequency of exposure and duration of exposure, from the studies reviewed for this report.

TABLE 3-5. SUMMARY OF EXPOSURE ASSUMPTIONS USED IN RISK ASSESSMENTS					
Study	**Receptor**	**Activity Evaluated**	**Exposure Duration (yrs)**	**Exposure Frequency**	**Exposure Time**
Johns 2008	Children	Sports	3 (ages 8 -10)	261 (d/yr)	3 (hr/d)
	Teenager	Sports	7 (ages 11 -18)	261 (d/yr)	3 (hr/d)
CalEPA 2007	Children	Playground	12 (ages 1- 12)	185 (d/yr)	2 (hr/d)
NIPH 2006	Adult	Sports	20 (ages 20-40)	6 (months)	20 (hr/wk)
	Juniors	Sports	3 (ages 16-19)	4 (months)	14 (hr/wk) + 2 hr/month/3 months
NIPH 2006	Older Children	Sports	3 (ages 12-15)	6 (months)	12 (hr/wk)
	Children (train/matches)	Sports	4 (ages 7-11)	6 (months)	12 (hr/wk)
NIPH 2006	Children (cup tournaments)	Sports	4 (ages 7-11)	5 (2.5 d/tournament, 2 tournaments/yr)	17 hr/tournament (light exertion) 7 hr/tournament

3.5 Potential Biomarkers Indicative of Exposure to COPCs

Biological markers, or “biomarkers,” may be used to evaluate human exposure to certain environmental contaminants by providing an indication of absorbed dose. Biomarkers may be the contaminant itself, a metabolite of the contaminant or a physiological indicator, such as a protein which is somehow affected by levels of the contaminant in the body. Biomarkers may be measured in various media, including but not limited to blood, urine, or feces.

An example of a commonly used biomarker is lead in blood, which is a reliable, commercially available test performed by certified laboratories meeting a set of criteria to ensure the accuracy of the measurement. Lead measured in other media, although used in research settings, is neither practical nor readily available and the results are not easily interpreted. In the case of lead, there are good data available to interpret the results. For most other environmental contaminants, data are limited or do not exist which will help to interpret the results. Interpretation of results may include the ability to make a conclusion about the severity of the exposure or the risk for developing health effects from the exposure and can also drive decisions about treatment or case management. To date, there are only a few cases where biomarkers can be used for quantitative exposure assessments.

Certain criteria guide whether a biomarker is a reliable indicator of exposure to a certain contaminant. For biomarkers to have some practical applications they should:

- Have testing and collection methods which provide consistent results, are reproducible and are standardized across laboratories;
- Reflect exposure during the time period of interest;
- Not be influenced by genetic or other individual physiological factors;
- Be relatively inexpensive to analyze;
- Have a high positive predictive value (not give false positive results);
- Have substantial data available to assist in interpretation of the level;
- Be specific to the contaminant of interest.

There is no biomarker for crumb rubber *per se*, however there are biomarkers for some of the individual COPCs found in crumb rubber. These biomarkers can indicate whether a person has been exposed to a certain chemical without providing information as to the actual source of the exposure. As noted in Section 2.9, COPCs found in crumb rubber are also common in urban environments. For example, urinary 1-hydroxypyrene is a biomarker that reflects exposure to PAHs because it is a metabolite of pyrene, which is commonly found in PAH mixtures. Measurement of urinary 1-hydroxypyrene cannot show whether the source of PAH exposure was food, car exhaust, crumb rubber dust, or another common source in the urban environment. This is probably true of all COPCs found in crumb rubber. Currently, no COPC unique to crumb rubber has been identified and most of the COPCs do not have a reliable biomarker. Another factor limiting the utility of biomarkers as indicators of crumb rubber exposure is that there is wide variability in the chemical composition of the crumb rubber itself. Although biomarkers may be useful for researching exposure to COPCs in crumb rubber, any study designs need to account for factors such as unrelated sources of exposure and variability in results due to differences in individual physiologic and metabolic mechanisms.

3.6 Comparison Guidelines

There are no specific risk-based exposure guidelines for crumb rubber. Existing Federal (e.g. EPA's Medium Specific Screening Levels) or New York State guidance for ambient air levels and soil levels of COPCs may or may not be applicable depending on the standard and/or its use. Some more relevant guidelines are described below.

A. Federal Ambient Air Preliminary Remedial Guidelines (http://epa-prgs.ornl.gov/chemicals/download.shtml)

- are applicable where air samples have been collected as these criteria evaluate exposure once chemical constituents have moved into the gas phase and are inhaled by a receptor,

- are chronic inhalation values based upon lifetime exposure - only applicable as an initial screening value, and

- may need an appropriate adjustment reflecting a recreational type scenario.

B. Federal Soil Screening Criteria
(http://epa-prgs.ornl.gov/chemicals/download.shtml)

The soil screening criteria consist of three exposure pathways: ingestion, inhalation of particulates and volatiles from soils and dermal exposure.

1. Federal Soil Screening Criteria for Inhalation Exposure

- are not applicable to exposure to rubber granules because the volatilization model incorporates soil characteristics in predicting volatilization from soil into air, including:
  - soil moisture content,
  - bulk density,
  - soil/water partitioning of chemicals, and,
  - soil/organic carbon partitioning of chemicals.

2. Federal Soil Screening Criteria for Ingestion Exposure

- are applicable as screening criteria - conservative estimates of oral exposure associated with incidental ingestion of media, whether it be soil or crumb rubber, containing chemicals,

- are screening criteria, based upon a residential type scenario - would overestimate risk in a recreational scenario,
  - Non-cancer exposures are based upon a 6 year exposure duration (ages 1 – 6 years) for 350 days/year,
  - Cancer exposures are based upon a combined 30 year exposure (ages 1 – 6 years and 7 – 30 years) for 350 days per year averaged over a 70 year lifetime.

- may be appropriate to adjust based upon time of exposure and possibly gastric absorption (data gap at this time). Unknown whether gastric digestion is sufficiently similar between soil and rubber granules such that absorption of chemicals contained in crumb rubber would be similar to the absorption of chemicals in soil once ingested.

3. Federal Soil Screening Criteria for Dermal Exposure

- are possibly applicable and likely an overly conservative estimate of risk based on residential exposure scenario.

- For the dermal exposure route, the soil adherence factor term is a very sensitive parameter in assessing dermal contact. The skin adherence factor describes the amount of soil that adheres to the skin per unit of surface area and is based upon soil properties, part of the body and type of activity. The skin adherence characteristics of crumb rubber and/or crumb rubber dust as compared to soils are unknown.

- Dermal absorption of chemical constituents of crumb rubber needs to be evaluated to ensure that it is sufficiently similar to dermal absorption rates for soil.

C. NY DEC Subpart 375-6: Remedial Program Soil Cleanup Objectives (SCOs) (http://www.dec.ny.gov/regs/15507.html#15517)

- provide soil clean-up levels for different usage scenarios which are categorized as unrestricted residential, restricted residential, commercial and industrial scenarios. Recreational scenarios are typically compared to restricted residential or commercial scenarios. Comparison against unrestricted residential SCOs may also be to done to provide more protection although many of the numbers used for guidance in this category are for protection of ecological resources or based on rural background survey results and not protection of health.

- are either based on protection of public health, ecological resources or rural background, whichever value is lower. The rural background levels were developed by the New York State Departments of Environmental Conservation and of Health. For most of these values their use in risk assessments would tend to greatly overestimate risk for a recreational scenario.

- The soil screening criteria consist of three exposure pathways: ingestion, inhalation of particulates and volatiles from soils and dermal exposure and each have the same characteristics as identified in the Federal guidelines.

- due to the ubiquity of PAHs, metals and other COPCs in an urban environment, COPCs derived from the crumb rubber infill of synthetic turf fields and measured in available media, such as dust, could also be compared against urban background levels of these materials.

4.0 POTENTIAL HEALTH EFFECTS RELATED TO PHYSICAL PROPERTIES OF SYNTHETIC TURF FIELDS

The potential physical health effects associated with synthetic turf systems include heat-related illnesses, burns, injuries, abrasions, and infections. The concern for these adverse health effects is based on the distinct physical characteristics of synthetic turf systems which differentiate them from grass, dirt and asphalt fields. Consideration is also given to the variety of synthetic turf configurations and technologies which have evolved since the first fields were developed in the 1950s.

The older generation of synthetic turf systems were comprised of a carpet-like, short pile synthetic turf installed over a foam pad on an asphalt or concrete surface. Subsequent generations of synthetic turf systems have been developed. Longer and softer "grass fibers" have decreased the abrasiveness and the underlayment materials include rubber and foam pads for reducing risk of impact injuries. Many of the synthetic turf systems in use in New York City consist of a recycled SBR rubber pad or a foam pad underlayment topped with the synthetic fiber system. This fiber system is infilled with a cushioning infill material of crumb rubber that is produced from recycled tires that have been processed to the size of coarse sand. The crumb rubber material is spread two to three inches thick over the turf material and raked down in between the plastic fibers which simulate grass. The crumb rubber helps support the blades of fiber, and also provides a surface with some give, that feels more like the soil under a natural grass surface. Research in this area includes studies conducted by universities, the National Collegiate Athletic Association (NCAA), sports medicine associations, and public health departments.

Heat-Related Illness

Research focused on heat-related health and environmental effects is grounded in the observation that synthetic turf systems absorb radiant heat much more efficiently than grass and asphalt playing surfaces. This increase in temperature of the turf system may contribute to a local "heat island" effect, a phenomenon in which the absorption of heat by impervious surfaces increases surrounding ambient air temperature, and by doing so, may adversely affect players' health by increasing risk of heat-related illness. Research has documented that children who are not well hydrated are more prone to heat-related illness, therefore, increased water intake is recommended on hot days. In addition, the American Academy of Pediatrics, Committee on

Sports Medicine and Fitness provides recommendations to address the prevention of heat-related health effects during exercise for children and adolescents. The increased surface temperature of the synthetic turf systems may also cause burns and blisters. Two documented cases of foot burns have been found in the literature, the first case was of a football coach at Brigham Young University (Williams and Pulley 2002) and the second was of six Peruvian soccer players having burns and blisters on their feet as a result of playing on synthetic "pitch" (synthetic turf) (SI.com 2007).

Physical Injuries

In addition to potential heat-related effects, another concern raised about the use of synthetic turf materials is the potential for increased injury to players as compared to natural turf materials. Characteristics such as surface hardness, abrasive index and traction of the turf systems may have an effect on the injury rates seen as a result of playing on the synthetic turf surfaces.

Surface hardness is important due to the risk of concussion upon impact with the ground surface. Surface hardness has been shown to affect both player performance and player safety. Surface hardness is measured in Gmax: the higher the Gmax value, the harder the surface. The American Society for Testing and Materials (ASTM) has established an upper limit for surface hardness of 200 Gmax above which head trauma is more likely to occur and at which point the ASTM suggests repairing or replacing the surface. McNitt and Petrunak of the University of Pennsylvania are in the process of evaluating 10 different brands of synthetic turf in-filled surfaces in a long-term study. One of the parameters that they are evaluating is surface hardness or impact attenuation on "no wear" turf and "wear" turf which simulated turf after having up to 96 games played on it. Using two different ASTM Methods the hardness index remained well below the maximum Gmax rating of 200 for all scenarios tested (McNitt and Petrunak 2007c). A study conducted by Naunheim et al. (2002, 2004) evaluated the impact attenuation of three indoor fields: the first field was an indoor domed stadium with AstroTurf with a 5/8 inch foam underlayment, the second field was an indoor practice field with AstroTurf with a 1 inch foam underlayment, the third field was an infilled FieldTurf system with a shredded rubber base which replaced the indoor practice AstroTurf field. These fields were compared to the impact attenuation of a natural grass outdoor field measured at 72^{o}F and 32^{o}F. The change from a foam-based Astroturf system to a shredded rubber-based system (FieldTurf) had no effect on impact attenuation overall. However, areas in the shredded rubber-based field were significantly compacted; causing some sites to be much harder than the foam-based surface it replaced (Naunheim et al. 2004).

The Naunheim studies showed that the shredded-tire based system showed significant compaction in high-use areas of the field. However, these studies were conducted on indoor fields and the FieldTurf system used was installed over a graded surface of shredded tire and silica sand. The McNitt and Petrunak study did not show an increase in compaction of the fields with simulated wear. The fields evaluated in the McNitt and Petrunak studies were in-filled systems with either foam or rubber pads, similar to what has been installed in the New York City parks. The synthetic turf fields in New York City are in-filled systems with a shock pad made of either rubber or a foam pad. Furthermore, per the City's specifications for installation:

> "The warranty shall also guarantee a G-Max rating below 130 at the time of installation and below 180 for the remaining term of the warranty. Warranty shall clearly state that if test results show that G-Max rating has not been met, the manufacturer will repair or replace product within the warranty period as necessary to meet those requirements at no cost to the City."

Concerns over the potential for increased injuries associated with the use of synthetic turf systems have led to a number of studies to evaluate the potential for increased injuries. These studies, for the most part, do not differentiate between types of synthetic turf fields. Studies by Fuller et al. (2007a, b) and Steffen et al. (2007) evaluated the incidence of injuries of both female and male soccer players playing on synthetic turf systems compared to natural grass turf systems, while Meyers and Barnhill (2004) evaluated the incidence of injury among high school football players. Fuller et al. (2007a,b) concluded that there were no major differences between synthetic turf and natural grass in the incidence rate, severity, nature or cause of injuries sustained during training or match play of male and female collegiate soccer players. Meyers and Barnhill (2004) did find significant playing surface effects by injury time loss, injury mechanism, anatomical location of injury, and type of tissue injured. Natural grass fields actually had the higher incidences of injury time loss and more severe injuries such as head and neural trauma and ligament injuries. The synthetic turf fields had higher incidences of minor injuries such as surface/epidermal (skin) injuries, muscle related trauma and a higher incidence of injury occurrence during higher temperatures. Steffen et al. (2007) found that the incidence of acute injuries did not differ between synthetic turf and natural turf. However there was an increasing trend towards more ankle sprains on synthetic turf than natural grass and there was a higher incidence of severe injuries (more than 21 days lost playing time) with synthetic turf fields. The rate of minor injuries also tended to be lower on synthetic turf fields in the Steffen study. Differences in these results and conclusions may be a result of differences in sport (soccer versus football) and age of the athletes (college versus high school). In addition, the types of synthetic turf fields were not identified and the differences in the types of field may also play a role in the differences in the rates of injury between these studies.

Abrasiveness

Abrasiveness has also been raised as an issue, especially with older synthetic turf materials. New generation synthetic turf systems have been manufactured to be soft and more resilient, unlike older versions which were hard and abrasive. A study conducted by the University of Pennsylvania on 10 synthetic in-filled turf systems showed that all fields with infill material systems were less abrasive than the traditional, carpet-like Astroturf, and on-going maintenance tended to lessen the abrasiveness (McNitt and Petrunak 2007a).

MRSA

In addition to physical injuries, concern has been raised over the increased potential for bacterial infections, such as methicillin-resistant *S. aureus* (MRSA) infections, to occur in athletes playing on synthetic turf. Synthetic turf fields are very unlikely to harbor MRSA and they do not provide a hospitable environment for MRSA to colonize. McNitt et al. (2007) found no MRSA in any of the synthetic turf. Incidentally, the overall bacterial colony counts from natural turf fields far exceeded those of the synthetic turf samples. However, the risk of contracting community acquired MRSA is increased in the presence of skin breaks, such as burns and abrasion. Turf burns were associated in two studies with MRSA infection however there was no comparison with abrasions from other sources to determine whether there is some special feature of turf burns which makes them a better means of entry for the infectious agent. These outbreak were among football teams involved in intense training during warm weather and the major risk factors for infection were frequent physical contact, equipment sharing, body shaving and poor sanitary practices in the locker rooms and training facilities (Begier et al 2004, Kazakova et al 2005). In the context of poor hygienic practices among team members, the risk of community acquired MRSA may be increased if the users experience injuries involving skin breaks. The information available to date indicates that the new generation synthetic turf fields with crumb rubber infill are less abrasive and would not increase this risk.

4.1 Temperature of Synthetic Fields

Synthetic turf materials have shown significant temperature increases at the surface of the field and in ambient air above the playing field as compared to other surfaces such as grass and asphalt. Heat islands are areas of higher ambient temperature, typically in urban areas where grass and trees are replaced by heat absorbing surfaces, such as rooftops, roads and parking lots. This phenomenon occurs when direct sunlight hits the surfaces and they absorb heat. When this heat dissipates it can elevate ambient air temperatures. Synthetic turf fields absorb rather than reflect sunlight, causing the fields to emit heat, thus the elevated temperatures associated with synthetic turf materials may also contribute locally to a heat island effect, especially on sunny days with little wind. Heat islands in large cities have regional-scale impacts on energy demand, air quality, and public health. Synthetic turf fields may be one contributor to this effect, albeit a very small one, since building roof tops and roadways make up the majority of heat absorbent surfaces in cities.

Elevated surface temperatures of synthetic turf may result in heat-related injuries associated with direct contact such as burns or blisters. Elevated ambient air temperatures associated with synthetic turf fields may contribute to heat stress, although there are no specific published reports documenting such effects. However, since synthetic turf materials have been shown to elevate ambient temperatures above the field to temperatures in excess of 95°F, there is the potential for heat stress to occur in children. Studies have shown that children are less able to adapt to changes in temperatures, especially when humidity is high.

In order to address the elevated temperatures and potential heat stress associated with the use of synthetic turf materials, increased water intake and the installation of devices designed to reduce body temperature have been proposed for synthetic turf fields. Dehydration has been shown to be a significant contributor to elevated core temperatures in children. Therefore, increased water intake is recommended. In addition, the American Academy of Pediatrics has published recommendations for children and adolescent athletes to address heat stress and dehydration.

It is recommended that field operators educate field management staff, coaches and athletic staff, field users, and parents on the potential for heat-related illness and how to prevent it. Shaded areas should also be provided for athletes to rest and cool down, and drinking water fountains should be easily accessible for rehydration. In addition, the availability of alternate infill with lower heat absorption properties should be assessed.

4.1.1 Impact of Synthetic Turf Fields on Ambient and Surface Level Temperatures

Synthetic turf fields tend to significantly increase surface level temperatures and ambient air temperatures above the surface of the playing field in comparison to natural turf fields. Synthetic turf fields do tend to have higher temperatures than grass and asphalt playing surfaces (Adamson 2007; McNitt and Petrunak 2007d; Williams and Pulley 2002). However, this is not limited to SBR synthetic turf fields, research as far back as the early 1970s found that surface temperatures of synthetic turf were as much as 35-60° C (95° to 140° F) higher than natural turf grass surface temperatures (Buskirk et al. 1971 (as cited by McNitt and Petrunak 2007d)). This not only may affect players' health, but also may contribute to a local "heat island" effect, which is defined as an increase in urban temperature as compared to surrounding suburban and rural temperature (Rosenzweig et al. 2006).

The contribution of synthetic turf to urban heat islands is presently unknown. However, due to the increased temperatures measured on these synthetic turf systems, they may contribute local increased ambient temperatures, but their contribution to the overall urban heat island effect is likely to be small. Urban heat islands are created when grass and trees are replaced by impervious surfaces like rooftops and asphalt, which absorb heat. Summer temperatures in New York City are approximately seven degrees higher than surrounding suburban and rural areas due to this effect. Urban heat islands increase demand for energy (particularly air conditioning), intensify air pollution, and can lead to heat-related morbidity/mortality and excess mortality due to other causes such as heart disease. A study of heat island effect mitigation strategies conducted in New York City in the summer of 2002 found that increasing vegetation has a great effect on reducing temperatures and recommends planting street trees in open spaces as well as building living roofs to provide the greatest cooling potential by area (Rosenzweig et al 2006).

According to the NYC DPR, efforts are already underway to address this issue. Over the last ten years fewer than 300 acres of parkland (that's about 1 percent of the total acreage of parkland and less than 10 percent of the grass ballfields) have been converted to synthetic surfaces, including all of the asphalt yard 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 100,000 trees (Benepe 2007).

Various studies conducted at Universities have shown significant increases in synthetic turf temperatures as compared to natural grass and other surfaces and the ambient air. Temperatures measured at the University of Missouri's Faurot Field, on a 98° day registered 173°F on the surface of the synthetic grass. Nearby natural grass showed a temperature of 105°F on the surface. Temperatures taken at head-level height over the synthetic turf registered 138°F (Adamson, 2007). At Brigham and Young University, after the complaint of a coach receiving burns on his feet from the new synthetic turf field, an investigation was launched to determine the range of temperatures, the effect of water on cooling the fields and how the temperatures compared to other surfaces (Williams and Pulley 2002). Preliminary temperature measurements showed that the surface temperature of the synthetic turf was 37°F higher than asphalt and 86.5°F hotter than natural turf. Irrigation of the turf with cooling water for 30 minutes had a significant effect on surface temperature, dropping the temperature on the surface from 174°F to 85°F, but there was a rapid rebound effect with the temperature rising to 120°F in 5 minutes and to 164°F at 20 minutes (Williams and Pulley 2002). These investigators also found that the temperature of the turf was more dependent on the amount of light, rather than the air temperature. White lines and shaded areas are less affected because of reflection and decreased intensity of light, respectively. Average surface temperature measurements of natural and synthetic turf taken in the shade show an approximate 9.5° difference (66.35° F versus 75.89° F) between the two, respectively. However, the synthetic turf field's maximum temperature rose to 99° F while that of the natural turf rose to 75° F (Williams and Pulley 2002). The large synthetic turf study conducted by Penn State's Department of Crop Management and Soil Science tested 10 synthetic turf systems for surface temperatures and ambient air temperatures 3 feet above the field surface. The investigators tried to limit temperature measurements to days that were bright and sunny, because cloudy days resulted in more erratic measurements. The surface temperatures of the fields ranged from 113.7°F to 125.4°F using a LiCor Scheduler infrared thermometer. The ambient air temperatures registered 3 feet above the turf surface ranged from 78.1°F to 80.6°F (McNitt and Petrunak 2007d). The ambient air temperatures varied by a few degrees among the turfs, but did not appear to be correlated with the surface temperatures of the turf systems.

4.1.2 Potential Heat-Related Illnesses and Dermal Injuries

There are no specific published reports pertaining to heat stress from the use of synthetic turf fields, although heat stress and dehydration are potential risks for children playing in a high heat environment. Exercising children are able to dissipate heat effectively in a neutral or mildly warm climate. However, when air temperature exceeds 35°C (95°F), they have a lower exercise tolerance than do adults. It is important to emphasize that humidity is a major component of heat stress, sometimes even more important than temperature. Therefore, in general, exercising children do not adapt to extremes of temperature as effectively as adults when exposed to a high climatic heat stress (Anderson et al. 2000). These differences are due to:

1. Children have a greater surface area-to-body mass ratio than adults, which causes a greater heat gain from the environment on a hot day and a greater heat loss to the environment on a cold day.
2. Children produce more metabolic heat per mass unit than adults during physical activities that include walking or running.
3. Sweating capacity is considerably lower in children than in adults, which reduces the ability of children to dissipate body heat by evaporation.

At temperatures exceeding 115º F (46°C) the potential for dermal injuries due to burns increases. The extent of damage depends on surface temperature and contact duration (Naradzay and Alson 2006). Two reports have been identified documenting thermal burns (blisters) from contact with synthetic turf. The first is a report of a Bringham Young University coach getting "a blister on his feet through his tennis shoes" (Williams and Pulley 2002), and the second, a recent news report of six Peruvian soccer players having burns and blisters on their feet (SI.com 2007). The actual incidence of thermal burns as a result of contact with synthetic turf is unknown, however, children ages 4 and under are at greater risk from burn-related injury. Young children have a less developed keratinized layer in their epidermis than that of older children and adults, their skin burns at lower temperatures and more deeply (CT Safe Kids 2008).

4.1.3 Prevention of Heat-Related Illness and Dermal Injury

Overheating and dehydration are an issue for athletes of all ages during the height of the summer, whether on a grass field, an asphalt yard, or a synthetic field. Dehydration can lead to mild to severe heat-related illnesses, such as heat cramps, heat exhaustion and heatstroke. By coaches and players remaining conscious of their water intake and taking frequent breaks, the danger of heat exhaustion can be greatly minimized. The NYC DPR has taken the step of starting to install water "misters" near the benches of fields that might get particularly hot in an effort to allow players to cool down more easily (Benepe 2007). It is also recommended that shaded areas be provided for the players to rest and drinking water fountains be easily accessible. In addition, the availability of alternate infill with lower heat absorption properties should be assessed.

It has been found that children frequently do not feel the need to drink enough to replenish fluid loss during prolonged exercise. This may lead to severe dehydration. A major consequence of dehydration is an excessive increase in core body temperature. Thus, the dehydrated child is more prone to heat-related illness than the fully hydrated child. For a given level of hypohydration, children are subject to a greater increase in core body temperature than are adults. Water will help replace the fluids lost during exercise and is essential to proper cardiovascular function. Drinks with too much sugar (juices) or sugars such as fructose (soda pop) are not well absorbed and cause nausea (Davis et al. 1988). Fluids that contain caffeine are not recommended as caffeine acts as a diuretic, increasing urination and fluid loss. Caffeine can also cause agitation, stomachache, diarrhea, nausea, and an increased heart rate, all of which can lower performance. Salt tablets are not recommended as they may also cause nausea (AAP 2000; Goodale 2008; U.VA. 2004).

In general, exercising children do not adapt to extremes of temperature as effectively as adults when exposed to a high climatic heat stress. These differences are due to:

1. Children have a greater surface area-to-body mass ratio than adults, which causes a greater heat gain from the environment on a hot day and a greater heat loss to the environment on a cold day.

2. Children produce more metabolic heat per mass unit than adults during physical activities that include walking or running.

3. Sweating capacity is considerably lower in children than in adults, which reduces the ability of children to dissipate body heat by evaporation.

Exercising children are able to dissipate heat effectively in a neutral or mildly warm climate. However, when air temperature exceeds 35°C (95°F), they have a lower exercise tolerance than do adults. The higher the air temperature, the greater the effect on the child. It is important to emphasize that humidity is a major component of heat stress, sometimes even more important than temperature.

Proper health habits can be learned by children and adolescents. Athletes who may be exposed to hot climates should follow proper guidelines for heat acclimatization, water intake, appropriate clothing, and adjustment of activity according to ambient temperature and humidity. High humidity levels, even when air temperature is not excessive, result in high heat stress.

In addition, the American Academy of Pediatrics (Anderson et al. 2000) recommends the following for children and adolescents engaged in activities on hot days regardless of the playing surface or location:

1. The intensity of activities that last 15 minutes or more should be reduced whenever relative humidity, solar radiation, and air temperature are above critical levels. One way of increasing rest periods on a hot day is to substitute players frequently.
2. At the beginning of a strenuous exercise program or after traveling to a warmer climate, the intensity and duration of exercise should be limited initially and then gradually increased during a period of 10 to 14 days to accomplish acclimatization to the heat. When such a period is not available, the length of time for participants during practice and competition should be curtailed.
3. Before prolonged physical activity, the child should be well-hydrated. During the activity, periodic drinking should be enforced (e.g., each 20 minutes 150 mL [5 oz] of cold tap water for a child weighing 40 kg (88 lbs) and 250 mL [9 oz] for an adolescent weighing 60 kg (132 lbs)), even if the child does not feel thirsty. Weighing before and after a training session can verify hydration status if the child is weighed wearing little or no clothing.
4. Clothing should be light-colored and lightweight and limited to one layer of absorbent material to facilitate evaporation of sweat. Sweat-saturated garments should be replaced by dry garments. Rubberized sweat suits should never be used to produce loss of weight.

4.1.4 Techniques for Measuring Heat Effects from Synthetic Turf Fields

Air and surface temperatures can be measured a number of ways, including via an infrared thermometer (McNitt and Petrunak 2007d, Williams and Pulley 2002) or a traditional thermometer. Noncontact infrared (IR) thermometers use infrared technology to quickly and conveniently measure the surface temperature of objects. They provide fast temperature readings without physically touching the object. The user aims, pulls the trigger and reads the temperature on the LCD display. Lightweight, compact, and easy-to-use, IR thermometers can safely measure hot, hazardous, or hard-to-reach surfaces without contaminating or damaging the object. Also, infrared thermometers can provide several readings per second, as compared to contact methods where each measurement can take several minutes.

Temperatures of the subsurface can be taken with a soil thermometer (Williams and Pulley 2002). A soil thermometer is designed to measure the ground temperature. The thermometer, after being inserted into the ground, measures the temperature at the end of the probe.

Finally, the wet bulb globe temperature (WBGT), an index of climatic heat stress, which is influenced by air temperature, radiant heat, air movement, and humidity can be measured. A special apparatus for measuring WBGT can be used to assess heat stress conditions. It is noteworthy that 70% of climatic heat stress is due to humidity, 20% to radiation, and only 10% to air temperature (Anderson et al. 2000).

4.1.5 Summary of Information Reviewed on the Impact of Synthetic Turf on Ambient and Surface Temperatures

Table 4-1 summarizes the information reviewed for the assessment of the impact of synthetic turf on ambient and surface temperatures. A more detailed summary of each article can be found in Appendix B-3.

TABLE 4-1. SUMMARY OF INFORMATION REVIEWED ON THE IMPACT OF SYTHETIC TURF ON AMBIENT AND SURFACE TEMPERATURES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
Adamson 2007	• This article presents a series of temperature measurements conducted by the University of Missouri.	• Temperatures were measured at the University of Missouri's Faurot Field, on a 98° day and registered 173° F on the surface of the synthetic grass. Nearby natural grass showed a temperature of 105° F on the surface. Temperatures taken at head-level height over the synthetic turf registered 138° F.	• Methodology and equipment used in the temperature studies not discussed.
Benepe 2007	• Commissioner testimony focusing on the history of synthetic turf, synthetic turf today, the challenges of maintaining the parks and fields in light of the increased population of New York City and the increased use of the park facilities. • Provides statistics on the increased use of the parks as evidenced by the increase in permit hours.		
McNitt and Petrunak 2007d	• This study tested 10 synthetic turf systems for surface temperatures and ambient air temperatures 3 feet above the field surface. • The investigators also looked at the effect of irrigation on the temperature of the synthetic turf fields.	• The surface temperatures of the fields ranged from 113.7oF to 125.4°F. • The ambient air temperatures 3 feet above the turf surface ranged from 78.1°F to 80.6°F. However, the ambient temperature did not appear to be correlated with the surface temperatures of the turf systems. • The application of water cooled down all synthetic surfaces, but they rebounded quickly. • At the end of the experiment the irrigated fields averaged about 14 degrees cooler than the non-irrigated fields.	• Actual methods are not provided. • The study did not provide any discussion on discrepancy between this study and others concerning ambient air temperatures, where other studies found temperature differences and this one did not.
Rosenzweig, Solecki and Slosberg 2006	• This study evaluated heat island effect mitigation strategies for New York City in the summer of 2002. • These strategies include urban forestry, living/green roofs and light surfaces.	• The results of the study indicated that increasing vegetation has a great effect on reducing temperatures and recommends planting street trees in open spaces as well as building living roofs to provide the greatest cooling potential by area.	• No discussion of potential for synthetic turf fields to contribute to heat island effect.

TABLE 4-1. SUMMARY OF INFORMATION REVIEWED ON THE IMPACT OF SYTHETIC TURF ON AMBIENT AND SURFACE TEMPERATURES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
Williams and Pulley 2002	• This article presents a report by the authors on a series of heat studies conducted on synthetic surfaces at Brigham Young University.	• The results of the preliminary experiments showed that the surface temperature of the synthetic turf was 37° F hotter than asphalt and 86.5 ° F hotter than natural turf. • Irrigation of the synthetic turf with cooling water had a significant effect on surface temperature, dropping the temperature on the surface from 174 ° F to 85 ° F, but there was a rapid rebound effect with the temperature rising to 120 ° F in 5 minutes and to 164 ° F at 20 minutes. • Shading decreases the amount of heating of synthetic turf. Average surface temperature measurements of natural and synthetic turf taken in the shade show an approximate 9.5 ° difference (66.35° F versus 75.89° F) between the two, respectively. However, the synthetic turf field's maximum temperature rose to 99° F while that of the natural turf rose to 75° F.	• Actual methods are not provided. • Average temperatures between a 12-hour span are provided, but no back-up data for individual readings is provided. • No corresponding air temperatures provided for measurement time period. • Maximum temperatures were only provided for turf (synthetic and natural), not for asphalt. • Regarding the use of water as a coolant, water quickly cooled the surface temperature, but temperatures quickly rose. The material is hydroscopic and is not meant to retain water at the surface.

4.2 Hardness, Abrasiveness, Injury Types and Infection Risk of Synthetic Fields

In addition to potential heat-related effects, one of the concerns raised about the use of synthetic turf materials is the potential for increased injury to players as compared to natural turf materials. The different measurable factors that influence injury by type, frequency and severity are hardness, abrasiveness and traction. The standard method for measuring the surface hardness of synthetic turf is the American Standard Testing Method (ASTM) F355 Method A. Surface hardness has been shown to affect both player performance and player safety. Surface hardness is measured in Gmax: the higher the Gmax value, the harder the surface. The ASTM has established an upper limit for surface hardness of 200 Gmax above which head trauma is more likely to occur and above which ASTM suggests repairing or replacing the surface. ASTM (2000c) states:

> "The aim of this specification is to provide a uniform means and relatively transportable method of establishing this characteristic in the field based on historical data. According to historical data, the value of 200 G is considered to be a maximum threshold to provide an acceptable level of protection to users.
>
> The test method used in this specification (Procedure A of Test Method F 355), has been documented, through "unofficial" use for testing impact in fields for over 20 years. The development of this 2 ft fall height method can be traced back to the Ford and General Motors crash dummy tests of the 1960's, medical research papers from the 1960's and 1970's, and a Northwestern University study in which an accelerometer was fixed to the helmet of a middle linebacker to measure the impact received during actual play. This study found the impact to be 40 ft/lb that translates to the 20 lb at a height of 2 ft used in Procedure A of Test Method F 355. The maximum impact level of 200 average Gmax, as accepted by the U.S. Consumer Product Safety Commission, was adopted for use here."

The device to measure hardness is simply a hollow tube through which a 20 pound weight is dropped onto the surface from a height of two feet (ASTM 2000a). A device inside the weight measures how quickly the weight stops upon impact. The faster the weight comes to a stop, harder the surface.

Surface hardness is important due to the risk of head injuries upon impact with the ground surface. Surface hardness has been shown to affect both player performance and player safety. McNitt and Petrunak (2007c) evaluated surface hardness or impact attenuation on "no wear" turf and "wear" turf which simulated turf after having up to 96 games played on it. Using two different ASTM methods (Methods F355 and the Clegg Impact Soil Tester (CIST)), the hardness index remained well below the maximum Gmax rating of 200 for all scenarios tested

(McNitt and Petrunak 2007c). A study conducted by Naunheim et al. (2002, 2004) evaluated the impact attenuation of three indoor fields: the first field was an indoor domed stadium with AstroTurf with a 5/8 inch foam underlayment, the second field was an indoor practice field with AstroTurf with a 1 inch foam underlayment, the third field was an infilled FieldTurf system which replaced the indoor practice AstroTurf field. These fields were compared to the impact attenuation of a natural outdoor field measured at 72°F and 32°F. The change from a foam-based Astroturf system to a shredded rubber-based system (FieldTurf) had no effect on impact attenuation overall. However, areas in the shredded rubber-based field were significantly compacted; causing some sites to be much harder than the foam-based surface it replaced (Naunheim et al. 2004).

In addition to concerns raised about the hardness of synthetic turf systems, abrasiveness has been raised as an issue, especially with older synthetic turf materials. New generation synthetic turf systems have been manufactured to be soft and more resilient, unlike older versions which were hard and abrasive. Abrasiveness is measured by ASTM Method F1015. Friable foam blocks, made of rigid closed-cell isocyanurate, were attached to a weighted platform that is pulled over the turf surface in four directions. The weight of the foam that is abraded away determines the abrasiveness of the surface. An Abrasiveness Index is calculated by taking the weight loss of all four blocks in grams and dividing by 0.0606 per ASTM F1015. A study conducted on 10 synthetic turf systems showed that all fields with infill material systems were less abrasive than the older generation, carpet-like synthetic turf system, and on-going maintenance tended to lessen the abrasiveness (McNitt and Petrunak 2007a).

A number of studies have been conducted evaluating the potential for injuries occurring on synthetic turf versus natural grass. The studies have shown either no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by men or women (Fuller et al. 2007a, 2007b) or that injury rates are similar but that the type of injury varies between the two surfaces (Meyers and Barnhill 2004; Steffen et al. 2007). A study conducted by Meyers and Barnhill (2004) found that surface to skin injuries and muscle strains were more common on synthetic turf, while on the natural grass fields they documented a greater incidence of head concussions and ligament tears. A study conducted on young female football players (soccer players) conducted by Steffen et al (2007) showed that injury rates (i.e., the number of injuries per 1000 hours of exposure) were similar between synthetic turf and grass. However, there were differences in types of injuries between synthetic turf and grass. In matches, twice as many severe injuries occurred on synthetic turf as on grass; however, the rate for minor injuries was significantly lower when playing on synthetic turf than on grass. More ligament and knee injuries occurred on synthetic turf than on grass (Steffen et al 2007). None of the above studies documented the type of synthetic turf surfaces that were played on. In addition, differences between the studies may be due to the sport (soccer versus football) or the age of the athletes (collegiate versus high school).

In addition to physical injuries, there are concerns over the increased potential for severe bacterial infections, such as methicillin-resistant *S. aureus* (MRSA) infections, to occur in athletes playing on synthetic turf. Studies have shown that although synthetic turf burns provide a means of access for MRSA infections, physical contact and poor sanitary practices in the locker rooms and training facilities facilitate the transmission of the disease (Begier et al 2004; Kazakova et al 2005). Another study found that synthetic turf systems are not a hospitable environment for microbial activity, further indicating a lack of correlation between bacterial infections in athletes and bacterial skin infections (McNitt et al. 2007). Based on the above information, it does not appear that synthetic turf is a source of MRSA infection; however, turf burns may act as a means of entry for the MRSA infection. It is recommended that coaching staff be aware of the potential for MRSA transmission and infection among athletes. Should abrasions occur, they should be washed with soap and water and covered immediately. Athletic departments of schools utilizing these fields should engage in good hygienic practices in their locker rooms and treatment facilities. Uniforms should be washed and equipment (shoulder, hip and elbow pads, etc) should be periodically sanitized as they can be a reservoir for MRSA infection.

4.2.1 Assess Impact Attenuation of Different Field Surfaces

The NYC DPR's Capital Projects Team assesses the danger of head trauma from impact with the ground using a G-rating system which measures surface hardness (Benepe 2007). The surface hardness refers to the ability of a surface to absorb impact energy. Playing surface hardness affects both player performance and player safety. A soft field may create early fatigue in leg muscles, while fields that are hard may be dangerous when players fall. Therefore, a balance is sought between the two which maximizes playability while still protecting players. The standard method for measuring the surface hardness of synthetic turf is standard ASTM F355 Method A. The device is simply a hollow tube through which a 20 pound weight is dropped onto the surface from a height of two feet (ASTM 2000). A device inside the weight measures how quickly the weight stops upon impact. The faster the weight comes to a stop, the harder the surface. Surface hardness is measured in Gmax: the higher the Gmax value, the harder the surface. The ASTM upper limit is 200 Gmax; above that, they suggest repairing or replacing the surface. This number was originally generated from the auto industry and data regarding the force of a human head impacting a dashboard (McNitt 2002).

DPR has every synthetic field tested by an independent third-party to ensure compliance with Consumer Product Safety Commission standards, which state that a Gmax rating of 200 or above represents an increased risk of head trauma from a fall. When the DPR installs a field it has to have a rating of 130 at installation and can never be above 180 for the life of the 8 year warranty. When the NYC DPR installs these synthetic turf fields they generally have a rating of about 120, which is considered very safe. After six months, when the field settles and has received some use, that rating typically goes up to about 140 in the most heavily used parts of the field, but then, in general, that number will plateau over the next few years so it stays well below 200 (Benepe 2007). Natural grass fields have an average G-Max rating of approximately 80-140, depending on the moisture in the soil. For comparison, a muddy grass field will have a G-Max value of approximately 65, a frozen grass field will have a G-Max value of approximately 225 (Academy Sports Turf 2007), and an asphalt field will have a G-Max value of approximately 1440 (Hoerner 1997).

A number of studies have been conducted to measure surface hardness or impact attenuation of synthetic turf fields. The ability a surface has to absorb energy created by a player upon impact is referred to as surface hardness, or impact attenuation (McNitt 2000). In a study conducted by Penn State's Department of Crop and Soil Sciences, surface hardness measurements were conducted in accordance with two ASTM methods (F355 and the Clegg Impact Soil Tester (CIST)) on 10 different synthetic turf systems that represented a "no wear" and a "wear" scenario. Simulated foot traffic was first applied to the turf fields using a "Brinkman Traffic Simulator". The traffic simulator weighs 410 kg and consists of a frame with two 1.2 meter rollers, with steel "cleats" welded to them was pulled with a tractor. Two passes of the traffic simulator produces the equivalent number of cleat dents created between the hash marks at the 40-yard line during one National Football Game (Cockerham and Brinkman, 1989). Thus, 24 passes per week are equivalent to the cleat dents sustained from 12 games per week. Surface hardness and impact attenuation were then conducted in accordance with ASTM methods on “no wear” turf and “wear” turf which simulated turf after having up to 96 games played on it. The CIST and the F355 methods were used to measure surface hardness. The CIST method is similar to the F355 method, except it uses a 5 pound weight which has a smaller impact surface area. The Gmax generated by the CIST method is smaller than the F355 method. The CIST method is the ASTM standard for measuring the surface hardness of natural turf (ASTM 2000b). Under all scenarios tested, the hardness index remained well below the maximum Gmax rating of 200 or the comparable 135 rating of the CIST method (McNitt and Petrunak 2007c).

Naunheim et al. (2002, 2004) conducted studies evaluating the hardness of various fields in order to test the surfaces of football fields used by a professional team to determine their impact attenuation properties. Four playing surfaces used by a professional football team were tested. The first field was an AstroTurf (5/8-inch foam padding over concrete) field at a domed stadium, the second field was an indoor practice field with AstroTurf (1-inch padding over concrete), the third was an outdoor grass practice field, measured at 72° F and 32° F and the fourth field was the infill FieldTurf surface that replaced the AstroTurf (1-inch padding) in the indoor practice field. A computerized impact recording device (IRD) was used to determine whether a new shredded rubber-based turf improves impact attenuation. The device was dropped 20 times from a height of 48 inches onto each of the surfaces. Five different areas of each field were tested; the center of the field at the 30-yard line, the center of the field at the 50-yard line, the hash marks on either side of the 50-yard line, and the mid 30-yard line at the opposite end of the field. These areas were chosen because they would see the most use during game play. Of the five measurements, there was no difference in the measured surface hardness between the infill FieldTurf field and the AstroTurf field with one inch padding. Both of these fields had significantly less surface hardness than the AstroTurf with 5/8-inch padding and the measurements taken on the grass fields at both temperatures (Naunheim et al., 2002, 2004). The authors also note that the FieldTurf field evidenced surface compaction in high traffic areas resulting in areas that were harder than the foam-based AstroTurf field it replaced (Naunheim et al. 2004)

Table 4-2 summarizes the information reviewed for assessing surface hardness of synthetic turf fields. A more detailed summary of each article can also be found in Appendix B-3.

TABLE 4-2. SUMMARY OF STUDIES ASSESSING SURFACE HARDNESS OF SYNTHTIC TURF FIELDS			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
McNitt and Petrunak 2007c	• This study evaluated surface hardness and impact attenuation as part of a large project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time under no wear and wear scenarios. • Wear was simulated on the turf fields using the "Brinkman Traffic Simulator"	• The results show that after wear simulating up to 96 games, the hardness index remained well below the maximum Gmax rating of 200, indicating that the turf materials maintained their engineered hardness level after wear.	• Measurements only taken on two days during the summer, no readings during colder weather. For comparison, it would be informative to have data from actual playing fields instead of just from the experimental turf fields used in this study.
Naunheim et al 2002, 2004	• These studies compare the impact attenuation for a newer generation of synthetic turf as compared to older versions of synthetic turf used in indoor playing surfaces.	• Both the shredded rubber-based system (FieldTurf) and the foam-based AstroTurf field it replaced demonstrated g values of ~184. The g values of the other three fields included 261.6 (indoor domed stadium with AstroTurf and 5/8 foam padding), 264.4 (outdoor warm grass) and 398.2 (frozen outdoor grass field). • The change from a foam-based Astroturf system to a shredded rubber-based system (FieldTurf) had no effect on impact attenuation overall. However, areas in the shredded rubber-based field (FieldTurf) were significantly compacted, resulting in some sites to be much harder than the foam-based surface (AstroTurf) it replaced.	• Did not use ASTM Method F355 for measurement of Gmax, which is the standard method for testing hardness of synthetic turf. By using an alternate method, unable to compare with other studies, since this study's g-values are substantially higher than recordings noted elsewhere. Warm outdoor grass was noted as having a g-value of 264.4, however, it's Gmax value is typically cited as 140 or less. • The FieldTurf field underlayment consists of shredded tire and sand, not crumb rubber, with a infill material.

4.2.2 Assess Abrasiveness of Different Field Surfaces

The older generation of synthetic turf was carpet-like, harder and more abrasive than the "newer generation" of synthetic turf. The shorter fibers are stiffer and more abrasive. The more abrasive a surface, the more apt the surface is to cause friction burns when an athlete's bare skin comes into contact with the surface. Friction burns (turf burns) were a common complaint from athletes using the older generation of synthetic turf (Academy Sports Turf 2007). The "new generation" synthetic turf has been manufactured to be soft and spongy and more "grass-like". The newest generation of synthetic turf places a fine-textured canopy of fibers (the synthetic blades of grass) over a base of well-drained aggregate consisting of crumb rubber and in some cases sand. The fibers are then top-dressed with a layer of crumb rubber or a combination of crushed rubber and sand to provide extra padding and keep the grass upright. The infill also serves as a ballast to hold the carpet down and acts as a shock absorber to help prevent serious injuries and create a safer, more resilient surface (Academy Sports Turf 2007, Morrison 2005, Benepe 2007).

In Penn State's Department of Crop and Soil Sciences long-term study on 10 synthetic turf systems, abrasiveness of the synthetic turf systems were measured using ASTM Method F1015. Friable foam blocks, made of rigid closed-cell isocyanurate, were attached to a weighted platform that was pulled over the turf surface in four directions. The weight of the foam that is abraded away determines the abrasiveness of the surface. An Abrasiveness Index is calculated by taking the weight loss of all four blocks in grams and dividing by 0.0606 per ASTM F1015. All infill systems were less abrasive than the traditional, carpet-like, Astroturf. Grooming of the surfaces tended to lessen the abrasiveness. The test is being modified for use on natural turf.

Table 4-3 summarizes the information reviewed for the abrasiveness of synthetic turf fields. A more detailed summary of this article can also be found in Appendix B-3.

TABLE 4-3. SUMMARY OF ABRASIVENESS STUDIES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
McNitt and Petrunak 2007a	• This study evaluated the abrasiveness of various synthetic turf systems, including infilled systems and the traditional, carpet-like AstroTurf as part of a large project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time. • Surface quality was evaluated periodically as the systems were exposed to weather and simulated foot traffic, using the Brinkman Traffic Simulator. The effects of various maintenance activities on the playing surface quality of these systems were also evaluated.	• All infill systems were less abrasive than traditional Astroturf. Grooming of the surfaces tended to lessen the abrasiveness. The test is being modified for use on natural turf.	• No context provided for the Abrasiveness Index, other than comparison to AstroTurf which was used as the standard for abrasiveness.

4.2.3 Frequency of Injury in Different Playing Fields

Four types of traction have been defined by Shorten and Himmelsbach (2002) and they include translational, rotational, static, and dynamic traction (summaries from McNitt and Petrunak 2007e):

- Translational traction refers to the traction that resists the shoe's sliding across the surface. For the athlete, high translational traction equates to the shoe gripping the surface and low translational traction means the shoe tends to slip.
- Rotational traction refers to the traction that resists rotation of the shoe during pivoting movements. For the athlete, high rotational traction equates to a greater tendency for foot fixation during changes of direction and low rotational traction means the shoe tends to release from the surface more easily.
- Static traction is the resistance to sliding or pivoting when there is no movement between the shoe and the surface. Static traction forces tend to resist the initiation of sliding or pivoting.
- Dynamic traction is the resistance that occurs during a sliding or pivoting motion. Dynamic traction forces tend to resist or decelerate pivoting motions.

Because of the link between foot fixation and knee injuries, resistance to rotation (rotational traction) between the shoe and the ground should be as low as possible providing adequate translational traction is maintained (Shorten and Himmelsbach 2002). McNitt and Petrunak's on-going study of synthetic turf systems at the University of Pennsylvania compared the rotational and translational traction of 10 synthetic turf systems under "no-wear" and "wear" conditions, with and without grooming (McNitt and Petrunak 2007e). In addition, they tested two different types of turf shoes, a post-type cleat and a molded shoe. The study was conducted in accordance with the proposed traction standard ASTM WK486 (ASTM 2000c). The preliminary results of the study show there were few meaningful traction differences between synthetic turf systems in the no-wear scenario, although the traditional, carpet-like Astroturf measured consistently higher in linear traction compared to the infill systems. This trend was not evident in the rotational traction results. Measurements taken shortly after field grooming showed that translational traction tended to increase after grooming whereas rotational traction tended to have no change or trend slightly lower. During 2004, grooming resulted in a greater reduction in rotational traction compared to 2003. In addition, there continued to be a trend of increased translational traction after grooming for the no wear treatments but the trend was less evident in the treatments receiving wear. This was true regardless of shoe type. It may be that as these systems age, grooming will have a diminished affect on translational traction. When traction was measured on the various synthetic turf surfaces during wet conditions, traction was generally reduced. The overall significance of this data, as it relates to injury, is that, immediately after grooming, an athlete will experience increased translational (linear) traction and either no change or a slight decrease in rotational traction, thus allowing, for example, a football lineman more traction when pushing but affecting no change or a slight reduction in the rotational foot fixation that Shorten and Himmelsbach (2002) state has a direct affect on lower extremity injuries (McNitt and Petrunak 2007e).

The concerns over the potential for increased injuries associated with the use of synthetic turf systems have led to a number of studies comparing risk for increased injuries on synthetic turf versus natural turf. These studies have shown either no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by men or women (Fuller, et al 2007a, 2007b) or that injury rates are similar but that the type of injury varies between the two surfaces (Meyers and Barnhill 2004; Steffen et al. 2007). Studies by Fuller et al. (2007a, b), Meyers and Barnhill (2004) and Steffen et al. (2007) evaluated the incidence of injuries of both female and male soccer players playing on synthetic turf systems compared to natural grass turf systems. Fuller et al. evaluated the incidence of injuries occurring during matches (2007a) and during training (2007b) of a total of 106 male teams and 136 female teams over two competitive seasons and concluded that there were no major differences between synthetic turf and natural grass in the incidence rate, severity, nature or cause of injuries sustained during training or match play. Meyers and Barnhill (2004) compared the incidence of injuries of eight high school football teams over five competitive seasons playing on synthetic turf or natural grass fields. Statistical analyses indicated significant playing surface effects by injury time loss, injury mechanism, anatomical location of injury, and type of tissue injured. Natural grass fields had the higher incidences of injury time loss and more severe injuries such as head and neural trauma and ligament injuries. The synthetic turf fields had higher incidences of minor injuries such as surface/epidermal (skin) injuries, muscle related trauma and a higher incidence of injury occurrence during higher temperatures. Steffen et al. (2007) evaluated the risk of injury on synthetic turf compared to natural turf systems. Two thousand and twenty (2020) female soccer players from 109 teams participated in the study. The incidence of acute injuries did not differ between synthetic turf and natural turf. During matches, there was a higher incidence of severe injuries (more than 21 days lost playing time) found with synthetic turf fields. Also, the rate for minor injuries tended to be lower on synthetic turf fields than on grass fields. None of the above studies documented the type of synthetic turf surfaces that were played on. In addition, differences between the studies may be due to the sport (soccer versus football) or the age of the athletes (collegiate versus high school).

Table 4-4 summarizes the information reviewed for the assessment of the incidence of injuries sustained on synthetic turf fields. A more detailed summary of each article can also be found in Appendix B-3.

TABLE 4-4. SUMMARY OF INJURY STUDIES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
Fuller et al 2007a,b	• This study evaluated the incidence of injuries sustained by men and women football players (i.e. soccer), playing on either natural grass or "new generation" synthetic turf (i.e. synthetic turf with rubber crumb infill material).	• The studies concluded that there were no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by either men or women.	• Subjects were college athletes, with higher degrees of physical capabilities and conditioning.
McNitt and Petrunak 2007e	• Evaluated rotational and translational traction of 10 synthetic turf fields as a measure of the potential for lower limb injuries.	• Measurements taken shortly after field grooming showed that translational traction tended to increase after grooming whereas rotational traction tended to have no change or trend slightly lower. • As the fields aged, grooming resulted in a greater reduction in rotational traction compared to earlier measurements. • There continued to be a trend of increased linear traction after grooming for the no wear treatments but the trend was less evident in the treatments receiving wear. This was true regardless of shoe type.	• No standard value for comparison. Traction compared against traditional AstroTurf surface.
Meyers and Barnhill 2004	• A five year study was conducted to compare game-related, high school football injuries between natural grass and FieldTurf from 1998 to 2002.	• The results of the study indicate no significant differences between playing surfaces across injury categories and time of injury. However, there were observable differences between the two playing surfaces. • Natural grass fields actually had the higher incidences of injury time loss and more severe injuries such as head and neural trauma and ligament injuries. The synthetic turf fields had higher incidences of minor injuries such as surface/epidermal (skin) injuries, muscle related trauma and a higher incidence of injury occurrence during higher temperatures.	• The weather was characterized as dry and low humidity, resulting in hard, natural grass playing surfaces.

TABLE 4-4. SUMMARY OF INJURY STUDIES			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
Steffen et al 2007	• A retrospective cohort study to investigate the risk of injury on synthetic turf compared with natural grass among young female football players was conducted with 2020 players on 109 teams in 2005.	• Acute injury rates (i.e., the number of injuries per 1000 hours of exposure) were similar between synthetic turf and grass. However, there were differences in types of injuries between synthetic turf and grass. • Sprained ankles were the highest recorded injury, with an increasing trend towards more ankle sprains on synthetic turf. There was a higher incidence of severe injuries (more than 21 days lost playing time) with synthetic turf fields. Also, the rate for minor injuries tended to be lower on synthetic turf fields than on grass fields.	• Differences in synthetic turf types were not accounted for in the study • Players played on synthetic turf, grass, gravel and indoor floors, and the potential for injury due to varying play surfaces is unknown due to poor statistical power of the gravel and indoor floor cohorts. • Maintenance status of the synthetic turf and grass fields was not accounted for in the study. • Weather conditions were not noted in this study.

4.2.4 Assessment of Potential of *Staphylococcus Aureus* Infection Associated with Synthetic Turf

Methicillin-resistant *S. aureus* (MRSA) is a drug resistant bacteria implicated in severe, sometimes life-threatening or fatal infection in health care settings. Cases of community acquired severe infection with MRSA are becoming more common. Investigations of outbreaks among sports team members of MRSA in athletes have been published (Kazakova et al. 2005; Begier et al. 2004; CDC 2003). Turf playing fields were evaluated as a potential risk factor for MRSA infection. Two possible risk factors for contracting a MRSA infection from synthetic turf fields are a) an increased risk for skin abrasions and other injuries leading to open wounds and b) whether the fields themselves harbor the bacteria. Two studies (Kazakova et al. 2005) and Begier et al. 2004) were conducted with professional (Kazakova et al. 2005) and college (Begier et al. 2004) football teams to determine the relationship between synthetic turf and MRSA infections. Kazakova et al. (2005) and Begier et al. (2004) both concluded that skin abrasions and turf burns caused by synthetic turf provide a means of access for the MRSA infection. However, in both cases it was found that physical contact (due to position played), body shaving, equipment sharing, and poor sanitary practices in the locker rooms and training facilities facilitate the transmission of the disease (Begier et al. 2004; Kazakova et al. 2005). These studies evaluated team members involved in intensive training programs or summer sports practice.

McNitt et al. (2007) evaluated environmental bulk samples taken from a number of synthetic turf fields throughout Pennsylvania, ranging from elementary school to professional athletic fields and assayed them for total microbial growth as well as MRSA. In addition, they collected swab samples from common public areas, an athletic training facility as well as from the hands and face of random individuals. The investigators found no MRSA on any of the synthetic turf samples. *Staphylococcus aureus* was found, however, on blocking pads, weight equipment, stretching tables, and used towels, in addition to the hands of five randomly tested individuals. The McNitt study concluded that "These infilled systems are not a hospitable environment for microbial activity. They tend to be dry and exposed to outdoor temperatures, which fluctuate rapidly. Plus, the infill media itself (ground-up tires) contains zinc and sulfur, both of which are known to inhibit microbial growth. Considering the temperature range for growth of *S. aureus* is 7-48°C (44.6-118.4^{o}F), we didn't expect to find this bacterium in fields exposed to sunlight, since the temperatures on these fields far exceed 48°C frequently."

Based on the above information, it does not appear that synthetic turf is a source of MRSA infection; however, abrasions may act as a means of entry for the MRSA infection. The rates of abrasions on the types of synthetic turf fields with crumb rubber infill have not been characterized, but are likely to be lower than from team sports played on professional or older generation turf fields. It is recommended that coaching staff be aware of the potential for MRSA transmission and infection among athletes playing on any playing surface. Should abrasions occur, they should be washed with soap and water and covered immediately. Athletic departments of schools utilizing these fields should engage in good hygienic practices in their locker rooms and treatment facilities. Uniforms should be washed and equipment (shoulder, hip and elbow pads, etc) should be periodically sanitized as they can be a reservoir for MRSA infection.

Table 4-5 presents a summary of the studies that assessed the association of *S. aureus* infections with synthetic turf. A more detailed summary of each article can also be found in Appendix B-3.

4-5. SUMMARY OF STUDIES ASSESSING MRSA AND SYNTHETIC TURF FIELDS			
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**
Begier et al 2004	• A retrospective cohort study was conducted to investigate a MRSA outbreak in 10 members of a college football team who played on carpet-style synthetic turf.	• Turf burns were thought to facilitate infection and the authors suggest that eliminating turf burns would be the best way to prevent infection. The authors also note that study on the risk of abrasion from synthetic turf warrants further study. • Authors note that players with high physical contact rates during games or practices, equipment such as elbow pads, shaving of body hair and the whirlpool in physical therapy all had high associations with an increased risk of contracting MRSA.	• The study was a reflective cohort study; therefore, it did not include sampling of surfaces routinely contacted by the athletes and did not sample the whirlpool water to identify sources for the MRSA infections. The study evaluated activities conducted by college football players and thus likely presents more intensive use of the synthetic turf fields than would occur during recreational use of the fields.
Kazakova et al 2005	• A retrospective cohort study was conducted on members of the professional football team, the St. Louis Rams to evaluate potential causes or sources for the MRSA outbreak.	• The results of the statistical analysis of the data showed that all MRSA skin abscesses developed at turf burn sites. These sites were usually not covered, and the authors concluded that these abrasions were likely the entry point for transmission of MRSA.	• This study did establish a link between the occurrence of turf burns and MRSA infections; however, other factors, such as poor hygienic practices, may have contributed or caused the outbreak. Further study is needed to establish a causal link between synthetic turf burns and MRSA infections. The study evaluated activities conducted by professional football players, thus it more likely presents a more intensive use of the synthetic turf fields than would occur during recreational use of the fields.
McNitt et al 2007	• The objective of this study was to determine the microbial population of several infilled synthetic turf systems as well as compare them to natural turf grass fields. In addition, other surfaces from public areas and from an athletic training facility were also sampled.	• The study concluded that infill systems are not a hospitable environment for microbial activity.	• The study did not indicate temperature of field at the time of sampling

5.0 BENEFITS OF USING SYNTHETIC TURF FIELDS

5.1 Increased Access

Synthetic turf fields have increased versatility and high durability, and their installation will substantially increase access to playing fields. They typically last a long time and need little maintenance. The fields do not require weekly mowing, watering, fertilizing, seeding, or other time-intensive maintenance tasks. They also do not need to be "rested" like natural turf, nor does play need to be halted because of inclement weather due to their engineered drainage systems. Additionally, they are useable year-round, can be played on after heavy rain, and wear out much more slowly than natural grass.

In Brooklyn, the athletic field permits office estimates that synthetic turf fields can be permitted for 1,248 hours per year, which is 28% more than 972 hours per year for natural grass fields (Benepe 2007). Synthetic turf fields are a solution for meeting the growing need for field space in heavily developed urban neighborhoods.

5.2 Surface Hardness and Injury

In terms of surface hardness, synthetic turf fields are either as soft or softer than natural grass fields, especially in the colder months. Synthetic turf fields also provide a safer playing surface than asphalt fields. The "new generation" synthetic turf systems are designed to be as soft as grass and less abrasive than the "old generation" AstroTurf systems. A number of studies have been conducted evaluating the potential for injuries occurring on synthetic turf versus natural grass. The studies have shown either no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by men or women (Fuller, et al 2007a, 2007b) or that injury rates are similar but that the type of injury varies between the two surfaces (Meyers and Barnhill 2004, Steffen et al. 2007).

5.3 Health Benefits

Increased access to quality recreational facilities provides greater opportunities for children, youths and adults to exercise. Opportunities for active recreation and physical activity are critical to maintaining a healthy lifestyle. Over the past 20 years, the levels of obesity have doubled in the United States, and in New York City obesity is an epidemic. More than half of adult New Yorkers are overweight or obese, and nearly half of all elementary school children in NYC are either overweight or obese. Unhealthy weight gain, even during childhood, is related to diabetes, heart disease, asthma and depression (NYC DOHMH 2008).

5.4 Environmental Benefits

There are environmental benefits to these synthetic turf fields as well. These fields save potable water by eliminating irrigation needs. They also do not require the use of any chemical pesticides, herbicides, fertilizers and fuel-powered maintenance equipment (Benepe 2007).

6.0 RECOMMENDATIONS

Based on a review of the information available at the time of this review, the following recommendations are provided for the crumb rubber industry and operators of synthetic turf fields.

6.1 Chemical Make-up of Crumb Rubber

A review of the information in Chapter 2 has identified a lack of consistent test methods used for determining the chemicals in crumb rubber made from different source materials and from different processing techniques. Consistent and validated testing methods should be established through an objective process and complied with by the crumb rubber industry to determine the variability of infill material, including:

- Analyses of crumb rubber manufactured using mechanical grinding versus cryogenic processing methods.
- Analyses of crumb rubber produced from different sources (SBR granules versus EPDM granules versus TPE granules).

This information, along with the heat absorption and injury properties of synthetic turf fields, should be provided to prospective buyers.

6.2 Reduce Potential Health Effects Related to Heat Build Up

A review of the scientific literature identified heat build up as a potential health hazard of crumb rubber infill used in synthetic turf. Exposure to heat can result in heat illnesses including dehydration, heat cramps, heat exhaustion and heat stroke. To address potential heat exposures related to synthetic turf fields with crumb rubber, it is recommended that field operators:

- Educate field management staff, coaches and athletic staff, field users, and parents on the potential for heat-related illness, and how to recognize and prevent heat-related symptoms and illness.
- Assess the feasibility of adding heat mitigation measures to new and existing synthetic turf fields, such as accessible shade areas and drinking water fountains.
- Identify and implement the use of alternate infill material with lower heat absorption properties.

6.3 Assess Potential Inhalation Exposures

From the reviewed literature, it appears that inhalation may be the most likely route of exposure to the chemicals in crumb rubber. However, air measurements of COPC emissions conducted at synthetic turf fields, both indoors and outdoors, have shown levels to be non-detectable or similar to background levels. In addition, health risk assessments, using conservative estimates of inhalation exposure to PAHs, VOCs, and particulate matter, have not identified a significant risk to human health. However, additional air studies would provide more representative data for potential exposures related to synthetic field use in NYC, particularly among younger field users. Recommendations for future environmental studies include:

- Air measurements of COPCs in the breathing zones of users on both newly installed and older outdoor synthetic turf fields containing crumb rubber. Air monitoring targets should include PAHs, VOCs, and particulate matter, and should occur when the fields are hottest and during calm weather conditions for worst case scenarios; indoor turf fields in use should be included in such assessments.
- Background air sampling of COPCs in NYC. Air measurements should be taken simultaneously at nearby off-field sites, as well as natural and/or asphalt fields, in order to provide comparative data on exposures related to urban environments.

6.4 Protocol for Selecting and Purchasing Synthetic Turf Products

The Parks Department and other field operators should adopt protocols for selecting and purchasing synthetic turf and crumb rubber products. Such protocols should include requirements for suppliers and manufacturers to provide available information on: chemical content of products, potential COPC emissions from products over time, heat absorbency characteristics, injury factors, and other relevant health and safety information. In addition, protocols should provide for the continuous evaluation of new technologies, health and safety factors, and best practices for use and maintenance of synthetic turf fields.

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MSDS for Rubber Infill Materials provided by New York City Parks Department:

Synthetic Turf Manufacturers:
Aturf
Forever Green Athletic Fields, Inc

Rubber Infill Manufacturers:
Recycling Technologies Int'l, LLC
Re-Tek, Inc
SJM Group of New York

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APPENDIX A

MATERIAL SAFETY DATA SHEETS FOR SYNTHETIC TURF USED IN NEW YORK CITY

PRODUCT RT1 GROUND RUBBER

APRIL 2002

MATERIAL SAFETY DATA SHEET

RECYCLING TECHNOLOGIES INT'L, LLC
60 FILBERT ST.
HANOVER, PA 17331

INFORMATION (717) 633-9008 EMERGENCY (717) 633-9008 FAX (717) 633-9505

I. PRODUCT CHEMICAL & PHYSICAL CHARACTERISTICS

PRODUCT NAME Ground Rubber
APPEARANCE Black granular powder
SPECIFIC GRAVITY 1.13 to 1.27
VAPOR PRESSURE N/A
EVAPORATION RATE N/A

SOLUBILITY IN WATER Insoluble
ODOR Trace smell of vulcanized rubber
MELTING POINT N/A
VAPOR DENSITY N/A
BOILING POINT N/A

II. HAZARDOUS INGREDIENTS

MATERIAL (CAS)	% WT.	ACGIH/TLV	OSHA/PEL
NAPTHENIC/AROMATIC OIL(64742-01-4)	LESS THAN 25%	3 mg/M3	6 mg/M3
CARBON BLACK (1333-86-4)	LESS THAN 35%	3.5 mg/M3	3.5 mg/M3
TALC, RESPIRABLE DUST(14807-96-6)	LESS THAN 5%	2.0 mg/M3	2.0 mg/M3
ZINC COMPOUNDS(1314-13-2)	LESS THAN 3%	10 mg/M3	10 mg/M3

III. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT Ignition temperature of dust cloud
FLAMMABLE LIMITS N/A 608° F. approximately**

EXTINGUISHING MEDIA Water, foam, dry powder, water fog (DO NOT USE HIGH PRESSURE WATER)

FIRE FIGHTING PROCEDURES Heavy smoke and noxious gases may be formed under fire conditions, wear NIOSH approved breathing equipment.

UNUSUAL FIRE/EXPLOSION HAZARDS *Dust may be explosive if mixed with air in critical proportions in the presence of an ignition source

**Estimates based on data for 200 mesh synthetic & crude hard rubber dust; information contained in the NFPA Fire Protection Handbook.

IV. REACTIVITY INFORMATION

STABLE Yes

CONDITIONS TO AVOID Storage near fire or flame. Storage of hot material in hoppers due to potential spontaneous combustion.

HAZARDOUS DECOMPOSITION OR BY BY-PRODUCTS Thermal decomposition may produce carbon monoxide, carbon dioxide, zinc fume, sulfur dioxide, liquid and gaseous hydrocarbons.

V. HEALTH HAZARDS

ROUTE OF ENTRY Inhalation

CARCINOGENICITY Rubber is not listed as a carcinogen

SIGNS AND SYMPTONS OF EXPOSURE Skin itching, irritation of mucous membranes, eye irritation

MEDICAL CONDITIONS CAUSED BY EXPOSURE Could potentially aggravate allergies, due to dust exposure and/or inhalation

EMERGENCY PROCEDURES Wash with soap and water. Ordinary methods of personal hygiene are appropriate

VI. SAFE HANDLING

IF SPILLED Sweep or vacuum into disposal containers

WASTE DISPOSAL METHOD Product is not defined as hazardous waste. Follow Federal, State, and/or Local regulations

HANDLING AND STORING Do not store near open flame or ignition source

OTHER PRECAUTIONS If material burns, oils will be released. These must be disposed of by following Federal, State or Local regulations.

PRODUCT RTI GROUND RUBBER

VII. CONTROL MEASURES

RESPIRATORY PROTECTION Use any dust and mist respirator for up to 10 mg/M3

VENTILATION Yes **PROTECTIVE GLOVES** Recommended

EYE PROTECTION Use safety goggles to prevent dust entry

WORK/HYGIENIC PRACTICES Good personal hygiene, frequent washing with soap and water of exposed areas, remove and clean contaminated clothing

MATERIAL SAFETY DATA SHEET

CURED BLACK SBR RUBBER

Manufactured by: Re-Tek Inc.
3120 Claston Road
Central City, KY 42330
Phone#(502) 241-0980
Fax#(502) 241-0987

PRODUCT IDENTIFICATION

Generic ID: SBR (Cured)
Brand Name: SBR BLACK RUBBER GRANULES / STRANDS

HAZARDOUS INGREDIENTS

Hazardous Materials Descriptions and Proper Shipping Name: N/A
Hazardous Class: N/A
Chemical Family: N/A
Formula: N/A

INGREDIENTS

Name	CAS Registry No.	%
NR	80	44
CIS-Polybutadine	20	11
HAF Black	60	33
Oil(Softener)	10	5.5
Stearic Acid	2	1.1
Wax	2	1.1
Zinc Oxide	3	1.7
Sulfur	2	1.1
NOBS	.7	.4
ANTIOZ.	2	1.1

PHYSICAL DATA

Appearance and Odor: Black Rubber Granules-Characteristic Rubber Odor
Solubility in Water: Not Soluble
Specific Gravity: 1.20+/-.05 (Water = 1.0)
Boiling Point N/A
Vapor Pressure & Density: N/A
Evaporation Rate: N/A
Percent Volatile by Volume: N/A
pH N/A

FIRE AND EXPLOSION HAZARD DATA

Flash Point:	Not Determined
Flammable Limits:	N/A
Extinguishing Media:	Water, Foam, or Dry Chemical Extinguisher
Special Fire Fighting Procedures:	Firefighters to wear Self-Contained Breathing Apparatus
Unusual Fire/Explosion Hazard:	Product does not present any known explosion hazard

HEALTH HAZARD DATA

Effects of Overexposure:	None
Threshold Limit Value:	N/A
Permissible Exposure Limit:	N/A
Emergency and First Aid Procedures:	N/A

REACTIVITY DATA

Stability:	Stable
Conditions to Avoid:	None Known.
Hazardous Polymerization:	Will not occur
Hazardous Decomposition Products:	None

SPILL OR LEAK PROCEDURES

Pick or sweep up material and place in suitable container for disposal. Product is not defined as hazardous waste. Incinerate or landfill in accordance with applicable federal, state, and local regulations.

SPECIAL PROTECTION INFORMATION

Protective Equipment:	Eye protection should be worn
Ventilation:	Natural sufficient for normal handling. Mechanical exhaust required for hot processing such as curing or extrusion.
Other Protective Equipment:	None normally required for routine handling.
Hygiene Practices:	Maintain good personal hygiene when working with rubber compounds. Change soiled clothing regularly. Wash hands and other exposed skin surfaces thoroughly.
Handling and Storage:	No special precautions known to be needed.
Other Precautions:	Subjecting this product to further processing steps involving heat and/or exposure to nitrogen containing materials can form higher amounts of nitrosoamines which are believed to present a health hazard and are carcinogens in animals. Employees must avoid inhaling fumes from hot rubber processing.

518-669-9456

518-393-6141(fax)

SJM GROUP of New York
227 Seward Place – Suite 201
Schenectady, NY 12305
Sjmgroup@nycap.rr.com

SECTION I PRODUCT IDENTIFICATION

PRODUCT CODE:	All Whole Tire Products
PRODUCT NAME:	Reprocessed Ground Rubber
CHEMICAL FAMILY:	Not Applicable
HAZARD LABEL:	No Data
MOLECULAR FORMULA:	Not applicable
MOLECULAR WEIGHT:	No Data

NFPA RATINGS: (0-4) NFPA SPECIFIC HAZARDS

Health:	1
Flammability:	1
Reactivity:	0

SYNONYMS: Crumb Rubber, Fine Ground Rubber

SECTION II HAZARDOUS INGREDIENTS / IDENTITY INFORMATION

Composition: Mixture of natural and synthetic rubbers, carbon black, fillers and oils. White specs acceptable.

Components	CAS Number	%, Wt	OSHA PEL-TWA	ACGIH TLV-TWA
Reprocessed Rubber	NR :9003-31-0 SBR: 9003-55-8	40-55	15 mg/m^3*	10 mg/m^3**
Carbon Black	1333-86-4	27-33	3.5 mg/m^3	3.5 mg/m^3
Process Oil	64742-04-7	10-20	5 mg/m^3**	NA
Zinc Oxide	01314-13-2	1-5	5 mg/m^3**	10 mg/m^3
Sulfur	07704-34-9	1-5	NA	10 mg/m^3***
Stearic Acid	00057-11-4	1-5	NA	NA

* = Particulates Not Otherwise Classified (PNOC), 5 mg/m^3 respirable fraction
** = Total dust, 5mg/m^3 respirable fraction
*** = ACGIH TLV for Nuisance Dust
NA = Not Available/Not Applicable

SECTION III PHYSICAL / CHEMICAL CHARACTERISTICS

APPEARANCE: Black Granules with some white specs
SOLUBILITY IN WATER: Insoluble
SPECIFIC GRAVITY: 1.14±0.03
MELTING POINT: NA
NA
% VOLATILE BY VOLUME: <1% primarily water

ODOR: Rubber tire odor
VISCOSITY: NA
pH: NA
VAPOR PRESSURE:

VAPOR DENSITY: NA

518-669-9456

518-393-6141(fax)

SJM GROUP of New York

SECTION IV FIRE AND EXPLOSION HAZARD DATA

FLASHPOINT(COC): 475°F
AUTO-IGNITION TEMPERATURE: 700°F
FLAMMABLE LIMITS IN AIR % BY VOLUME: Upper: NA Lower: NA
EXTINGUISHING MEDIA. Water, Dry Chemical, Foam, or Carbon Dioxide.

SPECIAL FIRE FIGHTING PROCEDURES: All extinguishing media permitted - water recommended. Full emergency equipment with self contained breathing apparatus should be worn. During combustion, irritating and/or toxic gases and aerosols from decomposition products may be present.

UNUSUAL FIRE OR EXPLOSION HAZARD: This product will ignite when exposed to heat or flame. Rubber burns with intense heat and produces dense smoke. During an uncontrolled fire, incomplete combustion occurs which releases oil, soot(carbon black) and a wide range of hydrocarbon pyrolysis products.

DEFLAGRATION HAZARD: A dust explosion hazard exists with hard rubber in the powder form. Extreme precautions should be taken to prevent accumulations of rubber dust in the air surrounding work environments.

SECTION V REACTIVITY DATA

STABILITY: Material is stable.
CONDITIONS TO AVOID: Combustion.

INCOMPATIBILITY (MATERIALS TO AVOID): None known or expected.

HAZARDOUS POLYMERIZATION: Will not occur.

DECOMPOSITION PRODUCTS: Carbon monoxide, carbon dioxide, hydrogen, hydrogen sulfide, pentadiene, benzene, xylene, carbon, ash: (zinc oxide, titanium dioxide, silicon dioxide, calcium oxide, and magnesium), oxides of sulfur and nitrogen, sulfides, styrene, toluene, 4-vinyl-1-cyclohexene, 1,5-cyclooctadiene, 1,5,9- cyclododecatriene, various hydrocarbons, and various oxidized hydrocarbons.

SECTION VI HEALTH HAZARD DATA

Note: This product has not been tested by Rouse Rubber Industries, Inc. to determine its specific health hazards. The information provided in this section includes health hazard information for the product components.

CARCINOGENICITY: NTP? No IARC Monographs? Yes OSHA Regulated? No
CARCINOGENICITY/OTHER INFORMATION: This product contains petroleum oils similar to ones categorized by the International Agency for Research on Cancer (ISRC) as causing skin cancer in mice after prolonged and repeated contact. Any potential hazard can be minimized by using recommended protective equipment to avoid skin contact and by washing thoroughly after handling.

OCCUPATIONAL EXPOSURE LIMITS: See Section II.

SJM GROUP of New York

EFFECTS OF OVEREXPOSURE:

Acute:

Eyes: Slight to moderate eye irritation.
Skin: Moderately irritating.
Inhalation: Irritating to mucous membranes and respiratory tract.

Ingestion: Acute effects of rubber ingestion not determined.

Chronic: There is sufficient evidence for the carcinogenicity of solvent extract from heavy parafinnic distillates in experimental animals.

ADDITIONAL MEDICAL AND TOXICOLOGICAL INFORMATION: May aggravate pre-existing dermatitis. Certain rubber formulations contain trace nitrosamines, some of which are carcinogenic in animal experiments.

MEDICAL CONDITIONS GENERALLY AGGRAVATED BY EXPOSURE: Persons with pre-existing skin disorders may be more susceptible to irritating effects.

EMERGENCY AND FIRST AID PROCEDURES

Eye Contact: Flush thoroughly with water, see physician if eye irritation persists.
Skin Contact: Wash skin with soap and water.
Inhalation: Remove to fresh air.
Ingestion: Seek medical attention if large quantities are consumed.

SECTION VII PRECAUTIONS FOR SAFE HANDLING AND USE

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Collect in a manner appropriate for its physical condition

WASTE DISPOSAL METHOD: Dispose of in accordance with Federal, State, and Local regulations.

HAZARD LABEL INFORMATION: Store in a cool dry place.

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Store in a cool dry well ventilated area, away from direct sunlight.

OTHER PRECAUTIONS: Follow all applicable state, local, and federal regulations.

SECTION VIII CONTROL MEASURES

EYE PROTECTION: Use of safety glasses recommended as general safety practice at all times.

PROTECTIVE GLOVES: Wear gloves, minimize skin contact with product, and wash skin after handling.

VENTILATION: Ventilation should be provided at processing machinery to control fumes and odors. Fumes generated during processing or when overheated may by irritating. Respiratory protection is considered necessary where ventilation is not sufficient.

INGESTION: Not applicable.

APPENDIX B

LITERATURE SUMMARIES

APPENDIX B-1

SUMMARIES OF REVIEWED LITERATURE IN CHAPTER 2

A. MANUFACTURING PROCESSES OF RUBBER

SBR Tire Facts. Located on-line at: http://tireaccidents.com/basic_facts.htm. Accessed November 2007.

Initially, rubber was manufactured from natural plant sources using a vulcanization process that was discovered in 1893. In 1912, carbon was added to the process to strengthen rubber. Synthetic rubber took over as the major source of rubber in United States (US) the 1950s, and by 1990s, natural rubber had only 30% of the US market.

KemI, 2006. Synthetic Turf from a Chemical Perspective – a status report. Kemikalieinspektionen. Swedish Chemicals Inspectorate. July.

The authors present a summary of substances typically found in European tires as rubber, both natural and synthetic. Natural rubber is derived from sap from the rubber tree, *Hevea brasiliensis* and contains latex. Synthetic rubber is usually SBR or EPDM rubber. The EPDM rubber is newly manufactured rubber and with the exception of chromium and zinc, contains lower levels of hazardous substances; however this type of rubber is more expensive. The EPDM rubber also emits lower levels of the gaseous alkylated benzenes than the SBR. Other substances found in tires are carbon black (a reinforcing agent), polyethylene and polypropylene (stabilizers which slow down the reaction of the polymers with air and under the influence of light), aromatic oils, plasticizers, PAHs, phthalates, phenols, sulfur (vulcanizing agent), zinc, lead, copper, chromium, and cadmium.

Concentrations of different metals, phenols, and PAHs in different types of rubber granulates (recycled rubber, EPDM, and mixtures) were presented. Investigations have shown that zinc, lead, cadmium, copper, chromium, and mercury can leach from the rubber granulates, especially at higher pH. Phthalates and phenols are not chemically bound to the rubber polymers and can therefore leach from the material. Phenols and PAHs were found to leach from the material at neutral and high pH. It should be noted that the leachate tests were performed for the above-listed metals, phenols, and PAHs on the recycled rubber granulates and for zinc and benzo(a)pyrene on the EPDM granulates.

Overall, the following patterns were observed between the different types of rubber granulates presented in the study:

- Concentrations of lead, cadmium, copper, mercury, phenols, benzo(a)pyrene, and total PAHs were significantly higher in the rubber granulates manufactured from recycled rubber versus those manufactured from EPDM.
- Concentrations of chromium were significantly higher in the rubber granulates manufactured from EPDM versus those manufactured from recycled rubber.
- Zinc fluctuated in concentrations in all types of rubber granulates presented with no prevalence observed in one type of granulates versus another.
- Lead, cadmium, copper, chromium, zinc, phenols, and total PAHs were all present in the leachate prepared with recycled rubber granulates. Concentrations of metals and phenols were greater in the leachate with a higher pH. Total PAHs concentrations were greater in the leachate with a neutral pH.
- Benzo(a)pyrene was not detected in leachates prepared with both recycled rubber and EPDM.
- The concentration of zinc in the EPDM leachate was significantly less than the recycled rubber leachate.

A summary of the constituent concentrations in the rubber granulates as well as the leachate is presented below in Table B-1.

Table B-1
Components of Rubber Granulates and Associated Leachates
Table prepared using data from:
KemI, 2006. Synthetic Turf from a Chemical Perspective – a status report. Kemikalieinspektionen. Swedish Chemicals Inspectorate. July.

Analyte	**Concentration Range in Granulates (mg/kg) (Recycled Rubber and EPDM)**	**Concentration Range in Leachates (ug/L)[1]**	**Type of Rubber Granulate Leachate Test Performed On**
Lead	1.0-20 mg/kg	8.44–48.8	Recycled Rubber
Cadmium	0.12–2 mg/kg	0.078–0.12	Recycled Rubber
Copper	4.0–70 mg/kg	5.77–383	Recycled Rubber
Chromium	<2–5200 mg/kg	2.95–5.96	Recycled Rubber
Mercury	<0.005–0.04 mg/kg	ND-0.039	Recycled Rubber
Zinc	174–18,000 mg/kg	1220-7050 80	Recycled Rubber EPDM
Phenols	1120–33,700 mg/kg	568-3600	Recycled Rubber
Benzo(a)pyrene	0.12–3.1 mg/kg	ND	Recycled Rubber & EPDM
Total PAHs	1–76 mg/kg	11-3.4	Recycled Rubber

The strengths of the KemI study include:

- The paper provides a general understanding of groups of chemicals typically found in tires.

The potential limitations and data gaps of the KemI study include:

- This paper presents a summary of typical chemicals found in European tires as published by the Bureau de Liaison des Industries du Caoutchouc in 2001.
- No laboratory studies were conducted as part of this paper, and the studies that were conducted that formed the basis for the data from 2001 are not provided.
- Specific concentrations are not provided.

Swedish National Chemicals Inspectorate (KemI). 2003. HA Oils in Automotive Tyres – Prospects of a National Ban. Order No. 360760. Stockholm, Sweden.

Both of the above-listed articles were referenced for information on the contents of process oils used in the tire rubber manufacturing process. Process oils (also known as highly aromatic [HA] oils) are created by the extraction of lubricating oils to remove the aromatics. The resulting aromatic process oils are excellent plasticizers/softeners for tire rubbers. However, these oils are rich in PAHs (approximately 20-30%), including the carcinogenic PAHs. Typically the boiling point range of these oils is 250-680°C. The PAH content of the treated distillate aromatic extracts, also used in the rubber manufacturing process is approximately 1.8-13.9%. Table B-2 provides a summary of the components of HA oil.

Table B-2
Components of Process Oil Used as Softeners in Manufacture of Rubber
Table prepared using data from:
Swedish National Chemicals Inspectorate (KemI). 2003. HA Oils in Automotive Tyres – Prospects of a National Ban. Order No. 360760. Stockholm, Sweden.
KemI, 2006. Synthetic Turf from a Chemical Perspective – a status report. Kemikalieinspektionen. Swedish Chemicals Inspectorate. July.

PAHs[1]	Naphthenic Hydrocarbons
Fluoranthene (0.0011%)	Paraffinic Hydrocarbons
Pyrene (0.00256%)	Monoaromatic Hydrocarbons
Benzo(a)fluorene (0.00009%)	Diaromatic Hydrocarbons
Benzo(a)anthracene (0.00342%)	
Chrysene (0.0395%)	
Benzo(b)fluoranthene (0.00729%)	
Benzo(e)pyrene (0.01132%)	
Benzo(a)pyrene (0.00134%)	
Dibenz(a,j)anthracene (0.00046%)	
Dibenz(a,h)anthracene (0.00057%)	
Indeno(1,2,3-cd)pyrene (0.00062%)	
Benzo(g,h,i)perylene (0.00179%)	
Anthanthrene (0.00066%)	

[1] Percentages listed are concentrations and were converted from mg/kg values in the literature

Willoughby, B. 2006a. PAHs and Other Organics in Tyres – Origins and Potential for Release.

Willoughby, B., 2006b. Rubber-its Implications to Environment and Health. International Association for Sports Surface Science, Technical Meeting, Dresden 2006. (Powerpoint and summary)

Willoughby provides information on the processing of tire rubbers, what chemicals are involved, what chemicals are created, and what chemicals are picked up on the tires while in service. Chemicals focused on include phthalates, monoalkylphenols, cadmium, amines, carbon disulfide, zinc, PAHs, and benzene.

The principal tire rubber polymers are natural rubber obtained from the latex of the *Hevea brasiliensis* tree and a SBR polymer, a product of the oil industry. Prior to vulcanization, rubber is visco-elastic. After vulcanization, rubbers have ultimate elastic performance. The vulcanization procedure suppresses viscous behavior and enhances the elastic behavior; it also links molecules together (crosslinking) which creates a single molecule of infinite molecular weight. The polymers of infinite molecular weight cannot flow, cannot be melted or dissolved and will recover elastically from forced strains. Sulfur vulcanization for tire rubbers is a well established procedure.

The chemistry of this procedure relies on a variety of chemicals including a vulcanizing agent (sulfur), accelerators and activators, inhibitors or retarders (stop a premature reaction), antioxidants (protect against heat), antiozonants (protection in service), fillers (carbon black) for reinforcement, and softeners (process oils). The chemicals do not include phthalate plasticizers, monoalkylphenols, or cadmium. But, vulcanization does create new products. Some of the chemicals that are used in the manufacturing process, created by the manufacturing process, and picked up on the tires while in service are summarized below and in Table B-3.

- Some of the accelerators create amines and carbon disulfide.

- The amines can create ketones by a side-chain oxidation.
- Aromatic oils are used as plasticizers/softeners for tire rubbers; they improve processing and product performance.
- Benzene may be present from the rubber polymer/carbon black interaction and may also be taken up by the tire rubber while in service. Benzene and rubber will have a strong affinity for each other.
- Phthalates and alkylphenols are not ingredients of tire rubber but can be picked up from the environment while the tires are in service.
- Zinc oxide is an activator in sulfur vulcanization and forms zinc salts as a byproduct of the vulcanization process. Zinc will almost always be found in leachates from tire rubbers which use vulcanization performed with sulfur.

Table B-3
Sources of Select Chemicals Associated with Tire Rubbers
Table prepared using data from:
Willoughby, B., 2006b. Rubber-its Implications to Environment and Health. International Association for Sports Surface Science, Technical Meeting, Dresden 2006. (Powerpoint and summary)

Used During Tire Rubber Processing	Created During Tire Rubber Processing	Picked Up By Tires While in Service
Sulfur (vulcanizing agent)	Amines (created from accelerators)	Benzene
Aromatic oils (softeners)	Carbon disulfide (created from accelerators)	Phthalates
Benzene (polymer/carbon black interaction)	Ketones (MIBK, cyclohexanone): created from amines by a side-chain oxidation	Alkylphenols
Zinc oxide (activator in sulfur vulcanization)	Zinc salts (byproduct of vulcanization process)	

Some general observations that were made about some of these chemicals in the presentation were as follows:

- There was no excess amount of benzo(a)pyrene found in tire factory air compared to outside air.
- Laboratory vulcanization of tires up to 200°C produced only 2-4 ring PAHs in air. Leachate tests on rubber granulates produced only 2-4 ring PAHs in leachate. The presentation concluded that the 5-ring PAHs will stay in the vulcanized rubber.
- PAHs were measured in sand in a children’s playground that contained used tire components; distribution of PAHs detected did not reflect tire rubber.

Benzene was observed in air above tire granulates at concentration of 2.3 $\mu g/m^3$ but typical urban air concentrations of benzene are much higher.

B. MANUFACTURE OF RUBBER TIRES

Tires contain many different substances but approximately 40% is rubber. Rubber consists of elastic polymers that are obtained directly from plants (natural rubber) or manufactured from petroleum (synthetic rubber).

Natural rubber, obtained from the latex of rubber trees, accounts for about 23% of all rubber consumed in the United States. The balance is synthetic rubber. Of the synthetic rubbers, SBR and polybutadiene rubber are most important, accounting for 71% of synthetic rubber production (Mechanical-Engineering-Archives 2006, IISRP 2007).

A variety of specialty synthetic rubbers, such as butyl, EPDM rubber, polychloroprene, nitrile, and silicone, account for the balance of synthetic rubber production (Mechanical-Engineering-Archives 2006, IISRP 2007).

A typical scrapped automobile tire weighs 9.1 kg (20 lb). Roughly 5.4 kg (12 lb) to 5.9 kg (13 lb) consists of recoverable rubber, composed of 35% natural rubber and 65% synthetic rubber. Steel-belted radial tires are the predominant type of tire currently produced in the United States. A typical truck tire weighs 18.2 kg (40 lb) and also contains from 60 to 70% recoverable rubber. Truck tires typically contain 65% natural rubber and 35% synthetic rubber (SBR Tire Facts, 2007). Although the majority of truck tires are steel-belted radials, there are still a number of bias ply truck tires, which contain either nylon or polyester belt material.

Mechanical-Engineering-Archives, October 15, 2006. Located on-line at: http://www.makinamuhendisi.com/mechanical/mechanical-engineering-archives/269-Types-of-Rubber.html, Accessed January 31, 2008.

This web site provides a summary of different types of rubbers, including natural rubber and synthetic compounds classified as rubber.

International Institute of Synthetic Rubber Products, Inc (IISRP), Synthetic Rubber Summaries, Emulsion styrene-butadiene rubber, Solution styrene-butadiene rubber, Butyl rubber, polybutadiene rubber, and ethylene-propylene rubber manufacturing processes. Loated on-line at: http://www.iisrp.com/synthetic-rubber.html. Accessed November 2007.

This website provides a summary of different types of synthetic rubber manufacturing processes, including emulsion SBR, solution SBR, butyl rubber, polybutadiene rubber, and ethylene-propylene rubber.

Firestone, SBR Tires (Duradene), Technical Specifications on different types of rubber used in tires: solution-SBR.
Dow Chemical Company, Solution-SBR, Technical Specifications on different types of rubber used in tires: solution-SBR, high cis-polybutadiene, and cold polymerized emulsion-SBR.

Summaries of the Firestone and Dow Chemical Company rubber components are summarized in these technical specifications. Although this is a small portion of the different rubber manufacturers, a similarity between the two vendors is readily apparent, even between three different types of rubber, solution SBR, cold polymerized emulsion SBR, and high cis- polybutadiene rubber. In general, the following similarities were observed between the two manufacturers for the compounds used to produce the rubber:

- The polymer used to produce solution-SBR contained approximately 18-40% bound styrene.
- The oil content in the polymer ranged from 27.3-32.5% in solution-SBR and cold polymerized emulsion SBR. Oils used include aromatic oils, high viscosity naphthenic oil, and treated distillate aromatic extract oil.
- Besides the polymer used, the other components of the rubber were similar between manufacturers and the relative proportions (parts by weight) of these other components ranged as follows:
    - Carbon black: 50.00 – 68.75
    - Zinc oxide: 3.00
    - Stearic acid: 1.00 – 2.00
    - Sulfur: 1.5 – 1.75
    - TBBS: 0.9 – 1.50
    - Naphthenic or aromatic oil: 5.00 – 15.0

The components summarized above are the principal components of the major type of rubber (SBR) used for the manufacturing of crumb rubber and therefore have the potential to have a significant presence in crumb rubber. As discussed in subsequent sections of this report, some of these components have been found to be prevalent in crumb rubber, including zinc (from the zinc oxide), benzothiazole compounds (from TBBS), and PAHs (possibly from the oils used). These compounds are therefore chemicals of potential concern in crumb rubber and may be attributed to the SBR used in the manufacturing of crumb rubber.

Cocheo V ; Bellomo ML ; Bombi GG 1983. Rubber Manufacture: Sampling And Identification Of Volatile Pollutants American Industrial Hygiene Association Journal 44(7):521-527.

This study involved sampling and analysis of volatile contaminants in ambient air resulting from several rubber goods manufacturing processes. However, only samples collected in the vulcanization and extrusion areas of a tire retreading operation are summarized below as these relate to potential components of crumb rubber.

Table B-4

Summary of Chemicals Used in a Rubber Goods Manufacturing (Tire Retreading) Facility

Table prepared using data from:
Cocheo V; Bellomo ML ; Bombi GG 1983. Rubber Manufacture: Sampling And Identification Of Volatile Pollutants
American Industrial Hygiene Association Journal 44(7):521-527.

Source	Chemical	CAS Number
Polymers	Natural rubber (polyisoprene)	9003-31-0
	Styrene butadiene rubber	9003-55-8
	Cis-polybutadiene	9003-17-2
Vulcanizing Agents	Sulfur	7704-34-9
	Tetramethylthiurame sulfide	87-91-6
Accelerators	Diphenylguanidine	103-06-7
	2-Mercaptobenzothiazole	149-30-4
	N-cyclohexyl-2-benzothiazolylsulfenamide	95-33-0
	2-(N-morpholinyl)mercaptobenzothiazole	102-77-2
	Hexamethylenetetramine	100-97-0
Activators	Zinc oxide	1314-13-2
	Zinc carbonate	10476-83-2
	Stearic acid	57-11-4
Antiozonants	2,2,4-Trimethyl-1,2-dihydroquinoline (polymer)	147-47-7
	N,N’-(1,3-dimethylbutyl)-p-phenylenediamine	793-24-8
	Paraffinic wax	NA
Antioxidants	Alkylphenols	NA
	Resorcinol	108-46-3
	2,6-Diterbutylhydroquinone	2444-28-2
Retarders	N-cyclohexylthiophthalimide	17796-82-6
Plasticizers	Aliphatic oil	NA
	Aromatic oil	NA
	Naphthenic oil	NA
	Bis(2-ethylhexyl)phthalate	117-81-7
	Coumarone-indene resin	NA
Extenders	Silica gel	7631-86-9
	Carbon black	7440-44-0

NA = Not available or not applicable

Table B-5

Chemicals Detected in Ambient Air in a Rubber Goods Manufacturing (Tire Retreading) Facility

Table prepared using data from:
Cocheo V ; Bellomo ML ; Bombi GG 1983. Rubber Manufacture: Sampling And Identification Of Volatile Pollutants
American Industrial Hygiene Association Journal July, Vol.44, No.7, p.521-527.

Chemical Group	Vulcanization Area of Facility	Extrusion Area of Facility
Straight-chain Alkanes	Heptane	heptane
	octane	octane
	nonane	nonane
	decane	decane
	undecane	undecane
	dodecane	dodecane
	tridecane	tridecane
	tetradecane	tetradecane
	pentadecane	pentadecane
	hexadecane	hexadecane
	heptadecane	heptadecane
	octadecane	octadecane
	eicosane	eicosane
	heneicosane	
	docosane	
Cycloalkanes	Methylcyclohexane	methylcyclohexane
	trans-1-isopropyl-4-methylcyclohexane	trans-1-isopropyl-4-methylcyclohexane
	cis-1-isopropyl-4-methylcyclohexane	cis-1-isopropyl-4-methylcyclohexane
	1-isopropyl-3-methylcyclohexane	1-isopropyl-3-methylcyclohexane
	Indane	
Cycloalkenes	Styrene	styrene
	1-isopropyl-4-methyl-1,4-cyclohexadiene	1-isopropyl-4-methyl-1,4-cyclohexadiene
	1-methyl-3-(1-methylvinyl)cyclohexene	
	5-methyl-3-(1-methylvinyl)cyclohexene	5-methyl-3-(1-methylvinyl)cyclohexene
	1-methyl-4-(1-methylvinyl)cyclohexene	1-methyl-4-(1-methylvinyl)cyclohexene
	dimethylstyrene	dimethylstyrene
	cyclodecatriene	
	p-ter-butylstyrene	p-ter-butylstyrene
		4-vinylcyclohexene
Aromatic Hydrocarbons	benzene	benzene
	toluene	toluene
	ethylbenzene	ethylbenzene
	xylenes	xylenes
	isopropylbenzene	isopropylbenzene
	propyl benzene	propyl benzene
	1-isopropyl-4-methylbenzene	1-isopropyl-4-methylbenzene
	1-isopropyl-2-methylbenzene	1-isopropyl-2-methylbenzene
	tetramethylbenzene	
	1,2,3,4-tetrahydronaphthalene	
	1,3-diisopropylbenzene	1,3-diisopropylbenzene
	1,4-diisopropylbenzene	1,4-diisopropylbenzene
	dimethylpropylhexahydronaphthalene	dimethylpropylhexahydronaphthalene
	nonylbenzene	
	1,6-dimethyl-4-isopropyl-1,2,3,4-tetrahydronaphthalene	
	decylbenzene	
	1-phenylnaphthalene	1-phenylnaphthalene
	tridecylbenzene	
		cyclodecatriene

Table B-5

Chemicals Detected in Ambient Air in a Rubber Goods Manufacturing (Tire Retreading) Facility

Table prepared using data from:

Cocheo V ; Bellomo ML ; Bombi GG 1983. Rubber Manufacture: Sampling And Identification Of Volatile Pollutants American Industrial Hygiene Association Journal July, Vol.44, No.7, p.521-527.

Chemical Group	Vulcanization Area of Facility	Extrusion Area of Facility
Phenols	2-isopropyl-6-methylphenol	2-isopropyl-6-methylphenol
	2,6-di-ter-butyl-4-ethylphenol	2,6-di-ter-butyl-4-ethylphenol
Phthalates	diethylphthalate	diethylphthalate
	diisobutylphthalate	diisobutylphthalate
	di-n-butylphthalate	
	bis(2-ethylhexyl)phthalate	
Others	benzaldehyde	
	triisobutylene	triisobutylene
	tetraisobutylene	tetraisobutylene
	cyclohexylisothiocyanate	
	2,6-di-ter-butyl-p-quinone	2,6-di-ter-butyl-p-quinone
	di-ter-butylthiophene	1,2-ditoylethane

C. CHEMICALS IDENTIFIED IN RECYCLED TIRES

California Environmental Protection Agency (CalEPA). 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Sacramento, CA: Office of Environmental Health Hazard Assessment.

Discussion is provided in Chapter 3 of the CalEPA document on the substances released by recycled tires and where in the tire production process the substance most likely originated. The authors presented the findings from a review of published studies that identified chemical constituents released by recycled or used tires. 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. Leaching times varied, ranging from 17 hours to six months. In some studies, whole tires were used, but more often tires shreds, chips or crumb was tested. In general, substances released include 15 metals, 20 VOCs and 14 SVOCs. Table B-4 summarizes the most highly detected analytes and potential sources of these analytes.

The discussion focuses on metals (zinc, iron, manganese, barium, lead, and chromium), VOCs (MIBK, naphthalene, acetone, toluene, TPH, MEK), and SVOCs (benzothiazoles, aniline, phenol, diphenylnitrosoamine and dimethylnitrosoamine). The following bullets summarize the results presented in this report.

- Metals:
    - Zinc, iron, and manganese were detected most frequently. Iron and manganese are components of the steel belts and beads while zinc oxide is used as an activator in the vulcanization process. Since the production of crumb rubber removes approximately 99% of the steel belting and bead material, this should reduce the release of iron and manganese from the recycled tire material.
    - Barium was also detected in several instances which could be a result of its use to catalyze the synthesis of polybutadiene rubber.
    - The presence of lead in several instances may be due to its former use as an activator in the vulcanization process, in the form of lead oxide.
    - The presence of chromium in several instances may be due to its use in steel production; however, removal of the steel wire during the production of crumb rubber should reduce the release of chromium.

- VOCs:
    - MIBK and naphthalene were detected at the highest concentrations. MIBK may result from its use in the production of rubber antioxidants and naphthalene can originate from carbon black.
    - Other VOCs detected may result from the use of petroleum oils and coal tar fractions in tire production: acetone, toluene, ethyl benzene, TPH, PAHs, and MEK.
    - Conclusions could not be drawn about the release of VOCs from surfaces using this crumb rubber due to the lack of data.

- SVOCs:
    - Five different benzothiazoles were detected; these compounds have been proposed as environmental markers for tire-derived material. Benzothiazoles are used in tire production to accelerate the vulcanization process, as antioxidants, and to help bond the metal wire and metal belts to the tire rubber.
    - Aniline was detected and could be due to its addition to tires to inhibit rubber degradation.
    - Phenols detected may be due to use of petroleum oils and/or coal tar fractions as softeners and extenders in tire production. Also, steel cords and fabrics comprising the belts were treated with phenol/formaldehyde to improve their adhesion to rubber.

  - The detection of two nitrosamines (diphenyl and dimethyl) 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.

Table 2 in this CalEPA study identifies each chemical constituent and lists all studies that identified this constituent and the concentration reported.

The strengths of the CalEPA study include:

- Provides a comprehensive list of constituents leached from various forms of rubber (whole, shredded, chipped and crumb)

The potential limitations and data gaps of the CalEPA study include:

- Multiple studies with various methods and using varying types of tires and tire products were evaluated and reported. The correlation between data from studies that evaluated rubber forms other than crumb rubber and the composition of crumb rubber is unknown. However, the source of crumb rubber can be comprised of many different tire products. Therefore, this study is useful in providing a broad database on the chemical composition of tires from which crumb rubber is manufactured.
- The laboratory studies reported in this paper generally consisted of laboratory studies where tire samples were incubated in aqueous solutions, which do not mimic natural gastric digestion. The availability of chemical constituents for absorption due to gastric digestion was evaluated separately and reported in this paper. Shredded tires used in the studies still contain the metallic components and the end product was not necessarily washed. This would be in contrast with waste tire processing which removes metal belts and metal beads and the rubber end product is typically washed.
- The preparation and analytical methods employed were not presented.

Table B-6
Chemicals Potentially Released by Recycled or Used Tires

Table prepared using data from:
California Environmental Protection Agency (CalEPA). 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Sacramento, CA: Office of Environmental Health Hazard Assessment.

Analyte Detected (Maximum concentrations provided in units of ng released/g of tire, unless otherwise stated)[1]	**Suspected Source of Contaminant**
Metals (in order of most frequently detected)	
Zinc (2,320,000)	Zinc oxide used as activator in vulcanization process
Iron (1,100,000)	Component of steel belts and beads
Manganese (5800)	Component of steel belts and beads
Barium (1700)	Catalyst for synthesis of polybutadiene rubber
Lead (920)	Former use of lead oxide as an activator of vulcanization process
Chromium (500)	Component of steel belts and beads
VOCs (in order of concentration detected, highest to lowest)	
Methyl Isobutyl Ketone (1151)	Used in the production of rubber antioxidants
Naphthalene (1100)	Carbon black used as filler in tires
Toluene (280)	Use of petroleum oils as softeners in tire production
Benzene (218)	Use of petroleum oils as softeners in tire production
Acetone (115)	Use of petroleum oils as softeners in tire production
Methyl Ethyl Ketone (17)	Use of petroleum oils as softeners in tire production
SVOCs	
PAHs (140)	Use of petroleum oils as softeners in tire production
Benzthiazole compounds (100,000 ng/g crumb rubber)	Used to accelerate the vulcanization process during tire production and to help bond the metal wire and metal belts to the tire rubber
Aniline (742)	Added to tires to inhibit rubber degradation
Phenol (10)	May be due to the use of petroleum oils as softeners and extenders in tire production or because of the treatment of the steel cords and fabrics comprising the belts with phenol/formaldehyde to improve their adhesion to the rubber
Diphenylnitrosoamine (7 ug/L in leachate)	Used to inhibit both the vulcanization process during tire production and the decomposition of rubber in the finished product
Dimethylnitrosoamine (7 ug/L in leachate)	Used to inhibit both the vulcanization process during tire production and the decomposition of rubber in the finished product

[1] Units of ng released per gram of tire provided by authors to allow predictions of how much of each chemical would be released if a child ingested a specific amount of the tire shred.

D. DIFFERENT TYPES OF CRUMB RUBBER AND MANUFACTURING PROCESSES

Mechanical-Engineering-Archives, October15, 2006. Located on-line at: http://www.makinamuhendisi.com/mechanical/mechanical-engineering-archives/269-Types-of-Rubber.html, Accessed January 31, 2008.

Crumb rubber usually consists of particles ranging in size from 4.75 mm (No. 4 sieve) to less than 0.075 mm (No. 200 sieve).

Three methods are currently used to convert scrap tires to crumb rubber. The crackermill process is the most commonly used method. The crackermill process tears apart or reduces the size of tire rubber by passing the material between rotating corrugated steel drums. This process creates an irregularly shaped torn particle with a large surface area. These particles range in size from approximately 5 mm to 0.5 mm (No. 4 to No. 40 sieve) and are commonly referred to as ground crumb rubber. The second method is the granulator process, which shears apart the rubber with revolving steel plates that pass at close tolerance, producing granulated crumb rubber particles, ranging in size from 9.5 mm (3/8 in) to 0.5 mm (No. 40 sieve). The third process is the micro-mill process, which produces a very fine ground crumb rubber in the size range from 0.5 mm (No. 40 sieve) to as small as 0.075 mm (No. 200 sieve).

In some cases, cryogenic techniques are also used for size reduction. Essentially, this involves using liquid nitrogen to reduce the temperature of the rubber particles to minus 87^{o}C (-125^{o}F), making the particles quite brittle and easy to shatter into small particles. This technique is sometimes used before final grinding.

North Carolina Department of Environment and Natural Resources (DENR), Division of Pollution Prevention and Environmental Assistance, Manufacturing Crumb Rubber. Located on-line at: http://www.p2pays.org/ref/11/10504/html/usa/usechip.htm. Accessed November 2007.

Crumb rubber is created by a combination of several size reduction techniques. These techniques can be divided into two major categories, mechanical grinding and cryogenic reduction.

Mechanical (Ambient) Grinding

Mechanical grinding is the most common process used for making crumb rubber as rough-faced granules and is performed at ambient temperatures. Typically, synthetic turf fields with a blend of crumb rubber and sand use a mechanically ground crumb rubber; the rough-faced, irregular shaped granules help hold the sand in place. The following steps are employed for the mechanical grinding process:

(1) The rubber is mechanically broken down into small particles using a variety of grinding techniques (i.e., cracker mills, granulators, etc.).
(2) Steel components are removed by a magnetic separator.
(3) The tire-reinforcing materials, or fiber components (i.e., cotton, nylon, rayon, polyesters, fiber glass, and metal) are separated by air classifiers or other separation equipment.

Advantages of mechanical grinding systems are as follows:

- Systems are well established and can therefore produce crumb rubber at a relatively low cost.
- Systems are easy to maintain.
- Systems require few people to operate and service.
- Replacement parts for these systems are easy to obtain and install.

Cryogenic Processing

Typically, fields that are 100% rubber infill (i.e., no sand) use a cryogenically processed rubber crumb. The following steps are employed for the cryogenic process:

1. The shredded rubber is frozen at an extremely low temperature by liquid nitrogen.
2. The frozen rubber compound is shattered into small particles like broken glass.
3. Steel components are removed by a magnetic separator.
4. Fiber components are separated by air classifiers or other separation equipment.

Advantages of cryogenic processing systems are as follows:

- Processes are cleaner and faster than mechanical grinding.
- Process can produce fine mesh size crumb rubber and smooth-faced granules.

One significant disadvantage to the cryogenic processing is the slightly higher cost due to added cost of cooling (i.e., liquid nitrogen).

Sunthonpagasit, N., Hickman, HL. 2003. Manufacturing and Utilizing Crumb Rubber from Scrap Tires. Journal of Municipal Solid Waste Professionals. November/December. 13(7). Located on-line at: http://www.forester.net/mw_0311_rubber.htm

The article from the Journal for Municipal Solid Waste Professionals presents a summary on the manufacturing process of crumb rubber. The two processes described above, ambient grinding and cryogenic processing, are mentioned. In addition, two emerging technologies are discussed.

- Surface Modification Technology: Size-reduced rubber is exposed to fluoride or bromide gas. The gas will cause a change to the outer layer of the rubber particles, which allows it to blend with urethane for excellent bonding.
- Devulcanization Technologies: This technology breaks the carbon-sulfur bonds of rubber by ultrasonic (high intensity ultrasonic vibrations fracture sulfur-sulfur bonds), chemical (sulfur and chemical additives are blended with scrap tire pieces in a mill or internal mixer to cut the sulfur-sulfur bonds), bio-processing (biological processes of microorganisms break the sulfur-sulfur bonds), or ozone-knife technology (ozone rich atmosphere breaks the sulfur-sulfur bonds). Once the sulfur-sulfur bonds are broken, the material can be recombined with polymers in a greater percentage.

E. CHEMICALS OF POTENTIAL CONCERN IN CRUMB RUBBER

MSDS for Rubber Infill Materials provided by New York City Parks Department (see Appendix A for MSDSs)

Synthetic Turf Manufacturers:
Aturf
Forever Green Athletic Fields, Inc
Rubber Infill Manufacturers:
Recycling Technologies Int'l, LLC
Re-Tek, Inc
SJM Group of New York

Norwegian Institute of Public Health and the Radium Hospital (NIPH). 2006. Synthetic Turf Pitches – an assessment of health risks for football players:

This study provides a summary of VOCs detected in indoor environments with synthetic turf containing recycled rubber granulates. Recycled rubber granules were selected to evaluate potential exposure as they were found to contain the highest concentrations of chemicals, as compared to TPE or EPDM rubber.

Objective: The objective was to evaluate potential volatile pollutants in indoor air in the presence of synthetic turf containing recycled rubber granulates.

Method: The sampling and analytical methods used were not provided in this study.

Results: Table B-7 summarizes those compounds detected at a concentration greater than or equal to 2.0 $\mu g/m^3$; compounds are organized by chemical groups as well as by concentrations detected. The table demonstrates that aromatic hydrocarbons, benzothiazole, MIBK, and acetone are off-gassing at higher concentrations than other VOCs. Compounds off-gassing have been shown throughout this paper to be part of the tire manufacturing process (see Table B-8 for a summary).

The strengths of the NIPH study include:

- The study does document that VOCs are degassing from rubber granulates used in synthetic turf.

The potential limitations and data gaps of the NIPH study include:

- The applicability of the indoor air quality to outdoor applications is low. An indoor assessment would likely over represent outdoor air quality.

Reddy, CM., Quinn, JG. 1997. Environmental Chemistry of Benzothiazoles Derived from Rubber. Environmental Science & Technology. 31(107).

Although the ultimate purpose of this study was to determine whether benzothiazoles would be an environmental problem with roads containing crumb rubber material-modified asphalt, it contained useful information in regards to the benzothiazole content of crumb rubber as well as the potential for these compounds to leach from crumb rubber. Three benzothiazole compounds were investigated: benzothaizole (BT), 2-hydroxybenzothiazole (HOBT), and 2-(4-morpholino)benzothiazole (24MoBT). Two of these compounds, BT and HOBT, are breakdown products in some of the vulcanization accelerators and antioxidants added to rubber during manufacturing. 24MoBT is an impurity in some of the vulcanization accelerators and antioxidants added to rubber during manufacturing.

Two of the tests performed for this study provided useful information on the crumb rubber material. It should be noted that the quality control analyses (i.e., internal standard recoveries, method blanks, laboratory duplicates, and blank spike recoveries) performed with these studies yielded acceptable results.

Objective: The objective was to determine whether benzothiazoles would be an environmental problem with roads containing crumb rubber material-modified asphalt.

Method (Test #1): Analysis of Benzothizole Compounds in Crumb Rubber

- <u>Crumb Rubber Material:</u> GF80A obtained from Rouse Rubber, St. Louis, MO.
- <u>Preparation of Sample:</u> A sample of crumb rubber material (~150 µm diameter) was refluxed in methanol for 2 hours, cooled, and filtered through 1.2 µm glass fiber filter. The filtrate was diluted with deionized water and extracted three times with methylene chloride. The extracts were combined, concentrated to 1 mL and solvent exchanged into hexane.
- <u>Cleanup of Sample Extract:</u> The extract was put on an activated silica gel column for cleanup. Two fractions were collected. The first fraction was collected using 15 mL of a 50/50 mixture of

hexane/methylene chloride; this fraction was not analyzed. The second fraction, which contained the benzothiazole compounds, was collected using 15 mL of an 80/20 mixture of methylene chloride/acetonitrile and then concentrated to a smaller volume.

- Analysis: The second fraction from the extract cleanup was analyzed using GC/MS in the selected ion monitoring (SIM) mode.

Method (Test #2): Leaching of Benzothiazole Compounds from Crumb Rubber

- Crumb Rubber Material Leachate: GF80A obtained from Rouse Rubber, St. Louis, MO.
- Preparation of Sample: Approximately four grams of the crumb rubber material (~150 µm diameter) were shaken with deionized water in a sealed centrifuge tube at 25°C for 24 hours. The pH of this mixture was ~ 5. The mixture was then filtered through a glass fiber filter. The crumb rubber material was then returned to the centrifuge tube, another 100 mL deionized water were added and the mixture was leached for another 24 hours. This was then repeated three more times for a total of five times. Each of the five filtrates was extracted three times with 30 mL of methylene chloride. The methylene chloride extracts were combined and concentrated.
- Analysis: The methylene chloride extract was analyzed using GC/MS in the SIM mode.

Results (Tests #1 and 2): The analysis of the crumb rubber material for the benzothiazole compounds yielded values similar to published literature values for these compounds for tire particles. Approximately 171 mg/kg of benzothiazole and 80.9 mg/kg of 2-hydroxybenzothiazole were detected in the crumb rubber material. Approximately 50% of the total amount of these compounds in the crumb rubber material were leached or solubilized into the deionized water. The study assumed that based on the leachability of 50% of the benzothiazole compounds with 150 µm diameter particles, higher leachability in water can be expected in ordinary tire particles with diameters <100 µm. The tests demonstrated that the benzothiazole compounds which have been noted as originating from the tire or rubber manufacturing processes should be retained as a chemical of potential concern for crumb rubber.

The strengths of the Reddy and Quinn study include:

- The study contains useful information in regards to the benzothiazole content of crumb rubber as well as the potential for these compounds to leach from crumb rubber.
- The quality control analyses (i.e., internal standard recoveries, method blanks, laboratory duplicates, and blank spike recoveries) performed with these studies yielded acceptable results.

The potential limitations and data gaps of the Reddy and Quinn Study include:

- None

Table B-7

Chemicals Detected in Indoor Air in Presence of Synthetic Turf with Rubber Granulates

Table prepared using data from:

Norwegian Institute of Public Health and the Radium Hospital (NIPH). 2006. Synthetic Turf Pitches – an assessment of health risks for football players: described in Chapter 3

By Chemical Group[1]		**Order of Concentration Detected (Highest to Lowest, values in parenthesis are concentrations detected in samples in ug/m3)**
Straight-chain Alkanes	Octane Decane Undecane Dodecane Pentadecane	Toluene (15.3, 85.0) Butenylbenzene isomers (82.5) Benzoic acid (19.3, 81.0) Diethenylbenzene isomers (65.7) Xylene Isomers (9.6, 13.1, 25.5) Ethylbenzene aldehyde isomers (34.7) Benzothiazole (15.7, 31.7) 1,1'-Biphenyl (15.6) Hexenylbenzene isomers (15.5) Acetone (9.5, 15.3) 4-Methyl-2-pentanone (12.7) Alpha-pinene (10.5) 3-Phenyl-2-propenal (10.2) Cyclohexanone (9.8) Unidentified naphthalene derivative (9.3) Pentenylbenzene isomers (7.3) Junipene (7.2) Pentanedioic acid dimethyl ester (6.8) Ethylbenzene (3.3, 6.7) Styrene (3.2, 6.1) Ethylcyclohexane (5.6) Formaldehyde (5.5, 6.5) 2-Butoxyethanol (5.3) Decane (5.0) Octane (4.6) Undecane (3.1, 4.6) Acetaldehyde (2.9, 4.3) Nitromethane (4.1) 1-Propylbenzene (4.0) Acetic acid (4.3) Dodecane (3.7) 1,2,3-Trimethylbenzene (3.2) 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) Hexanal (2.0) 1,2-Propanediol (2.0) 1-Methoxy-2-propanol (2.0)
Cylcoalkanes	Ethylcyclohexane	
Cycloalkenes	Styrene Alpha-pinene Limonene 3-Carene 2,3-Dihydro-1,1,3-trimethyl-3-phenyl-1H-indene	
Aromatic Hydrocarbons	Toluene Butenylbenzene isomers Diethenylbenzene isomers Xylenes 1,1'-Biphenyl Pentenylbenzene isomers Ethylbenzene Hexenylbenzene isomers Unidentified naphthalene derivative 1-Propylbenzene 1,2,3-Trimethylbenzene 2-Methylnaphthalene Benzene	
Ketones	Acetone 4-Methyl-2-pentanone Cyclohexanone	
Aldehydes	Ethylbenzene aldehyde isomers 3-Phenyl-2-propenal Formaldehyde Acetaldehyde Hexanal	
Esters	Pentanedioic acid dimethyl ester	
Alcohols	2-Butoxyethanol 1,2-Propanediol 1-Methoxy-2-propanol	
Organic Acids	Benzoic acid Acetic acid	
Others	Benzothiazole Nitromethane Junipene	

[1] Compound order in each chemical group is presented from highest concentration detected to lowest concentration detected

Crain W, Zhang J. 2006. Hazardous Chemicals in Synthetic Turf (Revised). Rachel's Democracy & Health News #873, September 21.

Crain W, Zhang J. 2007. Hazardous Chemicals in Synthetic Turf: Follow-Up Analyses. Rachel's Democracy & Health News #992, April 12.

These articles summarize analyses performed on two synthetic turf samples (brand name A-Turf) collected from Manhattan's Riverside Park on two separate dates and from three synthetic turf samples (brand name Field Turf) collected from Parade Grounds in Brooklyn and Roosevelt Park in Manhattan. Details on sample collection procedures were not provided in these articles.

Objective: The objective was to determine the chemical constituents of rubber granules in synthetic turf samples.

Method: The analyses included PAHs (via soxhlet extraction) and/or metals (via microwave digestion with nitric acid). Metals analysis was only performed on samples collected from Riverside Park.

Results: Six carcinogenic PAHs (benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(a)pyrene, benzo(k)fluoranthene, and dibenzo(a,h)anthracene) and zinc were found to be present at concentrations above the NYSDEC Remedial Program Soil Cleanup Objectives. In addition, lead and arsenic were detected in these samples.

The strengths of the Crain and Zhang study include:

- The extraction and digestion methods they used for PAHs and metals, respectively, are very efficient and rigorous extraction methods.

The potential limitations and data gaps of the Crain and Zhang study include:

- The authors identified three PAHs that exceeded NYSDEC Remedial Program Soil Cleanup Objectives (SCOs): chrysene, dibenzo(a,h)anthracene and benzo(b)fluoranthene. The authors selected the most stringent SCOs, the SCOEs for unrestricted residential land use, for comparison. The use of these SCOs is highly conservative for evaluating recreational exposure to chemicals in soil. The NYS DEC developed restricted residential SCOs protective of recreational land use, as discussed in their Brownfield Cleanup Program Development of Soil Cleanup Objectives Technical Support Document (NYSDEC and NYS DOH 2006). Although all six detected PAHs exceed the restricted residential SCOs in at least one sample, the SCOs for benzo(b)fluoranthene, benzo(a)pyrene, and dibenzo(a,h)anthracene are all set at NYSDEC's rural soil background concentration and are not based on health-risk.
- No information provided on sample collection methods

Mattina, MJI, Isleyen, M., Berger, W., Ozdemir, S. 2007. Connecticut Agricultural Experiment Station, Department of Analytical Chemistry (CT Ag Station). Examination of Crumb Rubber Produced from Recycled Tires (AC005). New Haven, CT.

Objective: The Department of Analytical Chemistry at the Connecticut Agricultural Experiment Station (CAES) was hired by Environment and Human Health Inc (EHHI) to analyze crumb rubber produced from used tires. The potential for compounds volatilizing from the crumb rubber, the identity of volatilized compounds, and the potential for organic or inorganic analytes to leach from the crumb rubber were investigated.

Method (Test #1): Volatilization of Compounds from Crumb Rubber:

- <u>Sample Preparation:</u> Approximately 0.25 grams of the crumb rubber was added to a 2 mL vial. The vial was capped and pierced with a SPME needle. The SPME fiber used was coated with 100 µm nonbonded polydimethylsiloxane. The SPME fiber was exposed to the headspace in the vial for 42 minutes while the vial was warmed to 60 ºC. The SPME fiber was then removed from the vial and desorbed into the GC.

- Sample Analysis: The SPME fiber was desorbed into the GC and analysis was performed using MS on a DB-5MS column.

Results: Four compounds were detected at significant concentrations and included benzothiazole, butylated hydroxyanisole, n-hexadecane, and 4-t-octylphenol.

Method (Test #2): Leaching of Organic Compounds from Crumb Rubber:

- Sample Preparation: Approximately 17 g of crumb rubber were soaked in 50 mL of distilled, deionized water for seven weeks at ambient laboratory temperature. The leachate was filtered and 1.5 mL was transferred to a 2 mL vial. The vial was capped and pierced with a SPME needle. The SPME fiber used was coated with 100 µm nonbonded polydimethylsiloxane. The SPME fiber was exposed to the headspace in the vial for 42 minutes while the vial was warmed to 60 ºC. The SPME fiber was then removed from the vial and desorbed into the GC.
- Sample Analysis: The SPME fiber was desorbed into the GC and analysis was performed using MS on a DB-5MS column.

Results: Four compounds were detected at significant concentrations: benzothiazole, butylated hydroxyanisole, n-hexadecane, and 4-t-octylphenol.

Conclusions: Laboratory analyses using SPME of both water leachate and acidified leachate (after allowing crumb rubber to soak in deionized water and acidified water for a period of time) demonstrated that the same four compounds were leaching from the crumb rubber.

Method (Test #3): Leaching of Inorganic Analytes from Crumb Rubber:

- Sample Preparation: Two different scenarios were prepared.

(1) Approximately two grams of crumb rubber were transferred into 40 mL of distilled, deionized water in centrifuge tubes. The tubes were sealed and agitated at ambient temperature for 18 hours. The tubes were then centrifuged for 10 minutes at 3000 rpm.

(2) Approximately two grams of crumb rubber were transferred into 40 mL of distilled, deionized water in centrifuge tubes. The pH of the water was adjusted to 4.2, as recommended in SW-846 method 1312, Synthetic Preparation Leaching Procedure, which is designed to simulate acid rain scenario. The tubes were sealed and agitated at ambient temperature for 18 hours. The tubes were then centrifuged for 10 minutes at 3000 rpm.

- Sample Analysis: The leachates were analyzed by inductively coupled plasma/mass spectrometry (ICP/MS).

Results: Four metals were detected, zinc, selenium, lead, and cadmium. Significant increases in concentration were noted in the acidified water for zinc and cadmium.

The strengths of study include:

- Provides a screening type study to determine chemicals that will volatilize and leach from crumb rubber

The potential limitations and data gaps of the study include:

- The analysis was performed using a DB-5MS column which is typically used for the analysis of semivolatile compounds. It is unclear why the SPME fiber chosen was used for volatile constituents but analysis was performed using an analytical column designed for semivolatile organics. The potential for other components to be present may exist if (1) analysis had been performed on a column more appropriate for VOCs or (2) if a SPME fiber especially designed for semivolatiles had been employed. A more appropriate SPME fiber for semivolatiles would have been a 7 µm bonded polydimethylsiloxane fiber which is appropriate for moderately polar to nonpolar semivolatiles or a 85 µm partially crosslinked polyacrylate fiber which is appropriate for polar semivolatiles (two of the detected compounds were polar semivolatiles).

- The results reported for the amount of metals in water were reported in units of µg/kg tire. It is unclear how these units were generated and therefore, the results should be used with caution from a quantitative perspective.

RAMP, 2007. Synthetic Turf Chemicals:
http://www.albany.edu/ihe/SyntheticTurfChemicalsdar.htm

Objective: The objective was to determine the chemical constituents and variability of crumb rubber from five different synthetic turf manufacturers.

Method: Screening analyses of samples of crumb rubber from five synthetic turf manufacturers were performed for metals, SVOCs, and VOCs. VOC and SVOC analysis were performed using GC/MS.

Results: Select metals, phthalates, PAHs, n-nitrosodiphenylamine, and select VOCs were detected in one or more of the samples. The presence of the different chemicals in each sample and the concentration ranges were provided, demonstrating variability among the five samples. Metals detected at significant concentrations included arsenic, cadmium, chromium, cobalt, lead, manganese, thallium, and zinc, with cobalt, lead, manganese, and zinc detected in all five samples. SVOCs detected at significant concentrations included bis(2-ethylhexyl)phthalate, diethylphthalate, chrysene, fluoranthene, pyrene, and n-nitrosodiphenylamine, with bis(2-ethylhexyl)phthalate and pyrene detected in all five samples. VOC analysis was performed for only two samples. VOCs detected at significant concentrations included acetone, carbon disulfide, chloroform, ethylbenzene, methylene chloride, 4-methyl-2-pentanone, tetrachloroethene, toluene, xylenes, with acetone, carbon disulfide, 4-methyl-2-pentanone, and tetrachloroethene consistently detected in both samples.

Maximum concentrations (mg/kg) of the detected analytes were as follows:

Metals			
Arsenic: 1.0	Cadmium: 0.621	Chromium: 1.5	Cobalt: 141
Lead: 67.2	Manganese: 7.5	Thallium: 1.5	Zinc: 17,000
SVOCs			
Bis(2-ethylhexyl)phthalate: 203	Diethylhexylphthalate: 3.1	Chrysene: 3.8	Fluoranthene: 15.9
Pyrene: 28.3	n-Nitrosodiphenylamine: 7.03		
VOCs			
Acetone: 1.45	Carbon disulfide: 0.525	Chloroform: 0.732	Ethylbenzene: 0.337
Methylene chloride: 0.286	4-methyl-2-pentanone: 11.4	Tetrachloroethene: 0.28	Toluene: 0.0168
Xylene: 0.134			

Strengths of the RAMP study include:

- Provides a list of constituents of concern found in crumb rubber.
- Demonstrates variability of constituents in crumb rubber.

The potential limitations and data gaps of the RAMP study include:

- Detection limits for metals, VOCs, and SVOCs were elevated due to dilutions performed for the elevated concentrations of the detected analytes which would have exceeded the calibration range if not diluted.
- The procedure used for the preparation of samples for all methods was not provided and the analytical approach used for metals was not provided.
- Data have been flagged in the study as screening-level data and therefore should be used qualitatively in the analysis of the components of crumb rubber.

Norwegian Institute for Air Research (NILU). 2006. Measurement of Air Pollution in Indoor Synthetic Turf Halls. NILU OR 03/2006. Kjeller, Norway.

Studies were performed to determine the chemicals and concentrations present in airborne dust as well as indoor air from two different types of rubber granulate (SBR and TPE) which were present in synthetic turf in indoor facilities. Two samples of SBR were used with one which had been recently laid and one that had been in use for 1 year.

Objective: The objective was to determine the chemicals and concentrations present in airborne dust as well as indoor air from two different types of rubber granulate (SBR and TPE) which were present in synthetic turf in indoor facilities.

Method:

- Sampling: Airborne dust was collected for PM_{10} and $PM_{2.5}$ on separate 47 mm quartz fiber filters. The airborne dust (PM_{10}) to be analyzed for PAHs was collected on a 150 mm glass fiber filter with a polyurethane plug (PUF) using a high-volume (30 m^3/hour) sample method. VOCs were collected on a Tenax-adsorbent using active sampling. C_1-C_3 carbonyl compounds were collected on a silica-adsorbent impregnated with 2,4-dinitrophenylhydrazine using active sampling.
- Analysis: PAH samples were prepared by soxhlet extraction followed by GC/MS analysis. VOC samples were thermally desorbed followed by GC/MS analysis. Carbonyl samples were prepared using solid phase extraction followed by HPLC/UV analysis.

Results: Results of the airborne dust and gas phase showed the presence of PAHs, phthalates, other SVOCs, benzothiazoles, VOCs (toluene, MIBK) and aromatic amines.

Significant observations were as follows:

- Total PAHs ranged from 121-364 ng/m^3 in the gas phase and from 4.9-10.8 ng/m^3 in the particulate phase. Naphthalene concentrations in the gas phase ranged from 11.1-56.4 ng/m^3 and benzo(a)pyrene concentrations in the particulate phase ranged from 0.38-1.15 ng/m^3. There were no significant differences between the PAH concentrations in the air samples from the different types of granulates.
- The most prevalent phthalate in both the gas phase and the particulate phase was di-n-butylphthalate with concentrations ranging from 60-380 ng/m^3 in the gas phase and 31.4-51.7 ng/m^3 in the particulate phase. There were no significant differences between the phthalate concentrations in the air samples from the different types of granulates.
- Toluene concentrations in the gas phase ranged from 15,000 ng/m^3 to 85,000 ng/m^3 and MIBK concentrations in the gas phase ranged from nondetect (at 900 ng/m^3) to detected concentrations of 12,700 ng/m^3. The concentrations of MIBK were significantly lower in the air samples from the TPE granulates. In addition, the concentrations of total VOCs (136,000 ng/m^3) were lower in the air samples from the TPE granulates (compared to a maximum of 716,000 ng/m^3 with air samples from the SBR granulates).
- Benzothiazole was detected in the gas phase at concentrations ranging from 3400 to 31,700 ng/m^3, with the lower concentrations attributable to the air samples from the TPE granulates. 2-Hydroxybenzothiaole was the most prevalent benzothiazole compound in the particulate phase

from air samples generated with the SBR granulates with concentrations ranging from 346-566 pg/m^3; this compound was not detected (<0.05 pg/m^3) in the particulate phase air sample generated with the TPE granulates.

- The most prevalent aromatic amine in the particulate phase from air samples generated with the SBR granulates was n-isopropyl-n'-phenyl-p-phenylendiamine with concentrations ranging from 267-887 pg/m^3; this compound was not detected (<0.08 pg/m^3) in the particulate phase air sample generated with TPE granulates.

Conclusions: Higher VOC, benzothiazole, and aromatic amine levels were seen in the SBR air measurements than in the TPE air measurements. The TPEs generate less contamination than rubber granulate from used automobile tires.

The strengths of the NILU study include:

- The study does document that VOCs are degassing from rubber granulates used in synthetic turf.

The potential limitations and data gaps of the NILU study include:

- The applicability of the indoor air quality to outdoor applications is low. An indoor assessment would likely over represent outdoor air quality.

Plesser, T.S.W. and Lund, O. J. 2004. Potential health and environmental effects linked to synthetic turf systems - final report. Norwegian Building Research Institute, 0-10820.

The Norwegian Building Research Institute (NBI) conducted a study to evaluate the potential environmental and health effects linked to the use of synthetic turf systems. This study was conducted on behalf of the Norwegian Football Association.

<u>Objective (Test #1):</u> The objective was to determine the chemical constituents of rubber granulates from three manufacturers and EPDM granulates from one manufacturer.
<u>Method (Test #1):</u> Four rubber granulate samples from three manufacturers were evaluated, three based on recycled rubber and the fourth on EPDM. The rubber granulate samples were analyzed for metals, total PCBs, total PAHs, total phthalates and phenols at laboratory using European laboratory methods.
<u>Results (Test #1):</u> Lead, cadmium, copper, zinc, PAHs, phthalates (di-n-butylphthalate and diisononylphthalate) and phenols (4-t-octylphenol and iso-nonylphenol) were detected in all recycled rubber granulate samples. The authors note that PCBs were detected in one recycled rubber granulate sample whereas PCBs were not detected in the other recycled rubber granulate sample from the same manufacturer and all other recycled rubber granulate samples. Zinc concentrations were several orders of magnitude above other metals concentrations.
<u>Conclusions (Test #1):</u> The EPDM rubber granulate sample contained more chromium than the recycled rubber granulate samples. The zinc concentration in the EPDM sample was at a similar concentration as was detected in the recycled rubber samples, whereas the PAHs, phthalates and phenol concentrations were lower in the EPDM sample. PCBs were not detected in the EPDM sample.

<u>Objective (Test #2):</u> A volatilization study was conducted to evaluate organic emissions from rubber granulate samples.
<u>Method (Test #2):</u> Volatilization from rubber granulates was determined in the laboratory. The experiment consisted of heating 2 grams of rubber granulate was to 70°C (158º F) for 30 minutes, then analyzing the resulting gas.
<u>Results (Test #2):</u> The study found that a significant number of alkylated benzenes, trichloromethane and cis-1,2-dichloroethene volatilized from the samples.
<u>Conclusions (Test #2):</u> The authors noted that EPDM rubber gives off much smaller quantities of VOCs as compared to rubber granules manufactured from recycled rubber.

The strengths of the Plesser study include:

- The volatilization results are presented here as supplementary information to the bulk sample results, since the bulk samples were not analyzed for volatile organic compounds. However, it should be noted that the volatilization experiment was conducted in a laboratory at temperatures of 158º F. Although conducted at temperatures higher than ambient temperatures, outdoor synthetic turf fields have had temperatures documented at these levels.

The potential limitations and data gaps for the Plesser study include:

- The study only evaluated rubber granulate samples from three manufacturers. Due to the variability within samples from the same manufacturer, it is unknown whether the results presented in this study are representative of typical rubber granulate chemical composition and concentrations.
- The processes involved in the cited European analytical need to be further investigated to ensure these methods are valid techniques.
- Study does not explain presence of PCBs in one sample. PCBs are not a component of rubber and have not been found in any other studies.

Moretto, R. 2007. Environmental and Health Assessment of the Use of Elastomer Granulates (Virgin and from Used Tyres) as Infill in Third-generation Synthetic Turf. Villeurbanne Cedex, France: Environmental Assessment of Waste, Materials and Polluted Soils (EEDMS).

Purpose: This study provided an evaluation of the chemicals and ecotoxicity present in percolates after being transferred through different constituent materials of the synthetic turf as well as evaluates VOCs and formaldehydes emitted when the synthetic turf is used for an indoor sports facility.

Methods: Chemicals investigated were known to be in the composition of the filling materials and included total cyanides, phenols, total hydrocarbons, PAHs, total organic carbon, 15 metals, fluorides, nitrates, ammonium, chlorides, sulfates, pH, and conductivity. Experiments for chemical and ecotoxicity were performed in a controlled pilot setting as well as in-situ, with both settings yielding similar results.

Results: Concentrations of chemicals recorded through the different materials were relatively low and fell rapidly during the course of the experiment, indicating a reduction effect in terms of release rates. Emission experiments were performed in a controlled environment using emission chambers. Emissions of VOCs from synthetic turf containing EPDM granules was greater than synthetic turf containing TPE granulates and used tire granulates.

Strengths of the Morretto study include:

- An alternative approach for evaluating air quality through the use of emission test chambers, where environmental conditions can be controlled. Some detail is provided on the protocol used.
- The evaluation is a conservative assessment of outdoor air conditions.
- The study was conducted over 28 days, where the air quality results for Day 28 were assumed to be constant for chronic exposures.

The potential limitations and data gaps of the Moretto study include:

- Due to the limited amount of crumb rubber produced using EPDM or TPE, the overall usefulness of this study is minimal.

Based on all reviewed literature, Table B-7 provides a summary of the most significant chemicals of potential concern associated with the tire manufacturing process and it identifies where in the manufacturing process they may originate. Based on their use in the tire manufacturing process and thus potential presence in tires, these chemicals are of potential concern in crumb rubber which is manufactured from the tires.

Table B-8
Contaminants of Potential Concern Based on Tire Manufacturing Processes
Summary of Literature Reviewed

Potential Contaminant of Concern	Potential Source	Reference
METALS		
Aluminum	Aluminum alkyl catalyst used to polymerize EPDM rubbers	Mechanical-Engineering-Archives 2006
Barium	Used to catalyze the synthesis of polybutadiene rubber	CalEPA 2007
Chromium	Component of steel belts and beads of tires	CalEPA 2007
	Component of EPDM rubber	KemI 2006
Cobalt	Transition metal complex used as catalyst in manufacture of high cis polybutadiene rubber	IISRP 2007
Iron	Component of steel belts and beads of tires	CalEPA 2007
Lead	Lead oxide formerly used as an activator in the vulcanization process	CalEPA 2007
Manganese	Component of steel belts and beads of tires	CalEPA 2007
Nickel	Transition metal complex used as catalyst in manufacture of high cis polybutadiene rubber	IISRP 2007 USEPA 2005
Selenium	Age restorer	USEPA 2005
Vanadium	Vanadium chloride catalyst used to polymerize EPDM rubbers	Mechanical-Engineering-Archives 2006
Zinc	Zinc oxide and zinc carbonate used as activators in sulfur vulcanization	Cocheo et al. 1983 Willoughby 2006 CalEPA 2007 NYC MSDS: Recycling Technologies Int'l, LLC, Re-Tek, Inc., and SJM Group of New York
VOLATILE ORGANIC COMPOUNDS		
Acetone	Use of petroleum oils as softeners in tire production	CalEPA 2007
Benzene	Solvent used in polymerization process of polybutadiene rubber	IISRP 2007
	Rubber polymer/carbon black interaction	Willoughby 2006
	Can be taken up by tire while in service	Willoughby 2006
	Use of petroleum oils as softeners in tire production	CalEPA 2007
1,3-Butadiene	Used to create styrene-butadiene rubber as well as polybutadiene rubber	
Carbon disulfide	Created by some accelerators	Willoughby 2006
Chloromethane	Used in the manufacture of butyl rubber	IISRP 2007
Cyclohexane	Solvent used in polymerization process of Solution-SBR and polybutadiene rubber	Mechanical-Engineering-Archives 2006 IISRP 2007
Cyclohexanone	Created by side-chain oxidation of amines produced from accelerators	Willoughby 2006
Ethyl benzene	Use of petroleum oils as softeners in tire	CalEPA 2007

Table B-8
Contaminants of Potential Concern Based on Tire Manufacturing Processes
Summary of Literature Reviewed

Potential Contaminant of Concern	Potential Source	Reference
	production	
n-Hexane	Solvent used in polymerization process of Solution-SBR and polybutadiene rubber	Mechanical-Engineering-Archives 2006 IISRP 2007
	Used in preparation of butyl rubber	IISRP 2007
Methyl ethyl ketone	Use of petroleum oils as softeners in tire production	CalEPA 2007
Methyl isobutyl ketone	Created by side-chain oxidation of amines produced from accelerators	Willoughby 2006
	Used in the production of rubber antioxidants	CalEPA 2007
n-Pentane	Used in preparation of butyl rubber	IISRP 2007
Styrene	Styrene-butadiene rubber	
Toluene	Solvent used in polymerization process of polybutadiene rubber	IISRP 2007
	Use of petroleum oils as softeners in tire production	CalEPA 2007
SEMIVOLATILE ORGANIC COMPOUNDS		
Alkylphenols	Antioxidants	Cocheo et al. 1983
	Can be picked up from environment while tires are in service	Willoughby 2006
Aniline	Added to tires to inhibit rubber degradation	CalEPA 2007
Aromatic oil	Plasticizers, softeners	Cocheo et al. 1983 Willoughby 2006 KemI 2006 NYC MSDS
Benzothiazole compounds	Used in tire production to accelerate the vulcanization process, Used as antioxidants, Used to help bond metal wire and metal belts to tire rubber	CalEPA 2007
Benzothiazole	Breakdown product in some of vulcanization accelerators and antioxidants	Reddy and Quinn 1997
2-Hydroxybenzothiazole	Breakdown product in some of vulcanization accelerators and antioxidants	Reddy and Quinn 1997
2-(4-morpholino)benzothiazole	Impurity in some of vulcanization accelerators and antioxidants	Reddy and Quinn 1997
2-Mercaptobenzothiazole	Accelerator	Cocheo et al. 1983
2-(N-morpholinyl)mercaptobenzothiazole	Accelerator	Cocheo et al. 1983
Hydroquinone	Activator	USEPA 2005
Naphthenic oil	Plasticizers	Cocheo et al. 1983 NYC MSDS
Naphthalene	From carbon black used as filler in tires	CalEPA 2007
PAHs, including carcinogenic	Use of petroleum oils as softeners in tire	CalEPA 2007

Table B-8
Contaminants of Potential Concern Based on Tire Manufacturing Processes
Summary of Literature Reviewed

Potential Contaminant of Concern	Potential Source	Reference
PAHs	production	
Phenols	Use of petroleum oils as softeners and extenders, Steel cords and fabrics comprising belts treated with phenol/formaldehyde to improve the adhesion to the rubber	CalEPA 2007
Phthalates	Can be picked up from environment while tires are in service	Willoughby 2006
	Plasticizers	Cocheo et al. 1983 USEPA 2005
Diethanolamine	Accelerator	USEPA 2005
Alpha naphthylamine	Activator	USEPA 2005
p-Phenylenediamine	Activator	USEPA 2005
Diphenylnitrosoamine	Used to inhibit vulcanization process during tire production and inhibit the decomposition of rubber in finished product	CalEPA 2007
Dimethylnitrosoamine	Used to inhibit vulcanization process during tire production and inhibit the decomposition of rubber in finished product	CalEPA 2007
OTHER POTENTIAL ANALYTES		
Amines	Created by some accelerators	Willoughby 2006
Ammonia	Accelerator activator	USEPA 2005
Carbon black	Extenders, fillers, reinforcing agent	Cocheo et al. 1983 KemI 2006 NYC MSDS
Ethylene thiourea	Accelerator	USEPA 2005
Formaldehyde	Steel cords and fabrics comprising belts treated with phenol/formaldehyde to improve the adhesion to the rubber	CalEPA 2007
Silica	Extenders	Cocheo et al. 1983
Stearic acid	Activator	Cocheo et al. 1983 NYC MSDS
Sulfur	Vulcanizing agent	Cocheo et al. 1983 NYC MSDS

F. IMPACT OF ENVIRONMENTAL FACTORS ON SYNTHETIC TURF MATERIAL OVER TIME

Verschoor, AJ. 2007. Leaching of Zinc from Rubber Infill on Synthetic Turf (football pitches). March 12, 2007. (Abstract only)

This study assesses the environmental impact of zinc leaching from synthetic turf. The study uses the data presented in the study conducted by Hofstra (2007) on behalf of INTRON for the purpose of evaluating environmental risks. Hofstra evaluated zinc leaching from new, 1-year-old and 3-year-old turf, where two different types of aged samples were evaluated: 1) aged samples that were produced by laboratory exposure to UV equivalent to 1 or 3 years sunlight exposure in accordance with ISO 4892-3 and 2) aged samples that were taken from synthetic turf fields of different ages (1 and 3 years of use). The leaching test used was NEN 7383, developed for the assessment of the leaching of inorganic substances from building materials. In this test a vertical column is filled with rubber crumbs (<4 mm) and eluted by an upward flow of deionized water for approximately 3 weeks until a liquid to solid ratio (L/S-ratio) of 10 has been achieved. The pH is not controlled, but is determined by properties of the material (rubber). Measurement of the inorganic compounds, pH and conductivity is measured at a L/S-ratio of 10, and sometimes at lower L/S-ratios.

The data from the Hofstra study show that zinc concentrations in leachate from rubber crumbs of car and truck tires aged in the laboratory increase with aging; whereas in samples aged under field conditions zinc concentration increases with age for the car tire crumbs but not for truck tire crumbs. The study notes that trends of field emissions are more difficult to interpret because the variety in field samples is high. The author notes that leaching of zinc from rubber products is already known from studies with tire debris and from tires weathering alongside highways. A study on a plot where tires were piled showed that zinc concentrations in the groundwater were up to 6 times higher than the concentration in a control plot.

The strengths of the Verschoor study include:

- The study presents more detail than the Hofstra summary on the results of Hofstra's evaluation.

The potential limitations and data gaps of the Verschoor study include:

- The study does not offer any new research on leaching from synthetic turf
- This study shows that zinc leaches from the rubber infill material in synthetic turf; however, it does not address the adverse impact on the synthetic turf associated with aging either under laboratory or field conditions.

Kolitzsus, H.J. 2007. Synthetic Turf Surfaces for Soccer, What Owners of Soccer Pitches Should Know about Synthetic Turf. IST Switzerland, United States Sports Surfacing Laboratory USSL.

This paper evaluates the characteristics of modern synthetic turf products for owners who are considering installing new or updated synthetic turf fields. The authors note that current synthetic turf fields should last for 10 to 15 years and they do not consider UV radiation to be an issue as pile fibers are being produced by reliable manufacturers. The authors note that a test method to determine the resistance of synthetic turf to UV radiation has not been developed on the international level; however they do discuss an Austrian test method, OISS Regulation Synthetic Turf 2006, in which the pile fibers are exposed individually to a defined UV radiation for five months and then retested for tensile strength. The decrease of tensile strength is used to assess the UV stability of the fiber.

The strengths of the Kolitzsus study include:

- The usefulness of this study is in describing a potential test method for evaluating UV impacts on synthetic turf systems.

The potential limitations and data gaps of the Kolitzsus study include:

- No testing or documentation was provided to support statements concerning the impact of UV radiation on synthetic turf systems.

Brakeman L. 2005. Experts spell out the true cost of synthetic turf maintenance. Athletic Turf News, May 24, 2005; Located on-line at: www.athleticturf.net. Accessed November 2007.

This article presents a summary of presentations made at the Synthetic Turf Infill Maintenance seminar held in Dearborn, MI, sponsored by the Michigan Sports Turf Manufacturers Association. The following information was included in the summary:

Bruce Lemons, founder of Foresite Design and a founding member of the Synthetic Turf Council offered the following recommendations:

- Ensure that contracts stipulate that the carpet material is tested before the manufacturer sends it out to a finisher to apply the latex or polyurethane backing to confirm it is to specifications.
- Ensure that the contract stipulates that the measure of hardness of the field (Gmax) must remain within ±5%
- New monofilament fiber technology is being developed that offers better wear and performance characteristics and a longer guarantee than the current slitfilm technology.

Amy Fouty, the Athletic Turf Manager for Michigan State University offered the following information based on her experience maintaining the fields:

- Sewn seams are preferable to glued seams because they are stronger, more flexible and last longer.
- Line markings should be tufted in as much as possible because the paint spreads over the field when the field is groomed. The dried paint is abrasive, slippery and the lines smear.
- A field magnet is necessary to remove metal objects from the turf.
- Static electricity control is an issue for the first few years that requires spraying diluted fabric softener to control.
- The cost of maintaining the fields is greater than is typically thought. One year maintenance costs for the one indoor synthetic turf fields came to $22,760 for the following activities:
    - Seam repairs
    - Crumb rubber application
    - Spraying, sweeping and handpicking the field
    - Painting the field
    - Outside contractor consultation or training costs – $1,200 to $3,000 per day plus expenses
    - Repairs - $30 to $70 per linear foot
    - Crumb rubber - $.50 to $1.00 per pound applied

The strengths of the Brakeman study include:

This article presents first-hand experience on the use of synthetic turf systems and is presented in this report as ancillary information only.

APPENDIX B–2

SUMMARIES OF REVIEWED LITERATURE IN CHAPTER 3

A. INGESTION EXPOSURE

Summaries of Reviewed Literature

Johns, D.M. 2008. Initial Evaluation of Potential Human Health Risks Associated with Playing on Synthetic Turf Fields on Bainbridge Island, Windward Environmental LLC, Seattle, WA, January.

Johns developed a risk assessment to evaluate the potential risk to children and youths playing on outdoor synthetic fields. For the purposes of analyzing the potential health risks that might be associated with playing on synthetic turf fields in the Pacific Northwest, Johns constructed an exposure scenario for both a child ("child sport play scenario") and a teenager ("teenager sport play scenario") that actively participates in team sport play on a turf field. The results of this initial evaluation of sport play on synthetic turf fields are consistent with the findings of the other human health risk assessments evaluating the risks from using tire crumb in recreational settings. Despite the use of a highly conservative exposure model (assuming that children and teenagers playing on a sport team will use the turf fields 5 times a week for either 3 or 7 years), cancer risks resulting from dermal contact and through incidental ingestion of tire crumb were all several orders of magnitudes below the EPA risk threshold level of 1 in 1,000,000 and non-cancer risks were all less than the EPA threshold of 1.0.

Purpose: Both the Bainbridge Island Metro Parks and Recreation District and the Bainbridge Island School District are considering the replacement of current playing field surfaces with synthetic turf fields. The field at Battle Point Park currently is an all weather sand matrix, while the field at the high school is natural grass. There has been considerable discussion about the potential human health and environmental risks posed by synthetic turf fields, especially those that incorporate tire crumb into the turf. An evaluation of the literature and a site specific risk assessment was conducted to evaluate the potential risks posed by synthetic turf fields.

Methods: For the purposes of analyzing the potential health risks that might be associated with playing on synthetic turf fields in the Pacific Northwest, an exposure scenario was constructed for both a child ("child sport play scenario") and a teenager ("teenager sport play scenario") that actively participates in team sport play on a turf field. The child sport play scenario assumes that a child uses the turf field for 3 years (from age 8 to 10), and plays for 3 hours/day for 261 days/year (year-round play). The teenage sport play scenario assumes that a teenager uses the turf field for 7 years (from age 11 to 18), and plays for 3 hours/day for 261 days/year (year-round play). Exposure pathways included absorption through the skin from contact with tire crumb leachate, inhalation of VOCs, and ingestion of whole tire crumb particles.

Chemicals evaluated in the risk assessment include both carcinogens and non-carcinogens (arsenic, zinc, acetaldehyde, benzene, bis(2-ethylhexyl)phthalate, benzo(a)pyrene, MIBK, toluene, total carcinogenic PAHs, total PCBs, xylenes). Chemicals were selected based on availability of toxicological information, and are representative of all chemicals identified in tire crumb material to date. All concentrations used in the analysis were the highest measured concentrations listed in the following studies:

- Synthetic turf pitches – an assessment of the health risks for football players (prepared by NIPH 2006)
- Potential health and environmental effects linked to synthetic turf systems – final report (NBI, Plesser and Lund 2004)
- Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products (OHHEA 2007)

Results: The results of this initial evaluation of sport play on synthetic turf fields are consistent with the findings of the other human health risk assessments evaluating the risks from using tire crumb in recreational settings (CalEPA 2007, NIPH 2006, Hofstra 2007). Despite the use of a highly conservative exposure model (assuming that children and teenagers playing on a sport team will use the turf fields 5 times a week for either 3 or 7 years), cancer risks resulting from dermal contact and through incidental ingestion of tire crumb were all several orders of magnitudes below the EPA risk threshold level of 1 in 1,000,000 and non-cancer risks were all less than 1.0. Risks from the inhalation pathway are all well below the risk threshold for the child sport play scenario and also for the teenage sport play scenario for all chemicals except benzene and carcinogenic PAHs. For these two chemicals the risk estimate is at the risk threshold. It should be noted that the inhalation scenario used concentrations of VOCs found in facilities rather than in an open air environment. Using the indoor air value overestimates the likely risks associated with inhalation of VOCs in outdoor environments. The inhalation exposure scenario also assumed that VOC concentration throughout the exposure time remained at steady state to VOC concentrations reported for newly installed indoor turf fields. Moretto (2007) found that the total VOC concentration released from synthetic turf fields decreased over 70% after the first 28 days following installation. Reductions of this magnitude would result in inhalation risks to teenagers to below the threshold criterion of 1 in 1,000,000.

The strengths of the Johns study include:

- Provides a realistic, yet conservative exposure scenario to evaluate risks to human health after chronic exposure to crumb rubber
- No excess risk even with the use of conservative exposure values, thus strengthens argument that there is little health risk from ingestion exposure to crumb rubber.

The potential limitations and data gaps of the Johns study include:

- Used data available in literature for chemical concentrations including the use of indoor air concentrations as a surrogate for outdoor air; however, this is a conservative assumption, *i.e.* more health protective.
- Johns used standard USEPA default ingestion rates to estimate oral exposure. The ingestion of crumb rubber will more likely be due to hand-to-mouth activity ingestion of crumb rubber dust material adhering to the skin and not the ingestion of rubber itself. For this reason, the use of the USEPA standard soil ingestion factors appears to be a reasonable surrogate for the ingestion of crumb rubber.

California Environmental Protection Agency (CalEPA). 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Sacramento, CA: Office of Environmental Health Hazard Assessment.

The California Environmental Protection Agency (CalEPA)'s Office of Environmental Health Hazard Assessment (OEHHA) conducted an evaluation the health effects of recycled tires in playground and track surfaces. They evaluated two ingestion pathway scenarios, chronic hand-to-mouth activity by children aged 1 to 12 years old and a one- time ingestion of 10 g of crumb rubber by a 3 year old child. The 10 g ingestion rate is based upon the ingestion rate for a child with pica (CalEPA 2000; USEPA 2002). No studies have been conducted that quantitatively evaluate ingestion rates for synthetic turf pellet material for adults or children during routine use of a synthetic turf field. Using two sets of data (leachate data from the literature and leachate data from a gastric simulation study) for the acute study, CalEPA showed that with the exception of zinc from the literature data and aniline from the gastric simulation study, all the detected compounds with screening levels were below a level of concern. The dose calculated for the maximum detected zinc concentration was 5-fold higher than the subchronic minimum risk level. The maximum detected zinc concentration found in the literature was 18-fold higher than that measured in the gastric simulation study. In addition, it was also shown that the ingestion of these chemicals based upon both sets of leachate data would not pose a carcinogenic risk under these assumptions. The evaluation of chronic hand-to-mouth activity showed that calculated exposures were below levels associated with potential adverse health effects. However, cancer risk was calculated to be 2.9E-06, above the generally accepted cancer risk threshold of 1E-06 (i.e., one in one million).

Purpose: To evaluate playground surfaces 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).

Acute Ingestion Study – Literature Search for Leachate Data

Method: In the child ingestion scenario conducted by CalEPA, chemical concentrations were determined in two ways: 1) based on a literature review of various laboratory studies on leachate from various tire materials such as whole tires, tire shreds, chips and crumb and 2) based on the results of a gastric digestion simulation experiment.

In the first part of the CalEPA evaluation, a literature search was conducted and a list was compiled of chemicals detected in various leachate studies. CalEPA then calculated a dose to a 15 kg child using the maximum detected concentration for each chemical, assuming a one-time ingestion of 10 g of rubber pellet. They also assumed that each chemical was 100% bioavailable from the GI tract.

Results: These doses were compared against health-based screening levels. With the exception of zinc, all the detected compounds with screening levels were below a level of concern. The dose calculated for the maximum detected zinc concentration was 5-fold higher than the subchronic minimum risk level. It was also shown that the ingestion of these chemicals based upon the leachate data would not pose a carcinogenic risk under these assumptions.

Acute Ingestion Study – Gastric Digestion Simulation Study

Methods: In order to simulate the ingestion of crumb rubber by a child, CalEPA conducted a gastric digestion simulation test, in which three samples of shredded tire rubber were obtained from three recyclers. Forty grams of shredded tire rubber were added to each of three glass flasks. A fourth control flask received no rubber. Then 200 mL of a "gastric digestion" solution were added to simulate the environment of the human stomach. A citric acid-sodium citrate buffer was added to help maintain a constant pH of 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 °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. Metals were analyzed by EPA Method 6020, and SVOCs, including 16 PAHs, were analyzed by EPA Method 8270C.

Doses were again calculated assuming 10 g of rubber were ingested by a 15 kg child. Resulting acute doses were compared to non-cancer screening criteria and cancer guidelines.

Results: The gastric tire leachates contained 13 metals and 9 SVOCs that were present at lower levels or not at all in the control leachate. No PAHs were detected in the gastric digestion stimulation experiment. The Table below presents the analytical results from the gastric leachate experiments. Unfortunately, these measurements give no information on bioavailability, which was assumed to be 100% 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 the 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 ocyanobenzoic acid.

Chemicals detected in "gastric leachate" (μg/l)

Chemical	Reporting Limit	Tire Sample "G"	Tire Sample "S"	Tire Sample "O"	Control
Metals					
Antimony	0.5	110	42	1.7	ND
Arsenic	1	6.1	5.4	4.7	ND
Barium	1	130	110	870	4.2
Cadmium	0.25	2.2	2.8	1.1	.44
Chromium (total)	2.0	41	57	35	16
Cobalt	0.5	45	50	33	ND
Copper	0.5 – 50	1500	960	1600	8.3
Lead	0.5	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)-Benzothiazolone	36 – 190	640	450	480	ND
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
Benzldehyde, 3-Hydroxy-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

ND = Below Reporting Limit
From CalEPA 2007.

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 the risk assessment. Thus, the CalEPA value for leaching zinc as well as the majority of zinc values gathered from the literature, suggest that the value used in the risk assessment overestimates the dose.

For the risk evaluation on chemical concentrations based on the gastric digestion simulation experiment, aniline slightly exceeded the non-cancer screening criteria. The acute doses were below screening cancer guidelines.

Hand-to-Mouth Activity Study

Method: In order to evaluate chronic hand-to-mouth exposure, CalEPA used wipe samples to simulate exposure to chemicals in surfaces containing recycled tire rubber. It should be noted that these evaluations were for hard playing surfaces and not for crumb rubber exposure. To measure the chemicals that might be transferred to a child's hand through contact with the rubber playground surface made of recycled tires, a protocol from the US EPA (2003a) that was used to wipe sample arsenic from CCA-treated wood was modified for this study. Polyester wipes were put into a clean glass jar with 23 mL of distilled water (for metals or SVOCs) or isopropyl alcohol (for PAHs). A 1.1 kg cylindrical 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 analyzed by the following methods: calcium, iron, potassium and magnesium by EPA6010B; mercury by EPA 7471A; all other metals by EPA 6020; SVOCs by EPA 8270C; PAHs by GCMS-SIM.

Exposure was assumed from ages 1 through 12 years of age. Assumptions were made regarding hand-to-surface contact (23 times/hour), hand-to-mouth contact (7 times/hr), area of hand surface transferring chemical to mouth (20 cm^2), hand-to-mouth transfer efficiency (50%) and length of time at the playground (2 hours). The assumptions were used to calculate an ingested dose from hand-to-mouth contact.

Results: Ten metals (aluminum, antimony, barium, calcium, copper, iron, magnesium, mercury, potassium and zinc) and six PAHs (benzo(b)fluoranthene, chrysene, fluoranthene, naphthalene, phenanthrene and pyrene) were detected. Another 12 metals and nine PAHs were not detected in any sample. In addition, no SVOCs were detected in any wipe sample.

Calculated exposures were below levels associated with potential adverse health effects. However, cancer risk was calculated to be 2.9E-06.

The strengths of the CalEPA study include:

- Provides a method to quantitative method to evaluate potential ingestion of crumb rubber. Methods and concentrations used are conservative, therefore more than likely overestimating risk.
- Study is first to evaluate the potential “digestion” of crumb rubber in the GI tract by using a synthetic “gastric juice”.
- Study uses conservative parameters and shows relatively little risk under an acute ingestion scenario.
- Study uses very rigorous USEPA analytical methods for analysis of metals, VOCs and SVOCs.

The potential limitations and data gaps of the CalEPA study include:

- No field studies were conducted to evaluate actual exposure. Acute exposure by a three-year old was assumed. A value of 10 g was used as the ingestion rate based on EPA and CalEPA acute risk assessment guidelines for soil ingestion;
- Ingested doses from leachate were considered to be 100% bioavailable from the GItract;
- For the ingestion of crumb rubber, only acute exposures were assumed (*i.e.*, one-time, high dose) rather than long-term chronic exposure more typical of on-going recreational use;
- Lack of supporting studies relating the acute ingestion rate to ingestion that may occur during recreational use of a synthetic field by children, youths and adults;
- The preferential use of acute or subchronic screening criteria rather than chronic screening criteria;
- The use of leaching data obtained from various laboratory studies found in the literature. The maximum detected concentration of a chemical in the leachate was used for the evaluation, without regard to the form of the tire sample (whole tire, shredded tire, crumb rubber, etc), the composition of the leachate or the holding times for the leachate experiment,
- Lack of data on the actual leaching of chemicals from crumb rubber in the gastro-intestinal tract;

- For all the detected chemicals in the leachate studies, none were obtained using a methodology that would mimic human digestion. The 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. In addition, the leaching times were extremely variable, ranging from 17 hours to six months. These studies also utilized different starting material: whole tires, tire shreds, chips and crumb;
- The maximum detected concentrate of zinc in the leachate which was used to calculate a dose to a child that ingested crumb rubber was obtained by shaking tire chips in an aqueous solution at a pH of 2.5 for 67 hours. In children older than 2 years old, it has been shown that after meal, the $t_{1/2}$ gastric emptying time (the time it takes for the stomach to empty out half its contents) is about an hour or less and that the stomach will be empty about 4 hours after a meal (Heyman, 1998).
- Hand-to-mouth studies were conducted for hard rubber play surfaces and therefore may not be applicable to crumb rubber exposure; and
- Protocol for gathering wipe data for the hand-to-mouth exposures is overly conservative. Use of a 1.1 kg weight dragged across the surface of the rubber play surface would over estimate the amount of material adhered to the skin.

Norwegian Institute of Public Health and the Radium Hospital (NIPH). 2006. Synthetic Turf Pitches – an assessment of health risks for football players

A Norwegian study designed to evaluate potential exposure by child football (rugby) players to synthetic turf materials in indoor sports halls assumed a high-end chronic ingestion rate of 1 g of synthetic turf material per match/training session; however, no reference or supporting documentation was provided for this value. The study concluded that there was no elevated health risks associated with oral exposure to chemicals in recycled rubber granulates.

Objective: A study conducted by the Norwegian Institute of Public Health and the Radium Hospital evaluated the health risks to football players from exposure to synthetic turf fields. As part of the evaluation, the study evaluated the risk of oral exposure to chemicals present in recycled rubber granulates by children playing on synthetic turf material.

Method: Six month chronic exposure and one- to two-day acute exposure scenarios were evaluated, where it was assumed that a 30-kg child ingested 1 g of recycled rubber granulates per tournament, training session or match. This incidental ingestion rate was based upon an estimate of 0.5 to 1 g of material ingested per tournament, training session or match, although no justification was provided. Recycled rubber granules were selected to evaluate potential exposure as they were found to contain the highest concentrations of chemicals, as compared to TPE or EPDM rubber. In addition, it was assumed that the 100% uptake from the gastrointestinal tract occurred. The highest chemical concentrations detected in another Norwegian study (NILU 2006) were used to calculate the doses for a six-month exposure and for a two-day exposure. The doses were compared to available lowest NOAEL values for the most relevant biological end points (*e.g.* cancer, reproductive damage, organ damage).

Result: The study concluded that there was no elevated health risks associated with oral exposure to chemicals in recycled rubber granulates.

The strengths of the NIPH study include:

- Used conservative assumptions and concluded no elevated health risks, thus strengthens argument that there is little health risk from ingestion exposure to crumb rubber.
- Evaluations conducted under real "play scenarios" on crumb rubber surfaces.

The potential limitations and data gaps of the NIPH study include:

- The study evaluates oral exposure using air sample data from the NILU 2006 study.

- Although a six-month exposure was evaluated, on-going, multiple year chronic exposure typical of recreational use of a park by nearby residents was not evaluated.
- The study assumed 100% absorption of chemicals detected in recycled crumb rubber. The correlation between chemical concentrations in recycled rubber granulates and chemical concentrations that would leach from granulates due to gastric digestion was not determined.
- The study only evaluated a child's exposure, it did not evaluate youth/adult oral exposure.

Hofstra U. 2007. Environmental and Health Risks of Rubber Infill. Rubber Crumb From Car Tyres as Infill on Synthetic Turf. Summary. INTRON

INTRON is an independent organization providing quality assurance/quality control for products and processes in the construction sector. This organization conducted a literature review and limited experiments to evaluate potential human health and environmental effects associated with exposure to rubber infill from shredded car tires. For the ingestion route of exposure, the authors compared concentrations of heavy metals and phthalates detected in synthetic rubber materials found to levels established in the European Toy Directive and concluded that since the heavy metals concentrations in rubber infill material did not exceed these levels, heavy metals and phthalates do not result in adverse health effects to football players. They also considered the ingestion of organics not to be a relevant exposure scenario.

Objective: To evaluate potential human health and environmental effects associated with exposure to rubber infill from shredded car tires.

Methods: Laboratory experiments included composition analyses for the leaching of various chemicals. In these analyses fresh samples from production plants, samples from 1-year-old fields and 3-year-old fields were investigated. Also laboratory weathering tests were conducted and the leaching of 1-year old and 3-year-old infill samples was investigated on the laboratory-weathered samples. For the ingestion route of exposure, the authors compared concentrations of heavy metals and phthalates detected in synthetic rubber materials found to levels established in the European Toy Directive.

Results: The study concluded that since the heavy metals concentrations in rubber infill material did not exceed the levels established in the European Toy Directive, then the heavy metal and phthalate concentrations in the rubber infill material do not result in adverse health effects to football players. They also considered the ingestion of organics not to be a relevant exposure scenario.

The strengths of the Hofstra study include:

- It is assumed that this is a conservative assessment since the European Toy Directive standards were developed to protect chronic exposure to children.

The potential limitations and data gaps of the Hofstra study include:

- No supporting documentation is provided that supports study conclusions. Study data and citation list are not presented in this document;
- No information is provided on the analytical methods employed to analyze infill material or conduct weathering experiments;
- Applicability of using European Toy Directive standards as a means of determining potential adverse health effects from exposure to infill material is not evaluated; and
- No supporting documentation for concluding that the ingestion of organics is not a relevant exposure pathway.

New Jersey Department of Environmental Protection (NJ DEP). 2007. Preliminary Assessment of the Toxicity from Exposure to Crumb Rubber: Its use in Playgrounds and Synthetic Turf Playing Fields. White Paper Analysis. Trenton, NY: Division of Science, Research and Technology (T. LeDoux).

The New Jersey Department of Environmental Protection used the soil ingestion rates included in the calculations for determining soil cleanup standards as the assumed synthetic turf material ingestion rates and concluded that based on available data (no references provided) that ingesting up to 200 mg/day of synthetic rubber materials is not associated with adverse health effects.

The potential limitations and data gaps of NJDEP study include:

- No information provided as to what data and what exposure parameters were used in the assessment.

B. DERMAL EXPOSURE

Summary of Reviewed Literature

California Environmental Protection Agency (CalEPA). 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Sacramento, CA: Office of Environmental Health Hazard Assessment.

As part of CalEPA's evaluation of the health effects of recycled tires in playground and track surfaces discussed in the previous section, the dermal exposure pathway and the potential for dermal sensitization was evaluated. CalEPA determined that dermal absorption was an insignificant pathway when compared to ingestion of chemicals by hand-to mouth contact.

CalEPA evaluated the potential for allergic reaction from contact with rubber surfaces. Tires contain varying amounts of natural rubber, in addition to the more prevalent synthetic rubber, SBR. 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. The potential for skin sensitization was evaluated by performing laboratory tests on guinea pigs using tiles of SBR, EPDM, and loose crumb rubber (SBR). All SBR was from recycled tires. The authors noted that EPDM does not contain latex and is typically used as a top coat over other solid rubber surfacing containing latex. CalEPA determined that the dermal sensitization study was negative for the recycled tire playground material.

Purpose: To evaluate playground surfaces 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) dermal absorption through dermal contact and 4) skin sensitization via dermal contact (acute exposure).

<u>Dermal Exposure Assessment</u>

Methods: Dermal exposure was evaluated by determining dermal absorption rates, which predict the mass of a chemical that enters the body via absorption through the skin, for tire-related chemicals. These rates were compared to the chemical transfer rate determined for dislodged chemical residue as a result of hand-to-mouth activity by children playing on hard rubber playground surfaces. The authors cite an EPA hand-to-mouth chemical transfer rate of 50% (USEPA 2002). Dermal absorption rates for 20 tire-related chemicals were obtained from literature. A review of applicable studies indicated that children put their hands in their mouths approximately 7 times per hour (*i.e.*, every 8.6 minutes). Therefore, the authors concluded that in order to contribute significantly to the intake of tire-related chemicals, the dermal absorption should be on the order of 50% per 8.6 minutes of dermal exposure. The dermal absorption rates from the literature were normalized to an exposure duration of 8.6 minutes. All rates of dermal absorption were less than 1% per 8.6 minutes except for 4, 4'-methylene dianiline, which was 3.9 % per 8.6 minutes.

Results: The authors noted that the literature values for dermal absorption resulted in a significantly lower mass of chemical entering a child's body than the mass ingested due to hand-to-mouth activity. Therefore, the authors concluded that dermal contact was an insignificant route of exposure as compared to ingestion associated with hand-to-mouth activity and chose not to calculate dermal absorption of tire-related chemicals.

Skin Sensitization Study

Method: The skin sensitization testing consisted of three 6-hour 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 skin reddening. Negative and positive controls were employed. The negative control substance was high density polyethylene sheeting 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.

Results: No sensitization induced by the test materials was observed based on the test conducted. The authors also concluded that these surfaces would not cause skin reactions in children already sensitized to latex.

The strengths of CalEPA study include:

- The study provides a good method for evaluating the relative significance of chemical transfer into the body associated with dermal contact versus hand-to-mouth activity.
- The use of a standardized toxicological sensitization test to evaluate skin sensitization in an *in vivo* (guinea pig) test system.

The potential limitations and data gaps of CalEPA study include:

- The applicability of this study to dermal exposure to rubber infill material is low considering that the study evaluated hard rubber playground surfaces as the exposure medium.
- This study only applies to young child exposure, where hand-to-mouth contact rates by a three-year old were used, which eliminates the potential for contact by other body parts;
- Background wipe samples were conducted on concrete and not a grassy surface.
- No corroborating studies were presented as to the presence of latex allergens in the rubber material used in the studies.

Norwegian Institute of Public Health and the Radium Hospital (NIPH). 2006. Synthetic Turf Pitches – an assessment of health risks for football players

This Norwegian study was designed to evaluate potential exposure by adult, youths and older child football (rugby) players to synthetic turf materials in indoor sports halls assumed a high-end adherence factor of 1.0 mg/cm^2 as representative of a default value. This value is higher than either the geometric mean value of 0.1 or the 95th percentile value of 0.6 mg/cm^2 recommended by the USEPA (2004), however, no reference or supporting documentation was provided for this value. According to USEPA (2004) for the dermal exposure route, the soil adherence factor term is a very sensitive parameter.

Purpose: The Norwegian Institute for Air Research (NILU) compiled information on the occurrence and concentrations of chemical substances in rubber granulate and in sports hall air. The Norwegian Institute of Public Health and the Radium Hospital conducted an assessment of the potential risk of cancer and gentoxicity using the maximum detected indoor air concentrations compiled by NILU.

Methods: A study conducted by the Norwegian Institute of Public Health and the Radium Hospital evaluated the health risks to football players from exposure to synthetic turf fields. As part of the evaluation, the study evaluated dermal exposure by adult, youths and older child rugby players that were assumed to come in contact with dust/particles that are released from the rubber granulate while using the fields.

Analysis of rubber granulates and synthetic turf fibers were undertaken by AnalyCen AS while at NILU, analyses were carried out for selected elements and organic compounds. Leaching from synthetic turf fibre and rubber granulates was carried out using standardized methods. The leaching of heavy metals into water was measured by adding 200 g of rubber granulate or synthetic turf fibre to 2 L of water and leaving the solid material in contact with the water for 24 hours. To measure the leaching of organic compounds, 1 L of water and 100 g of rubber granulate were used with a contact time between the water and granulate of 48 hours.

It was assumed that parts of legs, arms, hands and face could be exposed. An adherence factor of 1.0 mg/cm^2 was selected as representative of a default value. This value is higher than either the geometric mean value of 0.1 or the 95th percentile value of 0.6 mg/cm^2 recommended by the USEPA (2004). Site-specific data obtained from the indoor halls on player exposure (i.e., hours per session, sessions per week) were determined from interviews with the indoor sports hall workers. Multiple exposure scenarios were considered. Adults, youths, older children and children were evaluated, where it was assumed they conducted training sessions or matches lasting from two to four hours per session, with multiple sessions per week over a six-month period of time. In addition, a short-duration exposure was evaluated for child players who are exposed only during tournaments lasting a few days.

The availability of chemicals for uptake by the skin was assumed to correspond with the chemical mass that leaches into water. It was determined that 0.06% of the mass of the rubber granules leached into water. In addition, 100% skin absorption was assumed for chemicals with no available skin uptake information.

Results: 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 the calculation of skin exposure, the authors used the leaching factor which gives the most leaching. Based on analyses and results for total organic carbon, it was decided to use a leaching figure of 60 mg/liter/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.

The resulting chemical doses available for skin uptake (by chemical class) ranged from 0.7 ng/kg/day for PCBs to 26.1 ng/kg/day for phthalates. These doses were deemed too low to result in any adverse health.

The NIPH study also considered allergic contact dermatitis qualitatively. The authors concluded that because the dose would be low and spread over a large contact area of skin, allergic contact dermatitis would not occur except for possibly on the feet. The authors concluded that since dust can accumulate in player's shoes, a higher dose over a smaller area could result in sensitivity.

The strengths of the NIPH study include:

- Provides a more realistic exposure scenario, although uses conservative exposure assumptions which would strengthen the results shown that there is limited risk from dermal contact.

The potential limitations and data gaps of the NIPH study include:

- The correlation between the leaching of chemicals into water in contact with rubber granules for 48 hours and leaching resulting from skin contact with rubber granules while playing on synthetic turf fields was not evaluated.
- No quantitative study was conducted to evaluate potential for allergic contact dermatitis.
- Cancer risks were only evaluated for adults.

New Jersey Department of Environmental Protection (NJ DEP). 2007. Preliminary Assessment of the Toxicity from Exposure to Crumb Rubber: Its use in Playgrounds and Synthetic Turf Playing Fields. White Paper Analysis. Trenton, NY: Division of Science, Research and Technology (T. LeDoux).

The New Jersey Department of Environmental Protection only considered allergic contact dermatitis and determined qualitatively that the potential exists for sensitive sub-populations to be allergic to crumb rubber. The author concluded that exposure to crumb rubber infill material has a high potential to cause allergic contact dermatitis in the 6 to 12% of the population that is allergic to rubber in some form. The author considered this risk to be highest in children rather than adults as they participate in activities more than adults do where dermal exposure is likely to occur. However, the author noted the lack of studies in this area.

The potential limitations and data gaps of NJDEP include:

- No data provided to support conclusions. Conclusion based only upon presence of natural latex in rubber and the percentage of the population that is allergic to latex.

Hofstra. U. 2007. Environmental and Health Risks of Rubber Infill. Rubber Crumb From Car Tyres as Infill on Synthetic Turf. Summary. INTRON

INTRON is an independent organization providing quality assurance/quality control for products and processes in the construction sector. Hofstra evaluated the dermal absorption and excretion of PAHs after exposure to tire crumb rubber by measuring PAH metabolites in the urine of adult football players. As part of the evaluation of human health and environmental effects conducted by Hofstra, laboratory studies were conducted that estimated the uptake of PAHs among football players due to skin contact with rubber infill material via the transfer of chemical to massage oil and Vaseline. In addition to the laboratory experiment, a field study was conducted among football players to determine the presence of PAH metabolites in the urine after they had intensive skin contact with rubber crumb on a synthetic field pitch. Although a low level of exposure to PAHs was evident, it could not be attributed specifically to the crumb rubber and could possibly be attributed to background exposures such as food.

Purpose: To evaluate potential human health and environmental effects associated with exposure to rubber infill from shredded car tires, including dermal exposure.

Method: Laboratory studies estimated the uptake of PAHs among football players due to skin contact with rubber infill material, where chemical transfer to massage oil and Vaseline was evaluated. Benzo(a)pyrene was used as a surrogate for all PAHs. The authors estimated a maximum average daily uptake for benzo (a) pyrene of 0.12 ng/kg of body weight per day for a professional football player exposure scenario. The authors noted that the "advised limit value for negligible risk level" is 1 ng/kg-day. In addition to the laboratory experiment, a field study was conducted among football players to determine the presence of PAH metabolites in the urine after they had intensive skin contact with rubber crumb on an synthetic field pitch. Urine samples from the players were collected during the days before and after the training. The urine samples were analyzed for 1-hydroxypyrene, a metabolite of pyrene, and a sensitive marker of internal PAH exposure.

Results: The authors concluded that PAH intake could not be determined with any certainty and if dermal uptake was occurring, it is within the range of PAH-exposure from other sources, such as food.

The strengths of the Hofstra study include:

- The study attempted to measure actual exposure of adult players to PAHs in crumb rubber by using the biomarker 1-hydroxypyrene.

The potential limitations and data gaps of the Hofstra study include:

- Laboratory methods and protocols were not presented.
- Field study protocol was not presented.
- No supporting documentation is provided that supports study conclusions. Study data and citation list are not presented in this document.
- The exposure parameters assumed for the professional football player exposure scenario were not provided.

Danish Technological Institute (DTI). 2005. Emissions and Evaluation of Health Effects of PAHs and Aromatic Amines from Tyres. Survey of Chemical Substances in Consumer Products, No. 54. Copenhagen DK: Materials Division

The Danish Technical Institute conducted in vitro migration tests to evaluate the leaching of chemicals from tire samples into synthetic sweat, which they then incorporated into a quantitative health assessment. Measurable concentrations of fluoranthene, pyrene, N-(1, 3-dimethylbutyl)-N´-phenyl-p-phenylendiamine (6PPD), and N-isopropyl-N´-phenyl-p-phenylendiamine (IPPD) were detected in the synthetic sweat. 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. The authors conclude that this finding is not only due to a higher amount of amines in the tires, but also due to the higher solubility of the aromatic amines in water.

Using the results of the synthetic sweat migration study, the investigators evaluated a scenario where toddlers and children were exposed by skin contact. They assumed that parts of the child'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. Calculated doses were compared with the available lowest NOAEL values for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). The authors concluded that there was no health risk from dermal contact to these chemicals.

Purpose: The Danish Technical Institute on behalf of the Danish National Agency of Environmental Protection conducted an evaluation of the migration and assessment of health effects of PAHs and aromatic amines from tires.

Methods: DTI conducted an in vitro test to measure the migration of PAHs and aromatic amines from the tire surface into synthetic sweat. A known area of the sample was exposed to synthetic sweat for one hour at 30^{o}C. The synthetic sweat was prepared according to ISO 12870:1997 (E) Synthetic sweat solution. The synthetic sweat is composed of 50 g lactic acid and 100 g sodium chloride dissolved in 900 ml water and diluted to a final 1 liter volume. Due to the different patterns and geometries of the tire samples, the area/volume of synthetic sweat during contact exposure was determined in such a way that the contact was one-sided. After the exposure period the rubber surface was rinsed with synthetic sweat and finally with de-mineralized water. The experiments were conducted in duplicate.

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 methylene chloride. The methylene chloride phase was dried two hours over dehydrated sodium sulfate. The methylene chloride phase was filtered from the sodium sulfate and concentrated to a final volume of 1 ml. The concentrate was analyzed for PAHs and aromatic amines after addition of internal standard to the original extract.

Results: Measurable concentrations of fluoranthene (0.029 – 0.277 ng/cm^2), pyrene (0.032 – 0.487 ng/cm^2), N-(1, 3-dimethylbutyl)-N′-phenyl-p-phenylendiamine (6PPD) (0.735 – 49.496 ng/cm^2), and N-isopropyl-N′-phenyl-p-phenylendiamine (IPPD) (ND to 10.197 ng/cm^2) were detected in the synthetic sweat. 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. The authors conclude that this finding is not only due to a higher amount of amines in the tires, but also due to the higher solubility of the aromatic amines in water.

Using the results of the synthetic sweat migration study, the investigators evaluated a scenario where toddlers and children were exposed by skin contact. They assumed that parts of the child’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. Calculated doses were compared with the available lowest NOAEL values for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). The authors concluded that there was no health risk from dermal contact to these chemicals.

The strengths of the DTI study include:

- The study used an in vitro method to determine the ability of constituents to leach into sweat.
- Used conservative risk assessment methods to determine the risk from dermal contact.

The potential limitations and data gaps of the DTI study include:

- The study’s focus was primarily on whole tires used in playgrounds, thus the samples were taken from whole tires and did not include crumb rubber;
- Exact methodology for application of the synthetic sweat was not defined;
- Analyses were limited to PAHs and aromatic amines

C. INHALATION EXPOSURE

Broderick, B. 2007a. Ambient Air Sampling for PAHs, Comsewogue High School Football Field, J.C. Broderick & Associates, Inc., October 30.

Broderick, B. 2007b. Ambient Air Sampling for PAHs, Schreiber High School Football Field, J.C. Broderick & Associates, Inc., October 30.

Purpose: Studies were conducted at two high schools in which PAH levels were measured in the air above and near the synthetic turf football fields due to concerns raised in a local TV news segment.

Methods: The air sampling was conducted utilizing laboratory supplied sampling tubes in accordance with NIOSH Manual of Analytical Methods, Method 5155 Polynuclear Aromatic Hydrocarbons by GC (8/15/94). Samples were collected on and around the athletic fields of the two high schools.

Results: Both studies showed no presence of detectable concentrations of PAHs above and around the football fields.

The strengths of the Broderick studies include:

- Actual measurements above an outdoor synthetic turf field.
- Used rigorous NIOSH Analytical methods for the analysis of PAHs in air.

The potential limitations and data gaps of the Broderick studies include:

- Study was conducted as a result of a local television news story regarding PAHs, thus the analysis was limited to PAHs and no other volatiles or particulates;
- Sampling protocol was not defined, there was no information in the report providing length of sampling (although can be calculated from the chain of custody); weather conditions at the time of sampling (temperature, wind speed), etc.

Instituto de Biomechanica de Valencia (IBV) 2006. Study of Incidence of Recycled Rubber from Tyres in Environment and Human Health. International Association for Sports Surface Science, Technical Meeting, Dresden

Purpose: A study conducted by the Spanish Instituto de Biomechanica de Valencia (IBV) together with recycling companies and a company that installs turf fields, evaluated the effect of recycled tires on the environment and health.

Methods: Air samples for PAH analysis were collected using PUF filters and high volume containers. Air samples for VOC analysis were collected in impassive containers while hydrogen sulfide was measured in situ using Drager tubes. Samples were obtained from the four corners of the field and at the center of the field.

Results: BTEX were detected at low concentrations, below European regulatory levels. A few PAHs were detected in the air samples also at concentrations below European regulatory levels. Hydrogen sulfide was not detected.

Conclusions: The study concludes that the VOCs and PAHs picked up in the samples are similar to the emissions generated by traffic in the zone of influence. And the values do not exceed any maximum value established by European legislation.

The strengths of the IBV study include:

- Study designed to measure contaminants from outdoor synthetic turf surfaces.

The potential limitations and data gaps of the IBV study include:

- No description of the sample collection methods or analyses performed.
- No supporting documentation provided.
- No citation list provided.

Moretto, R. 2007. Environmental and Health Assessment of the Use of Elastomer Granulates (Virgin and from Used Tyres) as Infill in Third-generation Synthetic Turf. Villeurbanne Cedex, France: Environmental Assessment of Waste, Materials and Polluted Soils (EEDMS).

Due to the prevalence of indoor sports halls, studies were conducted to evaluate VOC emissions from indoor synthetic turf systems. This study provided an evaluation of VOCs and formaldehydes emitted when the synthetic turf is used for an indoor sports facility. Using a controlled emission chamber, tests for VOC emissions were conducted in accordance with standard protocols for evaluating emissions from construction materials. Three turfs were evaluated, one using used tire granules, one using TPE granules and the third using EPDM granules. The paper concludes that the indoor air quality for sports halls with synthetic turf using any of the three rubber infill material types is “approximately the same magnitude” as ambient air quality, but notes that small sports halls with poor ventilation should be adequately ventilated when workers are installing synthetic turf.

Purpose: To evaluate simulated indoor air concentrations of VOCs and aldehydes in a controlled emission chamber in order to evaluate human health risks to users of the indoor field hall.

Methods: Three different types of rubber granules were evaluated: granules from used tires from French markets, virgin EPDM granulates and TPE granulates. Synthetic turf with green synthetic fibers and a band of white synthetic fibers, polyurethane glue, sand and the three types of rubber granulates comprise the materials used in the experiments. For each synthetic turf sample 0.15 m^2 in size, 2.625 kg sand and 2.25 kg rubber granules were used. The tests were conducted in accordance with protocols for determining VOC emissions from construction materials. The tests were conducted in controlled emission test chambers at an ambient temperature of 23 ± 2^oC and relative humidity of 50 ± 5%. The sampling and analysis of VOCs was conducted in accordance with the recommendations of NF ISO 16000-6 standard: Indoor air – Part 6: Dosage of volatile organic compounds in indoor air of premises and test enclosures by active sampling on the sorbent Texax TA, thermal desorption and chromatography in gaseous phase using MS/FID. The sampling and analysis of aldehydes was conducted in accordance with the recommendations of NF ISO 16000-3 standard: Indoor air – Part 3: Dosage of formaldehyde and other carbonylated compounds – Method by active sampling.

A risk assessment was performed which assumed athletes and workers installing the floors were exposed to these emissions in an indoor gymnasium. The receptors evaluated included: workers installing the synthetic turf floor, professional athletes and coaches, amateur athletes and spectators. Professional athletes and coaches are the most conservative receptors,, who are assumed to be exposed 8 hours a day, 365 days a year.

Results: The experiments detected total VOCs at 134 $\mu g/m^3$ at 28 days for the synthetic turf containing used tire granules; 118 $\mu g/m^3$ for synthetic turf containing TPE granules; and 490 $\mu g/m^3$ for synthetic turf containing EPDM granules.

The paper did not present hazard index or cancer risk estimates, rather qualitatively discussed the VOC results in the context of background air quality. The paper concludes that the indoor air quality for sports halls with synthetic turf using any of the three rubber infill material types is "approximately the same magnitude" as ambient air quality, but notes that small sports halls with poor ventilation should be adequately ventilated when workers are installing synthetic turf.

The strengths of the Morretto study include:

- An alternative approach for evaluating air quality through the use of emission test chambers, where environmental conditions can be controlled. Some detail is provided on the protocol used.
- The evaluation is a conservative assessment of outdoor air conditions.
- The study was conducted over 28 days, where the air quality results for Day 28 were assumed to be constant for chronic exposures.

The potential limitations and data gaps of the Morretto study include:

- European tire and synthetic turf products were evaluated. It is unknown whether the chemical composition of European rubber infill material is similar to rubber infill material manufactured in the United States. Also, it is unknown whether the rubber infill material in synthetic turf systems offered for sale in the Unites States is manufactured from tires manufactured in the United States.
- This study was conducted by groups tied to the tire and synthetic turf manufacturing industries.
- Indoor sports hall air quality was evaluated. This represents a highly conservative assessment of outdoor air quality.
- No air concentration results for chemical constituents were provided in the study.
- No risk calculations were conducted.

Norwegian Institute for Air Research (NILU). 2006. Measurement of Air Pollution in Indoor Synthetic Turf Halls. NILU OR 03/2006. Kjeller, Norway.

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 synthetic turf pitches. Sports halls with synthetic turf pitches are used for indoor football. These synthetic turf pitches consist of synthetic turf fibre and rubber granulates. NILU participated in a joint study with NIPH and measured indoor air concentrations of constituents of concern from synthetic turf, including VOCs and PAHs and NIPH (2006) conducted a risk assessment using the data. The measurements were taken in a hall with recently laid rubber granulate (SBR), a hall with rubber granulate (SBR) which had been in use for one year and a hall with granulate made from TPE. The authors conclude that the rubber infill material is a source of TVOCs in indoor sports halls, and even with adequate ventilation, TVOCs concentrations can be significant. The halls with SBR granulates had the highest TVOC concentrations. The hall with the TPE had the lowest TVOC concentrations.

Purpose: The Norwegian Institute of Air Pollution conducted a study to measure indoor air quality in sports halls that use synthetic turf system in order to generate data to be used in exposure studies (as described in NIPH 2006).

Methods: Three sports halls were selected, a hall with recently laid SBR granulate, a hall with SBR granulate which had been in use for one year, and a hall with granulate made from TPE. Particulate and gas-phase air samples were collected. The gas-phase samples were collected on a Tenax-adsorbent using active sampling in accordance with prEN ISO 16017, a standard method for the sampling and analysis of VOCs by sorbent tube/thermal desorption/capillary gas chromatography. The carbonyl compounds with one to three carbon atoms were collected on a silica-adsorbent impregnated with 2, 4-dinitrophenylhydrazine, using active sampling.

In addition, $PM_{2.5}$ and PM_{10} levels inside facilities with synthetic turf playing surfaces. Three halls were selected, a hall with recently laid SBR granulate, a hall with SBR granulate which had been in use for one year, and a hall with granulate made from TPE. Airborne dust was collected on a 47 mm quartz fiber filter with a flow rate of 2.3 m^3/hour. Separate filters were used for the PM_{10} fraction and the $PM_{2.5}$ fraction. The PM_{10} sample which was to be analyzed for PAH was collected on a 150 mm glass fiber filter with a flow rate of 30 m^3/hours. The sampling system was a Digital Automatic High Volume Aerosol Sampler (DHA-80) with an intake which complies with prEN12341. The chemical analysis of the airborne dust involved extracting part of the filter in a solvent in an ultrasound bath for 30 minutes. 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.

Results: The highest total PAH concentration detected was 363.7 ng/m3; the highest total VOC concentration was 716µg/m3. Both of the highest concentrations were from samples collected in halls with SBR rubber granulates. The authors noted slightly higher total VOC concentrations for samples collected when the sports halls were in use. They concluded that the mechanical working of the rubber granulates caused degassing to occur. Temperature effects on degassing were evaluated by conducting headspace tests at 6°C, 20°C, 27°C and 36°C. A reduction of 50% for benzothiazole and 22% for 4-methyl-2-pentanone was noted at a temperature change from 18 to 10°C. The authors conclude that the rubber infill material is a source of TVOCs in indoor sports halls, and even with adequate ventilation, TVOCs concentrations can be significant. The halls with SBR granulates had the highest TVOC concentrations. The hall with the TPE had the lowest TVOC concentrations.

The range of PM_{10} detected in the halls was 31 to 40 $\mu g/m^3$, while the measured concentrations of $PM_{2.5}$ were 10 to 19 $\mu g/m^3$. In the two halls with SBR granulate, it was calculated that 23 to 28% of the PM_{10} consisted of rubber, while 35% to 50% of the $PM_{2.5}$ was associated with the rubber particulate. Results of the airborne dust showed the presence of PAHs, phthalates, other SVOCs, benzothiazoles, and aromatic amines. Higher levels were seen in the SBR rubber air measurements than in the TPE air measurements. The maximum total SVOC concentration, including PAHs, was approximately11 ng/m^3. The maximum total phthalates concentration was approximately 134 ng/m^3. The maximum total concentration of other selected vulcanization and tire preservative compound, including benzothiazoles and aromatic amines, was approximately 2.2 ng/m^3. The study concludes that the use of rubber granulate from ground car tires adversely affects indoor air quality, even with ventilation. Rubber granulates produced from TPE generated less pollution. Also, the study shows the presence of organic chemicals which were not previously reported. The study recommends further research into adverse affects associated with latex exposure via the skin and air passages.

The strengths of the NILU study include:

- NILU conducted comprehensive sampling and analysis of the indoor air of the synthetic turf hall. Provides some insight as to materials off-gassing or contained in dust as a result of the crumb rubber

The limitations and data gaps of the NILU study include:

- The study evaluated indoor sport hall air quality at three specific sports halls in Norway. The applicability of the air quality to outdoor applications is low. An indoor assessment would likely over represent outdoor air quality. However, the study does document that VOCs are degassing from rubber granulates used in synthetic turf, although other sources for VOCs were noted (wooden wall panels, carpeted floors, ambient air).
- The source material for the rubber granulates may have a different chemical composition than rubber granulates manufactured in the United States.

Norwegian Institute of Public Health and the Radium Hospital (NIPH). 2006. Synthetic Turf Pitches – an assessment of health risks for football players

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 synthetic turf pitches. Sports halls with synthetic turf pitches are used for indoor football. These synthetic turf pitches consist of synthetic turf fibre and rubber granulates. NILU participated in a joint study with NIPH and measured indoor air concentrations of constituents of concern from synthetic turf, including VOCs and PAHs and NIPH conducted a risk assessment using the data. The measurements were taken in a hall with recently laid rubber granulate (SBR), a hall with rubber granulate (SBR) which had been in use for one year and a hall with granulate made from thermoplastic elastomer. The NILU (2006) study concludes that the rubber infill material is a source of TVOCs in indoor sports halls, and even with adequate ventilation, TVOCs concentrations can be significant. The halls with SBR granulates had the highest TVOC concentrations. The hall with the TPE had the lowest TVOC concentrations.

Although VOCs were detected, the exposure did not result in an elevated health risk. The authors noted that toxicological data was not available for many VOCs detected in the air samples. Benzene was the only carcinogenic VOC, and long-term exposure was evaluated for a total of 33 years of exposure. The resulting estimated cancer risk level was calculated to be 2E-06 and was considered to be negligible by the authors due to the conservative nature of the assessment. No adverse health effects were determined from all noncarcinogenic particulates. For particulates, PAH concentrations were determined to be within the range of background and were not attributable to rubber granulates.

Purpose: The companion study to NILU (2006) was conducted by the Norwegian Institute of Public Health and the Radium Hospital and evaluated the health risks to football players from exposure to synthetic turf fields. As part of the evaluation, the study evaluated inhalation exposure by adults, youths as well as older and younger children who play, train or play cup tournaments at indoor sports halls in Norway.

Methods: Site-specific data obtained from the indoor halls on player exposure (i.e., hours per session, sessions per week) were determined from interviews with the indoor sports hall workers. Multiple exposure scenarios for each receptor were considered. Adults, youths, older children and children were evaluated with the assumption that they participated in training sessions or matches lasting from two to four hours per session, with multiple sessions per week over a six-month period of time. In addition, a short-duration exposure was evaluated for child players who are exposed only during tournaments lasting a few days. The following inhalation rates were assumed: adults 6 m^3/hour, youth 4.8 m^3/hour, older children 3.6 m^3/hour and children 1.8 m^3/hour.

The air concentration data from the NILU 2006 study was used in these evaluations. The highest VOC concentrations were evaluated in the risk assessment, where noncarcinogenic compounds were compared to No Observable Adverse Effect Levels (NOAELs).

Results: Although VOCs were detected, the exposure did not result in an elevated health risk. The authors noted that toxicological data was not available for many VOCs detected in the air samples. Benzene was the only carcinogenic VOC, and long-term exposure was evaluated for a total of 33 years of exposure. The resulting estimated cancer risk level was calculated to be 2E-06 and was considered to be negligible by the authors due to the conservative nature of the assessment.

The NIPH also conducted a similar risk evaluation for the respirable dust results in the NILU (2006) study. The highest of the PM2.5 and PM10 air concentrations, 40 µg/m3 of PM10, was used in evaluating potential adverse health effects associated with the inhalation of particulates. The PM10 concentration for each of the chemical groups was determined by multiplying the intake rate of rubber granulate PM10 by the concentration of each chemical group detected in rubber granulate to determine the uptake rate for each chemical group. No adverse health effects were determined from all noncarcinogenic VOCs and particulates. For particulates, PAH concentrations were determined to be within the range of background and were not attributable to rubber granulates.

The strengths of the NIPH study include:

- Conservative inhalation rates were used.

The potential limitations and data gaps of the NIPH study include:

- This study evaluates indoor air quality in sports halls, and as such, would represent highly conservative estimates of potential adverse health effects associated with outdoor air exposure at parks where synthetic turf with rubber infill material is used. It is noted that the air sample used for determining VOC concentrations was collected in a sports hall while the hall was being ventilated.

Hofstra. U. 2007. Environmental and Health Risks of Rubber Infill. Rubber Crumb From Car Tyres as Infill on Synthetic Turf. Summary. INTRON

INTRON is an independent organization providing quality assurance/quality control for products and processes in the construction sector. This organization conducted a literature review and limited experiments to evaluate potential human health and environmental effects associated with exposure to rubber infill from shredded car tires. This study concluded that emissions of hazardous substances from rubber infill material do not pose a risk, based on a review of available literature. They supported this conclusion with their own analysis of the rubber infill, which identified only very limited amounts of volatile chemicals.

Purpose: To evaluate the potential human health and environmental effects associated with exposure to rubber infill from shredded car tires including through inhalation exposure.

Methods: A literature review and limited experiments were conducted to evaluate human health via inhalation exposure.

Results: This study concluded that emissions of hazardous substances from rubber infill material do not pose a risk, based on a review of available literature. They supported this conclusion with their own analysis of the rubber infill, which identified only very limited amounts of volatile chemicals. They reference literature calculations which show that the daily uptake of PAHs by inhalation of fine dust in an indoor hall by an adult training for 20 hours a week during the winter season, is limited in comparison to the PAH uptake from other sources.

The strengths of the Hofstra study include:

- None noted at this time

The limitations and data gaps of the Hofstra study include:

- No supporting documentation provided.
- No citation list.
- The summary does not provide any information on the basis for determining that the inhalation exposure pathway does not pose an adverse health risk.

Williams PB, Buhr MP, Weber RW, Volz MA, Koepke JW, Selner JC. 1995. Latex allergen in respirable particulate air pollution. J Allergy Clin Immunol. 95(1 Pt 1):88-95.

Natural latex is used in a wide variety of materials including tires. Latex sensitization has become an important health issue. Because urban air contains numerous black particulates, which may consist of tire dust, this study evaluated whether respirable particles in urban air samples contain natural latex. The study concludes that latex antigens are extractable from rubber tire fragments, which are abundant in urban air samples, and suggests that airborne particles could contribute to the increase in both latex sensitization and asthma.

Purpose: Williams et al. evaluated whether respirable particles in urban air samples, which may be airborne tire fragments, contain natural latex.

Methods: Particulate air pollutants were collected using rotary impaction sampling, high-volume air sampling with a PM10 sampler, and passive gravimetric sampling using greased glass plates. Samples were collected from air sampling locations in Denver, Colorado, as well as from the vicinity of moderately traveled roads. Air samples were analyzed using optical microscopy, chemical solubility tests, and mass spectrometry. Extracts of rubber tire fragments were also tested for elutable latex antigens by antibody inhibition assays.

Results: The study concluded that latex was identified in air samples and milled material from automobile tires. The study concludes that latex antigens are extractable from rubber tire fragments, which are abundant in urban air samples, and suggests that airborne particles could contribute to the increase in both latex sensitization and asthma.

The strengths of the Williams et al. study include:

- The study indicates the potential for particulates generated from rubber tires to contain latex, a known allergen.

The potential limitations and data gaps of the Williams et al. study include:

- The applicability of this study to particulates generated from rubber infill material is unknown.

D. CHILD AND ADULT USAGE PATTERNS ON SYNTHETIC TURF FIELDS

Benepe, A. (2007). Oversight – The Use of Synthetic Turf in City Parks. Testimony by the Commissioner. Hearing before the City Council Committee on Parks and Recreation. December 13.

On December 13, 2007, Commissioner Adrian Benepe testified before the City Council Committee on Parks and Recreation. His testimony discussed the history of synthetic turf, synthetic turf today, the challenges of maintaining the parks and fields in light of the increased population of NYC and the increased use of the park facilities. In addition, he provides statistics on the increased use of the parks as evidenced by the increase in permit hours. Finally he touches upon the health and safety aspects of using synthetic turf.

Morrison, L. (2005). Natural and Synthetic Turf: A Comparative Analysis. San Francisco Recreation and Parks. December.

The San Francisco Recreation and Park Department has been embarking on a program to increase the quality and the capacity of the athletic fields of San Francisco. One element of this program is the building of several new soccer fields with the latest generation of synthetic turf. The focus of this document is to compare the relative costs and benefits of synthetic and natural turf on soccer fields. The advantages of synthetic turf for soccer fields are well known and include the following: reduced maintenance costs, significant increases in playing time, and a superior playing surface. An analysis comparing synthetic and natural turf focused on these issues: their relative installation costs, the expected life span of the fields, their relative annual maintenance costs, their respective capacities for amount of play, their relative safety, and their relative impacts on the environment. In 2003, the Department constructed two new soccer fields with the latest generation of synthetic turf. The preliminary results have been overwhelmingly positive and the Department has several proposals for more such projects. With these two new soccer fields, the Department has found that the new synthetic fields increase by 50 to 100% the amount of play possible on fields, since these new synthetic fields do not have to be shut down for periods of maintenance and rehabilitation and they rarely have to be closed because of rainy weather. Furthermore, unlike their natural turf counterparts, they do not require the imposition of a ceiling on the amount of play allowed in order to protect the quality of the field.

The strengths of the Morrison study include:

- Provides a good overview of a municipality’s experience with installing new synthetic turf soccer fields

The potential limitations and data gaps of the Morrison study include:

- Specific to San Francisco

California Environmental Protection Agency (CalEPA). 2007. Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products. Sacramento, CA: Office of Environmental Health Hazard Assessment.

The CalEPA study provides three (3) studies that were found that surveyed the time and frequency that children spend at a playground. The data suggests that the children frequent the playgrounds multiple times per week and on an order of one to two hours per visit. The CalEPA study cited a recently completed 2005 USEPA exposure assessment of children playing on CCA- treated wooden playscapes which used an average time of two hours of playtime.

The strengths of the CalEPA study include:

- Compilation of playground frequency data

The limitations and data gaps of the CalEPA study include:

- Literature survey;
- Pertained to use of playgrounds and playscapes, not sport fields;
- Does not pertain to use of synthetic turf fields.

APPENDIX B-3

SUMMARIES OF REVIEWED LITERATURE IN CHAPTER 4

A. TEMPERATURE OF SYNTHETIC FIELDS

Summaries of Reviewed Literature

Benepe, A. 2007. Oversight – The Use of Synthetic Turf in City Parks. Testimony by the Commissioner. Hearing before the City Council Committee on Parks and Recreation. December 13.

On December 13, 2007, Commissioner Adrian Benepe testified before the City Council Committee on Parks and Recreation. His testimony discussed the history of synthetic turf, synthetic turf today, the challenges of maintaining the parks and fields in light of the increased population of NYC and the increased use of the park facilities. In addition, he provides statistics on the increased use of the parks as evidenced by the increase in permit hours.

Adamson C. 2007. Synthetic Turf Fields Present Unique Dangers. University of Missouri – Columbia, College of Agriculture, Food and Natural Resources. Located on-line at: http://cafnr.missouri.edu/research/turfgrass.php. Accessed on October 12, 2007.

This article presents a series of temperature measurements conducted by MU's "turf expert". Temperatures were measured at the University of Missouri's Faurot Field (outdoor synthetic infilled turf system (FieldTurf)), on a 98°F day and registered 173°F on the surface of the synthetic grass. Nearby natural grass showed a temperature of 105 °F. Temperatures taken at head-level height over the synthetic turf registered 138 °F.

The strengths of the Adamson study include:

- Provides a temperature measurements of an actual outdoor turf field

The potential limitations and data gaps of the Adamson article:

- Methodology and equipment used in the temperature studies not discussed.

Williams, C.F. and Pulley, G.E. 2002. Synthetic Surface Heat Studies. Brigham Young University. Located on-line at: http://cahe.nmsu.edu/programs/turf/documents/brigham-young-study.pdf. last Accessed on October 12, 2007.

This article presents a report by the authors on a series of heat studies conducted on synthetic surfaces at Brigham Young University. The University installed Field Turf synthetic turf on one-half of the football practice field and the other half was installed with a sand-based natural turf field.

Purpose: After the complaint of a coach receiving burns on his feet from the new synthetic turf field, an investigation was launched to determine the range of temperatures, the effect of water on cooling the fields and how the temperatures compared to other surfaces.

Methods: Preliminary temperature measurements were taken at the surface, six inches above and five feet above the surface of the synthetic turf, natural turf, bare soil, asphalt and concrete using an infrared thermometer. In addition, a soil thermometer was used to measure 2 inches below the synthetic turf. Temperatures were taken before and after irrigation.

A more detailed study was conducted in which three aspects of light were measured along with relative humidity. The soccer and football fields were treated as two sources of synthetic turf, and the natural turf area of the football field was treated as one source of natural turf. Asphalt, concrete and bare ground areas were also measured.

Results: The results of the preliminary experiments showed that the surface temperature of the synthetic turf was 37 ^{o}F higher than asphalt and 86.5 ^{o}F hotter than natural turf. Irrigation of the synthetic turf with cooling water for 30 minutes had a significant effect on surface temperature, dropping the temperature on the surface from 174 ^{o}F to 85 ^{o}F, but there was a rapid rebound effect with the temperature rising to 120 ^{o}F in 5 minutes and to 164 ^{o}F at 20 minutes.

The results of the more detailed study are summarized in the table below.

Summary of Temperature Readings taken between 7AM and 7PM (^{o}F)

Surface	**Surface - Average Temperature**	**Surface - Maximum Temperature**	**Subsurface (2 in.) - Average Temperature**	**Subsurface (2 in.) - Maximum Temperature**
Soccer Field	117.38	157	95.33	116
Football Field	117.04	156	96.48	116.75
Natural Turf	78.19	88.5	80.42	90.75
Asphalt	109.62	ND	NM	NM
Concrete	94.08	ND	NM	NM
Bare Soil	98.23	ND	90.08	ND

Where: ND = No data/not determined; NM = Not measured

The average temperatures at the surfaces were highest on the synthetic turf fields, followed by asphalt, bare soil, concrete and natural turf. The average temperatures 2 inches below the surface were highest in the synthetic turf football field followed by the synthetic turf soccer field, bare soil and natural turf.

These investigators also found that the temperature of the turf was more dependent on the amount of light, rather than the air temperature. White lines and shaded areas were less affected because of reflection and decreased intensity of light, respectively. Average surface temperature measurements of natural and synthetic turf taken in the shade show an approximate 9.5 ^{o} difference (66.35^{o} F versus 75.89^{o} F) between the two, respectively. However, the synthetic turf field's maximum temperature rose to 99^{o} F while that of the natural turf rose to 75^{o} F.

Conclusion: The authors state that cooling the fields for an event is a priority and although water is effective at cooling the surface temperatures, the volume of water needed for cooling is (increased due to poor engineering (infiltration and percolation). In addition, it appears that direct sunlight is primarily responsible for the highest heating of the fields as shown by the lower temperatures of the turf field taken in the shade versus taken in direct sunlight.

The strengths of the Williams and Pulley study include:

- Provides an overview of temperatures over different surface types

The potential limitations and data gaps of Williams and Pulley study include:

- Actual methods are not provided.
- Average temperatures over a 12-hour span are provided, but no back-up data for individual readings.
- No corresponding air temperatures provided for measurement time period
- Maximum concentrations only provided for turf (synthetic and natural), none for other surfaces. Asphalt readings at the surface were only 8° less than the synthetic turf readings but no maxima provided for comparison. In addition, for the subsurface temperatures, the bare soil subsurface temperature is within 5° of the subsurface synthetic turf readings but no maxima provided for comparison.

- The authors state that the hottest surface temperature recorded was 200° on a 98° day, however, the data were not mentioned in summary tables which provided average and maximum temperatures. No back-up information was provided for this result.
- Water quickly cooled the surface temperature, but temperatures quickly rose. The material is hydroscopic and is not meant to retain water at the surface. McNitt and Petrunak (2007d) directly addressed this issue in their paper and suggested the use of a nonionic wetting agent to address the problem

McNitt, A.S. and Petrunak, D. 2007d. Evaluation of Playing Surface Characteristics of Various In-Filled Systems. Temperature and Color. Penn State Department of Crop and Soil Sciences. On-Line: last accessed on October 12 2007 at http://cropsoil.psu.edu/mcnitt/infill.cfm

This paper presents the results of a multi-year project evaluating the performance of 10 synthetic turf systems. Nine of the systems are in-filled synthetic turf systems with a foam or rubber underlayment pad. The tenth system is the traditional, carpet-like AstroTurf. Due to the rapid advancement in the synthetic turf systems, the investigators are conducting this long-term project to evaluate how these fields perform over time. This study evaluates the increases in temperature seen with these systems. The 10 synthetic turf systems were tested for surface temperatures and ambient air temperatures 3 feet above the field surface. The investigators tried to limit temperature measurements to days that were bright and sunny, because cloudy days resulted in more erratic measurements. The surface temperatures of the fields ranged from 113.7 ^{o}F to 125.4 ^{o}F using a LiCor Scheduler infrared thermometer. The ambient air temperatures registered 3 feet above the turf surface ranged from 78.1 ^{o}F to 80.6 ^{o}F. The ambient air temperatures varied by a few degrees among the turfs, but did not appear to be correlated with the surface temperatures of the turf systems.

Purpose: The temperature studies are part of a large project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time. Surface quality will be evaluated periodically as the systems are exposed to weather and simulated foot traffic. At this time four years of data have been collected during this multi-year study. The effects of various maintenance activities on the playing surface quality of these systems will also be evaluated.

Method: The large synthetic turf study conducted by Penn State's Department of Crop Management and Soil Science tested 10 synthetic turf systems for surface temperatures and ambient air temperatures 3 feet above the field surface. An attempt was made to measure temperatures on bright, clear days. The investigators also looked at the effect of irrigation on the temperature of the synthetic turf fields. On two separate days, the fields were irrigated with 0.5 inches of water and the temperatures measured from 11:15 AM to 3:15 PM.

Results: The surface temperatures of the fields ranged from 113.7 to 125.4° using a LiCor Scheduler infrared thermometer. The ambient air temperatures registered 3 feet above the turf surface ranged from 78.1 to 80.6°. The ambient air temperatures varied by a few degrees among the turfs, but did not appear to be correlated with the surface temperatures of the turf systems. The application of water cooled down all synthetic surfaces, but they rebounded somewhat after 15 minutes and stayed stable for 90 and 210 minutes, respectively for each of the two sampling days. At the end of the experiment the irrigated fields averaged about 14° cooler than the non-irrigated fields.

The strengths of the McNitt and Petrunak study include:

- Study is an on-going study of many different synthetic turf fields under a variety of conditions.

The potential limitations and data gaps of McNitt and Petrunak study:

- Actual methods are not provided.
- Provided no discussion on discrepancy of finding no ambient air effects 3 feet above the turf surface in comparison to the Williams and Pulley (2002) study and the results documented at the University of Missouri in Adamson (2007).

Rosenzweig, C., W.D. Solecki, and R. Slosberg. 2006. Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces. A report to the New York State Energy Research and Development Authority.

Urban heat islands, a phenomenon where impervious surfaces absorb heat, and when this heat dissipates, causes elevated ambient air temperatures. They are created when grass and trees are replaced by surfaces such as rooftops and asphalt, which absorb heat. Urban heat islands have regional-scale impacts on energy demand, air quality, and public health. Rosenzweig and coworkers conducted a study of heat island effect mitigation strategies for NYC in the summer of 2002. These strategies include urban forestry, living/green roofs and light surfaces.

Objective: To evaluate the city-wide heat island effect and to determine the impact of mitigation strategies on the temperature in the New York Metropolitan Region.

Methods: The study used a regional climate model (MM5) in combination with observed meteorological, satellite and GIS data to determine the impact of each of the mitigation strategies on surface and near-surface air temperature in the New York Metropolitan region over space and time. In addition to a city-wide study, the investigators also looked at six smaller case study areas which included:

- Mid-Manhattan West
- Lower Manhattan East
- Fordham Bronx
- Maspeth Queens
- Crown Heights Brooklyn
- Ocean Parkway Brooklyn.

The mitigation strategies included urban forestry, light surfaces and living roof tops. The summer of 2002 was chosen as the time period for the study. A remote sensing and GIS data library were developed to characterize the numerous dimensions of NYC's heat island. New York City's heat island was characterized on heat-wave days. The Penn State/NCAR MM5 regional climate model was used to test the various mitigation scenarios. The model is a state-of-the-art three-dimensional, non-hydrostatic model that dynamically simulates the interactions among a range of land-surface cover and climate variables. The mitigation scenarios were then evaluated based on their cost-effectiveness at reducing air temperature and resulting energy demand.

Results: All the mitigation strategies had a significant temperature impact. The results of the study indicated that increasing vegetation has a great effect on reducing temperatures and recommends planting street trees in open spaces as well as building living roofs to provide the greatest cooling potential by area. This combined strategy offers more potential cooling than any individual strategy. Among the single-strategy scenarios, light-colored surfaces, light-colored roofs, and living roofs can potentially reduce the summer peak electric load more than the other strategies.

The strengths of the Rosenzweig et al. study include:

- Documentation of the “heat island” effect in an urban environment.
- Provides recommendations to reduce “heat island” effects.

The potential limitations and data gaps of the Rosenzweig et al. study include:

- No discussion of potential for synthetic turf fields to contribute to heat island effect.

Potential for Heat-Related Illnesses and Dermal Injuries

Summaries of Reviewed Literature

Nardazay, J. and Alson, R. 2006. Burns, Thermal. eMedicine from WebMD. Obtained on-line. Last accessed 11/2007 at http://www.emedicine.com/emerg/topic72.htm

This review article presents information on thermal burns. Soft tissue is burned when it is exposed to temperatures above 115º F (46°C). The extent of damage depends on surface temperature and contact duration. At temperatures above 120°F, it only takes 3 seconds to burn a child's skin severely enough to require surgery.

The strengths of the Nardazay and Alson article:

- Article is a general reference regarding thermal burns and their treatment and management.

The potential limitations and data gaps of the Nardazay and Alson article include:

- None noted at this time.

Anderson, S.J., Griesemer, B.A., Johnson, M.D., Martin, T.J., McLain, L.G., Rowland, T.W., Small, E. 2000. American Academy of Pediatrics (AAP). Committee on Sports Medicine and Fitness. Climatic Heat Stress and the Exercising Child and Adolescent. Pediatrics. 106(1):158-159

Policy statement by the American Association of Pediatrics, Committee on Sports Medicine and Fitness, summarizing the approaches for the prevention of the detrimental effects of children’s activity in hot or humid climates, including the prevention of exercise-induced dehydration. In general, exercising children do not adapt to extremes of temperature as effectively as adults when exposed to a high climatic heat stress. These differences are due to:

1. Children have a greater surface area-to-body mass ratio than adults, which causes a greater heat gain from the environment on a hot day and a greater heat loss to the environment on a cold day.

2. Children produce more metabolic heat per mass unit than adults during physical activities that include walking or running.

3. Sweating capacity is considerably lower in children than in adults, which reduces the ability of children to dissipate body heat by evaporation.

Exercising children are able to dissipate heat effectively in a neutral or mildly warm climate. However, when air temperature exceeds 35°C (95°F), they have a lower exercise tolerance than do adults. The higher the air temperature, the greater the effect on the child. It is important to emphasize that humidity is a major component of heat stress, sometimes even more important than temperature.

Strengths of Anderson article include:

- Paper provides a good overview and summary of a policy statement regarding the prevention of heat stress in children by the American Academy of Pediatrics.

The potential limitations and data gaps of the Anderson article include:

- None noted at this time

SI.com 2007 Reuters February 2007. Located on-line at: http://sportsillustrated.cnn.com/2007/soccer/02/07/bc.soccer.latam.peru.pitches/index.html. , Accessed January 30, 2008.

A recent news report from SI.com indicated that six players suffered burns on the soles of their feet after playing on an synthetic pitch in blazing sun. Peruvian Club Sporting Cristal said that the players were unable to train properly this week because of burns and blisters on the soles of their feet.

The strengths of the SI.com article include:
- Evidence of burns as a result of playing on synthetic turf surface

The potential limitations and data gaps of SI.com article include:
- Article is a brief news article, no specifics regarding air temperature, turf temperature, length of time players on field, etc.
- Only useful as anecdotal evidence of thermal injury from turf.
- Type of turf not provided, only described as "synthetic pitch" installed in 2005.

Anderson, S.J., Griesemer, B.A., Johnson, M.D., Martin, T.J., McLain, L.G., Rowland, T.W., Small, E. 2000. Climatic Heat Stress and the Exercising Child and Adolescent. Pediatrics. 106(1):158-159

Article presents a policy statement summarizing the approaches for the prevention of the detrimental effects of children's activity in hot or humid climates, including the prevention of exercise-induced dehydration.

Children frequently do not feel the need to drink enough to replenish fluid loss during prolonged exercise. This may lead to severe dehydration. A major consequence of dehydration is an excessive increase in core body temperature. Thus, the dehydrated child is more prone to heat-related illness than the fully hydrated child. For a given level of hypohydration, children are subject to a greater increase in core body temperature than are adults. Although water is an easily available drink, a flavored beverage may be preferable because the child may drink more of it. Another important way to enhance drinking is by adding sodium chloride (approximately 15 to 20 mmol/L, or 1 g per 2 pints) to the flavored solution. This has been shown to increase voluntary drinking by 90%, compared with unflavored water (Wilk and Bar-Or 1996). The above concentration is found in commercially available sports drinks. Salt tablets should be avoided, because of their high content of sodium chloride.

Proper health habits can be learned by children and adolescents. Athletes who may be exposed to hot climates should follow proper guidelines for heat acclimatization, fluid intake, appropriate clothing, and adjustment of activity according to ambient temperature and humidity. High humidity levels, even when air temperature is not excessive, result in high heat stress.

In addition, the American Academy of Pediatrics recommends the following for children and adolescents:

A. The intensity of activities that last 15 minutes or more should be reduced whenever relative humidity, solar radiation, and air temperature are above critical levels. For specific recommendations, see Table 1. One way of increasing rest periods on a hot day is to substitute players frequently.

B. At the beginning of a strenuous exercise program or after traveling to a warmer climate, the intensity and duration of exercise should be limited initially and then gradually increased during a period of 10 to 14 days to accomplish acclimatization to the heat. When such a period is not available, the length of time for participants during practice and competition should be curtailed.

C. Before prolonged physical activity, the child should be well-hydrated. During the activity, periodic drinking should be enforced (e.g., each 20 minutes 150 mL [5 oz] of cold tap water or a flavored salted beverage for a child weighing 40 kg (88 lbs) and 250 mL [9 oz] for an adolescent weighing 60 kg (132 lbs)), even if the child does not feel thirsty. Weighing before and after a training session can verify hydration status if the child is weighed wearing little or no clothing.

D. Clothing should be light-colored and lightweight and limited to one layer of absorbent material to facilitate evaporation of sweat. Sweat-saturated garments should be replaced by dry garments. Rubberized sweat suits should never be used to produce loss of weight.

Table 1. Restraints on Activities at Different Levels of Heat Stress*

WBGT		Restraints on Activities
^{o}C	^{o}F	
<24	<75	All activities allowed, but be alert for prodromes 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, cut down further duration of other activities)
>29	>85	Cancel all athletic activities

*Adapted from Anderson, et al. (2000). From the American Academy of Pediatrics, Committee on Sports Medicine and Fitness. WBGT is not air temperature. It indicates wet bulb globe temperature, an index of climatic heat stress that can be measured on the field by the use of a psychrometer. This apparatus, available commercially, is composed of 3 thermometers. One (wet bulb [WB]) has a wet wick around it to monitor humidity. Another is inside a hollow black ball (globe [G]) to monitor radiation. The third is a simple thermometer (temperature [T]) to measure air temperature. The heat stress index is calculated as WBGT 5 0.7 WB temp 1 0.2 G temp 1 0.1 T temp. It is noteworthy that 70% of the stress is due to humidity, 20% to radiation, and only 10% to air temperature.

Limitations and data gaps of Anderson et al. article:

- None, paper provides a good overview and summary of a policy statement regarding the prevention of heat stress in children.

B. HARDNESS, ABRASIVENESS, INJURY TYPES AND INFECTION RISK OF SYNTHETIC FIELDS

Assess Impact Attenuation of Different Field Surfaces

Summary of Reviewed Literature

McNitt, A.S. and Petrunak, D. 2007c. Evaluation of Playing Surface Characteristics of Various In-Filled Systems. Surface Hardness (Gmax). Penn State Department of Crop and Soil Sciences. Located on-line at: http://cropsoil.psu.edu/mcnitt/infill.cfm. Accessed on October 12 2007.

This paper presents the results of a multi-year project evaluating the performance of 10 synthetic turf systems. Nine of the systems are in-filled synthetic turf systems with a foam or rubber underlayment pad. The tenth system is the traditional, carpet-like AstroTurf. Due to the rapid advancement in the synthetic turf systems, the investigators are conducting this long-term project to evaluate how these fields perform over time. This preliminary data provided the early results of the surface hardness or impact attenuation tests on “no wear” turf and “wear” turf which simulated turf after having up to 96 games played on it. Using two different ASTM methods (Methods F355 and the Clegg Impact Soil Tester (CIST)), the hardness index remained well below the maximum Gmax rating of 200 for all scenarios tested.

Purpose: To evaluate the surface hardness and impact attenuation of 10 synthetic turf systems over time. Surface quality will be evaluated periodically as the systems are exposed to weather and simulated foot traffic. The effects of various maintenance activities on the playing surface quality of these systems will also be evaluated.

Methods: Surface hardness and impact attenuation were conducted in accordance with ASTM methods on “no wear” turf and “wear” turf which simulated turf after having up 96 games played on it. Simulated foot traffic was first applied to the turf fields using a “Brinkman Traffic Simulator”. The traffic simulator weighs 410 kg and consists of a frame with two 1.2 m rollers, with steel “cleats” welded to them was pulled with a tractor. Two passes of the traffic simulator produces the equivalent number of cleat dents created between the hash marks at the 40-yard line during one National Football Game (Cockerham and Brinkman, 1989). Thus, 24 passes per week are equivalent to the cleat dents sustained from 12 games per week (McNitt and Petrunak 2007b). They used the Clegg Impact Soil Tester (CIST), and the F355 method to measure surface hardness. The average of six CIST and three F355 measurements taken in different locations on each subplot was used to represent the surface hardness of each subplot. The F355 method is ASTM’s method for testing surface hardness of synthetic turf, the CIST is the ASTM method for testing surface hardness of natural turf. Both devices use a similar method to measure hardness and are simply hollow tubes through which a 20-lb weight (F355 method) or a 5-lb weight (CIST) are dropped onto the surface from a height of 2 feet (ASTM 2000a, b). A device inside the weight measures how quickly the weight stops upon impact. The faster the weight comes to a stop, harder the surface.

Results: For the no-wear scenario, the F355 method generated Gmax readings ranging from 62.1 (NexTurf) to 113.3 (AstroTurf). Under the “wear” scenario, the Gmax readings ranged from 69 (NexTurf) to 126.2 (AstroTurf). It is clear from the results that even after wear simulating 96 games, the hardness index remained well below the maximum Gmax rating of 200. The authors also correlated the readings of the CIST to the F 355 method. Gmax generated by the CIST method is smaller than the F355 method, the authors calculated that a Gmax of 135 from the CIST is comparable to the Gmax rating of 200. All the in-filled synthetic turf systems had a lower Gmax rating than the traditional, carpet-like AstroTurf using the CIST.

The strengths of the McNitt and Petrunak study include:

- Use of an ASTM standard, allows for reproducibility

The potential lmitations and data gaps of McNitt and Petrunak study include:

- Measurements only taken on two days during the summer, no readings during colder weather;
- For comparison, it would be informative to have data from actual playing fields instead of just from the experimental turf fields used in this study.
- Gmax comparisons with natural grass fields undergoing the same "wear" treatment would be informative as well.
- Data is from relatively new fields, although undergoing a "wear" scenario, data from aged fields and the effects of weathering of the fields will provide useful information.

Naunheim R, McGurren M, Standeven J, Fucetola R, Lauryssen C, Deibert E. 2002. Does the Use of Synthetic Turf Contribute to Head Injuries? J Trauma. 53(4):691-694.

Study evaluates the surface hardness of two indoor AstroTurf fields, one with a 5/8-inch pad and the second with a 1-inch pad. Both measurements were compared to an outdoor natural turf field at 72 degrees. The study showed that additional 3/8-inch padding significantly decreased the surface hardness measurement of the AstroTurf field. The outdoor grass field's surface hardness measurement was also significantly lower than the AstroTurf with the 5/8-inch padding.

Purpose: Cerebral concussion is a common injury among football players, and with the occurrence of several high profile career-ending injuries, other risks for concussion need to be explored such as the impact attenuation of synthetic turf.

Methods: Three playing surfaces used by a professional football team were tested. The first field was an AstroTurf (5/8-inch foam padding over concrete) field at a domed stadium, the second field was an indoor practice field with AstroTurf (1-inch padding over concrete) and the third was an outdoor grass practice field. A computerized impact recording devise was used to determine whether a new shredded rubber-based turf improves impact attenuation. The devise was dropped 20 times from a height of 48 inches onto each of the surfaces. Five different areas of each field were tested; the center of the field at the 30-yard line, the center of the field at the 50-yard line, the hash marks on either side of the 50-yard line, and the mid 30-yard line at the opposite end of the field. These areas were chosen because they would see the most use during game play.

Results: The g-values at all three fields were statistically different. The g-value for the indoor domed field (AstroTurf – 5/8 inch padding) was 261.6, the g-value for the indoor practice field (AstroTurf – 1 inch padding) was 183.9 and the g-value for the outdoor grass practice field was 246.4. The results show that the addition of 3/8 foam padding significantly increases the attenuation of surface impact.

The strengths of the Naunheim study include:

- Provides a comparison of natural and traditional synthetic turf systems. Natural systems were measured for hardness during warm (72^{o}F) weather.

Limitations and data gaps of Naunheim et al. study:

- Did not use ASTM Method F355 for measurement of Gmax, which is the standard method for testing hardness of synthetic turf. By using an alternate method, unable to compare with other studies, since this study's g-values are substantially higher than recordings noted elsewhere. Warm outdoor grass was noted as having a g-value of 264.4, however, cited Gmax value is 140 or less.

- The authors did not provide information regarding the ages of the synthetic turf systems which may impact the readings

Naunheim R, Parrott, H, Standeven J. 2004. A Comparison of Synthetic Turf. J Trauma. 57(6):1311-1314

This study is a continuation of the 2002 study. An in-filled, shredded rubber-based FieldTurf system was installed in the indoor practice facility to replace the AstroTurf field with the 1-inch foam backing. In addition, surface hardness measurements were conducted on the outdoor natural turf field at a temperature of 32^{o} F. A comparison was made between all five measurements, which includes the three surface hardness evaluations from the 2002 study. The study showed comparable surface hardness measurements between the FieldTurf system in the practice field and the AstroTurf field with the 1-inch pad that it replaced.

Purpose: Cerebral concussion is a common injury among football players, with an estimated incidence of 10%. Concussions occur as a result of collisions with other players and with the ground. Attempts have been made to decrease the injuries by modifying equipment and playing surfaces. Recently, newer forms of synthetic turf have been marketed increasingly to high schools and colleges as a way to decrease impacts. This study compares the impact attenuation of a newer generation of synthetic turf as compared to older versions of synthetic turf.

Methods: The impact attenuation properties of a new indoor practice field consisting of FieldTurf (infilled, shredded rubber-based system) were compared with the same field that had previously consisted of AstroTurf (1-inch foam padding over concrete). The remaining three surfaces tested were an outdoor grass field tested at 32°F, the same field tested at 72°F, and an indoor AstroTurf field in a domed stadium. A computerized impact recording device (IRD) was used to determine whether a new shredded rubber-based turf improves impact attenuation. The device was dropped 20 times from a height of 48 inches onto each of the surfaces. The IRD used in this study was a self-contained unit that has been used to test cricket fields in Australia. The IRD has been used for many years in the packing and shipping industries and is considered a reliable tool for detecting impacts. The authors chose it for this study because it allows the field to be tested in situ, rather than removing a portion of the field. In this study, removing a portion of the rubber based field would have disturbed the compacted rubber fill and changed the results of the test.

Five different areas of each field were tested; the center of the field at the 30-yard line, the center of the field at the 50-yard line, the hash marks on either side of the 50-yard line, and the mid 30-yard line at the opposite end of the field. These areas were chosen because they would see the most use during game play.

Results: Both the FieldTurf and the AstroTurf field it replaced demonstrated g values of ~184. The g values of the other three fields included 261.6 (indoor domed stadium), 264.4 (outdoor warm grass) and 398.2 (frozen outdoor grass field). The change from the AstroTurf system (1-inch foam padding over concrete) to a FieldTurf (in-filled shredded rubber-based system had no effect on impact attenuation overall. However, areas in the shredded rubber-based field were significantly compacted; causing some sites to be much harder than the foam-based surface it replaced.

The strengths of the Naunheim study include:

- Provides a comparison of a variety of natural and two different synthetic turf systems (AstroTurf with 5/8 and 1 inch foam padding and in-filled FieldTurf with a shredded rubber padding). Natural systems were measured for hardness at different times of year.

The potential limitations and data gaps of Naunheim et al. study include:

- Did not use ASTM Method F355 for measurement of Gmax, which is the standard method for testing hardness of synthetic turf. By using an alternate method, unable to compare with other studies, since this study's g-values are substantially higher than recordings noted elsewhere. Warm outdoor grass was noted as having a g-value of 264.4, however, its Gmax value is 140 or less.
- Does not provide a correlation with ASTM Gmax of 200.
- FieldTurf field used shredded tire, and not crumb rubber with infill material.

C. ASSESS ABRASIVENESS OF DIFFERENT FIELD SURFACES

Summary of Reviewed Literature:

McNitt, A.S. and Petrunak, D. 2007a. Evaluation of Playing Surface Characteristics of Various In-Filled Systems. Abrasion. Penn State Department of Crop and Soil Sciences. Located 0n-line at: http://cropsoil.psu.edu/mcnitt/infill.cfm. Accessed on October 12 2007.

This paper presents the results of a multi-year project evaluating the performance of 10 synthetic turf systems. Nine of the systems are in-filled synthetic turf systems with a foam or rubber underlayment pad. The tenth system is the traditional, carpet-like AstroTurf. Due to the rapid advancement in the synthetic turf systems, the investigators are conducting this long-term project to evaluate how these fields perform over time. The abrasiveness of the synthetic turf systems were measured using ASTM Method F1015. All infill systems were less abrasive than the traditional, carpet-like, Astroturf. Grooming of the surfaces tended to lessen the abrasiveness. The test is being modified for use on natural turf.

Purpose: The abrasiveness studies are part of a large, long-term project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time. Surface quality will be evaluated periodically over time as the systems are exposed to weather and simulated foot traffic. The effects of various maintenance activities on the playing surface quality of these systems will also be evaluated.

Method: In Penn State's Department of Crop and Soil Sciences long-term study on 10 synthetic turf systems, abrasiveness of the synthetic turf systems were measured using ASTM Method F1015. Friable foam blocks, made of rigid closed-cell isocyanurate, were attached to a weighted platform that was pulled over the turf surface in four directions. The weight of the foam that is abraded away determines the abrasiveness of the surface. An Abrasiveness Index is calculated by taking the weight loss of all four blocks in grams and dividing by 0.0606 per ASTM F1015.

Results: All infill systems were less abrasive than Astroturf. Grooming of the surfaces tended to lessen the abrasiveness. The test is being modified for use on natural turf.

The strengths of the McNitt and Petrunak study include:

- The use of a standardized testing method to conduct the test
- Developing a modified test to measure abrasiveness of natural turf

The potential limitations and data gaps of the McNitt and Petrunak study include:

- No context provided for the Abrasiveness Index, other than comparison to AstroTurf
- Data is from relatively new fields, abrasiveness data from aged fields and the effects of weathering of the fields will provide useful information.

D. FREQUENCY OF INJURY IN DIFFERENT PLAYING FIELDS.

Summary of Reviewed Literature

McNitt, A.S. and Petrunak, D. 2007e. Evaluation of Playing Surface Characteristics of Various In-Filled Systems. Traction. Penn State Department of Crop and Soil Sciences. Located 0n-line at: http://cropsoil.psu.edu/mcnitt/infill.cfm. Accessed on October 12 2007.

This paper presents the results of a multi-year project evaluating the performance of 10 synthetic turf systems. Nine of the systems are in-filled synthetic turf systems with a foam or rubber underlayment pad. The tenth system is the traditional, carpet-like AstroTurf. Due to the rapid advancement in the synthetic turf systems, the investigators are conducting this long-term project to evaluate how these fields perform over time. The traction of these systems under "no-wear" and "wear" conditions, with and without grooming was evaluated. Grooming resulted in a greater reduction in rotational traction and there continued to be a trend of increased linear traction after grooming for the no wear treatments but the trend was less evident in the treatments receiving wear. This was true regardless of shoe type. It may be that as these systems age, grooming will have a diminished affect on linear traction. When traction was measured on the various synthetic turf surfaces during wet conditions, traction was generally reduced. The overall significance of this data, as it relates to injury, is that, immediately after grooming, an athlete will experience increased translational (linear) traction and either no change or a slight decrease in rotational traction, thus allowing, for example, a football lineman more traction when pushing but affecting no change or a slight reduction in the rotational foot fixation that Shorten and Himmelsbach (2002) state has a direct affect on lower extremity injuries.

Purpose: The traction studies are part of a large, long-term project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time. Surface quality will be evaluated periodically over time as the systems are exposed to weather and simulated foot traffic. The effects of various maintenance activities on the playing surface quality of these systems will also be evaluated. These traction studies will provide information regarding the propensity of the synthetic turf fields to cause lower limb (knee and ankle) injuries.

Method: The rotational and translational traction of 10 synthetic turf systems under "no-wear" and "wear" conditions, with and without grooming was evaluated. Traction was measured using "Pennfoot" which conforms to the proposed traction standard ASTM WK486 (American Society for Testing and Materials, 2000c) standard traction measurements. Pennfoot consists of a frame which supports a steel leg with a cast aluminum foot pinned on the lower end of the leg. The simulated foot was cast from a size 10 foot mold and the foot can be fitted with different athletic footwear. Two holes located on top of the foot are used for connection with the leg. The first hole located toward the toe allowed the elevation of the heel off the ground and distribution of the weight to the ball of the foot. All traction measurements were taken in this study with the forefoot in contact with the surface and the heel of the foot raised off the ground. Translational traction was measured with Pennfoot, by a single pulling piston that is connected to the heel of the foot and creating linear force. The pressure applied to the piston is created with a motorized hydraulic pump and monitored with a pressure transducer connected to a computer. Linear traction is thus measured as the amount of horizontal force (N) required to maintain translational movement at the given rate. In the primary experiment all traction measurements were taken using a vertical force, or loading weight of 237 lbs. and a Nike Air Zoom high top shoe. During 2004, a standard 7 post shoe was tested. In addition select surfaces were tested in both wet and dry conditions and traction on all surfaces was measured at a lower loading weight (119 lbs.).

When using Pennfoot to measure rotational traction, the rotating horizontal force is created by two pistons which are horizontally mounted on angle iron 38.1 cm above the ground as measured with the machine in position to take a measurement. A strike plate was connected to the simulated leg for the pistons to push against. A lower collar around the simulated leg prevented it from tilting while the rotational force was applied.

Results: The preliminary results of the study show there were few meaningful traction differences between synthetic turf systems in the no-wear scenario, although the traditional, carpet-like Astroturf measured consistently higher in linear traction compared to the infill systems. This trend was not evident in the rotational traction results. Measurements taken shortly after field grooming showed that translational traction tended to increase after grooming, whereas rotational traction tended to have no change or trend slightly lower. During 2004, grooming resulted in a greater reduction in rotational traction compared to 2003. In addition, there continued to be a trend of increased linear traction after grooming for the no wear treatments but the trend was less evident in the treatments receiving wear. This was true regardless of shoe type. It may be that as these systems age, grooming will have a diminished affect on linear traction. When traction was measured on the various synthetic turf surfaces during wet conditions, traction was generally reduced. The overall significance of this data, as it relates to injury, is that, immediately after grooming, an athlete will experience increased translational (linear) traction and either no change or a slight decrease in rotational traction, thus allowing, for example, a football lineman more traction when pushing but affecting no change or a slight reduction in the rotational foot fixation that Shorten and Himmelsbach (2002) state has a direct affect on lower extremity injuries.

The strengths of the McNitt and Petrunak study include:

- The use of a standardized testing method to conduct the traction test
- Provides a mechanical test for the measurement of traction under a variety of field conditions. Also allows for the evaluation of different turf shoes and their ability to provide traction on the different synthetic turf systems.

The potential limitations and data gaps of the McNitt and Petrunak study include:

- Data is from relatively new fields, although undergoing a "wear" scenario, data from aged fields and the effects of weathering of the fields will provide useful information.

Adamson C. 2007. Synthetic Turf Fields Present Unique Dangers. University of Missouri – Columbia, College of Agriculture, Food and Natural Resources. Located on-line at: http://cafnr.missouri.edu/research/turfgrass.php. Accessed on October 12, 2007.

This article presents a series of traction measurements conducted by MU's "turf expert". Four turf types, three natural grasses and MU's Faurot Field (outdoor synthetic infilled turf system (FieldTurf)) were tested for traction using a contraption of cleats, weights to simulate an athlete's weight and a torque wrench-like tool. When the simulated cleated foot was completely planted in Faurot Field, it needed an average of 110 ft-lbs of torque to twist free. Natural surfaces needed 81 to 85 ft-lbs to twist fee. In some areas of Faurot field, 120 ft-lbs of torque was measured. However, the difference only occurred when a cleat was fully planted in the field. When only a portion of the cleat simulating the ball of a foot was planted, the force needed to twist free was the about the same on all surfaces.

The strengths of the Adamson study include:

- Provides traction measurements of an actual outdoor turf field

The potential limitations and data gaps of the Adamson study include:

- Methodology and equipment used in the traction studies not discussed.

- Compared synthetic turf field to outdoor fields, but no description of a “normal” range. Synthetic turf traction measurements were higher than natural turf in the “whole foot” measurements, but no discussion of how high is a problem.

Fuller CW, Dick RW, Corlette J, Schmalz R. 2007a. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation synthetic turf by male and female football players. Part 1: match injuries. Br J Sports Med. 41 Suppl 1:i20-26.

Fuller CW, Dick RW, Corlette J, Schmalz R. 2007b. Comparison of the incidence, nature and cause of injuries sustained on grass and new generation synthetic turf by male and female football players. Part 2: training injuries. Br J Sports Med. 41 Suppl 1:i27-32.

The incidence of injuries sustained by men and women football players (i.e. soccer), playing on either natural grass or “new generation” synthetic turf (i.e. synthetic turf with rubber crumb infill material) was evaluated.

Purpose: The first study evaluated the incidence of injury during match play (Fuller et al., 2007a), while its companion study evaluated the incidence of injury during practice (Fuller et al., 2007b).

Methods: These prospective studies evaluated men’s and women’s football (soccer) match injuries as recorded by the National Collegiate Athletic Association’s (NCAA) Injury Surveillance System (ISS) over the 2005 and 2006 seasons. Between the two seasons 106 men’s teams and 136 women’s teams were evaluated. Eighteen men’s and women’s teams used synthetic turf as their home fields. An injury was defined as “any physical complaint sustained by a player during a football match that prevented a player from taking a full part in training or match play activities for one or more days beyond the day of injury.” Injury severities were grouped as minimal (1-3 days), mild (4-7 days), moderate (8-28 days) and severe (>28 days and season ending injuries). Athletic trainers that worked with the team and were qualified Health Professionals recorded every match and practice injury according to the specific NCAA-ISS criteria, including details such as type of surface (natural vs. synthetic turf), location, type, diagnosis, severity and cause (acute/gradual onset, contact/non-contact).

Results: Both studies concluded that there were no major differences in the incidence, severity, nature or cause of injuries sustained on natural grass or synthetic turf by either men or women.

The strengths of the Fuller et al. studies include:

- Study was conducted within the NCAA framework and used qualified health professionals to evaluate injuries sustained at every match and practice according to specific guidelines.

The limitations and data gaps of the Fuller et al. studies include:

- Subjects were college athletes, with higher degrees of physical capabilities and conditioning. Adult recreational users may not be as physically conditioned as college athletes. Child recreational users will not be as skilled or as conditioned as these athletes;
- The potential exists that the injuries were the result of random events unrelated to playing surfaces, such as collisions or rough play.
- The weather was not characterized. Depending on the weather, surface conditions can change.

Meyers M, Barnhill BS. 2004. Incidence, causes, and severity of high school football injuries in FieldTurf versus natural grass. Am J Sports Med. 32:1626-1638

This study compared the incidence of injuries of eight high school football teams over 5 competitive seasons playing on synthetic turf or natural grass fields. Statistical analyses indicated significant playing surface effects by injury time loss, injury mechanism, anatomical location of injury, and type of tissue injured. Natural grass fields actually had the higher incidences of injury time loss and more severe injuries such as head and neural trauma and ligament injuries. The synthetic turf fields had higher incidences of minor injuries such as surface/epidermal (skin) injuries, muscle related trauma and a higher incidence of injury occurrence during higher temperatures.

Purpose: A five year study was conducted to compare game-related, high school football injuries between natural grass and FieldTurf from 1998 to 2002. FieldTurf is considered a new generation of synthetic turf composed of a polyethylene/polypropylene fiber blend stabilized with a graded silica sand and ground rubber infill.

Methods: A total of 8 high school football teams were evaluated over 5 competitive seasons for injury incidence, injury category, time of injury, injury time loss, player position, injury mechanism, primary type of injury, grade and anatomical location of injury, type of tissue injured, head and knee trauma, and environmental factors. All athletes who participated in the study were given pre-participation physical examinations. Any athlete with a known preexisting congenital or developmental factor that predisposed the individual to injury was excluded. Any athlete that acknowledged, complained or was observed with any medical or orthopedic problem severe enough to compromise the athlete’s performance or endanger his health was excluded. Certified athletic training staff filled out injury surveillance forms to document the nature and extent of injuries. The study evaluated reportable injuries, defined as any game-related football trauma that resulted in an athlete missing all or part of a game; time away from competition; any injury reported or treated by the athletic trainer or physician; and all cranial/cervical trauma reported. Reportable injuries were categorized as to time lost as a result of the injury, the severity of the injury and category of injury (i.e., player-to-player collision, player-to-turf collision, injuries attributed to shoe-surface interaction during player contact, injuries attributed to shoe-surface interaction without player contact, and muscle-tendon–related overload). Injuries were also classified as to whether they were acute, recurrent or associated with overuse. The circumstances surrounding the injury were documented. Weather conditions were also evaluated.

Results: The results of the study indicate no significant differences between playing surfaces across injury categories and time of injury. A significantly greater incidence of minor injuries such as abrasions, contusions, and lacerations requiring 0 days of time loss were observed for athletes competing on FieldTurf. However, a greater number of injuries, ranging from 1 to 2 days of lost time and 22 days or more of lost time, were associated with competing on natural grass. A greater number of injuries from being stepped on, fallen on, or kicked while competing on FieldTurf as well as the higher incidence of noncontact, running, or sprinting injuries were observed for players competing on FieldTurf. The authors note that a literature review suggests that the more consistent synthetic composition may allow for greater opportunity for injury because of overextension and greater fatigue potential of muscles as players perform at a greater rate of acceleration, speed, and torque. The authors note other risk factors for injury resulting from synthetic turf: pivoting, change of direction, direct contact with an opposing player, deceleration, unfortunate mishaps (e.g., piling on, moving pileup), being jolted during an uncontrolled or compromised movement, equipment, and the abrasiveness of synthetic surfaces. A higher incidence of skin surface/epidermal injuries and muscle strains/spasms were documented on FieldTurf, which the authors theorized may be a result of greater velocity of play and fatigue potential. However a greater incidence of concussion and ligament tears were observed on natural grass. A higher incidence of cranial/cervical trauma was observed on natural grass. Higher incidences of cervical strains were observed on FieldTurf. Greater incidences of first-degree and total concussions combined, as well as a greater incidence of ACL-involved trauma were observed on natural grass. Of the environmental factors, the only significant observation was an increase in injuries on FieldTurf during temperatures ≥70°F when compared to cooler temperatures.

The strengths of the Meyers and Barnhill study include:

- Provides a breakdown of types of injuries sustained on synthetic turf

The limitations and data gaps of the Meyers and Barnhill study include:

- Subjects were high school athletes, with varying degrees of physical capabilities and conditioning. This may have confounded the results of this study; however, recreational users would also exhibit varying physical abilities and conditioning.
- The potential exists that the injuries were the result of random events unrelated to playing surfaces, such as collisions or rough play..

Steffen K, Andersen TE, Bahr R. 2007. Risk of injury on synthetic turf and natural grass in young female football players. Br J Sports Med. 41 Suppl 1:i33-37.

This study evaluated the risk of injury on synthetic turf compared to natural turf systems. Two thousand and twenty (2020) female soccer players from 109 teams participated in the study. The incidence of acute injuries did not differ between synthetic turf and natural turf. Sprained ankles were the highest recorded injury, with an increasing trend towards more ankle sprains on synthetic turf. There was a higher incidence of severe injuries (more than 21 days lost playing time) with synthetic turf fields. However, the rate for minor injuries tended to be lower on synthetic turf fields than on grass fields.

Purpose: A prospective cohort study to investigate the risk of injury on synthetic turf compared with natural grass among young female football players was conducted with 2020 players on 109 teams in 2005.

Methods: All players were screened for previous injuries and joint and muscle function at the start of the study. Only non-injured players took part in the study. Injury type (time-loss, acute, overuse, and recurrent), turf type (natural turf, synthetic turf, gravel or indoor field), location of injury, type of injury and injury circumstances were recorded over an eight-month period by 18 physical therapists recruited as "injury recorders" and assigned to the teams (typically 5 to 7 teams each). Coaches were asked to keep a log of the requested data. In addition to injury type, injuries were classified into three severity categories according to the time it took until the player was fully fit to play: minor (1-7 days), moderate (8-21 days) and major (greater than 21 days).

Results: Acute injury rates (i.e., the number of injuries per 1000 hours of exposure) were similar between synthetic turf and natural grass for training sessions and match play. However, there were differences in types of injuries between synthetic turf and grass, and there appeared to be an increasing trend in ankle, ligament and knee injuries that occurred on synthetic turf than on grass. In matches, twice as many severe injuries occurred on synthetic turf as on grass; however, the rate for minor injuries was significantly lower when playing on synthetic turf than on grass. A severe injury was categorized as an injury that resulted in over 21 days of lost playing time. There was not enough data for the playing time on gravel or indoor surfaces to make a comparison with natural and synthetic turf surfaces.

The strengths of the Steffen et al. study include:

- Provides a breakdown of types of injuries sustained on synthetic turf
- Evaluates female athletes

The potential limitations and data gaps of the Steffen et al study include:

- Differences in synthetic turf types were not accounted for in the study
- Players played on synthetic turf, grass, gravel and indoor floors, and the potential for injury due to varying play surfaces is unknown.
- Maintenance status of the synthetic turf and grass fields was not accounted for in the study.
- Weather conditions were not noted in this study.
- Data recording relied on coaches keeping logs. Physical therapist "injury recorders" were assigned to the teams, however, each therapist had multiple teams to follow.

F. ASSESSMENT OF POTENTIAL OF STAPHYLOCOCCUS AUREUS INFECTION ASSOCIATED WITH SYNTHETIC TURF.

Summary of Reviewed Literature

Kazakova SV, Hageman JC, Matava M, Srinivasan A, Phelan L, Garfinkel B, Boo T, McAllister S, Anderson J, Jensen B, Dodson D, Lonsway D, McDougal LK, Arduino M, Fraser VJ, Killgore G, Tenover FC, Cody S, Jernigan DB. 2005. A clone of methicillin-resistant *Staphylococcus aureus* among professional football players. *N Engl J Med.* 352(5):468-475.

Study was conducted with professional football team to determine the relationship between synthetic turf and an outbreak of MRSA infections. The study concluded that skin abrasions and turf burns caused by synthetic turf provide a means of access for the MRSA infection. However, it was found that physical contact (due to position played) and poor sanitary practices in the locker rooms and training facilities facilitate the transmission of the disease.

Purpose: Methicillin-resistant *S. aureus* (MRSA) is an emerging source of infections in the community population. During the 2003 season, eight cases of MRSA were identified in 5 of the 58 Ram players. A retrospective cohort study was conducted on members of the professional football team, the St. Louis Rams.

Methods: Activities and hygiene practices were observed and data was collected on players concerning their team positions, health care exposures, use of saunas, whirlpools, and training and therapy equipment and antimicrobial use. Surfaces and shared items, including weight-training equipment, towels, saunas and steam rooms and water from the whirlpools and therapy pool were sampled. In addition, 0.1 m^2 areas of synthetic turf in areas where the highest number of tackles were recorded were sampled.

Results: The results of the statistical analysis of the data showed that all MRSA skin abscesses developed at turf burn sites. These sites were usually not covered, and the authors concluded that these abrasions were likely the source and vehicle for transmission of MRSA. Infection only occurred in players with high-contact positions, such as lineman and linebackers. The authors also noted suboptimal hygienic practices among players. MRSA was not detected in any environmental or nasal samples; however, the author's note that MRSA was found on environmental samples that matched the MRSA found in nasal samples, suggesting that the environment may have lead a role in the transmission of MRSA among team members.

Strengths of the Kazakova et al. study include:

- This study established the potential for environmental surfaces to assist in the transmission of MRSA.

- This study did establish a link between the occurrence of turf burns and MRSA infections.

The potential limitations and data gaps of Kazakova et al. study include:

- Factors, such as poor hygienic practices, may have contributed or caused the outbreak. Further study is needed to establish a causal link between synthetic turf burns and MRSA infections.
- No skin swabs were obtained to determine if players already carrying MRSA on skin.
- The study evaluated activities conducted by professional football players. This study likely presents more intensive use of the synthetic turf fields than would occur during recreational use of the fields. However, the potential for and the occurrence of turf burns through recreational activities on synthetic turf should be evaluated.

Begier EM, Frenette K, Barrett NL, Mshar P, Petit S, Boxrud DJ, Watkins-Colwell K, Wheeler S, Cebelinski EA, Glennen A, Nguyen D, Hadler JL; Connecticut Bioterrorism Field Epidemiology Response Team. 2004. A high-morbidity outbreak of methicillin-resistant Staphylococcus aureus among players on a college football team, facilitated by cosmetic body shaving and turf burns. *Clin Infect Dis*. 39(10):1446-1453.

Study was conducted with a college football team to determine the relationship between synthetic turf and an outbreak of MRSA infections. The study concluded that skin abrasions and turf burns caused by synthetic turf provide a means of access for the MRSA infection. However, in it was found that physical contact (due to position played) and poor sanitary practices in the locker rooms and training facilities, and personal hygiene (body shaving) facilitate the transmission of the disease.

Purpose: Athletics-associated methicillin-resistant *Staphylococcus aureus* (MRSA) infections have become a high-profile national problem with substantial morbidity. Begier, *et al*. conducted a retrospective cohort study in 2003 of the 100 members of a college football team in order to investigate an MRSA outbreak.

Methods: Athletes with skin lesions were evaluated. Swab specimens from the anterior nares of players, trainers, and coaching staff were obtained. Swab samples from the groin, axillae, and nares of patients with recurrent infections were obtained for culture. Ten of 100 players were identified with MRSA skin infections. Trainers, coaching staff, non-football players and athletes on opposing teams were not identified with MRSA skin infections. Two of the players with MRSA skin infections were hospitalized. Athletic trainers, coaching staff and infected players were questioned regarding player routines and hygienic practices at the athletic facility, and all players were questioned to assess skin injuries, hygienic practices and other exposures during the outbreak period.

Results: The results of the retrospective study indicate that players with the highest contact rates had the highest rates of infection. Players who practiced body shaving also higher significantly higher risk of infection, as three of four players with infections of sites covered by the football uniform had recently shaved these areas. Use of elbow pads was also associated with a higher risk of infection. Risk of MRSA infections increased significantly with more-frequent whirlpool sharing because of unproven and limited water disinfection practices. Those who shared the whirlpool 2 times a week were 12 times more likely to have infections due to MRSA than were those who never shared the whirlpool.

Conclusion: Turf burns were thought to facilitate infection and the authors suggest that eliminating turf burns would be the best way to prevent infection. The authors also note that study on the risk of abrasion from synthetic turf warrants further study.

Strengths of the Begier *et al*. study include:

- This usefulness of this study is in demonstrating that turf burns were not the cause of but may be an entry port for MRSA

The potential limitations and data gaps of the Begier et al. study include:

- The study was a reflective cohort study; therefore, it did not include sampling of surfaces routinely contacted by the athletes and did not sample the whirlpool water to identify sources for the MRSA infections.
- The study evaluated activities conducted by college football players. This study likely presents more intensive use of the synthetic turf fields than would occur during recreational use of the fields. However, the potential for and the occurrence of turf burns through recreational activities on synthetic turf should be evaluated.

McNitt, A.S., Petrunak, D., Serensits, T. 2007. Evaluation of Playing Surface Characteristics of Various In-Filled Systems. A Survey of Microbial Populations in Infilled Synthetic Turf Fields. Penn State Department of Crop and Soil Sciences. Located on-line at http://cropsoil.psu.edu/mcnitt/infill.cfm. : Accessed on October 12 2007.

Study evaluated environmental bulk samples taken from a number of synthetic turf fields throughout Pennsylvania, ranging from elementary school to professional athletic fields and assayed them for total microbial growth as well as MRSA. In addition, they collected swab samples from common public areas, an athletic training facility as well as from the hands and face of random individuals. The investigators found no MRSA on any of the synthetic turf samples. Staph was found, however, on blocking pads, weight equipment, stretching tables, and used towels, in addition to the hands of five randomly tested passersby.

Purpose: The MRSA studies are part of a large project undertaken by Penn State to evaluate the playing surface quality of various infill systems over time. Surface quality will be evaluated periodically as the systems are exposed to weather and simulated foot traffic. The effects of various maintenance activities on the playing surface quality of these systems will also be evaluated. Because of the recent reports of MRSA infecting athletes, there has been a growing concern that synthetic turf fields are playing a role in the increased rate of infection seen in athletes. The objective of this study was to determine the microbial population of several infilled synthetic turf systems as well as compare them to natural turf grass 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.

Methods: Investigators obtained samples from infilled synthetic turf systems located at facilities throughout Pennsylvania, ranging from elementary schools to professional facilities. Infill materials were sampled from areas designated as a high use or a low use area of the field. Approximately 2-3 mL of infill material was collected by scooping with a sterile test tube directly from the infill material on the field. Tufts of pile fibers were collected by snipping the fibers from the background and adding them to a sterile test tube. For comparison purposes, soil samples from native soil a sand-based synthetic turf field were collected. In addition, samples were randomly collected from surfaces in public spaces as in various surfaces in an athletic training area using sterile swabs. Random individuals were also tested by swabbing their hands and face. Samples were cooled and processed as soon after collection as possible.

For the infill material, fiber and soil samples, 0.075 g material was transferred to a test tube with 10 ml sterile 0.1% peptone broth and agitated for 30 seconds. Serial dilutions of the liquid were plated up to a 10^{-3}dilution on both R2A agar for total organism populations and on Baird Parker agar, a selective media for *Staphylococcus*. Duplicate plates were made for each media and dilution level. Petri plates were covered in parafilm and incubated at room temperature for 72 hours and counted soon afterward. Colonies on the Baird Parker agar were also counted again after 5 days. Colonies were counted and the numbers of colony forming units (CFUs) were calculated per g of material. For those samples obtained by sterile swabs, the petri dishes were wiped with the swabs and colony counts were made after 72 hours and colonies on the Baird Parker agar were counted again after 5 days.

Results: Microbial growth on the infill materials were primarily fungi and bacteria. Some fields had predominately one type of organism, while others contained a variety of organisms. The study found no trace of *Staphylococcus aureus* bacterium in any of the 20 infilled synthetic turf fields and two natural grass fields tested in various locations in Pennsylvania using three procedures, selective media, gram stain or latex agglutination tests. The Penn State study also found low overall microbial populations in the synthetic turf systems. In fact, the microbe population of natural turfgrass far exceeded populations found in the infill systems. Staph was found, however, on blocking pads, weight equipment, stretching tables, and used towels, in addition to the hands of five randomly tested passersby.

Conclusions: The study concluded that "These infilled systems are not a hospitable environment for microbial activity. They tend to be dry and exposed to outdoor temperatures, which fluctuate rapidly. Plus, the infill media itself (ground-up tires) contains zinc and sulfur, both of which are known to inhibit microbial growth. Considering the temperature range for growth of *S. aureus* is 7-48°C, we didn't expect to find this bacterium in fields exposed to sunlight, since the temperatures on these fields far exceed 48°frequently."

The strengths of the McNitt et al. study:

- Actual study of the turf material itself.
- Provided good methodology for evaluation of the *S. aureus*,
- Sampled equipment as well as the hands of five random people to show that *S. aureus* is present in common areas.

The potential limitations and data gaps of the McNitt et al. study:

- Study did not indicate temperature of field at the time of sampling