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, 2006). 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 manufacturing, 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 (2006), 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 1.2, is approximately 1.8-13.9%. A table summarizing the components of HA oil can be found in Appendix B-1 (Table B-6).

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 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.

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 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, 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, 2006). 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 2.

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 2, 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-7).

2.6 Analytic Methods for Identifying COPCs in Crumb Rubber

Based on the studies reviewed, direct measurement of crumb rubber for extractable organic compounds should 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 should 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. 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 (2007) 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. Additional tests could be performed to determine the variability of infill material, including:

- Analyses of crumb rubber that is manufactured using mechanical grinding versus crumb rubber that is manufactured using cryogenic processing.

- Analyses of crumb rubber produced from different sources (i.e. SBR granules versus EPDM granules versus thermoplastic elastomer [TPE] granules).

Following these tests, differences in potential leaching and off-gassing associated with these materials could be determined.

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 & 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 1.01 mg/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, 2004
PAHs	naphthalene 2-methylnaphthalene chrysene fluoranthene pyrene	0.000100 mg/g tire not provided 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 & Zhang, 2006 and 2007

TABLE 2-1: CHEMICALS OF POTENTIAL CONCERN MATRIX: CRUMB RUBBER BASED ON ANALYSES PERFORMED IN THE LITERATURE REVIEWED				
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	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 & Quinn, 1997
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	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*
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	3-6 carcinogenic PAHs	0.06 – 8.58 mg/kg	Rubber granules from synthetic turf samples	Crain & Zhang, 2006 and 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,l)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, 2004
Phenols	4-t-octylphenol iso-nonylphenol	49.8 – 33,700 mg/kg 1120 – 21,600 mg/kg	Crumb rubber (recycled rubber)	Plesser, 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, 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, 1983
	n-C8 through n-C15	Indoor air with synthetic turf including rubber granulates	NIPH, 2006
	n-hexadecane	Crumb rubber headspace	CT Ag Station, 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, 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, 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, 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, 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	CT Ag Station, 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, 1983
	4-t-octylphenol	Crumb rubber headspace	CT Ag Station, 2007
Phthalates	diethylphthalate diisobutylphthalate di-n-butylphthalate bis(2-ethylhexyl)phthalate	Indoor air in tire-retreading factory	Cocheo, 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, 1983
	nitromethane junipene	Indoor air with synthetic turf including rubber granulates	NIPH, 2006
	butylated hydroxyanisole	Crumb rubber headspace	CT Ag Station, 2007
	trichloromethane cis-1,2-dichloroethene	Crumb rubber headspace	Plesser, 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	CT Ag Station, 2007
Amines	aniline nitrosodimethylamine n-nitrosodiphenylamine	Tire shred leachate	CalEPA, 2007
Benzothiazole compounds	benzothiazole 2-hydroxybenzothiazole 2-(4-morpholino)benzothiazole	Crumb rubber leachate	Reddy, 1997
	benzothiazole	Crumb rubber leachate	CT Ag Station, 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	CT Ag Station, 2007
Other	butylated hydroxyanisole	Crumb rubber leachate	CT Ag Station, 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

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
Barium*	Pigments; in manufacture of rubber, photographic paper, x-ray contrast material, ceramics/bricks; also used with metals, oil, glass, plastic, pyrotechnics	Ambient air, food, water, contact with barium-containing products; 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)	**Source**
Vegetables	4.2 μg/kg (wet weight, ww)	Tateno T, et al. [PAHs] produced from grilled vegetables. *J Food Hyg Soc Jpn*, 1990; **31**: 271-76.
Fruit	0.716 μg/kg (ww)	Falcó G, et al. [PAHs] in foods: human exposure through the diet in Catalonia, Spain. *J Food Prot*, 2003; **66**: 2325-31.
Wheat grain	4.0 μg/kg	Jones, et al. Changes in the [PAH] content of wheat grain and pasture grassland over the last century from one site in the UK. *Sci Total Environ*, 1989;**78**: 117-130
Wheat flour	1.5 μg/kg	Dennis, et al. Factors affecting the [PAH] content of cereals, fats, and other food products. *Food Addit Contam*, 1991; **8**: 517-30.
Bran	5.5 μg/kg	Ibid.
Raw coffee beans	15.22-20.61 μg/kg	Houessou JK, et al. Effect of Roasting Conditions on the [PAH] Content in Ground *Arabica* Coffee and Coffee Brew. *J. Agric. Food Chem.* 2007, **55**: 9719–26
Roasted coffee beans	19.81-117.33 μg/kg	Ibid.
Brewed coffee	0.12-1.74 μg/L	Ibid.
Olive oil	26.3 μg/kg (ww)	Moret S, *et al.* [PAHs] in edible fats and oils; occurrence and analytical methods. *J Chromatogr A*, 2000; **882**(1-2): 245-53.
Oysters	1972.0 μg/kg	Sanders M. Distribution of [PAHs] in oyster (*Crassostrea virginica*) and surface sediment from two estuaries in South Carolina. *Arch Environ Contam Toxicol. 1995;***28**(4):397-405
Smoked fish	784.5 μg/kg	Akpan, et al. [PAHs] in fresh and smoked fish samples from three Nigerian cities.*Bull Environ Contam Toxicol*, 1994; **53**(2): 246-253.
BBQ beef	42.5 μg/kg	Lodovici M, et al. [PAH] contamination in the Italian diet. *Food Addit Contam*, 1995; **12**(5): 703-713.
Grilled frankfurters	790.4 μg/kg	Larsson BK, et al. [PAHs] in grilled food. *J Agric Food Chem.* 1983;**31**(4):867-73.
Lamb sausage	45.43 μg/kg	Mottier P, et al. Quantitative determination of [PAHs] in barbecued meat sausages by gas chromatography coupled to mass spectrometry. *J Agric Food Chem.* 2000;**48**(4):1160-6