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. VOCs are a mixture of chemicals that can cause eye, nose, throat and skin irritation. At high exposure levels, some VOCs can also cause organ damage. Metals can cause nervous system effects and organ damage. 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 and 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 constituents 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.

A number of human health risk assessments have been conducted to evaluate exposure to the constituents in crumb rubber, primarily conducted by State Agencies, consultants and

industry groups. These health 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 followed by conservative screening risk assessment techniques. 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 2005, 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: a health risk as a result of ingestion, dermal or inhalation exposure was not identified for crumb rubber exposure.

Based upon a review of the available literature, it appears that inhalation may be the primary route of exposure for contact to chemicals in crumb rubber. This is particularly the case since most air measurements documenting COPC emissions from synthetic turf fields were performed in indoor synthetic turf halls. Studies evaluating oral and dermal routes used surrogate concentrations for exposure and a number of conservative assumptions pertaining to ingestion rates, dermal contact rates, bioavailability, etc., and thus these evaluations are a theoretical and conservative estimate of exposure and risk. 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.

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). It should be noted that these studies were not designed to mimic the physiologic digestion of the tire materials. In order to evaluate potential health effects, these studies were used as a surrogate for ingestion studies and thus likely overestimated risk.

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° 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, 2006) 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 for zinc and chrysene in poured in place rubber padding. However, a number of uncertainties and assumptions tend 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 an appetite condition 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. 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.

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 author's present a list of uncertainties that may increase exposure or decrease exposure for this exposure 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,
- 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.

The CalEPA (2007) report shows a slight increase in cancer risk 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 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 should also be conducted.

- There is little information regarding the outdoor air concentrations of COPCs at synthetic turf fields. The majority of the data have been generated from indoor 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 turf halls and showed no risk to human health. Though indoor air concentrations would typically be higher and provide with a conservative estimate during risk assessments, research measuring constituent concentrations at breathing zone levels for children, youths and adults using the outdoor fields should be conducted to give more representative data for NYC park use related exposures. Ambient air monitoring should occur when the fields are hottest and during calm weather conditions for worst case scenarios. It is recommended that outdoor particulate sampling be conducted while the synthetic turf fields are in use to measure the potential generation of particulate matter. Total particulates, PM10, PM2.5 and concentrations of COPCs bound to the particulate should be measured in both newly installed and older fields.

- There is little available information on the background concentrations of the COPCs in New York City air and soils. It is 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.

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 limited exposure via the oral route to these children. 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 MADEP uses an oral absorption factor of 28% in its risk assessments. These values are well below the 100% the 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 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 the 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 surrogate 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 Used to Assess Exposure to COPCs 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, based upon determined chemical levels 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)*). The directive provides EU-wide standards on physical and mechanical properties, flammability, chemical properties, electrical properties, hygiene, and radioactivity. 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.

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. 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 a lot of variability among various samples. 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 author's present a list of uncertainties that may increase exposure or decrease exposure for this exposure 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,
- 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 playground (or track?) 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. 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.

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 in leachate was the only compound from the literature values that showed concentrations that may be of an increased health risk. Although this study attempts to mimic gastrointestinal 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° 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

TABLE 3-1. COMPILED INGESTION RATES

Study	Ingestion Rate		Source of Ingestion Rate
	Adult	Child	
			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 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.

3.1.4 Models Assessing Absorption, Distribution, Metabolism, and Excretion of COPCs via Ingestion

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 Exposure via Ingestion

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**	**Study Relevance**
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. For these chemicals the risk estimate is at the risk threshold.	The inhalation scenario used indoor VOC levels which overestimates the likely risks associated with inhalation of VOCs in outdoor environments.	Relevant
CalEPA 2007	• Evaluated chronic hand-to-mouth activity by 1-12 yr olds playing on playground padding • Evaluated one time ingestion of 10 g crumb rubber by 3 yr olds	• 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	Somewhat relevant

TABLE 3-2. SUMMARY OF INGESTION STUDIES				
Reference	**Evaluation**	**Major Conclusions**	**Major Limitations**	**Study Relevance**
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.	Relevant
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. • No supporting documentation for concluding that the ingestion of organics is not a relevant exposure pathway.	Slightly relevant
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	Somewhat relevant

3.2 Dermal Exposure

All users of outdoor synthetic fields are expected to have dermal contact with the crumb rubber. Anecdotally, there are claims that crumb rubber adheres to the socks of those playing on the fields. It would also be expected that any dust released by the crumb rubber would adhere to the skin, especially if the users are sweaty. In addition, because of the presence of natural latex rubber and synthetic rubber in tires as well as potentially other allergy-inducing compounds, there is a potential for skin sensitization to occur in sensitive individuals. 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 appears that dermal contact with tire crumb would not pose a significant health risk. Latex allergen was also evaluated using a guinea pig model and did not show sensitization after exposure (CalEPA 2007).

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. 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 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 internal PAH exposure. 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.

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 unproven.

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 sensitive 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.

3.2.4 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.

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	Study Relevance
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.	Relevant
NIPH 2006	Risk assessment evaluating potential exposure by adult, youth and older child football (rugby) players to synthetic turf materials in indoor sports halls assumed a high-end adherence factor of 1.0 mg/cm2 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).	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 (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).	Relevant

TABLE 3-3. SUMMARY OF DERMAL EXPOSURE STUDIES				
Reference	**Type of Evaluation**	**Major Conclusions**	**Major Limitations**	**Study Relevance**
NJ DEP 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.	Slightly Relevant
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.	Relevant
Jones 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.	Relevant

3.3 Inhalation Exposure

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 2005, 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 (2005) 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 constituent concentrations at breathing zone levels for children, youths and adults using the outdoor fields could be conducted to give more representative data on exposures related to urban field use. Ambient air monitoring should occur during hot weather and calm wind conditions to approximate worst case exposure scenarios. Outdoor particulate sampling could be conducted during actual or simulated use to measure the potential generation of particulate matter. Total particulates, PM10, PM2.5 and concentrations of COPCs bound to the particulate can be measured. In addition, background air sampling should be conducted off-site simultaneously since synthetic turf fields are located in urban environments and since the majority of the compounds observed in the crumb rubber are also contained in vehicular exhaust.

3.3.1 Study Methods and Findings Related to Inhalation Exposure

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 2005). 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 2005).

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 (2005) 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.

Additional 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 NYC park use related exposures. Ambient monitoring should occur when the fields are hottest and during calm weather conditions for worst case scenarios. In addition, concurrent background air sampling should be conducted simultaneously since the synthetic turf fields are located in an urban environment and since the majority of the compounds observed as coming from the crumb rubber are also contained in vehicular exhaust.

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 PM10 and PM2.5 (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. 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. 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/m3. 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/m3.

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. However, this is not an immediate concern since literature on airborne latex as a contributor to asthma and allergies in the urban environment is limited at this time, and since the majority of exposure comes from roadways and other sources such as house paint.

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.

It is recommended that outdoor particulate sampling be conducted while the synthetic turf fields are in use. Total particulates, PM10, PM2.5 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 to the increase in both latex sensitization and asthma. Concurrent background sampling should occur in order to determine the actual effect of the synthetic turf fields on outdoor air quality above the fields.

3.3.3 Assessment of Airborne Levels of Particulate Generated during Use of synthetic fields

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. 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. It is recommended that outdoor particulate sampling be conducted while the synthetic turf fields are in use. Total particulates, PM10, PM2.5 and concentrations of COPCs bound to the particulate should be measured. Concurrent background sampling should occur in order to determine the actual effect of the synthetic turf fields on outdoor air quality above the fields.

3.3.4 Models of absorption/distribution/metabolism/excretion of contaminants via the inhalation route

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.

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**	**Study Relevance**
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	Relevant
IBV 2005	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.	Somewhat Relevant
Moretto 2007	Emissions from three different types of rubber granules were evaluated in controlled emission test chambers at an ambient temperature of 23 ± 2°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.	Somewhat Relevant
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 PM10 and PM2.5.	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.	Relevant
NIPH 2006	This study evaluated the health risks to football players from exposure to	Exposure by football players to volatile organic compounds did not result in elevated health	This study evaluates indoor air quality in sports halls, and as such, would represent	Relevant

TABLE 3-4. SUMMARY OF INHALATION STUDIES				
Reference	**Type of Evaluation**	**Major Conclusions**	**Major Limitations**	**Study Relevance**
	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.	risks. Concentrations of polynuclear aromatic hydrocarbons were found to be within the range of background and were not attributed to rubber granules.	highly conservative estimates of potential adverse health effects associated with outdoor air exposure at parks where synthetic turf with rubber infill material is used.	
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.	Slightly Relevant
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.	Somewhat Relevant

3.4 Summary of Exposure Assumptions Related to Risk Assessments

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

Table 3-5 summarizes these exposure assumptions:

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	261 (d/yr)	3 (hr/d)
	Teenager	Sports	7	261 (d/yr)	3 (hr/d)
CalEPA 2007	Children	Playground	12 (ages 1- 12)	185 (d/yr)	2 (hr/d)
NIPH	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
	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)
	Children (cup tournaments)	Sports	4 (ages 7-11)	5 (2.5 d/tournament, 2 tournaments/yr)	17 hr/tournament (light exert.) 7 hr/tournament

3.5 Comparison Guidelines

There are no specific risk-based exposure guidelines for crumb rubber. Existing Federal or 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.