Chemicals and particulates in the air above the new generation of artificial turf playing fields, and artificial turf as a risk factor for infection by methicillin-resistant *Staphylococcus aureus* (MRSA)
Literature review and data gap identification

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Executive Summary

The Office of Environmental Health Hazard Assessment (OEHHA) is evaluating the safety of the new generation of artificial turf playing fields. This new generation of turf contains artificial soil termed “infill.” Infill helps to soften the surface and prevent injuries. Infill also improves drainage.

Rubber crumb made from finely ground, recycled tires is commonly used as infill in the new generation of artificial turf. Tire rubber is a complex material, containing many naturally-occurring and man-made chemicals. Therefore, as part of its stewardship of tire recycling in California, the California Integrated Waste Management Board (CIWMB) has asked OEHHA to evaluate the following aspects of artificial turf playing fields:

1. Whether these fields emit levels of chemicals or particulates into the air that cause illness when inhaled.
2. Whether these fields infect athletes with the dangerous bacterium called methicillin-resistant *Staphylococcus aureus* (MRSA).

The following is our review of the published literature covering these two topics. In addition, we have attempted to identify data gaps that, when filled, will allow performance of a more accurate safety assessment.

Chemicals and Particulates Measured in the Air Above Artificial Turf Fields

Published studies were located that measured chemicals and particulates in the air above artificial turf playing fields. In all cases these fields contained crumb rubber infill. Prior to 2009, the most complete dataset was published by Dye et al. (2006). They identified almost 100 different chemicals and particulates. Another 200 chemicals were detected but not identified. This study covered fields in ***indoor*** stadiums.

Many of the chemicals identified by Dye et al. (2006) were also emitted into air by rubber flooring made of recycled tires. Similarly, laboratory studies of chemicals emitted into the air by crumb rubber made from recycled tires identified many of the same chemicals. A list of the chemicals and particulates emitted into the air during rubber manufacturing also overlapped with those identified by Dye et al. (2006). Therefore, the published literature suggests the data from Dye et al. (2006) are reliable.

In the spring of 2009 two studies were released that measured chemicals and particulates in the air above ***outdoor*** artificial turf fields containing recycled rubber crumb (New York State, 2009; TRC, 2009). Both studies targeted the same two fields in New York City. Totals of 65 and 85 chemicals were identified at relatively low concentrations in the air above the two fields. Many of these occurred at similar concentrations in the air sampled upwind of the fields. Concentrations of particulates above the fields were similar to the levels upwind of the fields. Both reports concluded that these fields did not constitute a serious public health concern, since cancer or non-cancer health effects were unlikely to result from these low-level exposures.

A comparison of the chemicals detected in the air above the same two artificial turf fields that comprised the studies by New York State (2009) and TRC (2009) shows that chemical concentrations were consistently higher in the New York State (2009) study, ranging from 1.7-fold to 85-fold higher. The reasons for these differences are unknown. These variable results highlight the difficulties faced in obtaining consistent results from potential point sources of outdoor air pollution. Despite this variability, both studies found that the chemical concentrations they measured were unlikely to produce adverse health effects in persons using these fields.

Is the Air Above Artificial Turf Fields Hazardous to Human Health?

OEHHA constructed a test scenario for an athlete playing soccer from ages 5 to 55 years on the new generation of artificial turf fields containing crumb rubber infill. The data from Dye et al. (2006) were used for chemical concentrations in the air above the fields, since this was the most comprehensive data set available at the time. Breathing rates were based on published data. Time spent on the fields for soccer games and practices was estimated.

From among the chemicals identified by Dye et al. (2006), eight appear on the California Proposition 65 list of chemicals known to the state to cause cancer. Exposure to five of these via inhalation (benzene, formaldehyde, naphthalene, nitromethane, styrene) gave increased lifetime cancer risks that exceeded one in one million (10^{-6}), generally considered the negligible risk level. In other words, more than one cancer case could be expected to occur in a hypothetical population of one million people regularly playing soccer on these artificial turf fields between the ages of 5 and 55. The highest risk was from nitromethane, which could cause about nine cancer cases in a hypothetical population of one million soccer players. While these estimated risks are low compared to many common human activities, they are higher than the negligible risk level of one cancer in a population of one million people. Data gaps exist that could lead to overestimates or underestimates of these risks.

Two of the chemicals identified by Dye et al. (2006) appear on the California Proposition 65 list as developmental/reproductive poisons (toluene and benzene). Using the same exposure scenario described above for soccer players, concentrations of both chemicals in the air above artificial turf soccer fields were below the Proposition 65 screening levels, suggesting a negligible risk of developmental or reproductive toxicity via the inhalation route of exposure.

From among the 20 chemicals detected at the highest levels by Dye et al. (2006), seven were also detected in the New York State (2009) study. Concentrations of these seven chemicals were from 5- to 53-fold higher in the air above indoor fields (Dye et al., 2006) compared to the air above outdoor fields (New York State, 2009). Concentrations of particulates were also higher in the indoor study. Therefore, using indoor data to calculate health risks from outdoor play overestimates the outdoor risks.

Does Artificial Turf Promote Infection of Athletes by the Bacterium Methicillin-Resistant Staphylococcus aureus (MRSA)?

MRSA Outbreaks in Sports

Staphylococcus aureus is a bacterium that can cause serious infections in humans. A strain has developed that is resistant to the antibiotic methicillin, termed methicillin-resistant *Staphylococcus aureus* (MRSA). This strain has caused a number of outbreaks in team sports including football, wrestling, rugby and soccer. Participation in contact sports increases the risk of infection by MRSA. Skin abrasions and other types of skin trauma also increase the risk of infection by MRSA. Person-to-person contact is the primary way MRSA is spread. Whether transmission occurs via inanimate objects (including playing surfaces) is less certain.

Artificial Turf and MRSA

It is not known if the new generation of artificial turf causes more MRSA infections than natural turf. However, one study of high school football demonstrated more "surface/epidermal injuries" for games played on the new generation of artificial turf compared to natural turf. Since skin trauma increases the risk of infection by MRSA, careful monitoring and treatment of such wounds may help prevent MRSA outbreaks.

It seems unlikely that the new generation of artificial turf is itself a source of MRSA, since MRSA has not been detected in any artificial turf field.

Data Gaps

- Using indoor data to estimate the health risks from outdoor fields probably overestimates those risks.
- Only two outdoor artificial turf fields were evaluated in the New York State (2009) study. The same two fields comprised the TRC (2009) study. Testing additional outdoor fields for the release of chemicals and particulate matter is warranted.
- Dye et al. (2006) did not determine what amount of each chemical was released by the artificial turf field and what amount was present in the ambient air. Therefore, future studies of artificial turf fields should include measurements from both above the fields and off of the fields.
- No study has measured the metals content of the particulates released by artificial turf fields. In addition, it is not known if field use increases particulate release.
- The variables of field age and field temperature should be monitored to determine whether they influence the release of chemicals and particulates into the air above these fields.
- Data are needed for the amount of time athletes spend on artificial turf playing fields. Data are needed for a variety of sports, age groups, and for both men and

women. Other subgroups with potentially heavy exposure to fields include coaches, referees, and maintenance workers.
- Only a single study was located that compared the rate of skin abrasions on the new generation of artificial turf to natural turf. This was for high school football. Similar studies are needed for other sports, age groups, and for both male and female athletes.
- No data were located on the seriousness of the skin abrasions suffered by athletes on the new generation of artificial turf compared to natural turf.
- The bacterium MRSA has not been detected in artificial turf fields. However, fields in California have not been tested. Therefore, fields from different regions of the state should be tested to verify that the new generation of artificial turf does not harbor MRSA or other bacteria pathogenic to humans.

Work in Progress

OEHHA is currently working to fill the above data gaps. OEHHA will sample air from above the new generation of artificial turf fields in outdoor settings and measure concentrations of potentially hazardous chemicals and particulates. Coaches will be surveyed to determine how much time athletes spend on these fields. Rates of skin abrasion will be measured on artificial and natural turf. Various components of the artificial turf, as well as soil and grass from natural turf, will be assayed for bacteria. Using these new data, OEHHA will determine whether the new generation of artificial turf playing fields releases chemicals or particulates into the air that pose an inhalation risk to persons using the fields. OEHHA will also determine whether artificial turf fields increase the risk of infection by dangerous bacteria such as MRSA.

Introduction

The California Tire Recycling Act (Public Resources Code 42870 et seq.) requires the California Integrated Waste Management Board (CIWMB) to develop new markets for recycled tires. The use of recycled tires in the new generation of artificial turf playing fields is one such new application. In the new generation of artificial turf playing fields, rubber crumb made from recycled tires serves as an artificial soil, filling in between the artificial blades of grass. This rubber infill softens the surface, helping to prevent injuries and facilitating rapid drainage. The infill is often recycled crumb rubber alone, or a combination of rubber and sand. Two other types of infill materials are new plastic granules and mulched coconut husks. The inclusion of an infill layer is one of the principal reasons the new generation of artificial turf outperforms previous generations.

The new generation of outdoor artificial turf playing fields has important advantages over natural turf. The fields can be used around the clock with little or no down time for repair, are weather resistant, and require no watering, fertilizer or pesticides. However, a number of unanswered questions remain concerning their safety for human health. Therefore, as part of their stewardship of tire recycling in California, CIWMB has contracted with the Office of Environmental Health Hazard Assessment (OEHHA) to evaluate the following two aspects:

1. Whether these fields emit chemicals or particulates into the outdoor air at levels that constitute a potential human health hazard via the inhalation route of exposure, and
2. Whether these fields increase the risk of infection by methicillin-resistant *Staphylococcus aureus* (MRSA).

This report summarizes what is available in the published literature about these two aspects, with emphasis on the crumb rubber component of the artificial turf fields. Most of the studies discussed in the report presented original data covering the volatile chemicals and particulates detected in the air above artificial turf fields, the volatile chemicals emitted by recycled rubber, and the association between skin damage and artificial turf to MRSA outbreaks in athletic teams. MRSA is of particular concern due to its identification as the causative agent in a number of infectious outbreaks in high school, college, professional and club sports (see Part II). A bibliography is also included at the end of the report listing relevant studies that were not cited in the text.

It should be noted that although one study discussed in this report did analyze the particulates in the air over these fields (Dye et al., 2006), the particulates were not analyzed for heavy metals, including lead. Therefore, there are no data with which to estimate the health risks from inhalation exposures to heavy metals emitted by these fields via airborne particulates.

After discussing the published literature, each section in this report lists conclusions and identifies data gaps. At the end of Part I, the available but limited data on chemicals and particulates in the air above artificial turf are used to estimate the risk of cancer or developmental toxicity to soccer players using these fields. This screen only addresses the inhalation route of exposure. As mentioned above, since Dye et al. (2006) did not measure the metals content of inhalable particulates, this screen does not address the hazards posed by the inhalation of heavy metals such as lead.

OEHHA is currently performing a study to fill the data gaps identified in this report. OEHHA will sample air from above the new generation of artificial turf fields in outdoor settings and measure concentrations of potentially hazardous chemicals and particulates. Coaches will be surveyed to determine how much time athletes spend on these fields. Rates of skin abrasion will be measured on artificial and natural turf. Various components of the artificial turf, as well as soil and grass from natural turf, will be assayed for bacteria. Using these new data, OEHHA will determine whether the new generation of artificial turf playing fields releases chemicals or particulates into the air that pose an inhalation risk to persons using the fields. OEHHA will also determine whether artificial turf fields increase the risk of infection by dangerous bacteria such as MRSA.

Part I: Chemicals and Particulates in the Air above Artificial Turf

Studies that measured chemicals and particulates in the air above the new generation of artificial turf playing field

Table 1 shows five studies that measured chemicals and particulates in the air above the new generation of artificial turf playing field. For the studies by Dye et al. (2006), the Instituto De Biomecanica De Valencia (IBV, 2006), van Bruggen et al. (2007) and Milone & MacBroom (2008), the fields contained rubber crumb manufactured from recycled tires. The rubber crumb in the fields measured by Broderick (2007) was also likely recycled material, although this was not specifically stated in the reports. All fields were outdoors except those in Dye et al. (2006), which were soccer pitches in three indoor stadiums in Norway. Therefore, it is likely that the concentrations of chemicals and particulates measured by Dye et al. (2006) were higher than what would have been measured had the fields been outdoors.

Study quality and characteristics

The studies by Dye et al. (2006) and van Bruggen et al. (2007) were performed by governmental institutes located in Norway and The Netherlands, respectively. The study by IBV was performed by a university-affiliated research institute in Spain. Broderick (2007) refers to J.C. Broderick & Associates, Inc., an environmental consulting and testing firm located in New York State. Milone & MacBroom refers to an environmental consulting firm located in Connecticut.

The study by Dye et al. (2006) is the most detailed of the five, presented in a formal institute report. Multiple air samples were collected from above three indoor soccer pitches, two of which contained infill of ground rubber; however, samples from outside the stadiums were not collected, so that no conclusions can be drawn concerning the concentrations of chemicals and particulates in the vicinities of these stadiums. Thus, it is difficult to assess which chemicals were released by the artificial turf and which were already present in the ambient air. The study included data on the environmental conditions during sampling such as temperature, relative humidity and barometric pressure. Indoor ventilation rates were not measured. The chemical and particulate sampling height(s) above the pitches were not indicated. This study measured volatile organic chemicals (VOCs), polycyclic aromatic hydrocarbons (PAHs) in the gas phase and associated with particulate matter ( ), phthalates in the gas phase, and particulate matter ($_{.5}$ and). Thirty-eight PAHs were assayed. Comparing the two fields containing infill made of ground rubber, there is generally good agreement between the chemicals and particulates detected over the two fields. For example, Table 6a in the report lists the concentrations of benzothiazole, toluene, 4-methyl-2-pentanone and total volatile organic compounds (TVOCs) measured over the two fields; the concentrations measured over the first field were within 0.7-, 5.6-, 1.0- and 2.5-fold, respectively, of the concentrations measured over the second field. For the three PAHs occurring at the highest concentrations over both fields (naphthalene, 2-methylnaphthalene, acenaphthylene), the values from the first field were within 2.7-fold of the values from the second field. With regard to particulate matter, the concentration of collected from the two fields was 40.1 and 31.7 micrograms per cubic meter (µg/), while $_{.5}$ was 17.3 and 18.8 µg/, again demonstrating good agreement between the two fields.

Dye et al. (2006) also measured the air above a field containing infill made of “thermoplastic elastomer.” Comparing this field to the other two fields containing recycled rubber infill, the air above the field containing thermoplastic elastomer contained lower levels of VOCs, PAHs (both in the gas phase and associated with particulates), total $_{.5}$ and the $_{.5}$ fraction consisting of rubber dust.

van Bruggen et al. (2007), also presented in a formal institute report, collected multiple samples from above four outdoor soccer fields made of artificial turf, as well as samples upwind of the fields to measure the ambient environmental levels. Weather data included wind speeds, and the heights above the fields where sampling was performed were also reported. This study only measured nitrosamines. Eight were assayed.

The short report from Broderick (2007) shows that while duplicate samples were collected from above two outdoor artificial turf fields, as well as off of the fields, no weather data (including wind speed) were presented. In addition, the reports do not indicate the height above the fields at which sampling was performed. This study only measured PAHs (in the gas phase and in particulates collected on a 2.0 µm filter). Sixteen PAHs were assayed.

The IBV (2006) study was in the form of a meeting presentation, available online at the Web site for the 2006 Dresden Conference entitled, “Impact of Sports Surfaces on Environment and Health.” Six samples were collected over a single outdoor artificial soccer pitch. No background air samples were collected from off the pitch. Thus, it is difficult to assess which chemicals were released by the artificial turf and which were already present in the ambient air. No weather data were reported, and few other methodological details were provided. This study measured VOCs, PAHs (whether in gas or particulate phase was not indicated), and hydrogen sulfide.

The most recent study (Milone & MacBroom, 2008) collected a single air sample from above each of two artificial turf fields in Connecticut. Four additional samples were collected from off of each field. Temperature, humidity and wind speed/direction data were included, and a sampling height of 4 feet above the surface was utilized. Analysis was for seven nitrosamines, 4-(tert-octyl)phenol and benzothiazole. These last two chemicals had been detected volatilizing from recycled rubber crumb analyzed under laboratory conditions (see study by Environment & Human Health, Inc. (EHHI, 2007) in Table 4).

Comparing studies

Dye et al. (2006) identified 94 chemicals in the air above artificial turf fields located in indoor stadiums. Over 200 additional VOCs were detected in this study (13 to 16 percent by weight), but not identified. By comparison, the IBV (2006) study detected 13

Table 1. Air measurements above artificial turf fields

Reference	Scenario	Chemicals/particulates measured
Dye et al., 2006	Three indoor soccer stadiums 10- 42-53% humidity One field 2 months old (other 2 ages not indicated) Two fields contained recycled rubber crumb (yielding values shown on right)	VOCs : 69 detected at ≥ 0.8 µg/ PAHs: 22 detected at ≥ 1.0 ng/ (mostly in the gas phase, some in the particulate fraction) Phthalates: 3 detected at ≥ 0.06 µg/ (in the gas phase) .5: total = 18.8 µg/, rubber = 8.8 µg/ : total = 40.1 µg/, rubber = 9.3 µg/ Twenty highest VOCs were (in µg/): toluene (85), butenylbenzene (82.5), benzoic acid (81), diethenylbenzene (41), benzothiazole (31.7), p- and m-xylene (25.5), ethylbenzaldehyde (19.7), acetonitrile (16.8), acetone (15.3), o-xylene (13.1), 4-methyl-2-pentanone (12.7), alpha pinene (10.5), 3-phenyl-2-propenal (10.2), cyclohexanone (9.8), pentenyl benzene (7.3), pentanedioic acid dimethylester (6.8), ethylbenzene (6.7), formaldehyde (6.5), hexenylbenzene (6.1), styrene (6.1) Ten highest PAHs (total in gas phase plus -associated) were (in ng/): naphthalene (2700 or 56 for two different methods), acenaphthylene (78.1), 2-methylnaphthalene (57.8), 1-methylnaphthalene (42.6), biphenyl (32.8), phenanthrene (25), fluorene (19.2), dibenzofurane (17), acenaphthene (14.2), pyrene (4.4) Three phthalates were (in µg/): dibutylphthalate (DBP, 0.38), diisobutylphthalate (DiBP, 0.13), diethylphthalate (DEP, 0.06)
IBV 2006	One outdoor soccer field containing recycled rubber crumb	VOCs: 5 detected (highest value in µg/): p- and m-xylene (4.4), toluene (3.1), o-xylene (2.5), ethylbenzene (2.2), benzene (0.4)

Reference	Scenario	Chemicals/particulates measured
		PAHs: 8 detected (highest value in ng/): phenanthrene (6.9), pyrene (4.2), fluoranthene (1.1), fluorene (0.92), anthracene (0.46), acenaphthene (0.32), naphthalene (0.3), acenaphthylene (0.21)
Broderick 2007	Two outdoor high school athletic fields containing rubber crumb	All 16 PAHs assayed were below the minimum detection level of 6.0 µg/
van Bruggen et al., 2007	Three outdoor fields containing recycled rubber crumb and one containing new rubber For fields with recycled rubber, one recently installed and two older than one year Sampling performed between 11- on sunny days at 30-100 cm above pitch	All eight nitrosamines assayed were below the minimum detection limit of 8-16 ng/
Milone & MacBroom 2008	Two outdoor fields containing recycled rubber crumb Sampling performed on summer days between 75 and with light winds	Seven nitrosamines were assayed: samples from both fields were below the minimum reporting limit of 1.0 to 1.4 µg/ 4-(tert-octyl)phenol: samples from both fields were below the minimum reporting limit of 0.19 to 0.21 µg/

Reference	Scenario	Chemicals/particulates measured
	Samples taken at 4 feet above surface	Benzothiazole: one field’s sample was below the minimum reporting limit of 0.19 to 0.21 μg/; the other field’s sample was 1.0 μg/ (includes correction for 39% sample spike recovery)

chemicals and Milone & MacBroom (2008) detected one. The two remaining studies utilized detection levels that were too high; as a consequence, no chemicals were detected.

The failure to detect PAHs in the study by Broderick (2007) is consistent with the data in Dye et al. (2006). The individual PAH levels in Dye et al. (2006) were all $\leq$ 2.7 µg/, while the individual PAH detection levels in Broderick (2007) were 6.0 µg/. Utilizing nitrosamine detection levels of 8-16 ng/, van Bruggen et al. (2007) did not detect nitrosamines above three outdoor fields containing recycled rubber. Some nitrosamines volatilize readily from soil and water surfaces, while others are considered nonvolatile. Their study was initiated after a single air measurement above an artificial turf field containing recycled rubber detected N-nitrosodimethylamine (NDEA) at 93 ng/. Similarly, Milone & MacBroom (2008) did not detect nitrosamines above two fields (reporting limits 1.0 to 1.4 µg/). Dye et al. (2006) also did not report any nitrosamines above two indoor fields containing recycled rubber, although the nitrosamine detection levels were not indicated in the report.

Table 2 shows a comparison of the concentrations of the eight PAHs and five VOCs detected by IBV (2006) to the highest values reported by Dye et al. (2006). Despite uncontrolled variables such as field age and temperature during sampling, all 13 chemicals detected by IBV (2006) were detected by Dye et al. (2006). For 12 of the 13, the concentrations were lower in IBV (2006). This might be expected, since the field in the IBV (2006) study was outdoors, while the fields in the Dye et al. (2006) study were indoors. For the eight PAHs, concentrations measured in IBV (2006) ranged from similar (pyrene) to 9000-fold (naphthalene) lower than the corresponding concentration measured in Dye et al. (2006). For the five VOCs the differences were less, ranging from 3-fold (ethylbenzene) to 27-fold (toluene) lower in the IBV (2006) study. The VOC benzothiazole was also detected over an outdoor field by Milone & MacBroom (2008); its concentration was 32-fold lower over this outdoor field compared to the concentration reported over indoor fields by Dye et al. (2006). Therefore, the data in IBV (2006) and in Milone & MacBroom (2008) support those of Dye et al. (2006) in that all 13 chemicals detected over outdoor fields were detected at higher levels over indoor fields. This suggests that persons using the new generation of artificial turf in outdoor settings are exposed to many of the same chemicals as persons exposed indoors, albeit at lower concentrations. Thus, exposure calculations for outdoor play based on the data from Dye et al. (2006) would probably overestimate exposure to most chemicals. Since neither the IBV (2006) study nor the Dye et al. (2006) study measured the background level of chemicals, it remains possible that the 13 chemicals discussed above were not emitted from the artificial turf, but were already present in the ambient air. However, due to the presence of a number of VOCs that Dye et al. (2006) considered to be typical rubber components (such as benzothiazole, 4-methyl-2-pentanone and styrene), the authors believed that the rubber infill was the source of many of the VOCs they detected.

Unfortunately, since the report of Dye et al. (2006) contained the only published values for $_{.5}$ and from above artificial turf fields, there are no other studies for comparison. As discussed above, the good agreement between the PM values from the two fields measured in the study by Dye et al. (2006) provide some assurance that the data are reliable. However, it is difficult to use these indoor data from Dye et al. (2006) to predict the concentrations of PM over outdoor artificial turf fields.

Table 2. Comparison of chemical concentrations measured in the studies of Dye et al. (2006) and IBV (2006)

Chemical	**Concentration in IBV (2006) (µg/)**	**Concentration in Dye et al. (2006) (µg/)[1]**	**[Dye]/[IBV]**
PAHs			
Acenaphthene	0.00032	0.014	44
Acenaphthylene	0.00021	0.078	371
Anthracene	0.00046	0.002	4.3
Fluoranthene	0.0011	0.004	3.6
Fluorene	0.00092	0.019	21
Naphthalene	0.0003	2.7 or 0.056	9000 or 187
Phenanthrene	0.0069	0.025	3.6
Pyrene	0.0042	0.004	1
VOCs			
Benzene	0.4	2.4	6
Ethylbenzene	2.2	6.7	3
Toluene	3.1	85	27
o-Xylene	2.5	13.1	5.2
p and m-Xylene	4.4	25.5	5.8

value reported

Conclusions

- Only five studies were located which quantified the chemicals and particles in the air above the new generation of artificial turf playing fields.
- The study by Dye et al. (2006) of indoor soccer stadiums provides the largest dataset: 69 VOCs at ≥ 0.8 µg/, 22 PAHs at ≥ 1.0 ng/ (mostly in the gas phase), 3 phthalates at ≥ 0.06 µg/ (in the gas phase), .5 at 18.8 µg/ and at 40.1 µg/ were detected.
- The chemicals identified by Dye et al. (2006), as well as their concentrations, are consistent with the other four studies.

Data Gaps

- A study similar to that of Dye et al. (2006), that assays a large range of VOCs and particulates over multiple fields, is needed for outdoor artificial turf fields, since use of the Dye et al. (2006) data for estimating the health risks from outdoor fields probably overestimates those risks.
- Dye et al. (2006) did not sample air from outside the stadiums for comparison to the indoor samples. Therefore, it is not possible to know what amount of each

chemical was contributed by the artificial turf field and what amount was present in the ambient air.

- Approximately 200 of the 300 VOCs (13 to 16 percent by weight) detected by Dye et al. (2006) were not identified, but were only reported as peaks on a graph. Therefore, potential health risks posed by these chemicals cannot be estimated.
- Many of the chemicals identified in the study of Dye et al. (2006) have no associated health-based screening levels, so that their health risks cannot be estimated. Thus, any attempt to classify these chemicals as carcinogens or developmental/reproductive toxicants will be an underestimate.
- The Dye et al. (2006) study provides the only data on particulate levels from above artificial turf playing fields. Data from above outdoor fields are needed, where the values are likely to be lower.
- Dye et al. (2006) did not measure the metals content of the airborne particulate matter ($_{.5}$ and). Thus, the health risks posed by inhaled particulates and the metals they contain, such as lead, cannot be determined.
- The effect of temperature on chemical and particulate levels has not been measured.
- The contribution of field age to chemical and particulate levels has not been measured.
- The effect of field use on the levels of either VOCs or particulates has not been measured. Thus, it is possible that air sampling before or during games would give different results.

Studies that measured chemicals emitted by rubber flooring made from recycled tires

CIWMB sponsored two studies (2003 and 2006) that measured chemical emissions from tire-derived rubber flooring. This type of flooring is used in indoor applications such as auditoriums and classrooms. The flooring contained at least 80 percent tire-derived rubber, making it chemically very similar to the crumb rubber infill used in many new generation artificial turf fields, including those in the study of Dye et al. (2006) and the other studies in Table 1. Emissions of individual chemicals were measured in environmental chambers and normalized to the surface area of flooring in each chamber, yielding chemical-specific emission factors. The data cannot be directly compared to the air concentrations from Dye et al. (2006). However, the emission factors were used to model the chemical concentrations expected to occur in a variety of indoor settings. Table 3 shows those concentrations for the largest rooms modeled: an auditorium and a classroom. The results for the largest rooms are presented since these are closest to the dimensions of the indoor stadiums in the Dye et al. (2006) study.

Table 3. Indoor emissions from tire-derived rubber flooring

Reference	Indoor area modeled	Modeled room chemical concentrations (µg/) based on measured emission factors
CIWMB, 2003	State auditorium, 70x70x15 ft, 73,500 3.5 air changes per hour Flooring samples tested contained at least 80% recycled styrene butadiene rubber and ethylene propylene diene monomer Chemical emission rates were determined at 14 days, modeled concentrations in right column are based on the highest measured emission rate for each chemical	VOCs 21 identified: α, α-dimethylbenzenemethanol (420), acetophenone (160), diethyl propanedioate (80), propylene glycol (47), 1-ethyl-3-methylbenzene (43), 1,2,4-trimethylbenzene (40), α-methyl-styrene (38), benzothiazole (37), 1-ethyl-4-methylbenzene (22), 1,2,3-trimethylbenzene (18), triethylphosphate (18), 1-ethyl-2-methylbenzene (13), 2-ethylhexyl acetate (11), cumene (5.5), 2-ethyl hexanoic acid (3.9), 1-methyl-2-pyrrolidinone (1.8), dodecane (1.4), naphthalene (0.99), nonanal (0.74), decanal (0.5), ethyl benzene (0.5)
CIWMB, 2006	State classroom, 960 x8.5 ft high, 8160 0.9 air changes per hour Most flooring samples contained ≥ 81% tire-derived rubber Chemical emission rates were determined at 14 days, modeled concentrations in right column are based on the highest measured emission rate for each chemical	VOCs 31 identified: benzothiazole (1677), methyl isobutyl ketone (154), m-/p- xylene (142), carbon disulfide (116), acetophenone (86), cyclohexanone (77), toluene (60), acetone (43), ethyl benzene (32), benzene (24), chlorobenzene (23), nonanal (22), n-undecane (21), octanal (18), styrene (17), acetaldehyde (16), butyraldehyde (14), α-methylstyrene (12), phenol (10), decanal (9), isopropyl alcohol (9), 1,2,4-trimethylbenzene (9), formaldehyde (7), n-decane (6), 1-ethyl-4-methylbenzene (6), 1,3,5-trimethylbenzene (6), naphthalene (4), hexanal (3), 4-phenylcyclohexene (3), 1,2,3-trimethylbenzene, o-xylene (2)

In the 2003 CIWMB study, eight of 21 chemicals emitted by the tire-derived flooring were also detected above artificial turf fields in indoor stadiums (Dye et al., 2006). Half of these (4/8) were modeled as occurring at higher concentrations in the auditorium compared to the stadiums. In the 2006 CIWMB study, 18 of 31 chemicals emitted by the flooring were also detected above artificial turf fields in indoor stadiums (Dye et al., 2006), with 16 of the18 occurring at higher concentrations in the modeled state classroom compared to the indoor stadiums. For those chemicals detected in CIWMB (2003) or (2006) but not in Dye et al. (2006), it is not known if they were even assayed in the latter study. There were six chemicals detected in both CIWMB studies and by Dye et al. (2006): 1,2,4-trimethylbenzene, 1-ethyl-4-methylbenzene, benzothiazole, ethylbenzene, naphthalene and nonanal. Three of these were emitted by 100 percent rubber crumb heated under laboratory conditions: 1,2,4-trimethylbenzene, benzothiazole and ethylbenzene (see Table 4). This suggests that these three chemicals in the air are reliable markers for the crumb rubber from recycled tires used as infill in artificial turf. Ethylbenzene and naphthalene were also detected by IBV (2006) and benzothiazole was detected by Milone & MacBroom (2008) in outdoor air above artificial turf fields (Table 1), while all except 1-ethyl-4-methylbenzene were emitted by sections of artificial turf maintained in environmental chambers (see next section, Moretto, 2007).

It should be mentioned that recycled tire rubber used as indoor flooring (CIWMB 2003) emitted hundreds of low-level VOCs that were not identified. Hundreds of low-level VOCs were also detected in the air over artificial turf in indoor stadiums (Dye et al., 2006). When all VOCs were totaled (TVOCs), they reached up to 716 μg/ in the Dye et al. study (2006) and exceeded one milligram (mg)/ in the CIWMB study (2003). The health effects from breathing low levels of many volatile organic chemicals have not been adequately studied. This lack of information should be noted when calculating the health risks from individual chemicals that were identified in these studies.

Conclusions

- Twenty of the VOCs released by tire-derived indoor rubber flooring (CIWMB 2003 and 2006) were also detected in the air above indoor soccer pitches made of the new generation of artificial turf containing rubber infill.
- For the more recent flooring study (CIWMB, 2006), 18 of 31 chemicals emitted by the flooring were also detected in the air above the turf (Dye et al., 2006). This demonstrates good agreement between the studies and supports using the data from Dye et al. (2006) for making health risk estimates via inhalation.
- Three VOCs were consistent markers for tire-derived rubber: 1,2,4-trimethylbenzene, benzothiazole and ethylbenzene.

Data Gaps

- Tire-derived flooring emitted hundreds of low-level VOCs that were not identified, while other identified chemicals had no associated health-based

screening levels. Therefore, the health risks posed by these chemicals cannot be estimated.
- Total VOCs (TVOCs) emitted by tire-derived flooring exceeded one mg/. Similar measurements of TVOCs should be made above artificial turf fields, since breathing low levels of a mixture of many VOCs may pose a health risk.

Laboratory studies of the emission of volatile chemicals from tire-derived crumb rubber infill

Three studies were located which analyzed the gaseous emissions from tire-derived crumb rubber infill in laboratory settings (Table 4). The studies by Plesser and Lund (2004) and EHHI (2007) analyzed samples of 100 percent rubber infill heated to 60-, while Moretto (2007) used whole sections of artificial turf (containing recycled crumb rubber infill) maintained at in environmental chambers.

Moretto (2007) identified 112 VOCs emitted from the artificial turf. This is more than reported in any other study. Twenty-seven of these were also detected by Dye et al. (2006) over artificial turf fields in indoor soccer stadiums. Moretto (2007) did not provide quantitative data on the amounts of chemicals that were released by the sections of artificial turf. Of the 12 VOCs identified by Plesser and Lund (2004), five were also detected by Dye et al. (2006). From among the four VOCs identified in EHHI (2007), only benzothiazole was also identified by Dye et al. (2006).

Conclusions

- The study by Moretto (2007) of artificial turf in environmental chambers confirmed 27 of the chemicals detected in indoor soccer stadium air by Dye et al. (2006). This supports the use of the data from Dye et al. (2006) for estimating the health risks posed by artificial turf playing fields.
- Benzothiazole was detected in two of three emissions studies in Table 4 (EHHI, 2007; Moretto, 2007), in both indoor flooring studies in Table 3 (CIWMB 2003 and 2008), and in air above artificial turf fields (Table 1; Dye et al., 2006; Milone & MacBroom, 2008). It appears to be a consistent and relatively high-level off-gassing product of rubber crumb made from recycled tires.

Data Gaps

- Many of the chemicals identified in the chamber emission study of Moretto (2007) were not detected in stadium air by Dye et al. (2006). This may be due to the conditions used by Moretto (2007): a sealed environmental chamber, maintained at , in which chemicals emitted at low levels have a chance to accumulate. Since chemical concentrations in the chambers were not provided in the report, this cannot be determined.

Table 4. Gaseous emissions per gram of tire-derived rubber in laboratory studies

Reference	Conditions	VOCs detected (in ng/g of rubber)
Plesser and Lund, 2004	Samples heated at for 30 minutes	Twelve VOCs detected: 1,2,4-trimethylbenzene (102), toluene (80), m/p-xylene (37), o-xylene (35), cis-1,2-dichloroethene (32), n-butylbenzene (31), p-isopropyltoluene (23), 1,3,5-trimethylbenzene (23), ethylbenzene (18), propylbenzene (15), iso-propylbenzene (12), trichloromethane (8)
EHHI, 2007	Samples heated at for 42 minutes	Four VOCs detected: benzothiazole (867), butylated hydroxyanisole or BHT alteration product (53), 4-(tert-octyl)-phenol (22), hexadecane (1.58)
Moretto, 2007	Samples off-gassed for 28 days in chambers at	112 VOCs detected, but emissions per gram of rubber not indicated

Chemicals and particulates emitted during rubber manufacturing

Due to the large numbers of chemicals and materials used to manufacture rubber, many occupational health studies have examined the safety of various steps in the manufacturing process. The studies listed in Table 5 measured the concentrations of volatile chemicals and particulates to which rubber workers have been exposed. While it is to be expected that the levels of these chemicals would be higher in factory air during the rubber manufacturing process compared to a setting where the rubber end product is used, such as in artificial turf infill, some of the more prevalent chemicals should be detected in both situations. Such a comparison can be a useful test of the validity of the studies presented in Table 1 that attempted to identify the chemicals and particulates above artificial turf fields containing recycled tire rubber as infill.

With respect to VOCs, Rappaport and Fraser (1977) measured six VOCs in a vulcanization area of a tire manufacturing plant. Three of these, toluene, ethylbenzene and styrene, were also detected by Dye et al. (2006) in indoor stadium air above new generation artificial turf containing recycled crumb rubber infill; the stadium concentrations were 51-fold, 73-fold and 78-fold lower than the factory concentrations, respectively. Cocheo et al. (1983) measured VOCs in the vulcanization and extrusion areas of a tire retreading factory. From among the 60 VOCs they identified, 15 were also detected by Dye et al. (2006) in the indoor stadium study; concentrations of the 15 VOCs were from 4-fold to 625-fold lower in the artificial turf application. Van Ert et al. (1980) investigated eight organic solvents used in a tire and tube manufacturing plant. Measurements were performed in the tire building and final inspection areas. Five of the eight solvents were also detected by Dye et al. (2006): heptane, toluene, octane, benzene and xylene. The concentrations ranged from 34-fold to 10,750-fold lower in the indoor stadium air compared to the factory air. Armstrong et al. (2001) identified five VOCs in rubber tire manufacturing plants. Of these, three (formaldehyde, benzene and toluene) were also identified by Dye et al. (2006), but at 34-fold to 238-fold lower concentrations. Lastly, two of four VOCs identified by Correa et al. (2004) in the outdoor air circulation area of a tire recapping unit were also identified by Dye et al. (2006); toluene and styrene were 131-fold and 7-fold lower in the air above indoor artificial turf fields compared to the tire recapping area. Thus, five separate studies of rubber manufacturing have detected VOCs that were also in the air over the new generation of artificial turf fields; in each case the chemical was at a lower concentration above the fields compared to the manufacturing setting. These findings support the use of the data from Dye et al. (2006) for estimating chemical exposures to persons using the new generation of artificial turf fields, at least until similar measurements can be performed in outdoor settings.

Nitrosamines have been detected by sampling air in rubber manufacturing plants (Table 5). Oury et al. (1997) measured total nitrosamines in tire factory air. The highest concentration detected was 2.3 μg/. Monarca et al. (2001) detected two nitrosamines (N-nitrosodimethylamine [NDMA] and N-nitrosomorpholine [NMOR]) in the range of 1-2 μg/ inside a styrene-butadiene rubber factory. Iavicoli and Carelli (2006) sampled air in a rubber manufacturing plant. While the great majority of air samples had no

Table 5. Chemicals and particulates released into the air during rubber manufacturing

Reference	Work area sampled	Chemicals and particulates measured
Nutt, 1976	Tire factory areas including mixing, extrusion, curing, pressing, trimming	Benzo[a]pyrene was Soxhlet-extracted from particulates: mean concentration of 49 factory air samples (12.3 ng/) was not significantly different from outside air B[a]P concentration
Rappaport and Fraser, 1976	Rubber vulcanization performed in the lab	Fourteen VOCs were identified, with the highest relative concentrations being methylbenzene, 4-vinylcyclohexene, styrene, tert-butylisothiocyanate, and 1,5,9-cyclododecatriene
Rappaport and Fraser, 1977	Tire vulcanization area in a factory	Six VOCs measured (mean values in µg/): toluene (4,371), ethylbenzene (486), styrene (473), 4-vinylcyclohexene (408), 1,5,9-cyclododecatriene (105), 1,5-cyclooctadiene (28.5)
Van Ert et al., 1980	Tire building and final inspection areas in two tire and tube manufacturing plants	Eight organic solvents measured (highest mean values in mg/): hexane (64), heptane (8.6), isopropanol (7.9), toluene (3.2), pentane (2.2), octane (1.9), benzene (1.3), xylene (1.3)
Cocheo et al., 1983	Vulcanization and extrusion areas in a tire retreading factory	Sixty VOCs measured, the following being the ten highest in concentration (mg/): diisobutyl phthalate (2.5), cyclohexene-1-methyl-4-(1-methylvinyl) (1.7), benzene (1.2), toluene (0.8), methylcyclohexane (0.8), dibutyl phthalate (0.5), heptane (0.5), 1-isopropyl-4-methylbenzene (0.45), 2,6-di-ter-butyl-4-ethylphenol (0.42), cyclododecatriene (0.4)
Heitbrink and McKinnery, 1986	Tire manufacturing plants: mixing and milling areas	Mean total aerosol ranges (in mg/): for mixing (0.08 to 1.54), for milling (0.2 to 1.22); mean respirable aerosol ranges (in mg/): for mixing (0.06 to 0.34), for milling (0.08 to 0.4)
Oury et al., 1997	Tire factory including steps of mixing, pressing, quality control and storage	Total nitrosamines (NDMA, NDEA, NDBA, NPIP, NMOR) were between 0.01 and 2.3 µg/ (range of 45 measurements)
Meijer et al., 1998	Rubber manufacturing areas in belt factory (compounding and mixing, calendaring, extruding, repair, curing)	"Inhalable dust" mean values ranged from 0.9 to 9.4 mg/
Fracasso et al., 1999	Rubber manufacturing areas included weighing, mixing, calendaring, compounding,	PAH concentration ranges (in µg/): phenanthrene (not detected), pyrene (0.006 to 0.213), benzo(a)anthracene (not detected to 0.005), chrysene (0.01 to 0.05), benzo(a)pyrene (not detected to 0.012), dibenzo(a,h)anthracene (0.003 to 0.106)

Reference	Work area sampled	Chemicals and particulates measured
	extruding	
Armstrong et al., 2001	Five rubber tire manufacturing plants	Aerosol particle concentrations (means in µg/): [<1 µm] (120); to [1 to 5 µm] (123); to [5 to 10 µm] (109); VOCs (means in mg/) formaldehyde (0.22), benzene (0.57), furfural (< 0.91), isopropyl alcohol (5.66), toluene (12.38)
Monarca et al., 2001	Styrene-butadiene rubber factory	Total mean =0.23 mg/; mean nitrosamines (in µg/): NDMA (0.98), NMOR (2.28); 17 PAHs were Soxhlet-extracted from , with the 10 highest (in ng/): dimethylnaphthalene (1200), naphthalene (400), pyrene (29), benzo(ghi)perylene (20), indeno(1,2,3-cd)pyrene (18), phenanthrene (12), benzo(b)fluoranthene (7.3), fluoranthene (7.0), benzo(a)pyrene (5.7), benzo(a)anthracene (2.3)
Ward et al., 2001	Rubber manufacturing plant: high exposure areas (reactor, recovery, tank farm, lab); low exposure areas (blending, baling, packaging, coagulation, water plant)	1,3-butadiene concentrations, mean 12 hour time weighted averages (in mg/) for: high exposure areas = 3.8, for low exposure areas = 0.15
Chien et al., 2003	Two tire shredding plants-chopping, shredding, granulating and storage areas	, means ranged from 0.23 to 1.25 mg/
Correa et al., 2004	Outdoor circulation area of a tire-recapping unit	In µg/ : toluene (11,100), styrene (44.3), 4-chlorotoluene (7.6), 4-chlorostyrene (9.0), benzo(a)anthracene (16.7 extracted from particulates), chrysene (17.5 extracted from particulates)
de Vocht et al., 2006	Tire factory: milling and mixing/curing departments	“Inhalable particulate matter” mean value was 0.3 mg/
Iavicoli and Carelli, 2006	Rubber manufacturing (e.g., belts, no tires)	Great majority of nitrosamine samples were below the limit of detection (0.06 µg/); however, some values were higher (in µg/): N-nitrosodimethylamine (0.35 for one sample), N-nitrosomorpholine (0.16, mean of 4 samples), N-nitrosodiethylamine (0.15, mean of 5 samples), N-nitrosodi-n-butylamine (0.06 for one sample)
de Vocht et al., 2008a	Polish rubber tire plant; departments sampled included crude materials, milling and mixing, pre-treating, assembly,	Geometric mean concentrations for the different departments ranged from: 1.7 to 5.8 mg/ for inhalable aerosols, <1.0 to 578 µg/ for aromatic amines

Reference	Work area sampled	Chemicals and particulates measured
	curing, finishing, storage	
de Vocht et al., 2008b	Rubber manufacturing in five European countries	Inhalable dust measured with personal samplers on workers, means ranged from 0.72 to 1.97 mg/

detectable nitrosamines (detection limit = 0.06 μg/), some had detectable levels, the highest being 0.35 μg/ for N-nitrosodimethylamine. All the above nitrosamine concentrations are above the minimum detection level of 8-16 ng/ used by van Bruggen et al. (2007) to analyze air samples from above outdoor artificial turf fields containing recycled rubber crumb (Table 1). There are at least two possible reasons for the failure of van Bruggen et al. (2007) to detect the volatile nitrosamines, given that they were present at detectable levels during manufacturing. First, most of the more volatile nitrosamines may have been emitted by the rubber crumb prior to field installation. Second, volatilization may be so rapid that the chemicals rapidly dissipate into the atmosphere.

PAHs have also been detected in the air of factories producing rubber (Table 5). Surveying the levels in factory air, all were well below the detection level of 6.0 μg/ used by Broderick (2007) when sampling the air above outdoor artificial turf fields containing recycled rubber crumb (Table 1). Thus, it is not surprising that Broderick (2007) failed to detect PAHs. Using lower detection levels, Dye et al. (2006) reported 22 PAHs at $\geq$ 1.0 ng/ in the air above artificial turf fields in indoor stadiums (Table 1). Comparing the PAHs detected by Dye et al. (2006) to those reported in the occupational studies in Table 5 yields the following: two of six PAHs detected by Fracasso et al. (1999), ten of 16 detected by Monarca et al. (2001), and none of two detected by Coorea et al. (2004) were also identified by Dye et al. (2006). The agreement between Monarca et al. (2001) and Dye et al. (2006) seems close; however, while six of the PAHs were at higher levels in factory air compared to the indoor stadium air, four were at higher levels in the stadium air. A possible explanation is that Dye et al. (2006) analyzed PAHs occurring in both the gas and particulate phases, while Monarca et al. (2001) only assayed the particulate phase. Thus, the more volatile PAHs might be expected at higher levels in the former case. The four PAHs detected at higher levels by Dye et al. (2006) were in fact the relatively volatile PAHs acenaphthylene, fluorene, phenanthrene and anthracene.

Values for respirable particulate (; particles capable of penetrating deeply into the lungs, into the region where gas exchange occurs) concentrations in factory air were distributed over a fairly narrow range: up to 400 μg/ in a tire manufacturing plant (Heitbrink and McKinnery, 1986), up to 352 μg/ in five tire manufacturing plants (Armstrong et al., 2001), and up to 1250 μg/ in two tire shredding plants (Chien et al., 2003). The concentrations were roughly ten-fold lower in the indoor stadium air measured by Dye et al. (2006), ranging up to 40.1 μg/, of which 9.3 μg/ was identified as rubber particulate. Inhalable particulate (relatively large particles, capable of being inhaled but not penetrating deeply into the lungs) concentrations in factory air were generally higher than respirable concentrations, ranging as high as 5800 and 9400 μg/ in the studies by de Vocht et al. (2008) and Meijer et al. (1998). These results for respirable particulates are similar to those for VOCs, in that concentrations above indoor artificial turf fields were much lower than those in the factories, including the tire shredding plant (Chien et al., 2003).

Conclusions

- A number of VOCs detected above third generation artificial turf fields by Dye et al. (2006) were also detected in the air of rubber manufacturing plants. In all cases, the concentrations were lower in the air over the artificial turf fields compared to the factory settings.
- For the nitrosamines, their levels in air above artificial turf fields and in rubber factory air suggest that either these chemicals volatilize from the rubber crumb prior to installation in a field, or their levels over a field are too low to detect.
- Air sampling data from rubber factories confirm most of the PAHs detected by Dye et al. (2006) in the air over artificial turf fields.
- Air sampling in rubber factories and tire shredding plants detected levels of respirable particulates ( ) that were approximately ten-fold higher than the levels measured above third generation artificial turf fields containing rubber crumb infill (Dye et al., 2006).

Data Gaps

- Measure the time dependence (as the fields age) of respirable particulate (.5 and) release from artificial turf fields containing rubber crumb.
- Determine if levels of respirable particulates (.5 and) vary with field use; i.e., are the levels in the air higher during games compared to periods when the fields are idle?

Estimating the risk of cancer and developmental/reproductive toxicity via inhaled air in soccer players on the new generation of artificial turf.

The purpose of this section is to estimate the increased lifetime cancer risk and increased risk of developmental/reproductive toxicity due to the inhalation of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) by soccer players using the new generation of artificial turf playing fields. To perform this screen, the chemicals detected above artificial turf fields were compared to the California Proposition 65 list of chemicals known to the state to cause cancer or developmental/reproductive toxicity.

As described earlier in this report, Dye et al. (2006) published a study analyzing the air above three artificial turf playing fields located indoors in Norwegian soccer stadiums. This section uses these values, along with published values for age-specific breathing rates, and estimated lifetime play scenarios for soccer players on artificial turf, to calculate the following for those chemicals that also appear on the California Proposition 65 list:

1. daily chemical intake rates averaged over a lifetime to estimate the increased lifetime cancer risk, and
2. daily chemical intake rates not averaged over a lifetime, for comparison to maximum allowable dose levels (MADLs) to estimate the increased risk of developmental/reproductive toxicity.

Estimating the daily intake of air above artificial turf playing fields

Table 6 estimates the daily intake of air by soccer players from above artificial turf playing fields. The breathing rates are recommended for persons in the indicated age group engaged in "heavy" activities over "short-term" intervals. The 1.5 and 2.0 hour intervals seem to us to be reasonable estimates for the time a soccer player spends playing a timed game or practicing.

Table 6. Intake of field air on days of artificial turf field use.

Age interval	**Breathing**	**Time of field use per day (soccer game or practice session)[2]**	**Total intake of field air per day of field**
5-15 years	1.9 /hr	1.5 hr/day	2.85 /day
16-18 years	1.9 /hr	2 hr/day	3.8 /day
19-55 years	3.2 /hr	2 hr/day	6.4 /day

[1] For 5-18 years: recommended mean value for short-term exposures to a child ≤ 18 years and performing heavy activities (US EPA Child-Specific Exposure Factors Handbook, September 2002, Table 7-14); for 19-55 years: recommended mean value for short-term exposures to adults performing heavy activities (OEHHA Technical Support Document for Exposure Assessment and Stochastic Analysis, September 2000, Table 3.9).
[2] Estimates based on length of timed game or practice session for ages < 16 years (1.5 hours) or ≥ 16 years (2 hours).
[3] Calculated by multiplying the value in column two by the value in column three.

Estimating the daily intake of air from above artificial turf playing fields averaged over a 70 year lifetime

The play scenarios shown in Table 7 are our best estimates for a lifetime of soccer play by a soccer enthusiast. The scenarios are not based on data. The daily intakes of air from above artificial turf fields were averaged over a 70-year lifetime, including 51 years of organized soccer play (from age 5 to 55). The daily intakes were also averaged over an entire year, since it was estimated that at most, 102 days per year (for the 19 to 22 year-old age group) would include use of artificial turf (Table 7). We consider this lifetime exposure rate of 0.464 /day (Table 7) a heaviest use scenario for soccer players, since this assumes all organized soccer games and practices over a lifetime would be on artificial turf.

Table 7. Intake of field air for 51 years of artificial turf field use (soccer) averaged over a 70-year lifetime.

inter-val	play scenario on artificial turf fields	air intake per day of field use (practice or game) for this play scenario	of use per year for this play scenario	of use per 70 year lifetime for this play scenario	field air intake for this play scenario averaged over a 70 year lifetime	field air intake normalized to body weight in /kg-d
5-15	Two 15-game club seasons/year with 30 associated practice days	2.85 /day	60 day/365 days	11 years/70 years	0.074 /day	0.0021
16-18	One 15-game club season/year with 15 associated practice days; one 10-week high school season (6 days/week)	3.8 /day	90 days/365 days	3 years/70 years	0.040 /day	0.0006
19-22	One 15-game club season/year with 15 associated practice days; one 12-week college season (6 days/week)	6.4 /day	102 days/365 days	4 years/70 years	0.102 /day	0.0015
23-55	One 15-game club season/year with 15 associated practice days	6.4 /day	30 days/365 days	33 years/70 years	0.248 /day	0.0034
Total					0.464 /day	

[1] Estimated age intervals for each soccer play scenario.
[2] Estimated play scenarios, with game or practice times as shown in Table 6.
[3] From fourth column of Table 6.
[4] Estimated games and practices per year for the corresponding play scenario.
[5] Estimated years of play for the corresponding play scenario.
[6] Calculated by multiplying columns three, four and five.
[7] Body weight means for combined males and females over each interval were: 35.6 kg for the 5-15 interval, 67.5 kg for the 16-18 interval (US EPA, 2002); 67.2 kg for the 19-22 interval, 74.0 kg for the 23-55 interval (US EPA, 1997).

Estimating the increased cancer risk from inhaling air above artificial turf fields

Eight of the chemicals identified in the air above indoor artificial turf fields (Dye et al., 2006) also appear on the California Proposition 65 list of chemicals known to the state to cause cancer (PAHs below 0.001 µg/ were not included). Table 8 shows the increased lifetime cancer risks from breathing each of these during soccer play on artificial turf fields. The risk for each chemical was calculated using the highest air concentration from among eight independent measurements over three different artificial turf fields (Dye et al., 2006). This may overestimate the true chemical concentration in the air. Risks for two age intervals per chemical were calculated, so that a safety factor of three could be added for the 5-15 year interval (US EPA, 2005). Five of the eight chemicals were associated with increased lifetime cancer risks that exceeded the broadly accepted negligible risk level of 10^{-6}: benzene, formaldehyde, naphthalene, nitromethane and styrene. Their increased cancer risks ranged from 1.6×10^{-6} for formaldehyde to 8.7×10^{-6} for nitromethane. Since these risks exceeded the 10^{-6} benchmark, it is important for future studies to measure the concentrations of these chemicals above outdoor artificial turf fields. In addition, their concentrations should be measured in the ambient air in the vicinities of the fields. Comparing the concentrations in the air over and off of the fields will establish which carcinogenic chemicals are emitted by artificial turf, and whether mitigation measures are required.

Table 8. Inhalation of chemicals from above artificial turf fields in indoor stadiums in Norway that also appear on the California Proposition 65 list of chemicals known to the state to cause cancer: increased lifetime cancer risks from soccer play.

Chemical	Age interval in years	field air intake in /kg-d	field air concentration of chemicals in mg/	chemical intake in mg/kg-d	Factor	Slope Factor in $(mg/kg\text{-}d)^{-1}$	lifetime cancer risk
Acetaldehyde	5-15	0.0021	0.0043	9.03×10^{-6}	3	0.01	5.0×10^{-7}
Acetaldehyde	16-55	0.0055	0.0043	2.37×10^{-5}	1	0.01	
Benzene	5-15	0.0021	0.0024	5.04×10^{-6}	3	0.1	2.8×10^{-6}
Benzene	16-55	0.0055	0.0024	1.32×10^{-5}	1	0.1	
Benzo[a]pyrene	5-15	0.0021	1.2×10^{-6}	2.52×10^{-9}	3	3.9	5.5×10^{-8}
Benzo[a]pyrene	16-55	0.0055	1.2×10^{-6}	6.6×10^{-9}	1	3.9	
Ethylbenzene	5-15	0.0021	0.0067	1.41×10^{-5}	3	0.0087	6.8×10^{-7}
Ethylbenzene	16-55	0.0055	0.0067	3.69×10^{-5}	1	0.0087	

Chemical	Age inter-val in years	field air intake in /kg-d	field air concentra-tion of chemicals in mg/	chemical intake in mg/kg-d	Factor	Slope Factor in $(mg/kg\text{-}d)^{-1}$	lifetime cancer risk
Formaldehyde	5-15	0.0021	0.0065	1.37×10^{-5}	3	0.021	1.6×10^{-6}
Formaldehyde	16-55	0.0055	0.0065	3.58×10^{-5}	1	0.021	
Naphthalene	5-15	0.0021	0.0027	5.67×10^{-6}	3	0.12	3.8×10^{-6}
Naphthalene	16-55	0.0055	0.0027	1.49×10^{-5}	1	0.12	
Nitromethane	5-15	0.0021	0.0041	8.61×10^{-6}	3	0.18	8.7×10^{-6}
Nitromethane	16-55	0.0055	0.0041	2.26×10^{-5}	1	0.18	
Styrene	5-15	0.0021	0.0061	1.28×10^{-5}	3	0.026	1.9×10^{-6}
Styrene	16-55	0.0055	0.0061	3.36×10^{-5}	1	0.026	

[1] From last column in Table 7. For the 16-55 interval, the value of 0.0055 is the sum of the values for the 16-18, 19-22 and 23-55 age intervals in Table 7.

et al., 2006; highest value from among eight independent measurements over three different artificial turf fields in indoor stadiums.

by multiplying column three by column four.

factor for the increased sensitivity of 2-15 year old children to carcinogens (US EPA, 2005).

cancer slope factors were taken from the OEHHA Toxicity Criteria Database available at .oehha.ca.gov except for nitromethane and styrene; nitromethane cancer slope factor is available at www.oehha.ca.gov/prop65/law/pdf_zip/NitromethaneNSRL120707.pdf ; styrene cancer slope factor from OEHHA, 2009, Public Health Goal for Styrene, under review.

lifetime cancer risks due to each chemical were calculated by multiplying columns five, six and seven and adding together the resulting risks for the two age intervals.

Estimating the risk of developmental/reproductive toxicity from inhaling air above artificial turf fields

Benzene and toluene were the two chemicals identified in Dye et al. (2006) that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity. Toluene is listed as a developmental toxicant, while benzene is listed as a developmental and male reproductive toxicant. For developmental toxicants, the subpopulation most at risk is pregnant females. Were a pregnant female to use these fields for a two hour interval, her exposure to benzene and toluene via inhaled air would be below the corresponding maximum allowable dose level (MADL, Table 9).

Table 9. Daily intake rates of chemicals inhaled via air from above artificial turf fields in indoor stadiums in Norway that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity: comparison to maximum allowable dose levels (MADLs).

Chemical	**Indoor field air concentration detected in Norwegian study (ug/)[1]**	**Chemical intake via field air (not averaged over lifetime) (ug/day)[2]**	**MADL (ug/day)[3]**
Benzene	2.4	15.4	49
Toluene	85	544	13,000

[1] Dye et al., 2006; highest value from among eight independent measurements over three different artificial turf fields in indoor stadiums.
[2] Calculated by multiplying the daily intake of field air for 19 to 55 year-olds (6.4 /day, Table 6) by the field air concentration shown in column two of this table.
[3] MADL = maximum allowable dose level, accessed 6/08 at http://www.oehha.ca.gov/prop65/pdf/2008MayStatusReport.pdf .

This section estimates the risk of cancer or developmental/reproductive toxicity in soccer players using the new generation of artificial turf playing field. A single study (Dye et al., 2006) was used as the source of VOC and PAH concentrations from above this type of field. Since Dye et al. (2006) was performed in indoor soccer stadiums, we believe it likely that the chemical concentrations over outdoor fields would be significantly lower, due to the dispersion of the chemicals into the atmosphere. Comparing Dye et al. (2006) to IBV (2006), as shown in Table 2 of this report, suggests that this is indeed the case. Support also comes from comparing the benzothiazole concentration measured indoors by Dye et al. (2006) to that measured by Milone & MacBroom (2008) outdoors: 31.7 compared to 1.0 μg/. Thus, the daily chemical intakes calculated in Tables 8 and 9 probably overestimate the intakes that would result from breathing air over outdoor artificial turf fields. More accurate estimates of the cancer and developmental/reproductive hazards will be possible when air from above additional outdoor synthetic turf fields is analyzed, along with background levels from off of the fields.

The lifetime soccer play scenarios are not based on data but on personal experience and informal discussions. Relevant data may exist that will help reduce the uncertainty in this component of the exposure assessment. Until those data are located, we consider this cumulative play scenario from ages 5 through 55 exclusively on artificial turf to represent a heaviest use scenario for soccer players. However, soccer is only one of many sports played on today's artificial turf fields. Football, lacrosse, baseball, softball and rugby are some others, along with the unorganized, informal play that predominates for young children under the age of five. All these modes of play have characteristic ages for participants, years of expected play, and time spent on the field per game. This will result in chemical exposures via inhalation that are different from those calculated above for soccer. In addition, the people who coach, supervise or referee these sports will each have different exposures, as will the people who maintain artificial turf fields. Therefore, the risks calculated for soccer players in Tables 8 and 9 should not be interpreted as covering the risks for other sports, age groups or occupations.

Lastly, it should be noted that most of the VOCs detected above artificial turf fields in the Dye et al. (2006) study were never identified. For example, for the field yielding the highest level of total volatile organic compounds (TVOCs, 716 ug/), 85 percent of the individual chemicals (representing about 20 percent of the mass of TVOCs) were not identified. This remains a significant source of uncertainty in assessing the health risks posed by these fields.

Conclusions

- The Dye et al. (2006) study provided the most complete dataset from which to calculate inhalation exposures to chemicals in the air above artificial turf playing fields.
- Lacking published data, the time that soccer players spend on artificial turf over a lifetime was estimated.
- Dye et al. (2006) quantified eight chemicals that appear on the California Proposition 65 list of chemicals known to the state to cause cancer.
- Estimated inhalation exposures of soccer players to five of these (benzene, formaldehyde, naphthalene, nitromethane and styrene) gave theoretical increased lifetime cancer risks that exceeded the insignificant risk level of 10^{-6} (OEHHA, 2006).
- Data from indoor fields were used to estimate outdoor exposures and calculate these cancer risks. In addition, it was assumed that all organized soccer play over a lifetime occurred on artificial turf fields. Together, these assumptions tend to overestimate the cancer risks for soccer players using artificial turf fields.
- Benzene and toluene were the two chemicals quantified by Dye et al. (2006) that also appear on the California Proposition 65 list of chemicals known to the state to cause developmental/reproductive toxicity. Their concentrations in the air over indoor artificial turf fields were below the associated screening levels for developmental/reproductive toxicity. This suggests there is a low risk for such health effects due to inhalation exposures in soccer players.

Data Gaps

- To calculate the inhalation health risks from outdoor artificial turf fields, an air sampling study similar to Dye et al. (2006) is needed, but it should be performed over outdoor fields, including ambient air samples from off of the fields.
- For more accurate exposure estimates, better data are needed for the hours per day, days per year, and years per lifetime that athletes spend using artificial turf playing fields. Data are needed for a variety of sports, ages and for both female

and male athletes. Use of these fields for informal play by children under the age of five should also be considered.

- Exposures to professionals such as coaches, referees and maintenance workers should also be estimated.
- Approximately 300 of 400 VOCs detected by Dye et al. (2006) were not identified, so that their health risks cannot be determined.
- Since the airborne particulates measured by Dye et al. (2006) were not analyzed for metals, including lead, the health risks they pose via inhalation cannot be determined.
- While most of the VOCs identified by Dye et al. (2006) do not have MADLs developed under Proposition 65, data exist indicating that some cause developmental/reproductive effects in test animals. Thus, additional screening is required to more fully evaluate these risks.
- Health risks due to high levels of total volatile organic compounds (TVOCs) have not been adequately assessed.
- The variable of field age should be investigated since chemical release may decrease with time, leading to lower health risks. Conversely, particulate release may increase with time.
- One possible mitigation measure that should be investigated for indoor fields is to increase the ventilation rate.

Part II: Artificial Turf as a Possible Risk Factor for Infection by Methicillin-resistant *Staphylococcus aureus* (MRSA)

Is artificial turf a risk factor for infection by MRSA?

Staphylococcus is a genus of gram positive bacteria commonly found on the surface of human skin. These bacteria can infect the skin, causing diseases such as impetigo and boils. *Staphylococcus aureus* (*S. aureus*) is a species that is particularly pathogenic to humans. Besides infecting skin, it can also cause food poisoning. If *S. aureus* from a skin infection moves internally, it can spread throughout the body, causing serious organ damage. Normally, only a small percentage of *S. aureus* skin infections progress to the point where hospitalization is required.

Methicillin is a broad spectrum antibiotic often used to treat *S. aureus* infections. However, methicillin-resistant *S. aureus* (MRSA) has developed. A number of outbreaks of MRSA have occurred in athletic teams, including high school, college, professional and club teams. Thus, it is important to identify modes of transmission of MRSA and other risk factors for infection.

MRSA outbreaks in human populations are considered to be one of two kinds. Outbreaks in hospitals often occur in persons with weakened immune systems. This is considered healthcare-associated MRSA. Outbreaks in the general community, in otherwise healthy individuals, are considered community-associated MRSA. Risk factors for community-associated MRSA include young age and playing a contact sport (Boucher and Corey, 2008). In the case of athletes, this may be due in part to the frequent physical contact that occurs during play, as well as the propensity of these athletes to have skin cuts and abrasions.

A number of community-associated outbreaks of *S. aureus* and MRSA have been described in sports settings (Table 10; Lindenmayer et al., 1998; MMWR, 2003; Huijsdens et al., 2006; Turbeville et al., 2006; Kirkland and Adams, 2008). The outbreaks included boils (furunculosis), other types of skin abscesses such as impetigo, and cellulitis. In a review of the sports medicine literature (59 infectious disease outbreaks between 1922 and 2005) by Turbeville et al. (2006), the most common causes of outbreaks were *S. aureus* (often MRSA, 22 percent of outbreaks) and herpes simplex virus (22 percent of outbreaks). The sports with the most outbreaks were football (34 percent of outbreaks), wrestling (32 percent of outbreaks), rugby (17 percent of outbreaks) and soccer (3 percent of outbreaks). These are all considered contact sports, with player-to-player contact that ranges from incidental to violent. However, these sports also result in forceful impacts between the players and the playing surface. In the cases of football, rugby and soccer, the surface would usually be an outdoor field of natural or artificial turf. For wrestling, the surface would most often be a vinyl-covered wrestling mat.

The outbreaks mentioned above suggest two possibilities for the high incidence of *S. aureus* skin infections in contact sports: the bacteria are transferred by player-to-player contact or by player contact with a contaminated playing surface. The data from health-care associated MRSA outbreaks, as well as those from sports-associated MRSA outbreaks (Turbeville et al., 2006; Benjamin et al., 2007; Boucher and Corey, 2008; Cohen, 2008; Kirkland and Adams, 2008), suggest that person-to-person contact is a major mode of MRSA transmission. Whether contact with outdoor playing surfaces, such as occurs during falls to the surface, promotes transmission of MRSA is less certain.

An association between MRSA infection and player-to-playing surface contact could have at least two different explanations. Such contacts could cause relatively long-lasting skin abrasions that serve as efficient portals of entry for MRSA, perhaps during subsequent player-to-player contacts. Alternatively, the playing surface itself might be a carrier of MRSA, such that player contact with the surface transfers MRSA to the previously uncontaminated skin.

An association between skin abrasions due to falls to the turf (termed turf burns) and skin infection by MRSA has been tested in two MRSA outbreaks among football teams. In a college football team, players with MRSA-induced boils were 7.2-fold more likely to have had skin abrasions from artificial turf (new generation) than uninfected players (Begier et al., 2004). Comparative data for burns received from natural turf were not presented. In a professional football team, eight of eight MRSA-induced skin abscesses occurred at the site of a turf burn. Whether the turf burn was received on artificial (old generation Astroturf®) or natural turf was not reported. The results of these two studies demonstrated an association between skin trauma due to falls to the playing surface and skin infections by MRSA. This suggests that traumatized skin is more susceptible to MRSA entry and infection. An association between skin trauma and MRSA infection has been suggested in other outbreaks among competitive sports teams, where skin trauma was produced by other means, including irritation by protective equipment (MMWR, 2003), body shaving (Begier et al., 2004) and falls to wrestling mats (Lindenmayer et al., 1998). Other studies also support an association between skin trauma and MRSA infection during contact sports (Bartlett et al., 1982; Sosin et al., 1989; Cohen, 2008; Kirkland and Adams, 2008). In consideration of these data, it seems justified to consider skin trauma in general, and turf burns in particular, to be risk factors for MRSA infection during competitive contact sports. Whether the incidence or severity of turf burn is greater on the new generation of artificial turf compared to natural turf is discussed below.

As mentioned above, a second possible explanation for why player-to-playing surface contact might be a risk factor for MRSA infection in competitive sports is that the playing surface itself is a source of MRSA. An inanimate object capable of transmitting infectious bacteria to humans is called a fomite. While player-to-player contact is considered the most important mode of sports-associated MRSA transmission, possible

Table 10. Sports-related skin abrasions and infections on artificial and natural turf

Reference	Sport	Turf type	Endpoint	Findings
Keene et al., 1980	American football at U. of Wisconsin	Old-generation Tartan Turf®	"Scrapes"	Significantly more ($p<0.001$) scrapes on artificial turf than on natural grass
Bartlett et al., 1982	High school American football	Not indicated	Boils (furunculosis) caused by *S. aureus*	Frequent open wounds or bruises were risk factors ($p<0.05$) for boils; concluded wounds and bruises are portals of entry for *S. aureus* into the body
Ekstrand and Nigg, 1989	Soccer played at different levels	Old-generation artificial and natural turf	"Abrasion injuries"	In three different studies, there were more abrasion injuries on artificial turf than on natural turf (severity not indicated)
Sosin et al., 1989	High school American football and basketball	Natural turf (wood floors for basketball)	Boils (furunculosis) caused by *S. aureus*	Players with >2 skin abrasions/week had 2.7-fold higher risk of infection ($p<0.01$); fomite contact not a risk factor
Begier et al., 2004	American football, one college team	New (third) generation artificial turf	MRSA-induced cellulitis and skin abscesses	Infected players were 7.2-fold more likely to have "turf burns" from artificial turf than uninfected players
Meyers and Barnhill, 2004	High school American football	New (third) generation artificial turf and natural turf	Injuries, including 0-day time loss (i.e., mild) and 1-22+ days time loss injuries	"Surface/epidermal injuries"(abrasions, lacerations and puncture wounds) were 9-fold more common on artificial turf compared to natural turf
Kazakova et al., 2005	Professional American football, one team	Old-generation Astroturf® and natural turf	MRSA-induced skin abscesses	8/8 infections occurred at site of turf burn; players reported more and more serious turf burns for games on artificial turf (2-3 per week); field swabs of artificial turf were negative for MRSA
Ekstrand et al., 2006	Elite soccer in Europe (male only)	New (third) generation artificial turf and natural turf	Time loss injuries	No difference in overall injury rate on artificial and grass; did not report skin abrasions, most of which are probably 0-day time loss
Benjamin et al., 2007	Various sports	Not indicated	MRSA infection	There is little evidence that MRSA infection occurs via fomite transmission; infection probably due to skin-to-skin contact
Fuller et al., 2007a	Collegiate soccer, male and female, matches only	New (third) generation artificial turf and natural turf	Time loss injuries occurring during matches	Overall injury incidence and severity similar on artificial and natural turf; only lacerations/skin lesions in men were higher (2.95-fold, $p<0.01$) on

Reference	Sport	Turf type	Endpoint	Findings
				artificial turf (relatively serious since they were time loss)
Fuller et al., 2007b	Collegiate soccer, male and female, training only	New (third) generation artificial turf and natural turf	Time loss injuries occurring during training	All injuries similar incidence and severity on artificial and natural turf
Steffen et al., 2007	Female soccer, under-17 league	Second and third generation artificial turf and natural turf	Acute, time loss injuries	Overall injury rate was the same on the artificial and natural turf; did not report skin abrasions, most of which are probably 0-day time loss
Andersson et al., 2008	Male elite soccer	New (third) generation artificial turf and natural turf	Number of standing and sliding tackles per player per game	Fewer sliding tackles on artificial turf compared to natural turf ($p<0.05$), possibly related to the risk of turf burn
Cohen, 2008	Various sports	Not indicated	MRSA infection	Risk factors identified: 1)skin-to-skin contact, 2)skin damage (such as mat burns in high school wrestling), 3)sharing equipment (e.g., towels)
McNitt et al., 2008	Not discussed	New (third) generation artificial turf and natural turf in Pennsylvania	Bacterial colony forming units (CFUs) cultured from turf samples	Rubber crumb from artificial turf yielded fewer CFUs on a per gram basis than soil from natural turf; no colonies were positive for *Staphylococcus aureus*
FIFA, undated	Male soccer, under-17 world championship games	New (third) generation artificial turf and natural turf	Time loss and total injuries during games	Overall injury incidence similar on the two surfaces

instances of fomite transmission have been reported. A MRSA outbreak in fencers is noteworthy, since this sport does not involve person-to-person contact (MMWR, 2003). The fencers used sensor wires under their protective clothing, which were shared by multiple fencers without cleaning. The wires were possible fomites for MRSA transmission in this outbreak. Shared soap bars were identified as a risk factor in a MRSA outbreak in a collegiate football team (odds ratio, 15.0; 95 percent confidence interval 1.69-180) (Turbeville et al., 2006). A shared weight room was the only common point of contact between a high school football team and the dance team (Kirkland and Adams, 2008). While only two football players and one dance team member became infected with MRSA, this may represent an example of fomite transmission. In a MRSA outbreak among members of a high school wrestling team, no risk factors for infection could be identified (Lindenmayer et al., 1998). Nonetheless, the study authors speculated that although most cases of transmission were probably due to wrestler-to-wrestler contact, the sharing of towels and locker room equipment, as well as shared wrestling mats, may have contributed. In emphasizing that fomite transmission of MRSA should be prevented, the National Collegiate Athletic Association (NCAA) medical guidelines recommend disinfecting wrestling mats before use.

One way to determine whether artificial turf is a reservoir for infectious MRSA is to inoculate bacterial cultures with various turf components or wipe test the components to measure bacterial growth. Very few such data have been collected from potential fomites associated with outbreaks of sports-associated MRSA, including artificial and natural turf. Following an outbreak of MRSA in a high school wrestling team, environmental sampling of the wrestling facilities failed to detect any MRSA (Lindenmayer et al., 1998). During a MRSA outbreak in a professional football team, environmental sampling included the stadium's artificial turf field, weight-training equipment, towels, saunas, steam rooms and whirlpool water (Kazakova et al., 2005). For the field sampling, one-foot square areas of Astroturf® located in the parts of the field with the highest numbers of tackles were wipe-sampled. No MRSA was detected; however, methicillin-sensitive *S. aureus* (MSSA) was detected in two samples of whirlpool water and on a gel-applicator stick used for taping ankles. The most recent test of whether artificial turf harbors MRSA is a study in which twenty new generation artificial turf fields were sampled at two locations per field (McNitt et al., 2008). The artificial blades of grass and infill material (crumb rubber or crumb rubber/sand mix) were sampled separately for bacterial culture. All field samples were negative for *S. aureus*. Quantitative data were only presented for the infill samples. Those samples contained unidentified bacteria at levels ranging from 0 to 80,000 colony forming units (CFUs) per gram of infill. In comparison, two samples of natural soil yielded 260,000 and 310,000 CFUs per gram of soil. *S. aureus* was detected on a number of surfaces including football blocking pads, weight equipment, a stretching table and used towels, demonstrating that the detection method for *S. aureus* was functional. Thus, considering the three studies described above, there is no evidence that artificial turf fields harbor *S. aureus* in general, or MRSA in particular. While these conclusions are based on a small number of samples, an absence of *S. aureus* from artificial turf playing fields is not unexpected, given the dry and often hot conditions of that environment.

As discussed above, skin trauma is a likely risk factor for MRSA infection in contact sports (Begier et al., 2004; Kazakova et al., 2005). Therefore, it would be informative to determine if falls to the new generation of artificial turf put players at greater risk for turf burns than falls to natural turf. It is also important to determine if the turf burns caused by artificial turf are more long-lasting or more prone to infection by *S. aureus* compared to burns received from natural turf.

Unfortunately, most injury studies comparing artificial and natural turf have concentrated on so-called "time-loss" injuries (Table 10). These are relatively serious injuries that cause at least some loss of practice or game time. The great majority of turf burns are not time-loss injuries, and would not have been monitored in those studies. However, some data on skin abrasions are available. In a study of college football played on the old generation of Tartan Turf®, players were described as acquiring significantly ($p<0.01$) more "scrapes" on artificial turf compared to natural grass (Keene et al., 1980). This was the only injury type that was significantly increased on artificial turf compared to natural turf. In a 5-year prospective study of injuries occurring on the new generation of artificial turf, both time-loss and 0-day time-loss (i.e., no playing time lost) injuries were recorded for eight high school football teams (Meyers and Barnhill, 2004). The latter category included "surface/epidermal injuries" that covered abrasions, lacerations and puncture wounds, but not contusions (i.e., bruises). This type of surface/epidermal injury had a 9-fold higher incidence on artificial turf (injury incidence rate = 0.9; 95% confidence interval = 0.5-1.4) compared to natural turf (injury incidence rate = 0.1; 95% confidence interval = 0.0-0.6). Players for a professional football team suffering a MRSA outbreak reported that skin abrasions happened more frequently and were more severe on first-generation Astroturf® (i.e., without infill) compared to natural turf, although no supporting data were presented (Kazakova et al., 2005). In a study of collegiate male and female soccer players that recorded time-loss injuries during official matches, only the incidence of "lacerations/skin lesions" in males was significantly higher (2.95-fold, $p<0.01$) on new generation artificial turf (i.e., with infill) compared to natural turf (Fuller et al., 2007a). However, this finding was not replicated in an identical study that covered injuries sustained during training (Fuller et al., 2007b). Lastly, male soccer players at the 2005 Federation Internationale de Football Association U-17 Championship in Peru played 86 matches on natural grass and 42 on new generation artificial turf (FIFA, undated). While skin abrasion incidences were not presented, the incidences of total injuries (0-day time-loss and time-loss) per player-hour were similar on the two surfaces.

Considering the small database presented above, two studies (one soccer and one football) found increased incidences of skin abrasions on the new generation of artificial turf compared to natural turf (Meyers and Barnhill, 2004; Fuller et al., 2007a), while two studies (both soccer) measured similar rates on both surfaces (Fuller et al., 2007b; FIFA, undated). No data were located on the relative severity of skin abrasions caused by the artificial and natural surfaces. Given that both studies by Fuller et al. (2007a and 2007b) only monitored time-loss injuries, these studies almost certainly missed the majority of skin abrasions, which do not cause loss of playing time. Furthermore, the FIFA (undated) study did not provide data on the incidence of skin abrasions, only on total injury incidence. This leaves only the football study by Meyers and Barnhill (2004) as evidence that new generation artificial turf puts football players at increased risk for skin abrasions relative to natural turf. Whether this conclusion is specific for male football players competing at the high school level is unknown, until studies can be performed for other sports and age groups.

Conclusions

- Participation in contact sports is a risk factor for infection by MRSA. Football and wrestling have recorded the most outbreaks.
- Person-to-person transmission of MRSA is the major mode of infection. Transmission by inanimate objects (termed fomites), such as the playing surface, is less well established.
- Skin abrasions and other types of skin trauma are risk factors for MRSA infection in contact sports.
- Whether the new generation of artificial turf causes more skin abrasions than natural turf has only been carefully addressed in a single study (Meyers and Barnhill, 2004) of male high school football players. In that study, artificial turf was associated with a 9-fold higher incidence of “surface/epidermal injury” compared to natural turf.
- Only one study has tested whether new generation artificial turf fields harbor MRSA (McNitt et al., 2008); none was detected in 20 fields in Pennsylvania.

Data Gaps

- Additional studies are needed to test the finding of Meyers and Barnhill (2004) that new generation artificial turf is associated with more skin injuries than natural turf. Studies should cover additional sports, age groups, and female participants.
- No study has reported on the severity of turf burn by the new generation of artificial turf compared to natural turf. Severity could include susceptibility to infection as well as the time required to heal.
- Additional new generation artificial turf fields should be sampled for MRSA and other bacteria pathogenic to humans, at different depths in the fields, and from different climatic regions in California.

Part III: Summary

Five studies were located that measured chemicals and particulates in the air above the new generation of artificial turf containing crumb rubber infill from recycled tires. The chemicals and particulates in the air over artificial turf were similar to those emitted by tire-derived rubber flooring, during rubber manufacturing, and in laboratory studies of rubber crumb heated in vessels. The most complete dataset, covering indoor artificial soccer fields in Norway (Dye et al., 2006), was used to estimate the risk of cancer or developmental toxicity. This screen only addressed the inhalation route of exposure in athletes using artificial turf fields for a lifetime of organized soccer play. Exposure estimates were used to calculate the increased lifetime cancer risk or risk of developmental toxicity for those chemicals appearing on the California Proposition 65 list. From among eight chemicals listed as carcinogens on the Proposition 65 list, exposure to five of these (benzene, formaldehyde, naphthalene, nitromethane and styrene) during a lifetime of organized soccer play exceeded the 10^{-6} negligible risk level. Since these risks exceeded the 10^{-6} benchmark, it is important for future studies to measure the concentrations of these chemicals above outdoor artificial turf fields. In addition, their concentrations should be measured in the ambient air in the vicinities of the fields. Comparing the concentrations in the air over and off of the fields will establish which carcinogenic chemicals are emitted by artificial turf, and whether mitigation measures are required.

Dye et al. (2006) also identified two chemicals appearing on the California Proposition 65 list as developmental/reproductive toxicants: toluene and benzene. Their concentrations in the air over indoor artificial turf fields were below the associated screening levels for developmental/reproductive toxicity, suggesting a low risk for such effects due to these two chemicals. This screen contains two steps that tend to overestimate the risks for both cancer and developmental toxicity. First, the screen utilizes data from indoor artificial turf fields to estimate exposures from outdoor fields. Second, the screen assumes that all organized soccer play from the ages of 5 to 55 occurs on artificial turf fields.

The scientific literature was also searched for studies addressing the possibility that artificial turf playing fields promote infection of athletes by methicillin-resistant *Staphylococcus aureus* (MRSA). While the data suggest that skin trauma is a risk factor for MRSA outbreaks in contact sports, it is less certain whether the new generation of artificial turf causes more skin trauma than natural turf. Whether artificial turf fields harbor MRSA has been tested in only a few studies. No MRSA has been detected in any indoor or outdoor natural or artificial turf field.

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Addendum, July 2009

Review of two studies released in the spring of 2009 that measured chemicals and particulates in the air above the new generation of artificial turf playing fields

Study quality and characteristics

The study of artificial turf fields containing recycled crumb rubber infill performed by New York State (2009) is the most comprehensive to date. To measure the chemicals released into the air by these fields, air sampling was performed over two fields, along with a sample taken upwind of each field to measure the ambient background. One field was four years old and one was less than one year old. Samples were analyzed for VOCs and sVOCs. Off-gassing experiments performed in the laboratory with recycled rubber crumb identified five chemicals which were added to the target list of chemicals: aniline, 1,2,3-trimethylbenzene, 1-methylnaphthalene, benzothiazole and tertbutylamine. Acceptable weather conditions for sampling were prescribed and followed (see Table 11). Particulate matter (and $_{.5}$) in air was measured in real-time with monitors placed over or upwind of each field. In addition, particulate matter was collected by wipe and vacuum sampling of field surfaces and analyzed by microscopy.

A total of 65 chemicals were identified in the air over the four-year-old field and 85 over the one-year-old field (twenty highest concentrations shown in Table 11). For many chemicals the upwind air sample contained similar concentrations. Since eight samples were collected over each field compared to only a single upwind sample, it is likely that had more upwind samples been collected, more chemicals would have been detected in the upwind air. Most of the chemicals were tentatively identified compounds (TICs), i.e., identified by their gas chromatography/mass spectrometry (GC/MS) peaks. TICs with match qualities of less than 85 percent of the GC/MS peaks were considered "unknowns" and not included in the health evaluation (see below). Of the 19 TICs shown in Table 11, 17 fell into this category. Therefore, from among the chemicals occurring at the twenty highest concentrations, only benzothiazole, octane and nonane were evaluated for health effects. The "unknowns" in Table 11 are indicated by asterisks.

Comparing the two fields shows good agreement for VOCs and sVOCs on the target list. Air samples from over the four-year-old field contained 17 chemicals on the target list. Air samples from above the one-year-old field contained the same 17 plus an additional three. For TICs the agreement was not as close. From among the 20 largest TIC peaks corresponding to air samples from either field (Table 11), only five were reported for both fields.

Chemicals of potential concern for adverse health effects were chosen for health evaluation based on three criteria: 1) low levels in laboratory and field blanks, 2) a concentration that was at least 35 percent higher in at least one field sample compared to the upwind sample, 3) match quality of the GC/MS peaks of at least 85 percent for TICs. These criteria yielded 15 and 16 chemicals of potential concern for calculation of inhalation health risks for the four-year-old and one-year-old fields, respectively.

Table 11. Air measurements above artificial turf fields: New York State (2009) and TRC (2009)

Reference	Scenario	Chemicals/particulates measured
New York State Department of Environmental Conservation and Department of Health, May 2009	Two outdoor playing fields made of new generation artificial turf containing recycled crumb rubber infill. One field was less than one year old, the second was four years old. No precipitation the day before sampling and during sampling, sampling on two consecutive days of light to moderate winds out of a constant direction, 77 to , sampling at multiple heights above the field (a few inches, three feet, six feet), a total of eight samples collected from each field. One sample collected upwind of each field (six foot height) to measure ambient background.	VOCs and sVOCs: 65 detected over one field, 85 detected over the second field. PAHs detected (in µg/): 2-dibenzofuranamine* (12), 3-dibenzofuranamine* (11), 4-dibenzofuranamine* (9), benzo[b]thiophene, 6-methyl-* (8.7). Phthalates: none detected. .5 and : both classes of particulates detected by real-time monitoring at approximately 15 µg/, similar concentrations over field and upwind of field; microscopy of wipe and vacuum field samples detected rubber particles in the millimeter range but not in the micron range. Twenty highest VOCs and sVOCs were (in µg/): cyclohexanol* (27), 5-hexen-2-ol, (.+/-.)-* (24), cyclopropane, 1-chloro-2-ethenyl-1-methyl* (23), 2-hexen-1-ol, (z)-* (22), pentanamide, 4-methyl-* (15), 1H-benzotriazole-5-amine, 1-methyl-* (13), benzenemethanol, arethenyl-* (13), nonanamide* (13), 2-dibenzofuranamine* (12), 3H-indazol-3-one, 1,2-dihydro-2-methyl-* (12), 3-dibenzofuranamine* (11), 4-dibenzofuranamine* (11), cyclopentanone-2* (10), benzene, 1-methoxy-4-(1-propenyl)-* (9.9), methanimidamide, N,N-dimethyl-N'-phenyl-* (9.6), benzo[b]thiophene, 6-methyl-* (8.7), benzothiazole (6.5), octane (6.2), nonane (3.2), 2-butene, (z)* (2.7).

*indicates tentatively identified compound (TIC) with a GC/MS peak match quality of less than 85 percent.

Table 11. (continued)

Reference	Scenario	Chemicals/particulates measured
TRC, 2009	Two outdoor playing fields made of new generation artificial turf containing recycled crumb rubber infill;	VOCs, sVOCs and metals: 8 VOCs and 1 metal were detected at the following highest concentrations (in µg/): acetone (51), ethanol (22), methylene chloride (9), 2-butanone (MEK) (3), chloroform (2.9), toluene (2.7), n-hexane (2.1), chromium (1.4), chloromethane (1.1); seven tentatively identified compounds (TICs) included

Reference	Scenario	Chemicals/particulates measured
	one grass field for comparison. One artificial turf field was less than three years old, the other was less than one year old. Air sampling was during the summer with temperatures from 79 to , sampling performed at three feet above the surface, 4-6 air samples collected from above each field. Two air samples collected from upwind of each field to measure ambient background.	isobutane, pentane, 2-methyl-1,3-butadiene (a.k.a., isoprene), 2-methylbutane. PAHs: none detected. Phthalates: none detected. .5 and : both classes of particulates detected by real-time monitoring at 3 to 50 µg/, similar concentrations over fields and upwind of fields.

Chemical concentrations in the air above the fields were compared to health-based screening levels, assuming continuous, lifetime exposures for athletes using the fields. These assumptions overestimate the risks, since athletes do not spend their entire lives on these fields. Non-cancer health effects were evaluated by calculating hazard quotients using the highest on-field concentrations. Most hazard quotients were very low, indicating a very low risk of non-cancer health effects. The highest ranged from 0.1 to 0.6 for the compounds 1,3-pentadiene, 1,4-pentadiene, (E)-1,3-pentadiene and 2-methyl-1,3-butadiene. Hazard quotients of less than one suggest that non-cancer health effects are unlikely.

Eight potential chemicals of concern were evaluated for their cancer risks based on their highest on-field air concentrations. The highest excess lifetime cancer risk was 4×10^{-5} for 1,3-pentadiene (using the cancer potency of 1,3-butadiene as a surrogate). However, the concentration of 1,3-pentadiene in the air upwind of the field corresponded to a 2×10^{-5} cancer risk. Thus, it was judged that the cancer risks posed by this chemical due to its occurrence in field air and ambient air were similar. Other potential carcinogens were either below the air concentration associated with the 10^{-6} cancer risk level or occurred in only one of eight field samples (as TICs). The report concluded that these chemical exposures did not constitute a serious public health problem, and posed small risks of either cancer or non-cancer health effects.

For the particulate matter size classes of $_{.5}$ and , real-time monitoring of one field showed no meaningful differences between the air concentrations over the field compared to upwind of the field. Technical problems were encountered in real-time monitoring of the second field. These data suggest these fields are not a source of $_{.5}$ or . Samples collected by wipe sampling and vacuuming both fields were analyzed by microscopy. Rubber particles were in the millimeter range. Particles small enough to be inhaled, in the 5-7 micrometer range, were crustal minerals such as quartz and calcite. Rubber particles were not in the respirable range. Both the wipe data and the air monitoring data indicate that recycled crumb rubber infill in new generation artificial turf fields is not a significant source of $_{.5}$ or .

TRC is an engineering and consulting firm which performed a study of artificial turf fields for the New York City Department of Health and Mental Hygiene (TRC, 2009). The study included air sampling from above and upwind of the same two artificial turf fields that were sampled for the New York State (2009) study. A single grass field was also sampled for comparison. Eight VOCs and one metal were detected in the air over the artificial turf fields. Three of the VOCs (2-butanone, chloroform, and n-hexane) were not detected in any of the upwind samples or over the grass field. In addition, seven TICs were detected, with four being specific to the artificial turf (isobutane, pentane, 2-methyl-1,3-butadiene, 2-methylbutane).

Monitoring of the air over and upwind of the artificial turf fields for $_{.5}$ yielded the same concentration range. $_{.5}$ concentrations ranged between 3 and 50 μg/ for both.

Comparing the target list chemicals detected over the artificial turf fields to those detected in the upwind samples or over the grass field, three were specific to the on-field samples: 2-butanone, n-hexane and chloroform. The concentrations of the first two chemicals were well below the corresponding New York State short-term and annual air guideline levels. Therefore, the chemicals were not considered for risk assessment. While the chloroform concentration was above the annual guideline level, the chemical was not considered for risk assessment because its presence over the single artificial turf field was thought to have resulted from drift from a nearby swimming pool commonly treated with chlorine. From among the four TICs that were specific to the artificial turf fields, three were well below their corresponding guideline values. The fourth, isoprene, does not have a guideline value. However, since it was detected in only one air sample as a TIC, and it was not detected when a bulk sample of crumb rubber was analyzed in the laboratory, it was not considered for risk assessment. Thus, a formal risk assessment was not performed for any chemical detected by air sampling. The report concluded that health effects were unlikely to result from the types of inhalation exposures expected to occur at these artificial turf fields.

Comparing studies

Table 12. Comparison of the chemical concentrations measured in air above artificial turf fields in the studies by Dye et al. (2006) and New York State (2009)

Chemical	**Concentration in Dye et al. (2006) (µg/)[1]**	**Concentration in NY State report (2009) (µg/)[1]**	**[Dye]/[NY State]**
Toluene	85	1.6	53
Benzothiazole	31.7	6.5	5
p- and m-Xylene	25.5	0.8	32
Acetone	15.3	0.6	26
o-Xylene	13.1	0.3	44
4-Methyl-2-pentanone	12.7	1.2	11
Ethylbenzene	6.7	0.3	22

value reported

Table 12 compares the concentrations of seven VOCs detected in air samples from above indoor and outdoor artificial turf fields. From among the 20 chemicals detected at the highest levels by Dye et al. (2006) (see Table 1), these seven were also detected by New York State (2009) (see Table 11). The concentrations can be compared to determine if the indoor study measured consistently higher concentrations compared to the outdoor study. The last column in Table 12 shows that the concentrations of these seven VOCs were from 5- to 53-fold higher in the air over indoor fields compared to outdoor fields. Therefore, as discussed in this report, using the indoor values from Dye et al. (2006) to calculate health risks overestimates the risks athletes face from inhaling the air above outdoor artificial turf fields containing crumb rubber infill.

Similar to the chemical concentrations discussed above, the concentrations of particulate matter (.5 and) were somewhat higher for the indoor study by Dye et al. (2006). The indoor study detected .5 and concentrations as high as 18.8 and 40.1 µg/, respectively. Ambient, background levels of particulates were not measured. Therefore, it was not possible to determine whether the particulates were released by the turf or were already present in the ambient, outdoor air. The outdoor studies by New York State (2009) and TRC (2009) did not detect these particulates above ambient, background levels (about 15 and 3-50 µg/, respectively). The indoor study used a chemical marker for tire rubber (N-cyclohexyl-2-benzothiazolamine) to quantify the rubber in the particulate matter. Rubber comprised from 23 to 50 percent of the .5 or . Using microscopy, the New York State (2009) study ruled out rubber as the source of the microscopic particles in the 5-7 micrometer range. Considering all three studies together, it appears that .5 and were at background levels in the air over outdoor artificial turf fields, but may have been present at above-background concentrations in the air above indoor fields.

Table 13 below shows a comparison of the chemicals detected in the air above the same two artificial turf fields that comprised the studies by New York State (2009) and TRC (2009). These are the eight chemicals that were specific to the air above artificial turf in the TRC (2009) study. Sampling for both of these studies was performed at the end of August and beginning of September 2008. The chemical concentrations were consistently higher in the New York State (2009) study, ranging from 1.7-fold to 85-fold higher. The reasons for these differences are unknown. These variable results highlight the difficulties faced in obtaining consistent results from potential point sources of outdoor air pollution. Despite this variability, both studies found that the chemical concentrations they measured were unlikely to produce adverse health effects in persons using these fields.

Table 13. Comparison of the chemical concentrations measured in air above the same two artificial turf fields in the studies by New York State (2009) and TRC (2009)

Chemical	**Concentration in NY State report (2009) (μg/)[1]**	**Concentration in TRC report (2009) (μg/)[1]**	**[TRC]/[NY State]**
2-Butanone (MEK)	-	3.0	-
Acetone	0.6	51.0	85
Chloroform	0.2	2.9	15
Chloromethane	0.1	1.1	11
Ethanol	-	22.0	-
n-Hexane	0.4	2.1	5
Methylene chloride	3.0	9.0	3
Toluene	1.6	2.7	1.7
Isobutane*	-	2.4	-
Pentane*	0.5	11.8	24
Isoprene (a.k.a., 2-methyl-1,3-butadiene)*	0.9	2.8	3
2-Methylbutane*	0.7	3.0	4

value reported, - not reported, * TIC

Conclusions

- The New York State (2009) report describes the most comprehensive study performed to date on the new generation of artificial turf containing recycled crumb rubber infill. Air sampling above two fields measured VOCs, sVOCs, and .5.
- A total of 65 chemicals were identified in the air above a four-year-old field and 85 over a one-year-old field. Many of these were detected at similar concentrations in the air samples taken upwind of the fields.

- Most of the chemicals detected were tentatively identified compounds (TICs), as identified by their GC/MS peaks, with match qualities of less than 85 percent of the peaks. Therefore, these were considered "unknown" chemicals and not evaluated for health effects.
- $_{.5}$ and levels were the same over one field and upwind of the field, suggesting the fields are not sources of PM release.
- Chemicals of potential concern were selected and evaluated for cancer and non-cancer health effects based on their measured air concentrations and assuming continuous, lifetime inhalation by athletes using the fields. These latter two assumptions tend to overestimate the health risks.
- Hazard quotients were all less than one, indicating a low risk of non-cancer health effects. Excess, lifetime cancer risks were either below the 10^{-6} risk level, were similar for the upwind and on-field samples, or the chemical was only detected in one of eight on-field samples. Therefore, the report concluded that these fields do not constitute a serious public health problem since the risks of health effects are low.
- The study by TRC (2009), monitoring the same two artificial turf fields as the New York State (2009) study, also concluded that health effects were unlikely to result from the types of chemical inhalation exposures expected to occur to athletes using these fields.
- The concentrations of chemicals in the air over indoor fields (Dye et al., 2006) were from 5- to 53-fold higher than their concentrations over outdoor fields (New York State, 2009). This demonstrates that using data from indoor fields to calculate the health risks from outdoor fields overestimates those risks.

Data Gaps (some of which are being addressed in the current OEHHA study of artificial turf)

- Only two artificial turf fields were evaluated in the New York State (2009) study. The same two fields comprised the TRC (2009) study. Testing additional fields for the release of chemicals and particulate matter is warranted.
- Testing fields of different ages and at different temperatures would help determine how those variables affect chemical and particulate release. In particular, fields near the end of their useful lifetime should be evaluated.
- More air samples from upwind of the fields should be collected on the same days as field samples to determine if chemicals measured over the fields are also present at similar concentrations in the ambient air.
- The air above fields was not tested for airborne metals. The previously reported finding of lead in dust sampled from some artificial turf fields indicates a potential for lead and other metals to become suspended in the air and possibly inhaled. Testing field air samples for metals is warranted.
- To estimate inhalation exposures it was assumed that athletes used the artificial turf fields continuously over their entire lifetimes. This overestimates the health risks. Data covering the time athletes spend on these fields would allow more accurate exposure and risk calculations and result in reduced risk estimates.
- In the study by New York State (2009), the relatively large number of TICs with peak match qualities below 85 percent indicates that these fields release many unidentified VOCs and sVOCs ("unknowns"). Some of these were at μg/ levels (Table 11). It is likely that the health risks posed by these chemicals, if any, will not be known for the

foreseeable future. The presence of a relatively large number of unidentified organic chemicals in the air over these fields is a potential health risk that cannot be evaluated at present.

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