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Human health risk assessments addressing artificial turf and crumb rubber

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Background

Public concern regarding the potential toxicological effects of exposure to artificial turf pitches has led to the publication of numerous human health risk assessments (HHRAs) on styrene-butadiene crumb rubber, the most common infill material used in these installations. An HHRA is a systematic, evidence-based process through which the potential for future adverse health effects can be estimated (as a probability) or characterized (identified or eliminated as a health concern). Unlike individual studies that look at the toxic components of crumb rubber, or how much of that toxic component is released, HHRAs follow a multi-step process in which the hazard (amount of toxicant released) is examined in relation to how or whether humans are exposed and whether adverse effects are in fact probable or possible at that exposure level. This process is necessary to distinguish between ***hazard*** (the presence of something harmful) and ***risk*** (the likelihood of being affected).

However, the quality of an individual HHRA is highly reliant on the knowledge and rigor applied to the process. The term "risk assessment" is used somewhat loosely in the grey and scientific literature, and so it is important to distinguish between those studies presenting preliminary or informal risk assessments *versus* those providing a much more rigorous analysis using standard methods and practices. In addition, because all HHRAs rely on a certain degree of expert judgement to account for unavoidable data gaps, it is critical for authors to fully describe the sources and limitations of the data used, and the methods or assumptions used to carry out the analysis. Finally, it is important to build relevant comparisons into the assessment, such that the knowledge user is able to understand how the results relate to other common exposures or activities.

To assist knowledge users in finding the most reputable sources of artificial turf information, we have compiled a table of the most recent HHRAs make meaningful contributions to the ongoing discussion on artificial turf. The HHRAs presented here meet the following criteria: 1) address the hazards and risks of third-generation artificial turf using styrene-butadiene crumb rubber infill or relevant comparisons; 2) are from peer-reviewed scholarly journals or public health or regulatory agencies with internal or external reviewers; 3) provide ample justification for the methods, data sources, and assumptions used; and 4) are in the English language. The studies were identified through a combination of periodic systematic literature search and other methods. To suggest additions or updates to this matrix, please contact Angela.Eykelbosh@bccdc.ca.

For reference, cancer risk is deemed negligible ("*de minimis*") when the excess lifetime cancer risk is at or below 1×10^{-6} (1 additional case of cancer per 1,000,000 exposed persons). Risk reduction is generally recommended when estimates exceed the maximum acceptable risk of 1×10^{-4} (1 additional case per 10,000 exposed persons). For non-cancer hazards, the level of concern is assumed to be negligible when the ratio of the estimated exposure dose to the reference dose is < 1 for a single chemical (a hazard quotient) or when these ratios are summed together for multiple chemicals affecting the same target organ or organ system (a hazard index). A hazard quotient or index > 1 indicates that adverse effects are possible, but is not a measure of the probability of adverse effects.

Table 1. Matrix of human health risk assessments addressing artificial turf and crumb rubber. Studies are presented in reverse chronological order. Abbreviations: 2-MBT, 2-mercaptobenzothiazole; HI, hazard index; PAH, polycyclic aromatic hydrocarbon; PCB, polychlorinated biphenyl; PCDD, polychlorinated dibenzodioxins; PCDF, polychlorinated dibenzofurans; PM_{10}, particulate matter less than 10 microns in size; SVOC, semi-volatile organic compound; VOC, volatile organic compound.

Authors	Material Studied	Contaminants	Users	Exposure Pathways	Supporting Data	Findings
Peterson et al. 2018	Crumb rubber and natural turf fields with soils impacted by urban pollution.	33 PAHs, heavy metals, VOCs, SVOCs, phthalates, and PCBs.	Youth outdoor player (6-18 years), youth indoor players (6-18 years), youth composite player (6-18 years), and adult child spectators.	Oral, dermal, and inhalation.	Supported values from the literature with data solicited from rubber recyclers and synthetic pitch installers.	The highest cancer risk (child spectator, 9 x 10-7) was well below *de minimis* levels. The highest hazard index (child spectator, HI = 1) indicated potential for adverse effects (primarily due to cobalt ingestion), but assumed that the child would consume 0.1 g of rubber per day, 4 days per week for 8 months of the year. For natural turf fields, with soils impacted by urban pollution (based on 95^{th} percentile value for contaminants commonly found in urban soils), the highest cancer risk (6×10^{-6}) and hazard index (0.7) were again for the child spectator.
ECHA 2017	Crumb rubber	PAHs, phthalates; formaldehyde, benzothiazole, benzothiazole-2-thiol, methyl isobutyl ketone; benzene; heavy metals.	Child players (3-6, 6-11 years), child goalkeepers (6-11 years), youth players (11-18 years), adult players and goalkeepers, and	Oral, dermal, and inhalation (dust and VOCs).	From the literature.	Neither the hazard estimates for non-cancer risks nor the excess lifetime cancer risk for PAHs approached thresholds of concern.

Authors	Material Studied	Contaminants	Users	Exposure Pathways	Supporting Data	Findings
			workers.			
RIVM 2017	Crumb rubber	PAHs, BPA, cadmium, cobalt, lead, phthalates, and 2-MBT.	Small child players (4-11 years), youth goalkeepers (7 years old), youth players (11-18 years), adult players (18-35 years), and lifelong exposed field players and goalkeepers)	Oral, dermal and inhalation	Obtained crumb rubber samples from 100 synthetic turf pitches in the Netherlands (6 samples from each pitches). These samples were chemically characterized and compared to values from the literature.	Most exposed adult player was a lifelong goalkeeper who played from age 4 to 50, and consistently swallowed 0.2 g of crumb rubber per session as a child (a pile the size of a quarter) and 0.05 g per session as an adult (3×10^{-6} for PAH exposure). The most exposed child was a 7-year-old goalkeeper who consumed 0.2 g of crumb rubber per session (HI = 0.26 for BPA exposure).
Pavilonis et al. 2014	New fibers, new rubber crumb, and rubber crumb from 7 existing fields	PAHs, VOCs, SVOCs, heavy metals	Young children (6-10 years), older children (11-15 years), teenagers (16-18 years), adults (≥ 19 years).	Dermal, ingestion, and inhalation	Bioassays, laboratory off-gassing studies	Results did not identify cancer or non-cancer risk from metals or SVOCs, although it was noted that lead levels varied widely and lead was found to be bioaccessible in simulated human fluid studies.
Ruffino et al. 2013	Four crumb rubber pitches, 1 thermoplastic elastomer pitch, 1	Benzene, toluene, xylene, PAHs, and heavy metals.	Child and adult players	Dermal contact with crumb rubber or "rainwater" leachate,	Collected 12 infill samples from each of 6 pitches in the city of Turin, Italy. Soil dust and gases also sampled.	No risk estimate for any of the individual exposure pathways exceeded thresholds on any synthetic or natural field for children or adults. However, for both children and adults, the cancer risk and non-

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	natural turf, and traffic-related air pollution.			and inhalation of dust and gases.		cancer hazard estimates for inhaling Turin's typical traffic-related air pollution were greater than for inhalation of dust and gases emitted from the natural or synthetic turf pitches. Synthetic pitches generated similar or better risk estimates than did the single natural turf.
Kim et al. 2012	Rubber chips from play-grounds	Metals, toluene, ethylbenzene, and phthalates.	Elementary, middle school, and high school children, as well as adults and children with pica.	Inhalation, ingestion, dermal	Measured chips in 50 school	Cancer and non-cancer risk at or below *de minimis* for all users, except children with pica who showed low-level cancer (1×10^{-4}) and non-cancer risk.
Ginsberg et al. 2011	Air sampled from 4 indoor and 1 outdoor artificial turfs.	VOCs, SVOCs, nitrosamines, PM_{10}, lead	Child (12 years old) and adult players (30 years old)	Inhalation	Stationary on-field and off-field monitoring, personal monitoring, and laboratory off-gassing studies.	Although a number of substances were found to be higher on artificial turf fields (especially indoors) compared to off-field locations, the cancer risk and non-cancer hazard derived from those concentrations were at or below *de minimis* levels for both children and adults. Comprehensive air quality analysis was necessary to differentiate emissions from artificial turf vs. urban contaminants or emissions from the players themselves.

Authors	Material Studied	Contaminants	Users	Exposure Pathways	Supporting Data	Findings
Menichini et al. 2011	Rubber granules from 13 outdoor fields.	PAHs, PCBs, PCDDs and PCDFs	Children	Inhalation	Stationary on-field and off-field samplers, and personal samplers worn at waist height to simulate exposure to children.	Estimated cancer risk for benzo[a]pyrene exposure at *de minimis* level (1×10^{-6}).
Vidair 2010	Crumb rubber from outdoor fields	$PM_{2.5}$, bound metals, and VOCs on in-use and (separately) hot outdoor fields, compared to natural turf.	Children (5-15 years), young adults (16-18 years) and adults (19-55 years)	Inhalation and skin infection	Air emissions during hot weather; bacteria present and abrasion rates on artificial turf compared to grass and sand fields.	No public health risk due to $PM_{2.5}$, lead in dust, or VOCs, although higher skin abrasion rates could increase the risk of skin infection. However, fewer bacteria were found on artificial turf compared to natural turf.
Lim and Walker, 2009	Rubber crumb from 2 outdoor fields, on hot summer days	SVOCs, VOCs, and PM	Children	Inhalation	Upwind, on-field, downwind, and laboratory off-gassing studies to identify turf-derived components. Simulated play during PM measurements.	Under hot weather conditions, SVOC, VOC, and PM emissions unlikely to pose a public health risk compared to contaminant exposures off-field. However, temperatures on the field were markedly higher compared to grass and sand surfaces.
Nilsson et al. 2008	Desk study	Benzothiazole; dicyclohexylamine, cyclohexanamine,	Young adults (16-19 years).	Dermal and oral only	Chemical and leaching studies to select substances of	No effects for the four chemicals studied, although maybe risk of

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		dibutyl phthalate.			concern.	allergic sensitization.
Vidair et al. 2007	Playground surfaces	Metals, VOCs, SVOCs,	Children (1-12 years)	Oral and dermal exposure	Wipe sample of playground surfaces and gastric digestion assays.	Found *de minimis* levels of risk for one-time ingestion of 10 g of tire shreds by a three-year-old, based on values from the literature and a gastric digestion bioassay; found slightly above *de minimis* cancer risk for chronic ingestion of chrysene; no skin sensitization in guinea pigs.
NIPH 2006	Two indoor artificial turf facilities	VOCs, dust, phthalates, and alkyl phenols.	Children (7-11 years), older children (12-15 years), juniors (16-19 years), adults (20-40 years).	Oral, dermal, and inhalation for children only; dermal and inhalation for all other groups.	Composition analyses, leaching, laboratory off-gassing studies, and dust wipe sampling.	Neither inhalation, nor dermal, nor oral exposure to the contaminants listed were considered to pose a public health risk, although authors note the unknown risk of developing asthma or allergy to compounds present in dust in indoor facilities.

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