Appendix A

OEHHA Synthetic Turf Study

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Public Review Draft

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Appendix A. Information for Study Design and Highlight of Recent Studies

A.1. Literature Review on Crumb Rubber, Tire, and Synthetic Turf Fields

In 2015, OEHHA searched the literature for studies on chemical composition of automotive tires and crumb rubber. We identified studies and reports published by U.S. and international researchers. Table A-1 summarizes these studies and reports. Based on these reports, we designed our Synthetic Turf Study (the Study) to address the gaps in our knowledge on understanding the potential exposures on the synthetic turf fields, release of chemicals from crumb rubber, and the composition of artificial biofluids used to extract crumb rubber. The Study carried out non-targeted chemical analyses using advanced instruments and cheminformatic algorithms, collected chemical vapors on active fields, applied dynamic extraction systems to enhance the accessibility measurements of chemicals using artificial biofluid to mimic the physiological conditions on the skin surfaces and at the gut linings, performed time-activity studies of soccer players in California, developed soccer-specific exposure parameters, developed toxicity criteria of tire-related chemicals, and assessed the non-cancer hazards and cancer risks of multiple routes of human exposure on synthetic turf fields.

Table A-1. Results of Literature Review Conducted by OEHHA in 2015

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
United States USEPA (2009) A scoping level field monitoring study of synthetic turf fields and playgrounds	Two synthetic turf fields and one playground	1) 2-3 air samples collected at each field and upwind locations, 1m above ground in close proximity to play 2) Wipe, crumb rubber, blade, mat samples	1) VOCs and PM_{10} analyses: • EPA Method TO-15 for VOCs • EPA Method 6020A for metals • EPA 9200.1 for lead extraction 2) Acid digestion for total extractable metals and bioaccessibility of lead (EPA 9200.1 for lead extraction)	1) Air sample data: • VOC concentrations were generally low and similar to those measured at upwind background locations. • PM_{10} concentrations were similar to upwind background levels. • Metal concentrations varied between fields; some were very similar to background levels and others were above. • Tire crumb fibers not observed • Air sampling and analysis methods found to be reproducible, but metal analyses found to have variability between samples. 2) Other sample data: • Surface wipe: levels of lead similar to blanks • Blade and crumb rubber: varied levels of total lead, chromium, cadmium, zinc, and arsenic	1) Limited sample size for all the media 2) Lack of SVOCs, VOCs, and PAHs analysis for crumb rubber and surface wipes 3) Lack of SVOCs and PAHs analyses for air samples 4) Incomplete bioavailability measurements for metals.	1) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 2) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, and metals (Task 4). 3) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, and metals (Task 4). 4) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
California OEHHA (2007) Evaluation of health effects of recycled waste tires in playground and track products	Three tire recyclers and three playgrounds	1) Three samples of shredded tires from three recyclers (two in CA, one in OH) 2) Wipe samples of three playground and sport track surfaces. Nearby cement surface wipe as background control 3) SBR tiles, EPDM tiles, SBR crumb	1) Shredded tires: • gastric digestion simulation: • EPA Method 6020 for metals • EPA Method 8270C for SVOCs 2) Surface wipes: metals, SVOCs, PAHs 3) Tiles and crumb: guinea pig skin sensitization test	1) OEHHA used the literature data to estimate the amount of chemicals that are available for ingestion uptake for children and assessed the hypothetical cancer and non-cancer risks based on a one-time ingestion for young children. 2) zinc and trichloroethylene exceeded their screening level for noncancer effects 3) cancer risk is below the *de minimis* level of one-in-a million risk 4) Gastric extract analysis shows: • low levels of metals and SVOCs • calculated exposure doses were at or below screening levels for noncancer effects; cancer risk is below the *de minimus* risk level 5) Wipe test results are: *playground surface wipes samples-* • contained 5 chemicals (zine, chrysene, fluoranthene, phenanthrene, and pyrene) at levels above background • estimated exposure levels were below health screening values for noncancer effects • cancer risk for chrysene is very slightly above the *de minimus* risk level *sport track wipe samples-* • found 5 PAHs (chrysene, fluoranthene, phenanthrene, naphthalene, pyrene) at levels above background • high school indirect ingestion via hand-to-mouth activities considered insignificant 6) Skin sensitization test shows these surfaces are not likely to cause skin sensitization in children, including children already sensitized to latex.	1)Focused on rubberized outdoor playground and tract field, not synthetic turf field 2)Lack of indoor field measurements 3)Incomplete gastrointestinal bioavailability measurement – only artificial gastric fluid stimulation was conducted 4)Limited number of fields 5)Hazard identification was based on literature data	1) Study will focus on synthetic turf materials (crumb rubber, artificial grass blades, backing material), and playground mats (Task 4). 2) Synthetic turf materials will be sampled from outdoor and indoor fields and playgrounds (Task 4c). 3) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). 4) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 5) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure to user of synthetic turf field and playground will be assessed based on sample data (Tasks 3 and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
California OEHHA (2010) Safety study of artificial turf containing crumb rubber infill made from recycled tires: measurements of chemicals and particulates in the air, bacteria in the turf, and skin abrasions caused by contact with the surface	1) four artificial turf fields and nearby natural turf fields for background comparison 2) three artificial turf fields and nearby natural turf fields as control 3) five artificial turf fields and two natural turf fields as control	1) air sampled for VOC analysis 2) sampled air multiple times throughout summer days 3) monitored ambient and field surface temperatures 4) air sampled for $PM_{2.5}$ and analyzed metals on the particulate matter 5) sampled for 3 hours intervals during active field use 6) infill and blade of grass from artificial turf fields and soil and grass from natural field	1-3) EPA Method TO-15 for VOCs 4-5) Analyzed $PM_{2.5}$ by weight and metal analysis by x-ray fluorescence 6) Bacteria cultured and 3 most prominent bacterial colonies quantified and identified, MRSA quantified	1)Field VOC concentrations vary during the day. 2)No effect of temperature on field VOC concentrations 3)By comparing estimated exposure concentrations and screening values for non-cancer effects, likely no adverse health effects from VOC exposure for athletes using these fields 4)Outdoor fields not a significant source of airborne $PM_{2.5}$ or heavy metals adhered to $PM_{2.5}$ 5)Compared to natural turf, fewer bacteria detected in artificial turf with crumb rubber infill, but higher abrasion rates observed for athletes using artificial turf 6)The overall effect of artificial turf on skin infection rates could not be determined.	1) Limited number of fields sampled 2) Variability in VOCs detected across fields 3) SVOCs not measured 4) Field variable such as age and field temp should be monitored to determine any influence on the release of chemicals and particulate levels. 5) Better data is needed about the amount of time athletes spend on fields for different sports and age groups, sexes. 6) Chemicals identified in chamber conditions were not identified above fields possibly due to chamber conditions. 7) Exposure for coaches, referees, and maintenance workers should be included. 8) More studies are needed to address the finding that artificial turf is associated with more skin injuries than natural turf.	1) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 2) Air samples will be collected from fields of various ages, in different locations and climate zones (Task 4c). 3) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, and metals (Task 4). 4) Air samples will be collected from fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 5) Exposure of and risk to users of synthetic turf field and playground will be assessed based on sample data (Tasks 3 and 7). 6) Crumb rubber samples from manufacturers will be subjected to exposure chamber measurements simulating environmental conditions and degradation processes (Tasks 4a and 4b). 7) Exposure of and risk to users of synthetic turf field and playground will be assessed based on sample data (Tasks 3 and 7). 8) Not addressing in this study

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
University of California, Davis He *et al.* (2011) Identification of Benzothiazole Derivatives and Polycyclic Aromatic Hydrocarbons as Aryl Hydrocarbon Receptor Agonists Present in Tire Extracts	Not applicable	Shredded inner tire tread	1) Total tire extraction using DMSO: Tire pieces soaked overnight and spun at 1500RPM for 15 minutes 2) Column Fractionation: • Treads extracted with toluene • Eluted with hexane and toluene in silica gel column • Fractions dried and re-suspended in hexane 3) Analyses: luciferase activity (for AhR-dependent gene expression)	1) Total tire extract induces luciferase in rodent and human cell lines 2) Total tire extract samples induce AhR dependent gene expression by binding to and stimulating AhR transformation and DNA binding 3) Fractions containing benzothiazole, some of its derivatives, and several PAHs were found to be capable of activating the AhR and AhR signaling pathway. 4) PAHs were previously known to be AhR agonists, but benzothiazole and its derivatives have not been reported.	Not applicable	Not applicable

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New York City Department of Health and Mental Hygiene Prepared by TRC, Windsor, CT. Denly *et al.* (2008) A review of the potential health and safety risks from synthetic turf fields containing crumb rubber infill	Not applicable	Not applicable	Not applicable	This study conducted a literature review that identified 11 different risk assessments on potential health effects from ingestion, dermal or inhalation exposure to crumb rubber. 1) All 11 studies concluded that exposure to COPCs from crumb rubber may occur, but the exposure via ingestion, dermal, or inhalation is too small to increase the risk for any health effect. 2) Risk assessments on oral and dermal exposures were based on theoretical estimates of exposure and risk. Given the overestimated parameters applied, these risk assessments may be conservative. The risk assessments addressed the potential increased susceptibility for children to chemical, but uncertainties existed in the risk assessment. 3) The report recommends that users of fields should be educated about the buildup of heat with crumb rubber infill in order to prevent heat-related illnesses.	1) Consistent test methods for determining chemicals in crumb rubber made from different source materials and by different processing techniques are needed. 2) Most of the data used in the risk assessments were from indoor fields. Studies on outdoor air concentrations of COPCs on newly installed and older synthetic turf fields, especially collected in hot and calm days, are needed to evaluate worst case scenario, and to better represent playing in parks. 3) There is a lack of background air concentrations of COPCs in NYC to compare to the air sample data. 4) High uncertainties are present in ingestion and dermal exposure assessments due to the lack of actual measurements.	1) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 2) Synthetic turf materials will be sampled from outdoor and indoor fields and playgrounds (Task 4c). 3) Air and particulate matter will be collected on fields and at upwind location nearby the fields. Upwind samples will serve as background controls for the field data (Task 4c). 4) Synthetic turf materials collected from manufacturers and fields, as well as particulate matter samples will be subjected to artificial biofluid extractions to simulate ingestion, inhalation, and dermal exposure doses.

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New York State Department of Environmental Conservation Lim (2008) A Study to Assess Potential Environmental Impacts from the Use of Crumb Rubber as Infill Material in Synthetic Turf Fields	Not applicable	Not applicable	Not applicable	The report conducted a literature review and proposed a study to examine the three major issues identified: 1) leaching of SVOCs from crumb rubber under acid rain conditions 2) leaching of metals from crumb rubber under acid rain conditions 3) off-gassing of VOCs under different temperature levels and heat	Not applicable	Environmental impacts will not be addressed in this study

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New York City Department of Health and Mental Hygiene Prepared by TRC, Windsor, CT. Vetrano (2009) Air quality survey of synthetic turf fields containing crumb rubber infill	1) Two outdoor crumb rubber fields One natural grass field	1) Four air samples per field, two upwind air background samples per field, plus field, trip, and lab blanks: • stationary samplers at three feet above ground surface • background and field samples collected at the same time • samples collected in late morning to afternoon over four separate days • field samples collected under simulated playing conditions 2) One-hour samples for VOCs analysis and two-hour samples other chemical analyses One crumb rubber sample per field	1) Air: SVOCs (17 PAHs and benzothiazole,69 VOCs, 10 metals, $PM_{2.5}$ Crumb rubber: 77 organic compounds (VOCs and some SVOCs) and 8 metals for matching to air COPCs	1) Eight VOCs detected in the air samples: • Five VOCs present in both the synthetic turf and natural grass field at levels below the New York State Department of Environmental Conservation (NYS DEC) guidelines for the Control of Toxic Ambient Air Contaminants • Three VOCs present only at the synthetic turf (two were below the guideline levels and the third, chloroform, exceeded guideline values) 2) No SVOCs detected in any samples 3) Zinc and chromium detected in air samples: • Zinc concentration exceeded the NYS DEC guideline value at the grass field • Chromium detected only in samples from the synthetic turf fields at levels above the NYS DEC guideline value, but was considered as a laboratory contaminant 4) $PM_{2.5}$ not detected at levels above background 5) Due to low number and levels of compounds detected in samples, it is unlikely that air constituents would cause any adverse health effects and do not warrant a risk assessment analysis for inhalation exposure	1) Limited fields sampled and limited sample size per field 2) Incomplete metal analysis in crumb rubber, air samples, and particulate matter 3) Lack of data for ingestion and dermal exposure assessment 4) Lack of multi-route exposure assessment	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 2) Samples will be subjected to CAM 17 metal analysis including lead and mercury (Task 4). 3) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements to support a multiroute exposure (including ingestion, inhalation, and dermal contact) assessment (Task 4) 4) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New York State Department of Environmental Conservation and New York Department of Health (Lim and Walker, 2009) An assessment of chemical leaching, releases to air and temperature at crumb-rubber infilled synthetic turf fields	1) Two fields of different ages on summer days when the temperature was above 80 degrees; collected over 2-day period 2) Four types of crumb rubber (ambient processed car, truck, and mixture, and cryogenic processed tire mixture) from tire processing facilities	1) Thirty-one random crumb rubber samples from 4 types of tire-derived crumb for leaching test, solvent extraction, and off-gassing tests 2) One surface runoff sample each at two synthetic field during rainfall events 3) Thirty-two Groundwater samples from downgradient wells 4) Ambient air and ambient particulate matter samples, surface wipe sampling, surface microvacuum sampling, ambient particulate matter monitoring, meteorological monitoring, (9 samples each from 2 fields) 5) Temperature survey (compared to nearby grass field)	1) Synthetic Precipitation Leaching Procedure test (SPLP, EPA SW-846 method 1312): acidic water (pH 4.2) extraction for 18 hours under agitation 2) Acid digestion using conc. nitric acid (EPA SW-846 method 6010B): determine lead content in crumb rubber sample 3) Off-gassing of VOCs and SVOCs from crumb rubber samples at 3 different temperature levels 4) Analyses: VOCs, SVOCs, PM, metals, tentatively identified compounds (TIC)	The report concluded that crumb rubber may be used as infill without significant impact on groundwater quality, when separation distance to groundwater table were addressed, and no clear cumulative impact on ambient air. The synthetic turf fields examined were not important contributors of exposure to particulate matter. 1) SPLP test results: • zinc, aniline, and phenol have potential to leach at levels above groundwater standards. • benzothiazole released but no standard for water. • leachate levels attenuated and diluted as leachate migrated through soil and entered the groundwater table • chemical leaching potential is dependent on the type of crumb rubber with truck tires reporting the highest leaching potential 2) Acid digestion test result: lead concentration in crumb rubber samples well below federal hazard standard for soil 3) Surface and ground water samples testing results: • surface water samples detected some metals at low levels • ground water samples found no zinc nor organics. 4) Ambient air, particulate, and wipe samples testing results: • air samples from two synthetic fields had low levels of many previously studied analytes that have been found in crumb rubber (common urban environmental contaminants, e.g., benzene, 1,2,4-trimenthylbenzene, ethylbenzene, carbon tetrachloride) • rubber dust was not identified in the respirable range 5) Temperature survey results: temperatures were increased on synthetic turf fields compared to grass fields suggesting that there is potential for heat-related illness	1) Author-Identified Data Gaps • Not analyzed for lead • Did not examine effects of solar radiation, compression or degradation • The strong absorption of VOCs and SVOCs to crumb rubber prevents quantitative analysis of the chemicals. • Only one surface water runoff sample analyzed. • Inadequate evaluation of particulate data 2) OEHHA-Identified Data Gaps • Limited fields sampled and limited sample size per field • Incomplete metals analysis • Lack of multi-route exposure assessment to support the conclusion	1) Samples will be subjected to CAM 17 metal analysis including lead and mercury (Task 4). 2) Crumb rubber samples from manufacturers will be subjected to exposure chamber measurements simulating environmental conditions and degradation processes (Tasks 4a and 4b). 3) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). 4) Ecological risk will not be evaluated in this study. 5) Particulate matter samples will be collected from fields of various ages, in different locations and climate zones. Samples will be subjected to artificial biofluid extraction, followed by targeted and non-targeted chemical analyses. (Task 4c). 6) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 7) Samples will be subjected to CAM 187 metal analysis, including lead and mercury (Task 4). 8) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Connecticut Department of Public Health (Ginsberg and Toal, 2010) Human health risk assessment of artificial turf fields based upon results from five fields in Connecticut AND Ginsberg *et al.* (2011b) Human health risk assessment of synthetic turf fields based upon investigation of five fields in Connecticut	1) Four outdoor synthetic fields (high school football or soccer fields) 2) One indoor synthetic field (collegiate facility) 3) One outdoor suburban grass area	1) three to four volunteers played for two-hour sampling period while wearing personal air sampling devices 2) stationary monitors were located at inches and three feet above the field 3) upwind samples taken off the synthetic fields 4) background air sample collected at a suburban location	VOCs, SVOCs, rubber-related SVOCs, PM_{10}, and lead	1) For both indoor and outdoor fields, personal sample concentrations of VOCs were higher than both stationary and background levels. 2) Benzothiazole and butylated hydroxytoluene (BHT) found above background levels and higher in stationary samples than personal samples. These concentrations were highest in indoor fields. 3) Generally low concentrations of PAH were found, but they are above background. 4) Naphthalene concentration above the indoor field was the highest among all the PAH detections in any fields. 5) Nitrosamines and PM_{10} were not found at concentrations above background levels. 6) Lead concentrations found in all samples were below the CT DEP Remediation Standard Regulation. 7) Four exposure scenarios were evaluated. • Cancer risks of crumb rubber exposure were at or below *de minimus* levels, with the greatest cumulative cancer risk (1.3×10^{-6}) occurred for children playing in indoor fields. • Benzene and methylene chloride contributed the most to each scenario for cancer risk • Noncancer hazard indices were below one for all scenarios.	1) Author-Identified Data Gaps: • Small number of field and sampling events • Not sampling in hot days • Did not study ingestion of rubber-related dust • Did not measure latex antigen in crumb rubber or PM_{10} • Limited information about the ability of benzothiazole to induce contact sensitization 2) OEHHA-Identified Data Gaps: • Incomplete metal analysis in air and particulate • No crumb rubber, artificial grass blade, or surface wipe measurements	1) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c). 2) The proposed sampling will occur in summer 2016 when it is hot (Task 4). 3) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). 4) Not addressing in this study 5) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed based on sample data (Tasks 3 and 7) 6) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, and metals (Task 4). 7) Crumb rubber samples will be collected from multiple manufacturers and fields of various ages, in different locations and climate zones (Tasks 4b and 4c).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
University of Connecticut Health Center Simcox *et al.* (2010) Artificial Turf Field Investigation in Connecticut Final Report	1) Four outdoor synthetic turf fields 2) One indoor synthetic field 3) One outdoor suburban grass area 4) Six additional fields for crumb rubber bulk sampling only (fields were different ages)	1) three to four volunteers played for two-hour sampling period while wearing personal air sampling devices 2) stationary monitors were located at inches and three feet above the field 3) upwind samples taken off the synthetic fields 4) background air sample collected at a suburban location 5) Five crumb rubber samples each from a total of 11 fields	1-4) Analysis for VOCs, SVOCs, rubber-related SVOCs, PM_{10} • EPA Method TO-15 for VOCs, • EPA Method TO-13A for SVOCs and PAHs, • NIOSH 2550 for targeted SVOCs • NIOSH 2522 for nitrosamines 5) Analyses for VOCs, SVOCs, lead • WOHL Method WG086.2 for VOCs • Modified EPA SW-84603050/ICP for lead	1) Newer field infill has more VOCs than older fields. 2) Four turf-related VOCs identified in field air samples. 3) Benzothiazole and 4-tert-(octyl)-phenol are the most commonly found SVOCs in air samples 4) Five PAHs and six SVOCs detected at concentrations higher than background levels 5) Benzothiazole and BHT detected in air samples from outdoor fields at concentrations above background. 6) Nitrosamines were not detected in air samples. 7) Field air PM_{10} levels were at or below background. 8) The highest concentrations of VOCs and SVOCs were found in the indoor field. 9) Lead found at levels below USEPA hazard level for soil.	1) Author-Identified Data Gaps: Profile from indoor field not well characterized due to confounding factors (lack of air circulation, other point sources within the facility) 2) OEHHA-Identified Data Gaps: • No ingestion or dermal exposure measurement and assessment • Small sample size	1) Indoor fields and playground mats will be examined in this study (Task 4c). 2) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7). 3) Crumb rubber, wipe, air, and particulate matter samples will be collected from multiple fields of various ages, in different locations and climate zones (Tasks 4b and 4c).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Connecticut Simcox *et al.* (2011) Synthetic Turf Field Investigation in Connecticut	1) Four outdoor synthetic turf fields 2) One indoor synthetic field 3) One outdoor suburban grass area 4) Six additional fields for crumb rubber bulk sampling only (fields were different ages)	1) Two study team members wore sampling canisters to collect personal air samples 2) stationary monitors were located at inches and three feet above the field 3) upwind samples taken off the synthetic fields 4) background air sample collected at a suburban location 5) crumb rubber from 11 fields	Personal air samples collected at waist height from members who played for 120 min on the field in July; stationary samples collected from 6 in and 3 ft above the turf surface. 1) Air samples analyzed by: 2) EPA TO-15 for VOCs 3) NIOSH Method 2550 for SVOCs 4) TO-13A for PAHs 5) NIOSH 2522 for nitrosamines 6) Crumb samples analyzed by: 7) WOHL method WG086.3 for VOC 8) modified EPA SW-846-3050/ICP for lead	1) Crumb rubber samples had lead levels below USEPA hazard level for soil. 2) Many VOCs found in personal air samples were not detected in upwind locations or stationary air samples on the fields. 3) VOC concentrations in personal samples collected form natural grass field and those collected from turf fields were within the same magnitude. 4) VOC levels in stationary samples collected on turf fields were similar to the levels in upwind background samples. 5) 21 VOCs' concentrations were higher in personal air samples collected from turf fields than those from grass fields and stationary samples on turf fields. VOC concentrations from the stationary samples were similar to the upwind backgrounds for turf fields. 6) Outdoor fields PAH levels in air generally similar to background levels. Several PAHs were found to be higher on air sampled from indoor fields than background air levels, with naphthalene having the highest concentration of all 7) 14 miscellaneous SVOC in air were detected at concentrations greater than background levels. BZT and BHT were the only two targeted SVOCs detected in turf air samples at levels above background. 8) Nitrosamine levels were non-detected. 9) PM_{10} levels in all field samples were lower than background levels.	1) Limited indoor field and total field sampled 2) Incomplete metal analysis in air and crumb rubber samples. No SVOCs or PAHs analysis for crumb rubber samples 3) No ingestion or dermal contact exposure evaluation and risk assessment	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Connecticut Mattina *et al.* (2007) Examination of Crumb Rubber Produced from Recycled Tires	Not applicable	Crumb rubber samples	1) Soil Phase Micro Extraction (SPME) 2) Analyzed for VOCs and metals 3) Leaching test	1) Benzothiazole, butylated hydroyanisole, n-hexadecane, and 4-(t-octyl) phenol were found volatilized from crumb rubber samples. 2) Concentrations of benzothiazole and butylated hydroyanisole were the highest among the four detected in the gas phase 3) These compounds along with several elements including zinc (highest level), selenium, lead, and cadmium leached from crumb rubber materials	1) Limited sampling with no field samples 2) Limited chemical analysis	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4).
Connecticut Agricultural Experiment Station (Li *et al.*, 2010a) 2009 Study of Crumb Rubber Derived from Recycled Tires Final Report	Not applicable	1) Crumb rubber samples 2) Alternative infill samples	1) SPME on both materials: analyses for VOCs 2) Leaching studies on effect of weathering on out-gassing and leaching of substances from crumb rubber • EPA Method 1312 • analysis for metals and organic compounds 3) Weathering measurement control exposure of crumb in outdoor environment: analyses for organic chemicals	1) SPME results: • Eleven volatile compounds were identified in all crumb rubber samples • Four of the eleven were identified in the gas phase over crumb rubber material and 6 were identified as PAHs • Benzothiazole present in the highest amount • VOCs detected in alternative infill products were xylenes and styrene and fewer in number of chemicals than those found in crumb rubber 2) Crumb rubber leaching test results: Benzothiazole and zinc were found to be the two major compounds leached from crumb rubber 3) Crumb rubber weathering measurements: Under controlled weathering of crumb rubber material, five compounds (benzothiazole, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, butylated hydroxyanisole) reached steady levels of outgassing at 20 days.	1) Limited sample size and data were only from uninstalled materials. 2) Incomplete chemical analysis 3) Data were not suitable for human health and exposure analyses	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Uninstalled synthetic turf materials and infield samples (crumb rubber, air, and wipe etc.) will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Connecticut Department of Public Health (2010) Factsheet. The CT DPH Risk Assessment of Artificial Turf Fields	Factsheet covering several Connecticut studies summarized in this table	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Connecticut Li *et al.* (2010b) Characterization of substances released from crumb rubber material used on artificial turf fields	Aged field samples from two fields	Uninstalled commercial synthetic turf infill samples from manufacturers or CT schools: 1) 13 crumb rubber 2) three alternative rubber materials	1) SPME fibers: analysis for VOCs, PAHs • Leaching test with modification of EPA method 1312: • extraction with distilled water or acidified water • agitation in shaker for 18 hours • analysis for VOCs, SVOCs, and metals • weathering measurements 2) Total content measurement: • methanol extraction • analysis for VOCs and SVOCs	1) SPME Results: • Identified 10 rubber-manufacturing related volatile chemicals in the vapor phase of all samples • BZT found in all samples, with lower levels in aged field samples • Significant reduction in levels of more volatile compounds in samples from aged field samples • Different compound profiles detected between recycled tire rubber and alternative rubber product • The concentration of volatile organic chemicals found in vapor (SPME) was lower than total amounts in rubber (methanol extraction) 2) Leaching Test Results: • BZT levels decreased in leachate over time following the natural weathering exposure • Zinc was found to be the highest leachable metal in all samples • There are different profiles of leachable metals between crumb and alternative infill samples • Under controlled weathering of crumb rubber material, volatile chemicals (benzothiazole, 1-methylnaphthalene, 2-methylnaphthalen, naphthalene) reached steady levels of outgassing at two weeks. 3) Total Content Measurement: • BZT found at the highest level in methanol extracts of rubber samples	1) Limited number of samples and fields 2) Data not suitable for ingestion and dermal exposure assessment	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Crumb rubber samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Connecticut Academy of Science and Engineering (2010) Peer Review of an Evaluation of the Health and Environmental Impacts Associated with Synthetic Turf Playing Fields	No applicable	Technical review of four preceding studies 1) Connecticut Agricultural Experiment Station (Authors: Li et al.), 2010. 2) Ginsberg et al., 2011. Human health risk assessment of synthetic turf fields based upon investigation of five fields in Connecticut 3) University of Connecticut Health Center (Authors: Simcox et al.), 2010. Artificial Turf Field Investigation in Connecticut Final Report 4) Connecticut Department of Environmental Protection, 2010. Artificial turf study: leachate and stormwater characteristics (not summarized in this table)	Not applicable	1) Results of studies reviewed by the Peer Review Committee: • PAHs, VOC, and rubber related SVOCs were off-gassed from crumb rubber, primarily benzothiazole • Some chemicals levels are greater than background levels. Levels of chemicals were typically higher in the indoor field compared to the outdoor field • Levels of some chemicals are higher in personal monitoring samples compared to stationary air samples • Risk assessment shows cancer risks are slightly above the *de minimus* (1.3×10^{-6}) and that children have the highest risk • Zinc levels exceed the concentration for acute toxicity in stormwater runoff that may potentially pose a risk to surface waters and aquatic animals. 2) Peer Review Committee conclusions • There is a limited (low) human health risk, but there is an environmental risk based on high zinc levels in the leachates and stormwater samples. • The statement that the cancer risk is above the *de minimis* level is an overstatement of the risk due to exposure overestimation, no background level subtractions, and the use of non-standard estimates for breathing rates and risk factors (use of conservative unit cancer risk values) used in the inhalation exposure assessment.	Not applicable	Not applicable

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Ginsberg *et al.* (2011a) Benzothiazole Toxicity Assessment in Support of Synthetic Turf Field Human Health Risk Assessment	A toxicity assessment of benzothiazole	Not applicable	Not applicable	1) Results based on assessment of data available in the literature: • Animal studies show BZT to have acute effects on the CNS and respiratory systems • No mutagenicity reported for BZT, but 2-mercapto-benzothiazole (2MBZT) shown to be mutagenic. 2-MBZT a chemical derivative commonly used as a surrogate for BZT. • No published subchronic or chronic studies for BZT, but studies on liver and kidney effects of 2MBZT are available. • Epidemiological studies suggest 2MBZT may be associated with bladder cancer in humans. 2) Author conclusions: BZT may be harmful at high levels	Not applicable	Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed on these chemicals (Tasks 3 and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New Jersey Pavilonis *et al.* (2014) Bio-Accessibility and risk of exposure to metals and SVOCs in artificial turf field fill materials and fibers	Seven synthetic fields	1) nine of new crumb rubber infill 2) eight new turf fiber products 3) seven crumb rubber infill field samples	1) Artificial biofluids extractions • three types of biofluids (lung, sweat, and digestive fluids) • metals, SVOCs and PAHs analyses • Metal extraction with nitric acid (acid digestion for total metal contents) of crumb rubber: analyzed metals with ICP-MS 2) SPME on crumb rubber ("total" extraction): SVOCs and analysis with GM-MS	1) PAHs detected at levels below the limit of detection, except low levels of naphthalene and acenaphthylene (just above limit of detection) 2) Benzothiazole was not found in any biofluids, but 2,2-benzothiazole (a dimer of BZT) was found in digestive fluid extracts. 3) 4-tert-octylphenol was found in lung fluid and sweat extracts. 4) Total extraction released more PAHs than the individual biofluid extractions. 5) Majority of metals were at concentrations below the limit of detection and were not different among all the sample types. 6) Lead was found in digestive, sweat and total extract fluid extracts of most field samples 7) Hazard quotient for each individual exposure routes were orders of magnitude lower than the reference doses of chemicals detected. The greatest non-cancer risks were for young children.	1) Lack of air, particulate matter, and wipe samples of the fields 2) Lack of VOCs analysis 3) These data gaps resulted in incomplete inhalation and dermal exposure assessments 4) Risk was assessed based on exposure to metals 5) No cancer risk evaluation included	1) Wipe, air, and particulate matter samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Task 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7). 4) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7). 5) Cancer and non-cancer risk assessment will be conducted based on chemicals data obtained from new crumb rubber and infield samples (Task 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
New Jersey Zhang *et al.* (2008) Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids	Three fields	1) seven samples of rubber granulates (artificial turf infill) 2) one sample artificial polyethylene grass fiber	1) Organic solvent extraction • dichloromethane Extraction (16 hours and concentrated by rotary evaporation) • PAH analysis with HPLC 2) Acid digestion • metal content: • microwave assisted digestion with nitric acid • metal content analyzed with ICP-MS 3) Biofluid extraction • three artificial biofluids (saliva, gastric fluid, intestinal fluid) • analysis for PAHs and metals	1) Solvent extraction results: Rubber granules had higher total PAH levels than the artificial grass fiber 2) Acid digestion results: • Two rubber samples had very large levels of Zn • Chromium and lead were detected in all rubber samples analyzed and grass fibers and grass fiber had the highest chromium level than the rubber • Arsenic and cadmium were detected in several samples (unspecified which sample types) 3) Biofluid extraction results: • Biofluid extraction of grass fiber had no detected PAHs • Lead was not detected in intestinal biofluid extracts of rubber samples, but was detected in intestinal biofluid extracts of grass fiber. Lead had a high bioaccessible fraction in grass fiber than in rubber. • With the exception of naphthalene, low bioaccessibility was noted for PAHs. • Aging of the field increases bio-accessibility of PAHs in artificial gastric fluid. 4) Conclusions: • Lead found in rubber samples at levels below NYS DEC soil standards. • Artificial grass fiber samples have a high content of chromium. • Lead in grass fiber is highly bioaccessible in digestive juices. • Rubber granules contain PAH and zinc levels above NYS DEC soil standards.	1) Limited number of samples and fields 2) Lack of air sampling 3) Lack of VOCs and SVOCs analyses 4) Lack of inhalation and dermal biofluid extractions	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Wipe, air, and particulate matter samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Task 4c). 3) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 4) Samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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University of Medicine and Dentistry of New Jersey Lioy and Weisel (2011) Crumb Infill and Turf Characterization for Trace Elements and Organic Materials	Seven fields	1) 9 uninstalled turf infill products, 2) 8 new turf products, 3) 7 crumb infill samples from 7 fields of various ages	1) Total extraction: • microwave digestion with nitric acid • analysis by ICP-MS for metal, 2) SPME: • GC-MS for VOCs and SVOCs 3) Biofluid extraction: • synthetic sweat, lung, and digestive (saliva, gastric, intestine) biofluids • analyses for trace metals, PAHs, SVOCs	1) No metal levels in infill samples were above NJ DEP soil standards 2) Lead, copper, and magnesium found to be higher in total extracts and digestive biofluids than lung and sweat biofluids. 3) Vanadium and chromium were higher in sweat than other fluids and total extractions. 4) PAHs levels were below detection limits in all biofluid extracts of all samples, with the exception of acenaphthylene in one lung biofluid sample and naphthalene in one total extract sample 5) A small amount of PAH present in new infills or field samples is bioavailable or readily released from the materials 6) No PAH in biofluid extracts or SPME at levels exceeding the soil standards 7) The greatest number of compounds were found in sweat extracts, and the least in digestive biofluid extracts.	Limited samples per field and lack of air and wipe samples	Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c).
Colorado Anderson *et al.* (2006) A Case Study of Tire Crumb Use on Playgrounds: Risk Analysis and Communication When Major Clinical Knowledge Gaps Exist	Not applicable	A case study presenting a model approach to address concerns regarding the safety of recycled tire crumb as a playground surface with limited exposure information	Not applicable	1) Results of literature Review: • The use of crumb rubber in playgrounds posed minimal hazard to children, but studies were done *in vitro.* • Risk assessment, genotoxicity, and ecotoxicity assays conclude that crumb rubber would not pose a risk to children or the environment. 2) Authors' Conclusion: No information needed to assess the exposure to crumb rubber products used in playgrounds was available in the literature, but risk can be communicated based on the available information in published literature, with statements acknowledging the existence of data gaps.	Lack of sufficient data to conduct an exposure assessment	Samples will be collected from multiple crumb rubber manufacturers and fields. These samples will be subjected to targeted and non-targeted chemicals analyses for VOCs, SVOCs, PAHs, and metals. An exposure assessment and human health risk assessment will be developed based on the field data (Tasks 2, 3, 4, 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Canada Birkholz *et al.* (2003) Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playground	Not applicable	tire crumb samples (unspecified origins)	1) Total extraction: dichloromethane and solvent-exchange to DMSO 2) genotoxicity assay, 3) Leachate of tire into water: • lethality assay • a battery of aquatic test representing the major trophic levels	1) No genotoxicity found for tire crumb extracts. 2) Leachate samples show positive toxicity towards bacteria, invertebrates, fish and algae, but toxicity reduced after leachate treated with sewage seed, nutrients, and aeriation. 3) Results suggest that there is little health risk to children from tire crumb in playgrounds and any ecotoxicity observed decreases as tire crumb ages.	1) Only genotoxicity potentials of leachates were evaluated 2) Lack of data for evaluating human health.	1) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed on these chemicals (Tasks 3 and 7). 2) Samples will be collected from multiple crumb rubber manufacturers and fields. These samples will be subjected to targeted and non-targeted chemicals analyses for VOCs, SVOCs, PAHs, and metals. An exposure assessment and human health risk assessment will be developed based on the field data (Tasks 2, 3, 4, 7).
Canada Beausoleil *et al.* (2009) Chemicals in Outdoor Artificial Turf: A Health Risk for Users?	Not applicable	A risk assessment review	Not applicable	Review of toxicological risk assessments in literature indicated low exposure to chemicals from artificial turf and that the risk to any players on the field is not a concern.	Not applicable	Not applicable

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Danish Technological Institute (Nilsson *et al.*, 2005) Emission and evaluation of health effects of PAHs and aromatic amines from tyres	Not applicable	1) 20 tires 2) 2 falling protection tiles base from granulated rubber	1) Solvent extraction • samples extracted with dichloromethane for 1 hour in ultrasonic bath, then extraction with 50/50 dichloromethane/ acetone • extract concentrated with cyclohexane then extraction with 90/10 dimethyl-formamide/water • analysis in GC-MS for PAHs 2) Thin layer chromatography (TLC) measurement • extraction with dichloromethane • TLC identification for aromatic amines 3) Sweat extraction: sample exposure to artificial sweat for 1 hour 4) Environmental treatment: exposed to un and elevated temperature	1) Many PAHs were identified in rubber granulates, predominantly PAHs of low molecular weight. 2) Aromatic amines present in higher concentrations than PAHs in the samples 3) A higher migration of amines (water soluble) than PAHs into the sweat 4) Sun and temperature increase the migration of PAHs and amines to sweat 5) A health assessment based on these selected PAHs and amines (shown to migrate to sweat) shows no significant health risk on exposure to chemicals released from recycled tires on playgrounds	1) Limited sample and no field investigation 2) Limited chemical analysis 3) Limited exposure evaluation, only dermal exposure was assessed	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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France Savary and Vincent (2011) Used Tire Recycling to Produce Granulates: Evaluation of Occupational Exposure to Chemical Agents	Occupational exposure measurement in four tire rubber granulate processing facilities	workers were fitted with pumps and sampling heads in breathing zones; static samples taken in workshops: 1) dust samples suspended in water, deposited on filter and examined using electron microscopy 2) VOCs trapped with sorbent tube and identified using gas chromatography	1) Dust: electron microscopy for morphology 2) Air: analysis for VOCs	1) Particle size distribution; separated the particle into three categories: 100-150 µm, 10-15 µm, and less than 10 µm 2) Microscopic analysis showed dust samples from shredders (used to produce rubber granulates) contain sulfur, carbon black, silicon and iron oxide at their surface 3) Dust levels are higher than those of the ambient background air 4) No VOCs were detected 5) Results indicate the need for enhanced ventilation systems in these facilities	1) Limited chemical analysis 2) No sample data and evaluation on other exposure pathway like dermal and indirect ingestion via hand-to-mouth	1) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 2) Samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Italy Ruffino *et al.* (2013) Environmental -sanitary risk analysis procedure applied to artificial turf sports fields	1) four artificial turf fields (SBR infill) of different ages 2) one artificial turf field (TPE infill) 3) one natural grass turf field	1) 1200 g sample of each artificial field 2) 1 kg soil from natural turf field 3) gas and dust samples were collected immediately above the ground for both synthetic turf and natural grass field, and a point located in the city center City center samples were collected to evaluate the influence of vehicle-emitted contaminants on the composition of gases and dust from turf fields	1) Organic analysis: • microwave-assisted extraction with dichloromethane • analyzed by GC-MS for benzene, toluene, xylenes, and PAHs 2) Metal analysis: • microwave-assisted extraction with nitric acid, perchloric acid (sulfuric and phosphoric acid for natural soil) • analyzed with ICP-OES 3) Tyler standard sieve: particle size distribution	1) Rubber granulates ranged in size from 1-3 mm; soil ranged from 0.01-10 mm. 2) Turfs made of rubber tires (SBR) have a higher PAH and xylene contents than turf made from thermoplastic elastomer (TPE). 3) Natural soil had higher concentrations of xylene and benzene and lower PAH levels than granulates. 4) Benzo[a]anthracene was found in all SBR samples 5) Zinc found in higher levels than other metals in SBR infill samples. 6) Lower levels of PAHs, benzene, toluene, and xylenes found in water leachate obtained from older fields; 7) Risk assessment shows the cumulative cancer risk is lower than the *de minimus* (1×10^{-6}) and the cumulative non-cancer hazard was lower than 1	1) Limited types of sample 2) Limited chemical analysis 3) Lack of ingestion exposure evaluation	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Italy Bocca *et al.* (2009) Metals contained and leached from rubber granulates used in synthetic turf areas	32 playgrounds	250 gram samples were taken from 12 sections of each playground and 50 gram of each section sample was pooled to obtain 1 representative sample per playground	1) Microwave acid digestion: • sample, nitric acid, hydrofluoric acid and perchloric acid digested in microwave oven for 20 min • analyzed with HR-ICP-MS and ICP-OES for metals 2) Acetic acid extraction: • extraction with acetic acid with shaking for 24 hours • analyzed with HR-ICP-MS and ICP-OES for metals 3) Water extraction: • two cycles of extraction with deionized water with shaking for 24 hours • analyzed with HR-ICP-MS and ICP-OES for metals	1) Granulates contained all the metals that were investigated in a wide range of varying concentrations 2) Zinc was consistently found to be present at the highest concentrations 3) Other metals present in high levels were aluminum, iron, and magnesium 4) All metals except cobalt, tin, and zinc were found at levels below the maximum allowable levels for soil. 5) Zinc and magnesium found to leach into water at the greatest levels, with zinc levels exceeding the standard in 14 samples 6) Leachability of cadmium, chromium, lead, and zinc were lower in water than in acid.	1) Limited field investigation 2) Limited chemical analysis 3) Lack of suitable data for human health risk assessment	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Italy Menichini *et al.* (2011) Artificial-turf playing fields: Contents of metals, PAHs, PCBs, PCDDs and PCDFs, inhalation exposure to PAHs and related preliminary risk assessment	13 playing fields	1) Rubber granulate collection same as Bocca et al., 2009 2) air samples of ambient air were taken for about 2-3 hours (the daily duration of a training session) for 3 days 3) samples were taken outside the field to get background estimates	1) Metal analysis: microwave digestion, same as Bocca et al., 2009 for 25 metals 2) PAH analysis: 3) extraction with dichloromethane then n-hexane 4) analyzed by HRGC-LRMS for nine PAHs 3) PCBs, PCDDs, PCDFs analysis: • same extraction as PAHs with additional elutions with n-hexane and dichloromethane • analyzed by HRGC-LRMS and HRGC-HRMS	1) In granulates, zinc is the only metal that was detected at levels above the Italian soil 'green area' threshold values and the NY State cleanup objective for soils, which require no use restrictions 2) There was large variability in PAHs but benzo[a]pyrene was the only PAH of major health concern that was detected at levels above the Italian standards 3) The sum of PCBs levels exceeded the Italian soil standards, while levels of PCDD and PCDF were below standards. 4) Air samples from an urban field had PAH levels similar to background levels, while samples from a field in an area of traffic had PAH levels slightly higher than background levels. 5) Risk assessment based on the benzo[a]pyrene concentration found at the high traffic field calculated an excess lifetime cancer risk of 1 x 10^{-6} (one in a million) for athletes with 30-year activity.	1) Limited sample types 2) Limited chemical analysis 3) Exposure through multiple pathways was not evaluated 4) Risk assessment focused on only benzo[a]pyrene	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7). 4) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed on these chemicals (Tasks 3 and 7).
Lee *et al.* (2012) Work Environment and Exposure to Hazardous Substances in Korean Tire Manufacturing	Occupational exposure measurements at two different plants of a tire manufacturing company	1) Personal air sampling in breathing zone analyzed in GC-MS 2) bulk rubber solvent analyzed for composition in GC-MS 3) total particulates measured every 6 months with microbalance	Air sample and rubber solvent sample analyses: PAHs, styrene, 1,3-butadiene, sulfur dioxide, carbon disulfide, hydrocarbons, rubber fume, PM	1) Nine PAHs detected in breathing zone air at levels below the limits of quantitation. 2) PAHs detected in personal air samples varied with different work processes at the facility. 3) Air sampled from locations for curing process had the most PAHs. 4) Levels of particulate matter corresponded with levels of rubber fume in the plants. Rubber fume levels in three air samples had concentrations above the UK maximum exposure limit. 5) Results reveal a need to improve ventilation system in tire manufacturing plants, especially at the curing process areas.	Lack of evaluations on other exposure pathways	Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Korea Kim *et al.* (2012) Health Risk Assessment of Lead Ingestion Exposure by Particle Sizes in Crumb Rubber on Artificial Turf Considering Bioavailability	Not applicable	test pieces of recycled ethylene propylene diene monomer (EPDM), an artificial turf filling, of sizes below 250 µm and above 250 µm (unspecified origins)	1) Total content analysis: decomposition with nitric acid and peroxide in microwave digestion system followed by decomposition on hot plate 2) Acid extraction: • hydrochloric aqueous solution • shook for one min and extracted for one hour 3) Artificial digestive extraction: • used to assess bioavailability • extraction for one hour in artificial gastric juice, pH adjustment, extraction for another one hour • two-hour extraction in artificial duodenal juice and bile • Decomposition via hot plate and extraction 4) Analysis: lead	1) Total content extraction leached out more lead than the acid and artificial digestion extractions. 2) A higher bioavailability for particles less than 250 µm using acid digestion than in digestion extraction. 3) Lead bioavailability for rubber particles below 250 µm for acid extraction was twice as high as for particles above 250 µm. 4) The hazard index from lead exposure was greatest in lower elementary grades children and lowest in high school children. Hazard index values were between 0.01 and 0.1 for the average scenarios. 5) For larger rubber particles, there is a 2x difference in the hazard index between the lead exposure levels estimated by digestion extraction and acid digestion methods. 6) For the worst exposure scenarios, hazard indices exceeded 1 for elementary school children.	1) Lack of field investigation and limited sample type examined 2) Limited chemical analysis 3) Limited exposure assessment, only evaluated for ingestion exposure	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Norwegian Institute of Public Health and the Radium Hospital (2006) Artificial turf pitches--an assessment of the health risks for football players	Four indoor sports halls	Air samples previously collected from the facilities	1) Analyses: VOCs, particles, phthalates, alkyl phenols, benzene, PCBs 2) Exposures occur through inhalation, skin contact, and swallowing; characterization based on adult, juniors, and children 3) Exposure duration and frequency based on the information from managers of the sports halls selected; information was used to select the worst-case scenarios	1) No increased health risk associated with airborne dust, PAHs, PCBs, phthalates, and alkyl phenols 2) For VOCs, no health risk associated with acute exposure, however there isn't much toxicity data available for the detected VOCs and it was not possible to perform any health assessment 3) No health risk associated with oral exposure to phthalates and alkyl phenols, based on theoretical exposure levels. 4) No health risk associated with dermal exposure to PCBs, PAHs, phthalates, and alkyl phenols, based on theoretical exposure levels. 5) The low levels of allergens present in the rubber would not likely lead to development of a contact allergy. 6) No increased cancer risks caused by exposure to benzene or PAHs in the halls	1) Limited field investigation and sample data 2) Limited chemical analysis 3) Lack of adequate data to support the multi-route exposure assessment	1)Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2)Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3)Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

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Norway Dye *et al.* (2006) Measurement of air pollution in indoor artificial turf fields	three indoor artificial turf fields 1) one new 2) one a year old 3) one made from TPE	Airborne dust collection	VOCs and PAHs	1)Quantities of airborne dust found at levels that would be expected for indoor environments and close to recommended norm. 2)Airborne dusts contained large quantities of rubber from turf granulates. 3)There are large portions of unidentified organic materials. 4)Total VOC levels were higher than normal or anticipated levels in indoor air. They are expected to be elevated over time even with proper ventilation. 5)Total VOC levels detected from field with TPE were lower than those with crumb rubber infill.	1) Lack of background control data, e.g., from outside of stadiums 2) Some unknown peaks were not identified but only reported as peaks 3) Many identified chemicals have no health screening levels, so health risk from exposure to these chemicals cannot be estimated. 4) Need air particulate data from outdoor fields. 5) Did not measure metal content of PM	1) Air samples will be collected nearby upwind locations to provide background information (Task 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed on these chemicals (Tasks 3 and 7). 4) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 5) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Portugal Gomes *et al.* (2010) Toxicological Assessment of Coated versus Uncoated Rubber Granulates Obtained from Used Tires for Use in Sport Facilities	Not applicable	2 rubber granulate coatings: 1) PVC coated rubber granulates, cross-linked alquidic polymer coated rubber granulates 2) uncoated raw rubber granulates	1) Granulates: • Extraction with acetone followed by petroleum ether • Extract passed through silica gel column • Analyzed in GC-MS 2) Leachates: • Extracted with dichloromethane • Concentrated in silica gel column followed by cyclohexane • Analyzed in GC-MS 3) Analyses: PAHs, heavy metals	1) Rubber granulates produced through cryogenic processes release fewer particulates into the air than mechanically produced granulate. 2) Coated granulates had a higher content of PAHs than raw granulates, but leached less PAHs into water than raw granulates. 3) Levels of heavy metals leached were small, except one of the two coatings tested had a leaching level of tin above the regulated limit 4) Coating of rubber granulates result in lower ecotoxicity compared to raw rubber granulates.	1) Lack of field investigation and limited sample size 2) Limited chemical analysis	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Spain Llompart *et al.* (2013) Hazardous organic chemicals in rubber recycled tire playgrounds and pavers	Nine urban playgrounds	1) 17 samples of floor tile compositions and carpet covers from nine playgrounds 2) seven commercial samples (two puzzle pavers, five recycled rubber tire tiles of different colors)	1) Ultrasound-assisted extraction with ethyl acetate for 15 min followed by GC-MS 2) Pressurized solvent extraction with ethyl acetate for 15 min followed by GC-MS 3) SPME of 500mg samples followed by GC-MS 4) Organic Analyses: 16 PAHs, vulcanization additives (e.g., benzothiazole), antioxidants, plasticizers	1) Large numbers of VOCs and SVOCs were found in playground samples 2) PAHs found in the vapor phase of all samples. Commercial samples had higher levels than playground samples. 3) Pyrene, naphthalene, phenanthrene, fluoranthene, and chrysene were the most abundant PAHs detected in playground samples. 4) Benzo[a]pyrene was found in five playground samples at low levels. 5) Phenanthrene and fluoranthene were the most abundant PAHs in commercial samples. Also, benzo[a]pyrene was present in high concentrations in these samples. 6) BZT was found in all playground samples and two commercial samples at low levels, while the other commercial samples had high levels of BZT. 7) 2-Mercaptobenzothiazole was found in playground samples but not in commercial samples. 8) 4-Tert-butlyphenol was found in half of playground samples at low levels, but high levels in all commercial samples. 9) BHT was found in all samples. 10) Phthalates were found in all samples and were higher in commercial samples. 11) SPME studies found that PAHs and vulcanization additives detected in samples are volatile and potential for inhalation exposure.	1) Limited sample and field types 2) Limited chemical analysis, no metal analysis 3) Bioavailability of chemicals in recycled tire rubber was not assessed.	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4). 3) Samples will be subjected to five to six artificial fluid extraction for bioavailability measurements (Task 4). Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7).

Report/Study	Field	Samples	Sample Preparation and Analysis	Results	Data Gaps	Task to Address Data Gaps[a]
Sweden KemI (Swedish Chemicals Inspectorate, 2006) Synthetic turf from a chemical perspective--a status report	Not applicable	Not applicable	Not applicable	1) Results from the literature reviewed: • Levels of PAHs and zinc shown to be above the Norwegian Pollution Control Authority (SFT) guidelines in run-off water. • Zinc shown to be predominant in the leachate from synthetic grass fibers and may pose a risk to aquatic organisms. • Particulate levels in dust at synthetic fields were found below national guidelines, but contained significant amounts of granulate. • Health assessment shows no increased risks from synthetic turf with crumb rubber infill 2) Authors' conclusion: although recycled tires contain substances that could be hazardous, concentrations of those substances when emitted are low and pose a low risk to aquatic environments, and probably do not pose harm to players on synthetic turf fields.	Author-Identified Data Gaps: 1) Need more knowledge of the hazardous chemical release from the rubber 2) Need more information on human exposure 3) Water quality should be studied more	1) Hazard identification evaluation will be conducted on chemicals of concern (Task 2). Exposure and risk to user of synthetic turf field and playground will be assessed on these chemicals (Tasks 3 and 7). 2) Multiple exposure pathways (e.g., inhalation, incidental ingestion, indirect ingestion via hand-to-mouth activities, dermal contact) will be examined. Risk from exposures via these pathways will be assessed (Tasks 3, 4, and 7). 3) Water quality will not be addressed in this study.
Taiwan Chang *et al.* (1999) Emission characteristics of VOCs from athletic tracks	Athletic tracks of various age: 1) 5 polyurethane type I 2) 9 poly-urethane type II 3) 5 synthetic rubber tracks	1) one gas sample per field collected by dynamic flux chamber method for VOC emission 2) For three newest fields: • three air samples taken at 1.5m above track in middle of lanes, • three samples taken at 1.5 m above ground sites at least 50m from track or any possible VOC source for VOC concentration at breathing height (background)	23 VOCs, SVOCs	1) 23 VOCs identified in a preliminary study 2) 19 VOCS quantified. Others were at levels below limit of quantitation. Hexanal was the most abundant compound emitted from tracks 3) Lower levels of VOCs were emitted from older synthetic tracks. 4) Tracks made of polyurethane type II and synthetic rubber have greater gas permeability and levels of VOC emitted decreased quickly with time. 5) VOC concentration at breathing height on the tracks were at similar levels to background	1) Limited field (track only) and sample (air only) types 2) Limited chemical analysis	1) Crumb rubber, wipe, and air samples will be collected from multiple fields of various ages, in different locations and climate zones Indoor fields and playground mats will be examined in this study (Tasks 4b and 4c). 2) Field samples will be subjected to targeted and non-targeted chemical analyses, including VOCs, SVOCs, PAHs, and metals (Task 4).

[a] The OEHHA Synthetic Turf Study is comprised of five separate tasks: 1) expert and public input and consultation, 2) hazard identification, 3) exposure scenario development, 4) sampling and analysis of new and in-field synthetic turf (Task 4a: Procedure development to analyze chemicals of concern in crumb rubber and artificial grass blades, Task 4b: New (not installed) crumb rubber—Sample collection and identification of chemicals extracted or emitted, Task 4c: Field samples of used (in-field) synthetic turf—Sample collection and analyses), 5) personal monitoring or biomonitoring study protocol development, 6) reporting, and 7) health assessment from play on synthetic turf fields.
2-MBZT: 2-mercapto-benzothiazole; AhR: aryl hydrocarbon receptor; BHT: butylated hydroxytoluene ; BZT: benzothiazole; CAM 17: Title 22 metals from California Code of Regulation Title XXII. The list includes Antimony (Sb), Arsenic (As), Barium (Ba), Beryllium (Be), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Selenium (Se), Silver (Ag), Thallium (Tl), Vanadium (V) and Zinc (Zn); COPC: chemical of potential concern; CT: Connecticut; CT DEP: Connecticut Department of Public Health ; NJ DEP: New Jersey Department of Environmental Protection; DMSO: dimethyl sulfoxide; DNA: deoxyribonucleic acid; EPA: Environmental Protection Agency; EPA TO-15: EPA Air Method, Toxic Organics - 15 (TO-15): Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS); EPDM: ethylene propylene diene monomer; GC-MS: gas chromatography-mass spectrometry; HPLC: high performance liquid chromatography; HRGC-HRMS: high Resolution Gas Chromatography coupled with High Resolution Mass Spectrometry; HRGC-LRMS : high Resolution Gas Chromatography coupled with low Resolution Mass Spectrometry; HR-ICP-MS: high resolution magnetic sector inductively coupled mass spectrometry; ICP: inductively coupled plasma; ICP-MS: inductively coupled plasma mass spectrometry; ICP-OES: inductively coupled plasma-optical emission spectrometry; MRSA: methicillin-resistant Staphylococcus aureus; NIOSH: The National Institute for Occupational Safety and Health ; NY: New York; NYC: New York City; NYS DEC: New York State Department of Environmental Conservation; OEHHA: Office of Environmental Health Hazard Assessment; OH: Ohio; PAH: polycyclic aromatic hydrocarbon; PCDD: polychlorinated dibenzodioxin; PCDF: polychlorinated dibenzofuran; PCB: polychlorinated biphenyl; PM: particulate matter; PM_{10}: inhalable particles with diameters that are generally 10 micrometers and smaller.; $PM_{2.5}$: inhalable particles with diameters that are generally 2.5 micrometers and smaller.; PVC: polyvinyl chloride; RPM: revolutions per minute; SBR: styrene butadiene rubber; SPLP: Synthetic Precipitation Leaching Procedure; SPME: soil phase micro extraction; SVOCs: semivolatile organic chemicals; TIC: tentatively identified compounds ; TLC: thin layer chromatography; TPE: thermoplastic elastomer ; UK: United Kingdom; USEPA: U.S. Environmental Protection Agency; VOC: volatile organic chemicals; WOHL: Wisconsin State Laboratory of Hygiene; and SFT: Norwegian Pollution Control Authority.

A.2. Highlights of Selected Recent Crumb Rubber Studies

Since the initiation of the current OEHHA Study in 2015, the United States federal government, the European Chemical Agency (ECHA), the National Institute for Public Health and the Environment (RIVM) in the Ministry of Health, Welfare and Sport of the Netherlands, and the Washington State Department of Health, have conducted field investigations, risk assessments, and a cancer cluster investigation of use of synthetic turf fields for sport activities. The researchers at Yale University (New Haven, Connecticut) conducted a chemical study on tire-derived consumer products and crumb rubber used for field installation. Together with the two pilot studies of recycled waste tires previously conducted by OEHHA (2007; 2010), these recent studies provide important information on understanding the chemical composition of crumb rubber, routes of exposure on synthetic turf fields, and health risks associated with sport activities on the synthetic turf fields. The designs and findings of these studies are highly relevant to the OEHHA Synthetic Turf Study and are summarized in the following paragraphs.

A.2.1 OEHHA Pilot Studies of Recycled Waste Tire and Synthetic Turf Fields

In 2007 and 2010, OEHHA conducted two pilot studies to evaluate the health effects for uses of recycled waste tires in playgrounds, track products, and synthetic turf fields.

The 2007 study examined the health risks posed to children participating in activities on outdoor playgrounds and track surfaces constructed with recycled waste tires. OEHHA assessed the risks of human exposures to tire-related chemicals via direct ingestion and indirect ingestion following hand-to-surface contacts. The study performed gastric digestion simulation measurements on tire shreds and identified 13 metals (antimony, arsenic, barium, cadmium, chromium, cobalt, copper, lead, molybdenum, nickel, selenium, vanadium, and zinc) and 9 semivolatile organic chemicals (SVOCs: o-cyanobenzoic acid, N-cyclohexyl-cyclohexanamine, benzothiazole, 2(3H)-benzothiazolone, 1H-isoindole-1,3(2H)-dione, cyclohexanone, N-cyclohexyl-formamide, aniline, and phenol) with levels higher in the tire-extracts than in the controls. The study chose a 10 gram ingestion amount for tire shreds based on the recommendation of acute soil ingestion rate for children from the OEHHA Risk Assessment Guidelines (OEHHA, 2000) and derived an acute hazard index of 2.2 for chemicals identified in the tire shreds via a one-time ingestion of 10 gram of the product for a 15 kilogram child. The increased lifetime cancer risk for chemicals identified in the tire shreds via a one-time 10 gram ingestion of the product by a three year old child was 3.7 in one hundred million (3.7×10^{-8}), below the *de minimis* (too trivial or minor for consideration) risk level of one in one million (less than 1×10^{-6}). The study also collected surface wipe samples on playground and nearby track surfaces made of recycled waste tires. Chemical analyses of these samples identified zinc and four polycyclic aromatic hydrocarbons (PAHs: chrysene, fluoranthene, phenanthrene, and pyrene) as chemicals related to the playground surfaces. The authors determined that the calculated indirect ingestion

dose following hand-to-surface contacts to the playground surfaces for a 15 kilogram child (approximately 33 pounds) were 200 to 8000-fold lower than the recommended dietary allowance for zinc and chronic non-cancer hazard reference doses of fluoranthene and pyrene, and concluded no adverse health concerns from this exposure. For the indirect ingestion of chrysene via hand-to-surface contacts to playground surfaces, the study reported an increased lifetime cancer risk of 2.9 in one million (2.9×10^{-6}) for exposures from 1 through 12 years of age. No non-cancer or cancer screening values are available for phenanthrene so no assessments could be made.

In 2010, OEHHA conducted a follow-up study to evaluate safety aspects of synthetic turf fields constructed with crumb rubber infill. This study investigated exposures of athletes to volatile organic chemicals (VOCs), particulate matter of aerodynamic diameter less than 2.5 microns ($PM_{2.5}$), and the potential for bacterial infection (particularly methicillin-resistant *Staphylococcus aureus*, MRSA) from contact with the field materials. The study identified no public health risk concerns from inhalation exposures to VOCs or $PM_{2.5}$. Although a higher rate of skin abrasions was reported in college soccer players competing on synthetic turf fields than on natural turf fields, the study found a smaller number of bacteria species and fewer bacterial colony forming units (CFU) on synthetic turf materials compared to soil and grass sampled from natural turf fields. The study, therefore, could not predict if an elevated rate of skin infection would result from using the synthetic turf fields.

A.2.2 NTP Toxicology Studies of Crumb Rubber

In response to a request from OEHHA, the National Toxicological Program (NTP) performed a series of studies on crumb rubber between 2016 and 2019. The program applied various technologies and biological models to elucidate the chemical composition, physical properties, and toxicity of crumb rubber.

NTP (NTP, 2019d) characterized the physical appearance of the crumb rubber and identified over a hundred crumb rubber-related chemicals with various levels of analytical confidence.

To elucidate potential cellular targets of toxicity following human ingestion, dermal, or inhalation exposure to crumb rubber, NTP conducted *in vitro* cytotoxicity studies using four human cell models (NTP, 2019b). NTP researchers prepared a cell-specific crumb rubber-conditioned medium for each cell model by pre-treating each cell-specific culture medium with crumb rubber for various time periods (3 hour to 7 days), various temperatures (at ambient to 60°C), and under frequent mixing. Before adding the media to the cell cultures, the researchers removed crumb rubber from the pre-treated media by centrifugation and sterilized the media by filtering through 0.22 µm sterile filters. The cell-specific crumb rubber-conditioned media (contained various amounts of fetal bovine serum, FBS) was toxic to the human small intestinal (FHs-74-Int) cells and the human skin-derived keratinocytes (HaCaT cells), but not to the human hepatocytes

(HepaRG cells). Despite the presence of known tire-related chemicals (e.g., 2-mercaptobenzothiazole, N,N'-diphenylguanidine, and 1,2-benzisothiazoline-3-one) in the crumb rubber-conditioned artificial lung fluid (ALF), no cytotoxicity was observed in the human peripheral lung (HPL-1D) cells cultured in this conditioned ALF. Based on the results of these *in vitro* studies and a feasibility evaluation of *in vivo* studies (NTP, 2019c), NTP (NTP, 2019a) conducted 14-day *in vivo* exposure studies using eight- to nine-week old female B6C3F/N mice. Mice were exposed via oral gavage to crumb rubber in corn oil, dosed feed, or mixed bedding. The studies did not find any treatment-related changes in the overall chemical profiles of the urines or plasma, but they detected high levels of potential tire-related chemicals in the urine or plasma of the crumb rubber-exposed animals compared to the control animals. The report described the results as follows:

"No biological relevant effects were observed on survival, food consumption, body weight, or organ weights following crumb rubber exposure by any route tested. Small changes in hematology parameters were observed in crumb rubber-treated groups, but none of these changes was considered biologically meaningful."

A.2.3 USEPA Crumb Rubber Study

Expanding a previously conducted scoping-level field monitoring study on synthetic turf fields (USEPA, 2009), the United States Environmental Protection Agency (USEPA), in collaborations with the Agency for Toxic Substances and Disease Registry (ATSDR) of the Centers for Disease Control and Prevention (CDC), and the Consumer Product Safety Commission (CPSC), led a tri-agency research effort to examine the potential human health risks from playing on synthetic turf fields and playgrounds constructed with crumb rubber. In a report (Part 1) released on July 2019 (USEPA and CDC/ATSDR, 2019), USEPA presented results of physical, chemical, and microbiological characterizations of crumb rubber and described the pathways of potential human exposures on the synthetic turf fields. USEPA concluded that:

"In general, the findings from the report support the premise that while chemicals are present as expected in the tire crumb rubber, human exposure appears to be limited based on what is released into air or simulated biological fluids."

Part 2 of the tri-agency research report will cover findings on potential human exposures to crumb-rubber-related chemicals and biomonitoring of human exposures while using the synthetic turf fields. ATSDR is currently conducting the biomonitoring study.

A.2.4 Dutch Soccer Field Study

In 2016, the National Institute for Public Health and the Environment (RIVM, the Institute) of the Ministry of Health, Welfare and Sport conducted an environmental health study to evaluate human health risks of playing soccer (known as football in the Netherlands) on synthetic turf fields in the Netherlands (National Institute for Public Health and the Environment, 2017a; National Institute for Public Health and the

Environment, 2017b). The Institute sampled crumb rubber from 100 randomly selected sport fields throughout the Netherlands. They conducted solvent extractions and leaching tests to determine the chemical composition of these samples. Results of the chemical analysis showed detections of PAHs, phthalates, benzothiazoles, phenols, polychlorinated biphenyls, and metals. Additionally, the Institute performed migration studies to estimate the chemical levels released from the samples into the air, artificial sweat, or artificial gastrointestinal fluids. The Institute evaluated the chemical exposures under five scenarios (soccer players of two levels of competitiveness and in various age groups, and a lifelong exposure) and estimated "*an additional cancer risk*" of 2.2 to 3.0 per million for goalkeepers (from PAHs exposure at ages 7 to 50 years via the ingestion, dermal, and inhalation pathways). Based on results of the risk assessment and "leukaemia or lymphoma" data from the Netherlands Cancer Registry, RIVM concluded that *"there are no indications that playing football on synthetic turf results in an additional risk of leukaemia and lymphoma."*

A.2.5 ECHA Risk Assessments of Rubber Granules

Upon a request from the European Commission in 2016, the European Chemicals Agency (ECHA, an agency of the European Union) assessed the human health risks from multi-route exposures (skin contact, ingestion, and inhalation) to chemicals released from rubber granules (also known as crumb rubber) on synthetic turf fields. The agency evaluated the exposures of children and adults playing on these fields, and field installation or maintenance workers by using information primarily from studies of the Member States of European Union. Based on the concentrations of PAHs reported in these studies, ECHA concluded (European Chemical Agency, 2017) that *"there is at most a very low level of concern from exposure to recycled rubber granules."* The report also described several uncertainties in the risk assessment:

- It was difficult to control the quality of waste tires used as infill material.
- There was insufficient knowledge about the toxicity of some chemicals, e.g., phthalates.
- There was insufficient information on the amount of direct oral ingestion of crumb rubber and dermal absorption of chemicals. The assumed intake parameters and absorption factor were probably overestimating the exposures.
- There was a lack of available concentration data for metals in crumb rubber.

In 2017, the European Commission requested ECHA to conduct a follow-up assessment to examine relevant substances, except PAHs, of concern to human health and the environment from the use of plastic and rubber granulates infills on synthetic turf fields. In the report published in 2021 (European Chemical Agency, 2021), ECHA identified approximately 350 chemicals potentially present in these infill materials. They recommended further assessment of the potential impacts to human health or the environment of several chemicals: zinc, cadmium, cobalt, copper, lead, zinc, 4-tert-

octylphenol, 4,4´-isopropylidene diphenol (BPA), bis(2-ethylhexyl)phthalate (DEHP), benzyl butyl phthalate (BBP) and benzothiazole-2-thiol.

A.2.6 Washington State Cancer Cluster Investigation of Soccer Players

Since 2009, the associate head soccer coach (Amy Griffin) of the women's soccer team at the University of Washington, has been compiling a list (the coach's list) of athletes (e.g., players of soccer, fast pitch, softball, basketball, football, ultimate Frisbee, and track) diagnosed with cancer (leukemia, non-Hodgkin lymphoma, Hodgkin lymphoma, cancers in the bone, soft tissue sarcoma, or cancers in the brain, etc.) and has expressed concerns of the number of soccer goalies who developed blood cancers (EHHI, 2022) . To determine if this concern warranted further public health response, the Washington State Department of Health (WA DOH) conducted a cancer cluster investigation to compare the incidence of cancers among soccer players on the coach's list to the expected incidence of cancers by assuming the rates of cancer among soccer players were the same as those in all Washington residents and used data from the Washington State Cancer Registry (WDOH, 2017). In the report, the authors also clarified the study objectives as follows:

"Notably, this investigation is not designed to add to our understanding of the risks or benefits of crumb rubber fields or to discover the causes of cancer among the people reported to the project team. These concerns could not be addressed due to the diversity of the types of cancer, the lack of known causes for most cancer in children and young adults, little information about the potential for chemicals in crumb rubber to cause toxic exposures, and no biological or environmental testing."

The WA DOH applied the three stages of the Department of Health Guidelines for Investigating Clusters of Chronic Disease and Adverse Birth Outcomes (WA Guidelines) in this investigation. The study determined that the cancer data on the coach's list met the Stage 1 criteria—*"at least 3 cases of the same or similar conditions, or a specific exposure of concern where a potential route of exposure is alleged as the cause of the cluster."* The WA DOH, then, conducted the Stage 2 investigation of an initial assessment of the incidence of cancer cluster. The Stage 2 investigation involved setting up criteria of cases to be included in the cancer cluster investigation: the time period of cancer diagnosis (2002 to 2015), age at time of diagnosis (6 to 24 years old), and soccer playing history (played soccer while living in Washington and played at least 0.4 years before cancer diagnosis). The study compared incidence of all types of cancer, leukemia, Hodgkin lymphoma, non-Hodgkin lymphoma among soccer players with cancer diagnosis on the coach's list and the expected incidences among the criteria-matched residents of Washington The Stage 2 investigation also explored the background rate of the blood cancers in Washington and the United States and searched the literature for knowledge of the childhood leukemia and lymphoma, crumb rubber, and the potential for exposures that could lead to the increase in cancer rates. The report presented the methods and findings of the Stage 2 investigation. The

investigation found lower incidences of cancer among the soccer players on Coach Griffin's list than the expected incidences of cancer among soccer players in Washington. Although there at least three cases in each of leukemia, Hodgkin lymphoma, and non-Hodgkin lymphoma reported among the soccer players on the coach's list, results of the literature search showed that the cancer data on the coach's list did not meet the criteria for proceeding to the Stage 3 investigation (identifying all soccer players ages 6 to 24 years old diagnosed with cancer in Washington from 2002 to 2015). Because of the limited knowledge on potential toxicity and exposures to chemicals from crumb rubber, the WA DOH decided to continually monitoring new research on health and environmental impacts of crumb rubber.

A.2.7 Chemical Study from Yale University

Researchers at Yale University (Benoit and Demars, 2018) investigated the extractable chemicals of two commercially available tire-related consumer products: household shredded tire mulch and crumb rubber infill used by installers of synthetic turf sport fields. The researchers cleaned, dried at 50 °C for 2 days, and grinded the products to various particle sizes. They conducted gas chromatography mass spectrometry analysis of the dichloromethane extracts of the 60-mesh sieve (250 µm and less particles) samples. Spectral data matching against the National Institute of Standards and Technology database identified a total of 92 organic chemicals (e.g., saturated or unsaturated long-chain hydrocarbons, PAHs and their methylated derivatives, aromatic hydrocarbons, benzothiazoles, and complex high molecular weight hydrocarbons) in the extracts. Among these chemicals, the authors determined that 9 chemicals were carcinogens and 20 were irritants. For the 0.84-mm sieve samples, they measured emission of volatile organic chemicals and identified a total of 11 chemicals (e.g., moderately long-chain or slightly branched hydrocarbons, methylated benzene, phenol, cyclohexane, propionic acid derivatives). They also conducted strong acid digestion on the 0.84-mm sieve samples and quantified the amount of cadmium, lead, and zinc in the digests. Among these metals, zinc had the highest extractable levels (8.8 to 23.2 g per kg), followed by cadmium (0.16 to 1.39 mg per kg). The levels of extractable lead (2.6 to 33.1 mg per kg) were not dramatically elevated compared to its levels in earth materials. They performed a simulated acid rain extraction under elevated temperature (80°C) on the ground product samples and found zinc (the only analyte measured) in the leachates. Comparing the analytical results of the tire products, the study found a high heterogeneity in chemical composition among bags of the same tire products from the same vendor. The authors concluded that it is *"difficult or impossible to assign fixed composition to a given labeled products"* and hard to compare the results across various studies.

A.3. References

Anderson ME, Kirkland KH, Guidotti TL*, et al.* (2006). A case study of tire crumb use on playgrounds: Risk analysis and communication when major clinical knowledge gaps exist. *Environ Health Perspect* **114**: 1-3.

Beausoleil M, Price K and Muller C (2009). Chemicals in outdoor artifical turf: A health risk for users?, Montreal Health and Social Services Agency, Public Health Branch

Benoit G and Demars S (2018). Evaluation of organic and inorganic compounds extractable by multiple methods from commercially available crumb rubber mulch. *Water Air Soil Pollut* **229**(3): 64.

Birkholz DA, Belton KL and Guidotti TL (2003). Toxiciological evaluation for the hazard assessment of tire crumb for use in public playgrounds. *J Air Waste Manag Assoc* **53**(7): 903-907.

Bocca B, Forte G, Petrucci F*, et al.* (2009). Metals contained and leached from rubber granulates used in synthetic turf areas. *Sci Total Environ* **407**: 2183-2190.

Chang F-H, Lin T-C, Huang C-I*, et al.* (1999). Emission characteristics of vocs from athletic tracks. *J Hazard Mater* **A70**: 1-20.

Connecticut Academy of Science and Engineering (2010). Peer review of an evaluation of the health and environmental impacts associated with synthetic turf playing fields.

Connecticut Department of Public Health (2010). The ct dph risk assessment of artificial turf fields.

Denly E, Rutkowski K and Vetrano KM (2008). A review of the potentail health and safety risks from synthetic turf fields containing crumb rubber.

Dye C, Bjerke A, Schmidbauer N*, et al.* (2006). Measurement of air pollution in indoor aritificial turf hall. Kjeller, Norway, Norwegian Institute for Air Research, Prepared for Norwegian Pollution Control Authority.

EHHI (2022). "Artificial turf: Cancers among players." from https://www.ehhi.org/turf-cancer-stats.php.

European Chemical Agency (2017). Annex xv report: An evaluation of the possible health risks of recycled rubber granules used as infill in synthetic turf sports fields.

European Chemical Agency (2021). Annex xv investigation report: Investigation into whether substances in infill material cause risks to the environment and human health that are not adequatelycontrolled – prioritisation and preliminary risk assessment. Helsinki, Finland.

Ginsberg G and Toal B (2010). Human health risk assessment of artificial turf fields based upon results from five fields in connecticut. Hartford, Connecticut, Connecticut Department of Public Health.

Ginsberg G, Toal B and Kurland T (2011a). Benzothiazole toxicity assessment in support of synthetic turf field human health risk assessment. *Journal of Toxicology and Environmental Health, Part A: Current Issues* **74**(17): 1175-1183.

Ginsberg G, Toal B, Simcox N*, et al.* (2011b). Human health risk assessment of synthetic turf fields based upon investigation of five fields in connecticut. *J Toxicol Environ Health A* **74**(17): 1150-1174.

Gomes J, Mota H, Bordado J*, et al.* (2010). Toxicological assessment of coated versus uncoated rubber granulates obtained from used tires for use in sport facilities. *J Air Waste Manag Assoc* **60**: 741-746.

He G, Zhao B and Denison MS (2011). Identification of benzothiazole derviatives and polycyclic aromatic hydrocarbons as aryl hydrocarbons receptor receptor agonists present in tire extracts. *Environ Toxicol Chem* **30**(8): 1915-1925.

Kim S, Yang J-Y, Kim H-H*, et al.* (2012). Health risk assessment of lead ingestion exposure by particle sizes in crumb rubber on artificial turf considering bioavailability. *Environ Health Toxicol* **27**.

Lee N, Lee B-k, Jeong S*, et al.* (2012). Work environments and exposure to hazardous substances in korean tire manufacturing. *Safety and Health at Work* **3**: 130-139.

Li X, Berger W, Musante C*, et al.* (2010a). 2009 study of crumb rubber derived from recycled tires final report, Connecticut Agricultural Experiment Station, Prepared for Connecticut Department of Environmental Protection.

Li X, Berger W, Musante C*, et al.* (2010b). Characterization of substances released from crumb rubber material used on artificial turf fields. *Chemosphere* **80**: 279-285.

Lim L (2008). A study to assess potential environmental impacts from the use of crumb rubber as infill material in synthetic turf fields, New York State Department of Environmental Conservation.

Lim L and Walker R (2009). An assessment of chemical leaching, releases to air and temperature at crumb-rubber infilled synthetic turf fields, New York State Department of Environmental Conservation.

Lioy PJ and Weisel C (2011). Crumb infill and turf characterization for trace elements and organic materials, New Jersey Department of Enviromental Protection, Prepared by Environmental and Occupational Health Sciences Institute.

Llompart M, Sanchez-Prado L, Lamas JP*, et al.* (2013). Hazardous organic chemicals in rubber recycled tire playgrounds and pavers. *Chemosphere* **90**: 423-431.

Mattina MI, Isleyen M, Berger W*, et al.* (2007). Examination of crumb rubber produced from recycled tires. New Haven, Connecticut, The Connecticut Agricultural Experiment Station.

Menichini E, Abate V, Attias L*, et al.* (2011). Artificial-turf playing fields: Contents of metals, pahs, pcbs, pcdds and pcdfs, inhalation exposure to pahs and related preliminary risk assessment. *Sci Total Environ* **409**: 4950-4957.

National Institute for Public Health and the Environment (2017a). Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate. The Netherlands.

National Institute for Public Health and the Environment (2017b). Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate - scientific background document.

Nilsson NH, Feilberg A and Pommer K (2005). Emissions and evaluation of health effects of pah's and aromatic mines from tyres, Danish Environmental Protection Agency.

Norwegian Institute of Public Health and the Radium Hospital (2006). Artificial turf pitches – an assessment of the health risks for football players.

NTP (2019a). Ntp research report on synthetic turf/recycled tire crumb rubber: 14-day exposure characterization studies of crumb rubber in female mice housed on mixed bedding or dosed via feed or oral gavage. Research Triangle Park, NC, National Toxicology Program.

NTP (2019b). Ntp research report on synthetic turf/recycled tire crumb rubber: Characterization of the biological activity of crumb rubber in vitro. Research Triangle Park, NC, National Toxicology Program.

NTP (2019c). Ntp research report on synthetic turf/recycled tire crumb rubber: Feasibility study in support of non-inhalation in vivo exposures of synthetic turf/recycled tire crumb rubber. Research Triangle Park, NC, National Toxicology Program.

NTP (2019d). Ntp research report on the chemical and physical characterization of recycled tire crumb rubber. Research Triangle Park, NC, National Toxicology Program.

OEHHA (2000). Air toxic hot spots program risk assessment guidelines part iv: Technical support document for exposure assessment and stochastic analysis. Oakland, CA, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

OEHHA (2007). Evaluation of health effects of recycled waste tires in playground and track products, Office of Environmental Health Hazard Assessment,.

OEHHA (2010). Safety study of artificial turf containing crumb rubber infill made from recycled tires: Measurements of chemicals and particulates in the air, bacteria in the turf, and skin abrasions caused by contact with the surface, Office of Environmental Health Hazard Assessment.

Pavilonis BT, Weisel CP, Buckley B*, et al.* (2014). Bioaccessibility and risk of exposure to metals and svocs in artificial turf field fill materials and fibers. *Risk Anal* **34**(1): 44-55.

Ruffino B, Fiore S and Zanetti MC (2013). Environmental–sanitary risk analysis procedure applied to artificial turf sports fields. *Environmental Science and Pollution Research* **20**(4980-4992).

Savary B and Vincent R (2011). Used tire recycling to produce granulates: Evaluation of occupational exposure to chemical agents. *Ann Occup Hyg* **55**(8): 931-936.

Simcox N, Bracker A and Meyer J (2010). Artificial turf field investigation in connecticut final report.

Simcox NJ, Bracker A, Ginsberg G*, et al.* (2011). Synthetic turf field investigation in connecticut. *Journal of Toxicology and Environmental Health, Part A: Current Issues,* **74**(17): 113301149.

Swedish Chemicals Inspectorate (2006). Synthetic turf from a chemical perspective – a status report.

USEPA (2009). A scoping-level field monitoring study of synthetic turf fields and playgrounds, U.S. Environmental Protection Agency.

USEPA and CDC/ATSDR (2019). Synthetic turf field recycled tire crumb rubber research under the federal research action plan final report: Part 1 - tire crumb characterization (volumes 1 and 2), U.S. Environmental Protection Agency, Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry.

Vetrano KM (2009). Air quality survey of synthetic turf fields containing crumb rubber infill. Windsor, Connecticut, TRC, Prepared for New York City Department of Health and Mental Hygiene.

WDOH (2017). Investigation of reported cancer among soccer players in washington state, Washington State Department of Health.

Zhang JJ, Han IK, Zhang L*, et al.* (2008). Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids. *J Expo Sci Environ Epidemiol* **18**(6): 600-607.