A STUDY TO ASSESS POTENTIAL ENVIRONMENTAL IMPACTS FROM THE USE OF CRUMB RUBBER AS INFILL MATERIAL IN SYNTHETIC TURF FIELDS

Prepared by Ly Lim, Ph.D., P.E.
Environmental Engineer
Bureau of Solid Waste, Reduction & Recycling
Division of Solid & Hazardous Materials
New York State Department of Environmental Conservation

June 17, 2008

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This study would have not been started without the support of Ed Dassatti, Director of the Division of Solid & Hazardous Materials (SHM), and the assistance and cooperation of so many people in and outside of the SHM Division at DEC.

Special thanks to Jeff Schmitt, Sally Rowland and Michael Caruso for their guidance and support and thanks to the Division chemists, especially to Pete Furdyna who will perform the column leaching test at the DEC laboratory. Many thanks to John Thompson and Dave Kiser of the DEC Region 8 office; Arturo Garcia-Costas, Robert Elburn, Paul John and their staff of the DEC Region 2 office for their assistance in the search for suitable sites for actual field monitoring programs.

I specifically acknowledge the assistance of Thomas Gentile, Randi Walker and Dirk Felton on air issues from Division of Air Resources; Scott Stoner and Shohreh Karimipour on water quality issues from Division of Water; and Timothy Sinnott from Division of Fish, Wildlife & Marine Resources. I thank Dr. Daniel Luttinger, Kevin Gleason and Dr. Thomas Wainman of the NYS Department of Health; Dr. David Carpenter of the State University of New York at Albany; Dr. Dana Humphrey of University of Maine; Dr. Robert Pitt of University of Alabama; and Dr. Simeon Komisar of Rensselaer Polytechnic Institute for their valuable input to the proposed study.

Special thanks to James Gilbert of the Empire State Development for all his assistance in the project. Finally, I thank the managers and staff of four scrap tire processing facilities across New York State, who greeted us warmly and provided all samples of crumb rubber needed for this study.

I. INTRODUCTION

Crumb rubber, also referred to as ground rubber, is finely ground rubber derived from recycled tires or scrap tires. Over 20 million scrap tires are generated annually in New York State (NYS). The R.W. Beck consulting firm estimated that in 2004, about 22.5 percent of NYS generated scrap tires were used to produce ground rubber (*1*). Ground rubber and ground rubber products derived from scrap tires have a wide range of customers, both inside and outside NYS, including: molded product producers, schools, sports stadiums, landscape firms, road construction firms and new tire manufacturers. Growth in ground rubber production is largely centered on the mulch products, playground materials, and sports fields markets. Crumb rubber with a size typically less than 1/16 inch is used as an infill material on synthetic turf fields to cushion the playing surface. Stated benefits over natural grass fields include reduced water needs and maintenance, avoided need for pesticides, herbicides or fertilizer, reduced injuries, and an "all-weather" playing surface. Out of the 850 artificial turf fields in the United States, NYS has about 150 fields (*2*).

Many governmental bodies including Norway, Sweden and California have recently reviewed the health issues associated with the use of crumb rubber as infill at playgrounds and synthetic turf fields. Their assessments did not find a public health threat (*3*). However, several recent preliminary studies by Crain et al. (*4*), Mattina et al. (*5*) and RAMP (*6*) indicated the presence of organic compounds, such as polycyclic aromatic hydrocarbons (PAH) and heavy metals, such as zinc, and raised concerns that these substances could have potential adverse impacts on the environment and public health, especially for children playing on these synthetic turf fields for extended time periods. On November 5, 2007, NYS Assembly member Englebright introduced a bill that would require a study of the environmental and health impacts of artificial turf and prevent installation of artificial turf until a study is completed (*7*). A week later, a similar bill was introduced by NYS Senator Jim Alesi (*8*). Under Environmental Conservation Law, § 27-1901 (ECL), crumb rubber is not considered a solid waste and therefore its use is not regulated as a solid waste under the DEC solid waste regulations or the ECL. However, to address these concerns, the DEC has initiated a study to assess the potential environmental impacts from the use of crumb rubber as an infill material in synthetic turf fields and to collect data that would be relevant for a public health and environmental assessment.

II. OBJECTIVES

1. Carry out a literature review to determine what information and data already exists relative to crumb rubber use in synthetic turf fields.
2. Design and implement a study to quantify the release of metals and organics from crumb rubber under various conditions, such as acid rain and extreme heat conditions, by laboratory, as well as actual field measurements.
3. Provide leaching and off-gassing data that may be useful for a public health and environmental assessment.
4. Collect surface temperatures and measures of heat stress.

III. OUTPUT

A written report that summarizes the leaching and off-gassing data gathered from both laboratory and field measurements. Based on the evaluation of leaching data, propose measures needed (if any) that could be used to mitigate potential environmental impacts, such as potential risk posed to water quality resulting from the drainage/runoff discharged from turf fields using crumb rubber as an infill material. The off-gassing (gas and particle release data), temperatures and measures of heat stress can be used to assess potential public health impacts. The report is scheduled to be completed by December 31, 2008.

IV. LITERATURE REVIEW AND ASSESSMENT

A brief literature review was done to assess existing data on environmental impacts of crumb rubber used as an infill material in synthetic turf fields. As the study progresses, any other relevant literature that is found will be evaluated. This literature review includes studies posted on the internet, newspaper articles, and even nontraditional sources such as literature from the rubber industry. A brief data summary for some studies is listed in the Appendix.

The following observations and needs for additional study are based on a review of the referenced studies.

1. Many organic compounds such as PAHs, and heavy metals such as zinc can leach from the crumb rubber that is used as an infill material at synthetic turf fields. Studies from France (9), Norway (*10,11,12*) and Canada (*13*), however, indicate that the concentrations are low for the majority of these leaching compounds and only local impacts are observed. Therefore, these studies conclude that the use of crumb rubber at a turf field results in minimal hazard to the receiving environment. On the other hand, based on leaching tests, a Dutch study (*14*) concludes that three substances: 4-t-octylphenol, copper and zinc exceed their surface water standards and, therefore, the untreated drainage water coming from artificial turf fields must not be discharged directly into surface water.

   <u>DEC suggestion</u>: Since local conditions and standards vary among countries, or even between states, it is prudent that further study be carried out to determine if and to what degree these substances would leach from the crumb rubber under various conditions. To ensure adequate protection for the environment, a realistic worst-case scenario should be developed and investigated.

2. The concentrations of the substances of concern reported in the literature vary greatly. The analytical test method used is one of several reasons for such variation. Some studies, Crain et al. (*4*) for example, use organic solvents to extract organic compounds from the crumb rubber. The method provides total concentrations, which would likely overestimate the actual release of the substances for this use of crumb rubber. Other studies, such as Mattina et al. (*5*), use more realistic leaching/off-gassing test methods. This study uses a leaching

test under acid rain conditions, and off-gassing measurement at an extreme heat condition. The Mattina et al. study (*5*), however, uses only a few grab samples to produce a preliminary report on the concentrations of the leaching compounds from crumb rubber.

DEC suggestion: A crumb rubber testing program with a larger sample size is suggested to ensure high quality data.

3. The Norwegian Institute for Water Research study (*11*) indicates that the ground rubber showed considerable variation in the chemical composition. This is most likely due to differences in the processing technology or different types of tires. In fact, at a scrap tire processing facility, it is difficult and impractical to separate waste tires and tire chips by tire manufacturer. There are two major types of crumb rubber manufacturing processes: ambient and cryogenic grinding. Ambient grinding occurs at room temperature when tire chips are finely ground to desired particle sizes. In the cryogenic grinding process, whole tires first are reduced to tire chips of approximately 3-inch size. These chips are then frozen using liquid nitrogen at -195 ^{o} C (-319^{o} F). Freezing converts the rubber to a brittle, glassy state in which it is easily shattered into tiny smooth-sided particles and separated from any adhering wire or fabric (*15*). Crumb rubber is also generated from different types of tires, such as car and truck tires, which have shown to have different leaching potential as reported in a Dutch study (*16*).

DEC suggestion: A study on the leaching potential of different types of crumb rubber is warranted.

4. A Canadian study (*13*) concludes that the use of ground rubber in playgrounds has insignificant impacts on the environment, because adverse impacts disappeared with aging of the tire crumb after three months in place in the playground. However, the Norwegian Institute for Water Research study (*11*) indicates that zinc poses a significant local risk to surface water, which receives runoff from the artificial turf. The concentrations of chemicals in the runoff were predicted in this study to decrease slowly so that environmental effects may occur over many years. A Dutch study (*16*) found that the concentration of zinc increases over time.

DEC suggestion: The contradictory results between these studies warrant an investigation on the aging effect of the crumb rubber.

5. Among the metals shown to leach from the crumb rubber in this literature review, zinc is an element of concern because of its highest concentration in the leachate (*5*). Zinc is added in the tire manufacturing process to strengthen the rubber. The zinc concentration in ground rubber is about 1.5% (*15*). Recent samples of crumb rubber tested display a range of 1.1 - 1.7% zinc (*4*). Although zinc is essential for plant growth, runoff with high zinc concentration may increase the potential for zinc toxicity (*17*). According to a Dutch study (*16*), the leaching rate of zinc from crumb rubber is up to 20 times greater than local leaching of zinc from agricultural applications of manure and pesticides. This study concludes that although human health risks posed by leaching of zinc are

negligible, it can present significant environmental risks, particularly for aquatic life.

DEC suggestion: Zinc's leaching potential and its effect on surface or ground water quality should be examined.

6. Heat effect is one of the emerging concerns associated with the use of crumb rubber at synthetic turf fields. Volatile organic compounds (VOCs) can be off-gassed from the crumb rubber, especially in an extreme heat condition which results in a very high surface temperature at these fields. In June 2002, researchers at Brigham Young University (BYU) in Utah reported that the hottest surface temperature recorded on the synthetic turf field was 200^o F (93^o C) on a day when air temperature was 98^o F (*18*). The University of Missouri turfgrass specialist, Dr. Brad Fresenburg, found that on a 98^o F day at the University's Faurot Field, the surface temperature on the synthetic field was 173^o F, while the nearby natural turf grass showed a temperature of 105^o F (*19*). In central Pennsylvania, researchers at Penn State University recorded surface temperatures at different brands of synthetic turf fields on separate occasions in 2003 and 2004. The highest temperature range of 128.8 – 160.7^o F was recorded on August 3, 2004 (*20*). Researchers at Columbia University showed that surface temperatures of synthetic turf fields in New York City could reach 160^o F on summer days (*21*). Therefore, it is reasonable to use 160^o F as a worst-case scenario for New York State. At this high temperature, some researchers consider it unsafe for children to be playing on these fields (*22*). Mattina et al. (*5*) used 60^o C (140 ^{o} F)

as a reasonably high temperature for its off-gassing study. However, the Norwegian study (*12*) used 70^{o} C (158 ^{o} F) in its off-gassing as a worst case for the risk assessment.

<u>DEC suggestion:</u> Off-gassing at several temperature levels, including a reasonable worst-case scenario for New York State should be evaluated. Also, the heat stress issue at turf fields should be investigated.

7. Some studies argue that the real impacts on the environment cannot be determined by utilizing laboratory tests and that actual field measurements should be carried out (*23*). For example, the Norwegian study (*10*) used actual field measurements of VOCs for its risk assessment, instead of laboratory test results.

<u>DEC suggestion</u>: To get a complete picture for this use of crumb rubber, in addition to laboratory testing, actual measurements of the substances of concern at the existing fields should be carried out.

8. A Norwegian study (*10*) found airborne particulate matter (PM) in three indoor stadiums that use crumb rubber infill. At one field, 30% of the PM_{10} fraction and 50% of the $PM_{2.5}$ fraction was rubber dust.

<u>DEC suggestion:</u> In addition to VOCs, and semi-volatile organic compounds (SVOCs), the potential presence of particulate matter such as $PM_{2.5}$ and PM_{10} above the synthetic turf fields should be investigated.

V. DEC PROPOSED STUDY

Based on the above assessment and objectives, the DEC study is designed to address three major issues: leaching of SVOCs and metals from the crumb rubber under acid rain conditions, off-gassing of VOCs under different temperature levels, and heat effect. The DEC study consists of five monitoring programs as follows:

A. LABORATORY ANALYSIS OF CRUMB RUBBER SAMPLES.

- Objective: Collect and analyze different types of crumb rubber currently processed in NYS for use as an infill at synthetic turf fields and quantify the release of metals and organics (both through leaching and off-gassing) under various conditions, including the worst-case scenarios.

- Sample collection: Unused samples of crumb rubber are collected at four scrap tire processing facilities in NYS with a production rate ranging from 0.5 to 10 million pounds of crumb rubber per month. Four different types of crumb rubber are anticipated at these facilities: ambient ground car tires, ambient ground truck tires, ambient ground mixed (car and truck tires), and cryogenic mixed crumb rubber. A total of about 30 samples of crumb rubber are randomly collected for the above four types of crumb rubber.

- Laboratory: All analyses will be carried out by a DEC contract laboratory, which is certified by the NYS Department of Health Environmental Laboratory Approval Program (ELAP).

- Test methods and test parameters for leaching and off-gassing analyses:

1) Leaching Test: The Synthetic Precipitation Leaching Procedure (SPLP) method is used to determine any SVOCs, including rubber related compounds such as benzothiazole, and 23 metals, including arsenic, cadmium, chromium, copper, lead,

mercury, vanadium, zinc, etc., leaching from the crumb rubber under an acid rain condition. The test method for SPLP is EPA SW-846 Method 1312 (*24*). This is an EPA standard method, which involves the mixing of 50 grams crumb rubber in one liter of acidic water at pH 4.2 while the solution is agitated for 18 hours. After the agitation period, the leachate is filtered and tested for SVOCs, rubber related compounds and 23 metals. This method would provide a worst case scenario for two reasons: a) the method pH 4.2 is slightly lower (more acidic) than the pH of rain water recorded in NYS which runs from 4.35 to 4.76 (DEC data); and b) the method includes 18 hours of agitation, while in practice, crumb rubber is tightly packed as an infill and not really being agitated. Therefore, this method may overestimate the release of compounds of concern, but will be useful to compare the release rates for different types of crumb rubber. To determine if the release rate is changing over time, a second SPLP test on the same sample will be carried out.

2) Off-gassing test: The EPA Method TO 15 Headspace approach (*25*) is used to determine any VOCs coming off from the crumb rubber at three different temperature levels: 20 ^{o}C (68 ^{o}F), 47^{o}C (117^{o} F) and 70 ^{o}C (158 ^{o}F). The 20 ^{o}C (68 ^{o}F) represents a temperature for an indoor field. The 47^{o}C (117^{o} F) is an average surface temperature recorded in the BYU study (*18*) for an outdoor field. Finally, the 70 ^{o}C (158 ^{o}F) is considered the realistic worst-case scenario for New York State. The test method TO 15 is a modification of the standard technique and used to evaluate the VOCs released when the crumb rubber is heated to the above specified temperatures in 50 minutes.

B. LABORATORY EXTENDED LEACHING ANALYSIS

- Objective: Determine a more realistic rate of organics and metals leaching from the crumb rubber over time by using a laboratory column test.

- Method: In this test, unused crumb rubber obtained from manufacturers is subject to intermittent synthetic rainfall. Percolate samples are collected and analyzed for metals and SVOCs after 18, 24, 30 and 36 inches of total synthetic rain, simulating one year of atmospheric exposure, based on actual pH monitoring data for NYS. Based on the results of Part A sampling program, tests may be conducted for ambient or cryogenic ground crumb rubber. The scope of work may be adjusted or finalized after analytical results of the contract laboratory crumb rubber sampling program (Program A) are available. This project will be conducted by DEC staff at the DEC laboratory. DEC staff will collect the samples and send them to an ELAP certified laboratory, the same laboratory used in Program A, for analysis.

C. WATER QUALITY MONITORING AT EXISTING FIELDS

- Objective: Collect water samples from the drainage pipes at the turf fields using crumb rubber as an infill material and investigate the presence of any metals and organic compounds. The concentration of these compounds will be compared with the NYS surface and ground water quality standards.

- Site selection: Two turf fields will be selected. One is a newer field, where the synthetic turf has been in use for no more than one year. The other is an older field (3-4 years old). A nearby natural grass field will also be selected for each turf field to be used for comparison purposes. The different ages of the turf fields will provide information concerning the aging effect of the crumb rubber. Each turf field should have a drainage discharge pipe, or a location where runoff samples can be collected. At a natural grass field, drainage pipes are not common. A site-specific device/method will be established to collect water runoff from a natural grass field.

- Turf field drainage system: There is no standard design for the drainage system at a turf field (*20*). In general, a drainage system is designed at each field to handle heavy rainfall events and includes collection of rainfall runoff and rainfall that percolates through the crumb rubber. Our objective is to sample only the rainfall that passes through the crumb rubber. This would provide a conservative estimate for impact on ground and surface water quality without significant dilution from runoff. Depending on the quality of the percolate in this monitoring program, further investigation of groundwater impact may be warranted.

- Test parameters: SVOCs, rubber related compounds and 23 metals including arsenic, cadmium, chromium, copper, lead, mercury, vanadium, zinc, etc.

- Sample collection: The timing of sample collection is important to ensure that a conservative estimate of runoff quality is obtained. During a heavy rainfall, the drainage water is largely diluted with overflow runoff. Therefore, the samples should be collected after the first flush and without evidence of overflow dilution. At each field, three representative runoff samples (total event composite) will be collected for each rainfall event. Three runoff samples will also be collected at the adjacent natural grass field, for comparison purposes. A complete sampling activity consists of at least three rainfall events. Runoff samples will be collected by DEC staff, or contract lab employees and sent to an ELAP certified laboratory for analysis. A detailed sampling protocol will be developed prior to sampling activities.

- Sample analysis: All analyses will be carried out by an ELAP certified laboratory.

- Other information, such as the type of crumb rubber installed, the crumb rubber loading rates and the design of the drainage system, if available, will be collected for each field.

D. AIR QUALITY MONITORING SURVEY AT TWO EXISTING FIELDS.

A comprehensive field air quality assessment would require sampling over a significant time period, including all of the seasons in which the fields are actively used. Therefore, this initial air quality monitoring survey will be performed to determine if VOC, SVOC, and, if feasible, particle emissions from the field surfaces are significant in relation to background air quality. The samples will be collected in the summer when temperatures are over 80 ^{o}F and the VOC and SVOC emissions are expected to be higher than other times of year. Any VOC and SVOC emissions from the playing field surface are expected to be relatively small in relation to industrial and mobile source emissions. Therefore, a flux chamber will be included to provide data that may be indicative of the potential for VOC and SVOC emissions from the playing fields. The use of a flux chamber will provide information that may help to interpret the planned ambient air sampling data. The results of this survey will be used to inform the need for further sampling.

- Objective: Determine if the potential emissions of VOCs and SVOCs from synthetic turf fields, using crumb rubber as an infill material, are significant enough to warrant a more extensive study. Assess the size distribution of particulate matter on the surface of these fields and, if feasible, measure ambient particulate concentrations.

- Site selection: Two turf fields will be selected by DEC. One is a newer field, where the synthetic turf has been in place for no more than one year. The other is an older field

(3-4 years old). The different ages of the fields may provide information concerning the relationship between the age of the field and amount of emissions from the synthetic surface, however a number of other factors, such as field use and condition, may also contribute to emissions from synthetic turf.

- Test parameters: VOCs and SVOCs (including rubber-related compounds such as benzothiazole), metals and particulate matter ($PM_{2.5}$ and PM_{10}). A target list of analytes will be developed when the off-gassing data from the laboratory study (Program A) are available.

- Sample collection: Three samples will be collected for VOCs and SVOCs on each field using a flux chamber in areas of the field selected that show different amounts of wear. The flux chamber sample will utilize a slight vacuum to increase the release of potential pollutants. The internal temperature of the flux chamber and the external field temperature near the flux chamber will be recorded. Simultaneous ambient air samples will be collected for VOCs and SVOCs above the flux chamber. These samples will be collected at a height of 3 to 5 feet above the field surface to be representative of a breathing zone. The feasibility of measuring ambient particulate matter on and away from the field will also be evaluated. If ambient particulate matter sampling is performed, those samples will be collected under conditions of actual or simulated field use. Background monitoring will also be performed to compare to field ambient air measurements since many of the constituents in crumb rubber are also present in urban air and soils. In order to determine the metal constituents of the particles and whether the particle size would be in the respirable size fraction, wipe samples and microvacuum filter samples will be collected from the surfaces at locations adjacent to the flux chamber sample collection. These samples will not be used to estimate ambient concentrations, but will be used to help inform judgments about turf athletic fields being a source of particulate matter. The particles collected with wipe samples and microvacuum filters will be analyzed by microscopy to determine relative size and metal constituents. The sampling time for the ambient measurements will be determined when a sampling protocol is prepared. Any contractual work will require a detailed sampling protocol which will be approved by DEC before any sampling activities. Any independent laboratory work will be performed by an ELAP certified laboratory.

- Weather conditions: Samples will be collected from two fields on warm and rather calm days (low wind) when the ambient temperature is at least 80^{o}F with no precipitation, and having significant direct sunlight.

E. TEMPERATURE SURVEY

A survey of temperatures at crumb rubber infilled synthetic turf fields will be performed. The goal of this survey is to provide data to help characterize temperature conditions at these kinds of turf fields during the warmer months of the year. Two kinds of temperature measurements will be taken. Surface temperature of synthetic fields will be recorded using an infrared thermometer. Also, a field-level heat stress measure will be taken using the most widely used index of heat stress, the Wet-Bulb Globe Temperature (WBGT). The data on the WBGT index provides the opportunity to evaluate the potential for heat stress during use of synthetic turf fields. Temperature measurements will be taken at different times during the day, during the summer and possibly early fall. Both kinds of temperature measurements will be made on the turf field and at an adjacent area of natural grass. We anticipate that these measurements will be taken at the same turf fields at which the air quality monitoring survey will be performed, but additional turf fields located elsewhere in the state may also be included in the temperature survey. A detailed temperature measurement plan for turf fields will be developed and approved prior to actual field measurements.

Among the above five monitoring programs, the sampling work plan for Program A (sample analysis) is complete. Detailed sampling work plans are being developed for other programs B (column leaching test), C (water sampling), D (air survey), and E (temperature survey). DEC is in the process of selecting representative sites for actual field measurements. Most of the field measurements will be carried in the summer and fall. The DEC study is expected to be completed by the end of this year.

VI. REFERENCES

(1) R.W.Beck, Inc. (2006), "Analysis of New York Scrap Tire Markets: 2006 Update". Available online at: http://www.nylovesbiz.com/pdf/pollution_prevention_recycle/tires_update2006.pdf. Accessed on 12/10/07.

(2) UCHC (2007), "Artificial Turf Full of Toxins That Can Cause Cancer", University of Connecticut Health Center News, Available online at: http://www.uchc.edu/ocomm/newsarchive/news07/nov07/toxins.html. Accessed on 12/10/07.

(3) CTDPH (2007), "Fact Sheet", Connecticut Department of Public Health, Environmental & Occupational Health Assessment Program. October 2007. Available online at: http://www.ct.gov/dph/lib/dph/environmental_health/pdf/artificial_turf_(2).pdf . Accessed on 12/10/07.

(4) Crain, William and Zhang, J. (2006), "Hazardous Chemicals in Synthetic Turf (Revised)", Rachel's Democracy & Health News #873, September 21, 2006. Available online at: http://www.precaution.org/lib/06/prn_toxins_in_synthetic_turf_rev.060921.htm. Accessed on 12/10/07.

(5) Mattina, M.I.; Isleyn, M.; Berger, W.; Ozdemir, S. (2007), "Examination of Crumb Rubber Produced From Recycled Tires", The Connecticut Agricultural Experiment Station, New Haven, CT. Available online at: http://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/examinationofcrumbrubberac005.pdf. Accessed on 12/10/07.

(6) RAMP (2007), "Synthetic Turf Chemicals". Rochesterians Against the Misuse of Pesticides. October, 2007. Available online at SUNY website at http://www.albany.edu/ihe/SyntheticTurfChemicalsdar.htm. Accessed on 12/10/07.

(7) NCEL (2007), "NY Assemblymember Englebright's Bill Would Require Study Health Impacts of Artificial Turf", National Caucus of Environmental Legislators, November 5, 2007. Available online at: http://ncel.net/newsmanager/news_article.cgi?news_id=181. Accessed on 12/10/07.

(8) Jim Alesi (2007), "Senator Alesi introduces legislation to assess the health and environmental impacts of synthetic turf." Available online at: http://www.senatoralesi.com/press_archive_story.asp?id=18264. Accessed on 12/17/07.

(9) Moretto, Robert (2007) "Environmental and health evaluation of the use of elastomer granulates (virgin and from used tyres) as filling in third generation artificial turf". http://www.aliapur.fr/media/files/etudes_documents/Environmental_Study_Report_EN.pdf. Accessed on 12/14/07.

(10) Norwegian Institute of Public Health and the Radium Hospital (2006), "Artificial turf pitches – an assessment of the health risks for football players", Oslo, January 2006. http://www.isss.de/conferences/Dresden%202006/Technical/FHI%20Engelsk.pdf.

(11) Norwegian Institute for Water Research (2005), "Environmental Risk Assessment of Artificial Turf Systems." December 19, 2005. http://www.isss.de/conferences/Dresden%202006/Technical/NIVA%20Engelsk.pdf

(12) Plesser, Thale (2004), "Potential health and environmental effects linked to artificial turf systems – Final report", Norwegian Building Research Institute, Oslo, September 10, 2004. Available online at: http://www.isss.de/conferences/Dresden%202006/Technical/NBI%20Engelsk.pdf.

(13) Birkholz, D.A., Belton, K.L., Guidotti, T.L., "Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds:, Journal of Air & Water Management Association, Vol. 53, July 2003.

(14) Dutch National Institute for Public Health & the Environment (2006), "Answers to Questions on Harmful Substances in Artificial Turf Fields", Public Health, Social Welfare & Sport, June 22, 2006.

(15) Snyder, Robert. H. (1998), "Scrap Tires: Disposal and Reuse:, Society of Automotive Engineers, Inc., Warrendale, PA.

(16) Verschoor, A.J. (2007), "Leaching of Zinc from rubber infill in artificial turf (football pitches)", RIVM Report 601774011/2007. Available online at: http://demo.openrepository.com/rivm/bitstream/10029/11459/1/601774001.pdf. Accessed on 12/14/07.

(17) Tucker, M.R. (1997), "Ground Rubber: Potential Toxicity for Plants", North Carolina Department of Agriculture & Consumer Services, Media Notes for North Carolina Growers, April 1997. Available online at: http://www.ncagr.com/agronomi/pdffiles/rubber.pdf. Accessed on 12/14/07.

(18) Williams, C. F. and Pulley, G.E. (2002), "Synthetic Surface Heat Studies". Available online at cahe.nmsu.edu/programs/turf/documents/brigham-young-**study**.pdf. Accessed on 2/11/08.

(19) Adamson, C. (2004), "Synthetic Turf Playing Fields Present Unique Dangers". Available online at: http://cafnr.missouri.edu/research/turfgrass.php Accessed on 2/11/08.

(20) McNitt, A.S. and Petrunak, D. "Evaluation of Playing Surface Characteristics of Various In-Filled Systems". Available online at: http://cropsoil.psu.edu/mcnitt/infill.cfm. Accessed on 2/11/08.

(21) Claudio, L. (2008) "Synthetic Turf: Health Debate Takes Root", Environmental Health Perspectives, Volume 116, Number 3, March 2008. Available online at: http://www.ehponline.org/members/2008/116-3/focus.html. Accessed on 4/7/08.

(22) Mount Sinai Children's Environmental Health Center (2007), "What to Know About Turf fields", Children's Environmental Health Center, email address info@cehcenter.org – Phone (212) 241-6145.

(23) Kolitzus, Hans J. (2006) "Investigation and Assessment of Synthetic Sports Surfaces in Switzerland Including Athletic and Soccer Facilities", http://isss.de/conferences/Dresden%202006/Technical/HJK%20Schweiz.pdf. Accessed on 12/14/07.

(24) USEPA – Method 1312. "Test Method for Evaluating Solid Waste, physical/chemical method – Synthetic Precipitation Leaching Procedure", US Agency for Environmental Protection. Available online at: http://www.epa.gov/sw-846/1_series.htm. Accessed on 12/14/07.

(25) USEPA (1999) Method TO 15, "Determination of Volatile Organic Compounds (VOCs) In Air Collected In Specially-Prepared Canisters and Analyzed by Gas

Chromatography/Mass Spectrometry (GC/MS)", US Agency for Environmental Protection. EPA/625/R-96/010b. Available online at: http://www.epa.gov/ttnamti1/airtox.html. Accessed on 12/14/07.

VII. APPENDIX - DATA SUMMARY FROM LITERATURE REVIEW

Data Summary	***References***
1. Preliminary Chemical Constituent Analysis for samples from New York City fields. Organics were extracted with organic solvents (unit: mg/kg) PAHs — Sample 1 — Sample 2 Benzo(a)anthracene — 1.23 — 1.26 Chrysene — 1.32 — 7.55 Benzo(b)fluoranthene — 3.39 — 2.19 Benzo(a)pyrene — 8.58 — 3.56 Benzo(k)fluoranthene — 7.29 — 1.78 Dibenzo(a,h)anthracene — 3.52 — 1.52 - Study conclusion: PAHs exceeding DEC's tolerable levels are at hazardous levels, and it is a cause for concern.	(4) Crain et al. (2006)
2. To perform off-gassing and leaching tests on crumb rubber samples collected at existing synthetic fields: * Vapor phase concentrations of compounds off-gassed (60 ^{0}C) Compound — ng/mLair/g tire Benzothiazole — 866.72 Hexadecane — 6.04 4-(tert-octyl)-phenol — 21.63 Butylated hyroxyanisole — 53.32 * Elements leached into water by Synthetic Precipitation Leaching Procedure (SPLP method) Element — In water (ug/kg tire) — Acidic water (pH 4.2) Zn — 20,957 — 55,010 Se — 246 — 260 Pb — 1.85 — 3.26 Cd — 0.07 — 0.26 - Study conclusion: under relatively mild conditions of temperature and leaching solvent, components of crumb rubber are leached into water and off-gassed. Further studies are warranted under both laboratory and field conditions.	(5) Mattina et al. (2007). (EHHI study)

3. Total analysis results. PAHs (mg/kg) Chrysene ND (2-25) - 3.8 Fluoranthene ND (.167) - 15.9 Pyrene 10.7 - 28.3 PHTHALATES (mg/kg) DEHP 10.8 - 203 Diethyl phthalate ND (3.36 - 25) - 3.1 VOCs (mg/kg) Acetone 0.84 – 1.45 Carbon disulfide 0.39 – 0.53 Chloroform ND (0.17) – 0.73 Ethylbenzene ND (0.17) – 0.34 Methylene chloride ND (0.15) – 0.29 4-methyl-2-pentanone 0.34 – 11.40 Tetrachloroethene 0.012 – 0.02 Toluene ND (0.17) – 0.02 Xylene ND (0.17) – 0.13 METALS (mg/kg) As ND (0.47 – 0.58) – 1.01 Cd ND (0.49 – 0.58) – 0.62 Cr ND (0.93 – 1.15) – 1.52 Pb 3.81 – 67.20 Zn 10,600 – 17,000	(6) RAMP study (2007)
4. a. Leaching study - using lysimeters with rain water and drinking water: - 15 kg/m2 (3.1 lb/ft2) crumb rubber - with rain water, percolate pH range: 7.1 – 7.85. - with drinking water, percolate pH range: 7.3 – 8.5. - concentrations of PAHs and metals are low, meeting French & EU standards. - certain elements have a very rapid decrease in release rates. b. Off-gassing study at 23^{o} C (73^{o} F) - emissions from crumb rubber are low (total VOCs = 134 ug/m3 at 28 days) - Study conclusion: no impacts in the short and medium term.	(9) Moretto Robert (2007) (French study)

5. To study air quality for indoor football fields by measuring concentration of VOCs (about 20^o C) - 234 chemical compounds were found (conc. > 0.1 ug/m3, of which 29 were identified). - total VOCs = 716 ug/m3 with ventilation on (est. 1000 ug/m3 without ventilation). - particulate matter PM10 = 31 - 40 ug/m3 and PM2.5 = 10-19 ug/m3 in three fields. - Study conclusion: crumb rubber contains chemicals that are potentially harmful to health. The concentrations of these substances are however extremely low and only present in low concentrations in the hall air. Concentrations > 2.0 ug/m3 of VOC (unit = ug/m3) toluene …………………………… 15.3 – 85.0 butenylbenzene (isomers) ……….. 82.5 benzoic acid……………………… 19.3 – 81.0 diethenylbenzene (isomers)………. 65.7 p- and m-Xylene…………………. 9.6 – 25.5 ethylbenzene aldehyde (isomers).... 34.7 benzothiazone……………………. 15.7 – 31.7 biphenyl…………………………... 15.6 acetone…………………………… 9.5 – 15.3 o-Xylene…………………………. 13.1 4-methyl-2-pentanone……………. 12.7 3-phenyl-2-propenal………………10.2 pentenylbenzene ((isomers)………. 7.3 pentanedioic acid dimethyl ester… 6.8 ethylbenzene……………………… 3.3 – 6.7 styrene……………………………. 3.2 – 6.1 hexenylbenzene (isomers)……….. 15.5 ethylcyclohexane………………… 5.6 formaldehyde……………………. 5.5 – 6.5 2-butoxyethanol…………………. 5.3 unidentified naphthalene derivative 9.3 octane…………………………….. 4.6 undecane…………………………. 3.1 – 4.6 acetaldehyde………………………2.9 – 4.3 nitromethane ……………………. 4.1 1-propylbenzene………………… 4.0 alpha-pinene……………………..10.5 cyclohexanone…………………... 9.8 junipene…………………………. 7.2 acetic acid……………………….. 4.3 decane………………………….. 5.0	(10) Norwegian Institute for Public Health and the Radium Hospital (2006)

dodecane………………………… 3.7 1,2,3-trimethylbenzene………….. 3.2 limonene………………………… 2.6 2-methylnaphthalene……………. 2.5 Benzene…………………………. 2.4 3-carene…………………………. 2.2 Pentadecane……………………... 2.2 2,3-dihydro-1,1,3-trimethyl- tri-phenol-1H-idene……………... 2.1 hexanal…………………………... 2.0 1,2-propanediol………………….. 2.0 1-methoxy-2-propanol……………2.0	
6. To study runoff quality from artificial turf fields. - the studies of rubber granulates based on recycled rubber showed considerable variation in the chemical composition. - zinc poses a significant local risk of environmental effects in surface water, which receives run-off from artificial turf. - the concentrations of alkylphenols and octylphenol exceed the limits for environmental effects in the scenario which was used. – the concentrations of chemicals in run-off from artificial turf are predicted to decrease slowly so that environmental effects may occur over many years. - Study conclusion: total quantities of hazardous substances, which are leached out into water are relatively small, so that only local effects can be anticipated.	(11) Norwegian Institute for Water Research (2005)
7. To perform total analysis, leaching test and off-gassing on crumb rubber. - chemical composition of products from a single manufacturer can vary considerably, but products from two different manufacturers can also show great similarity. - total concentration of lead, cadmium, copper and mercury is below the Norwegian pollution control authority’s standards for most sensitive land use and probably does not constitute an unacceptable environmental risk in the short or the long term. - an expanded risk assessment with changes in leaching properties over time is necessary to determine the degree to which the concentration of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols are actually harmful to people and the environment. - recycled rubber granulates give off a significant number of alkylated benzenes in gaseous form. - actual air quality monitoring above fields is recommended.	(12) Plesser (2004) Norwegian Building Research Institute

- Total analysis results:

Metals Concentration, mg/kg

Sample#	1	2	5	6
As	< 3	< 3	< 2	< 2
Pb	20	15	17	8
Cd	1	1	2	< 0.5
Cu	35	20	70	< 3
Cr	< 2	< 2	< 2	5200
Hg	0.04	0.04	< 0.03	< 0.03
Ni	< 2	< 1	< 5	< 5
Zn	7500	700	17000	9500

PAHs (mg/kg)

Sample#	1	2	5	6
Total 16 PAHs	51	74	76	1
Naphthalene	0.4	0.32	0.72	0.19
Acenaphthylene	0.6	0.79	1	< 0.08
Acenaphthene	< 0.2	< 0.2	0.32	< 0.08
Fluorene	0.4	0.55	0.68	< 0.08
Phenanthrene	4.8	5.9	5.8	0.43
Anthracene	0.6	0.55	0.76	< 0.08
Fluoranthene	7.8	11	11	0.12
Pyrene	23	37	34	0.16
Benzo(a)anthracene	1.4	1.9	1.8	< 0.08
Crysene	2.2	2.2	4.2	< 0.08
Benzo(b)fluoranthene	2.2	3.5	3.9	< 0.08
Benzo(k)fluoranthene	0.4	0.55	1.5	< 0.08
Benzo(a)pyrene	2.4	3.1	3	0.12
Indeno(1,2,3,cd)pyrene	0.8	0.95	1.4	< 0.08
Dibenzo(a,h)anthracene	<0.4	< 0.2	0.44	< 0.08
Benzo(g,h,I)perylene	3.4	5.8	5.1	< 0.08

Phthalates (mg/kg)

Sample#	1	2	5	6
Dimethylphthalate	<1.0	<1.0	<1.0	3.4
Diethylphthalate	<1.0	<1.0	<1.0	1.5
Dibutylphthalate	3.4	2.6	3.9	1.6
Benzylbutylphalate	1.3	2.8	1.9	<1.0
Diethylhexylphthalate	21	21	29	3.9
Di n-octylphthalate	<1.0	<1.0	<1.0	3.2
Diisononylphthalate	57	78		
Diisodecylphthalate	<1.0	<1.0		

Phenols (mg/kg) Sample# 1 2 5 6 4-t-octylphenol 33.7 27.8 19.6 0.050 4-n-nonylphenol <0.005 <0.005 <.005 <0.005 Iso-nonylphenol 21.2 21.6 9.12 1.12 -Leaching test with deionized water (pH 7.0) by rotating at 10 RPM for 24 hrs. Basis: 10 L water /1 kg tire granulate. Metal Concentration in the leachate, mg/L Sample# 1 2 5 6 Temp, C 27 26 27.8 27.7 pH 7.69 7.8 7.54 11.36 Zn (mg/L) 2.29 1.22 0.59 0.08 - Off-gassing at 70^{o} C for 30 minutes. VOC concentration (ug/kg) Sample# 1 2 5 6 Alkylated benzenes Toluene 80 56 28 9 Ethylbenzene 18 12 7.8 < 5 Propylbenzene 15 < 0.8 8.8 5 Iso-propylbenzene 0.7 12 < 5 < 5 n-butylbenzene 31 21 28 < 5 m/p-xylene 37 28 25 < 5 o-xylene 35 24 20 < 5 p-isopropyltoluene 23 8.6 17 < 5 1,2,4-trimethylbenzene 102 83 100 9.4 1.3.5-trimethylbenzene 23 18 19 <5 Chlorinated compounds (ug/kg) Trichloromethane 8 <5 <5 Cis-1,2-dichlorethene <5 <5 32 10	
8. To study the use of tire crumb in playgrounds. - Toxicity to all of the aquatic organisms tested was observed in the fresh aqueous extract, but activity disappeared with aging of the tire crumb for 3 months in place on the playground. - Study conclusion: the use of tire crumb in playground results in a minimal hazard to the receiving environment.	(13) Birkholz et al. (2003)

9. To perform leaching tests and study surface water impacts based on Dutch standards. - rubber granules from car tires are brought into contact with deionized water at a ratio of 10 L of water per kg of rubber granules. Leaching takes place for a period of 24 hrs for metals and 48 hrs for organics. - Study results: surface water standards were exceeded for three substances: 4-t-octylphenol, copper and zinc. - Study recommendation: Untreated drainage water should not be discharged directly to the surface water. Maximum concentration in the percolate: ug/L PAHs Naphthalene………………… 11 Acenaphthylene…………….. 0.46 Acenaphthene………………. < 0.5 Fluorene…………………….. 2.8 Phenanthrene……………….. 0.17 Anthrancene…………………0.03 Fluoranthene…………………0.09 Pyrene……………………… 0.13 Benzo(a)anthracene………… 0.03 Chrysene…………………..… < 0.01 Benzo(b)fluoranthene……..… < 0.04 Benzo(k)fluoranthene……..… < 0.01 Benzo(a)pyrene…………….… < 0.02 Indeno(1,2,3,cd)pyrene….…. < 0.01 Dibenzo(a,h)anthracene…..… < 0.01 Benzo(g,h,i)perylene……..…. < 0.06 PHTHALATES Dimethyl phthalate………….. 1.6 Diethyl phthalate……………. 8.3 Dibutyl phthalate……………. 3.3 Benzylbutyl phthalate……….. 0.3 Diethylhexyl phthalate………. 5.6 di-n-octyl phthalate………….. 4.4 diisononyl phthaltae…………. 2.7 diisodecyl phthalate…………. 1.0 4-t-octylphenol……………… 3.6 4-n-nonylphenol……………. 0.043 iso-nonylphenol…………….. 1.12	(14) Dutch study (2006)

METALS, ug/L As…………………………… 2.3 Ba…………………………… 11.0 Cd…………………………… 0.12 Co…………………………… 5.8 Cr…………………………… 6.0 Cu……………………………383.0 Hg…………………………... 0.039 Ni…………………………… 4.3 Pb…………………………… 49.0 Zn……………………………7050.0	
10. To study leaching potential for zinc, using 3 cm infill material: - estimated zinc load is 800 mg/m2/year. - this rate exceeds the critical load (2100 mg/m2/yr) stated in the Dutch Building Materials Decree in approximately 3 years. - the zinc load from crumb rubber is about 20 times higher than from agriculture (manure and pesticides). - the predicted concentrations in surface and groundwater may exceed environmental risk criteria. - measurements of field samples show that zinc concentration increases over time. Aging effect on zinc emission based on liquid/solid ratio of 10 for car and truck tires (mg zinc/kg tire)	(16) Verschoor (2007)

	Car tires		Truck tires	
Time (yrs)	Lab test	Field test	Lab test	Field test
0	4.6	4.6	12	12
1	33	32 (n=5)	43	37 (n=3)
3	45	57 (n=3)	62	26 (n=3)

11. To study leaching potential for 16 PAHs, various amines and benzothiazoles, organic nitrogen, DOC and zinc. - The common view of the study group is that real effects cannot be determined by using lab tests. Actual release of chemicals from the field should be measured. The study plans to use lysimeters to collect runoff from existing fields. No data obtained at the time of the report.	(23) Kolitzus et al. (2006)