

Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds

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ABSTRACT

Disposal of used tires has been a major problem in solid waste management. New uses will have to be found to consume recycled tire products. One such proposed use is as ground cover in playgrounds. However, concern has been expressed regarding exposure of children to hazardous chemicals and the environmental impact of such chemicals. We designed a comprehensive hazard assessment to evaluate and address potential human health and environmental concerns associated with the use of tire crumb in playgrounds. Human health concerns were addressed using conventional hazard analyses, mutagenicity assays, and aquatic toxicity tests of extracted tire crumb. Hazard to children appears to be minimal. Toxicity to all aquatic organisms (bacteria, invertebrates, fish, and green algae) was observed; however, this activity disappeared with aging of the tire crumb for three months in place in the playground. We conclude that the use of tire crumb in playgrounds results in minimal hazard to children and the receiving environment.

IMPLICATIONS

Reuse of tire crumb as playground covering is cost-effective waste management and prevents injuries in playgrounds, but its use has been limited by safety concerns. Hazard assessments associated with exposure to water-soluble chemical extracts of tire crumb suggest low risk for carcinogenicity or ecosystem impact. This is the first case where the standardized, multispecies Potential Ecotoxic Effects Probe (PEEP) index was used to determine whether a recycling industry was having an adverse effect on the environment. This may be a good model to use for assessing risk associated with other recycling industries.

INTRODUCTION

The environmental and human health risk of ground cover made from shredded tires for enhanced safety in playgrounds was investigated. Such products, if successful in the marketplace, may improve safety while providing a disposal option for recycled tires. Disposal of used tires has been a major problem in solid waste management.¹⁻³ Because of their elastic properties and tensile strength, tires present difficult challenges for physical disposal and reduction. Their hollow shape allows water to collect and creates a hazard caused by insect breeding. Combustion of tires at low temperatures is difficult to control and produces a variety of products that are unacceptable as emissions to air and residues, such as benzene, that may contaminate groundwater. Combustion at high temperature, which is typically conducted on a large scale in cement kilns, produces fewer emissions but has been criticized as a source of metal emissions and because of the potential to contribute to ambient air pollution.²

The unattractive options for disposal and destruction of used tires has resulted in an accumulation of discarded tires. Transport of used tires offsite is expensive and there is little demand for them, so they tend to accumulate in local junkyards and piles. Storage of used tires in large quantities presents a serious fire hazard. In Canada, this issue became the subject of intense media attention during and after the fire in Hagersville, Ontario, in 1990, when a stockpile of 14 million scrap tires burned uncontrolled for 17 days and forced the evacuation of 1700 residents.⁴ Smaller tire fires have occurred since then,³ but most facilities now maintain smaller piles in an effort to limit their hazard. Canadian provinces, except Ontario, now divert 70% of their scrap tires into recycling.⁴

Recycling and conversion into final product may not absorb all discarded tires that are produced, but it reduces

the load and therefore the disposal problem.⁵ The vulcanized rubber in tires has potentially desirable properties and a high energy content. Eventually, value-added products and markets for tire rubber may be developed that support tire recycling on a large scale. The market for recycled tires is encouraged by policies of the Canadian provincial governments but is limited by the available options for converting the recycled material into product. New uses will have to be found to consume recycled tire products.

A first step in developing such products is the conversion of the tire into a more manageable physical form. Tire crumb is shredded rubber obtained from spent vehicle tires. A search of the Internet found three companies currently engaged in the commercial production of tire crumb, in Florida, Belgium, and Portugal. (Many more firms are engaged in the manufacture of crumb rubber-modified asphalt.)

One such proposed use is as ground cover in playgrounds following shredding of the tires to produce a crumb. The advantage of using tire crumb, as opposed to sand or asphalt, in playgrounds is that its shock-absorbing properties reduce injuries to children using playground facilities.⁶ However, concern has been expressed in Alberta, as elsewhere, regarding exposure of children to chemicals associated with the tire crumb product and the environmental impact associated with offsite migration of such chemicals. Available data on the safety of tire manufacturing are not germane to the question of risk associated with completed, vulcanized, aged, and shredded tires, because exposure in the tire manufacturing industry is qualitatively different.⁷⁻⁹ Likewise, although the National Institute of Occupational Safety and Health has examined the safety of crumb rubber-modified asphalt paving in several health hazard evaluations, the exposures described (see, e.g., ref 8) apply to the heated and melted product in combination with asphalt. This study did not consider other possible health effects on children, such as sensitization and dermatitis. These were considered unlikely to be limiting factors in the use of tire crumb in playground surfaces.

DEFINITION OF THE PROBLEM

Recycling Activity in Alberta

Recycling has been a particular priority in the province of Alberta, Canada. Approximately 2 million tires are discarded annually in the province of Alberta, which has a population of 2.7 million. A cooperative program was developed between the Alberta Centre for Injury Control and Research and the Tire Recycling Management Association of Alberta to evaluate the environmental risk associated with the use of tire crumb on playgrounds in the province. The potential for local exposure of children

from surface runoff and puddles was the major concern expressed. Likewise, it was recognized that environmental concerns may arise regarding playground runoff from rain and snowmelt contaminating surface waters after collection by storm sewers and release to the aquatic environment. The study was therefore extended in scope to include components on health hazard and environmental impact.

Human Health Hazard

Health risk assessment for vulcanized rubber products has emphasized dermatitis and anaphylaxis associated with latex gloves, an exposure situation not applicable to this case. Rubber manufacturing is associated with hazards that do not apply in this case, in which the product is finished, aged, washed, and free of dust.^{4,5} The health hazard for children, if any, associated with the use of tire crumb in playgrounds depends on the presence of an intact pathway of exposure and direct contact with chemicals that may be present in tire crumb. This exposure may occur dermally (skin contact) or orally (via ingestion). Inhalation of volatile constituents is not a plausible route of exposure because no volatile compounds would be expected to remain in the shredded, solid material. Each of these exposure routes was assessed to determine the hazard associated with exposure, but ingestion represents the exposure route of greatest significance.

A qualitative exposure assessment reached the following conclusions: Oral ingestion was deemed to be low in overall hazard because ingestion of tire crumb on the ground is not likely, and the gastrointestinal tract is unlikely to be efficient in extracting toxic chemicals from tire crumb. Tire crumb does not contain chemicals with high vapor pressures; thus, exposure via inhalation was deemed inconsequential and the resulting hazard negligible. Dermal exposure was deemed to be unlikely and, therefore, to present low overall hazard. A carrier solvent more efficient than water would be needed to extract toxic chemicals from tire crumb in quantity, and a suitable nonpolar vehicle would be required to penetrate protective skin layers for significant absorption. This is implausible in a playground situation.

Cancer hazard was chosen as the outcome of greatest concern, both because the issue had been raised in the queries received and because it is one of the few biologically plausible hazards associated with low-level exposures to the chemicals most likely to be released. The objective of this part of the study was to determine whether ingestion of a small amount of tire crumb by small children poses a cancer hazard with respect to exposure of chemicals at levels likely to be encountered, as measured by relevant *in vitro* predictive assays.

Environmental Hazard

The environmental impact, if any, associated with the use of tire crumb in playgrounds depends on the presence of a mechanism of release into the environment of chemicals present in tire crumb that may bioaccumulate. This would probably only occur in the aquatic environment as a result of runoff or groundwater contamination. The objective of this part of the study was to determine whether waterborne constituents of tire crumb demonstrate toxicity to organisms in the aquatic environment.

METHODS

Human Health Hazard

Exhaustive extraction (Soxhlet, 16–18 hr) of 200 g of tire crumb was performed with dichloromethane, omni solvent grade, which was obtained from EM Science. SOS materials, as well as the dimethyl sulfoxide (DMSO), were obtained from Environmental Bio-Detection Products, Inc. The eluted constituents were exchanged into DMSO at final concentrations that were tested at 0.24–2.2 mg/mL of hydrocarbon in DMSO. Genotoxicity testing was then performed using the resulting extracts with and without S9 (liver homogenate) activation in the following systems: *Salmonella typhimurium* mutagenicity fluctuation assay (TA98, TA100, TA1535, and TA1537), SOS chromotest, and Mutatox. All Ames strains, as well as polychlorinated biphenyl-induced S9, were obtained from Molecular Toxicology, Inc. Extracts were tested for acute lethality using Microtox in serial dilution to identify toxicity thresholds using standard methods.^{10,11} Genotoxicity was defined as a minimum 1.5-fold increase in colony count relative to solvent controls, with a dose-dependent response. Marginal toxicity was defined as an increase in colony count not exceeding 1.5-fold and no dose-dependent response. Absence of toxicity was defined as a lesser increase in colony count and no dose-dependent response.

Environmental Toxicity

Tire crumb in 250-g samples was leached in 1 L of water to produce the test leachate. The leachate was filtered to remove particulate matter. The leachate was then tested using standard methods and control exposures¹² in a battery of aquatic tests representative of the major trophic levels in the aquatic receiving environment: luminescent bacteria,¹³ invertebrates,¹⁴ fish,¹⁵ and algae.¹⁶ Luminescent bacteria, *Vibrio fischeri*, were employed as a test organism following the procedures of Environment Canada.¹⁰ The microcrustacean *Daphnia magna* was used as a test organism following the procedures of Environment Canada.¹⁴ Toxicity testing using the fathead minnow, *Pimphales promelas*, was performed using the procedures of the U.S. Environmental Protection Agency.¹⁵ The

freshwater alga *Selenastrum capricornutum* was used to test for toxicity following the procedures of Environment Canada.¹⁶

Quality control for all toxicity tests was maintained by using a positive control for toxicity testing reference toxicants, following the procedures of Environment Canada.¹² Lauryl sulfate was used as the reference toxicant for luminescent bacteria. Sodium chloride was the reference toxicant for the invertebrate species, fathead minnow, and green alga.

Toxicity was quantified by derived toxic units (TU). This calculated value is derived from a probit analysis to determine the estimated concentration that produces an effect in 50% of the organisms tested (EC_{50}), which may be a lethal effect (LC_{50}) or an inhibitory effect (IC_{50}). The level so derived is inverted and multiplied by 100. This value has the property of increasing with increasing toxicity and is dimensionless because it is based on serial dilutions of the leachate.

$$TU = 100/EC_{50} \quad (1)$$

If the initial testing revealed a toxic response using aquatic organisms, two further sets of tests were performed. The toxicity of leachate from fresh tire crumb was compared with that from aged tire crumb that had remained in place on a playground for three months, by the same bioassays. The leachate was also modified by the addition of sewage seed and nutrients and by aeration of the filtrate for 5 days. The persistence of toxic response over time was then determined and toxicity assessed by calculating the Potential Ecotoxic Effects Probe (PEEP) index, which is a weighted formula reflecting the consistency of toxic responses in various test systems.¹⁴

RESULTS

Human Health Hazard

Table 1 presents the results of in vitro genotoxicity assays. No test was clearly genotoxic. No tests performed without microsomal activation demonstrated genotoxic activity. Seven tests were marginal after activation but did not meet the criteria for genotoxicity and are considered negative.

Environmental Hazard

Table 2 presents the results of species-specific lethality assays. Bioassays of leachate obtained from four tire crumb samples revealed that all samples were toxic to all four species tested (luminescent bacteria, invertebrates, fish, and green algae). Bioassay of leachate samples obtained from bulk tire crumb before and after aging revealed a 59% reduction in toxicity in leachates recovered

Table 1. Results of in vitro genotoxicity assays of solvent extracts of fresh tire crumb.

Sample	Ames Fluctuation Assay				SOS Test	Mutatox
	TA 98	TA 100	TA 1535	TA 1537		
Without Liver Activation						
Tire #1	NT	NT	NT	NT	NT	NT
Tire #2	NT	NT	NT	NT	NT	NT
Tire #3	NT	NT	NT	NT	NT	NT
With Liver Activation						
Alberta Environmental						
Rubber Products No. 1	NT	MT	MT	MT	NT	NT
Tire Recycling No. 2	MT	NT	NT	NT	NT	NT
Midwest Tire No. 3	MT	MT	NT	MT	NT	NT

Note: MT = marginal toxicity; NT = absence of toxicity.

from crumbs that had been in place on playgrounds for three months. The second phase of testing, which used inoculation of tire crumb leachates in the laboratory with nutrients and sewage seed followed by continuous aeration for 5 days, resulted in significant (73–86%) reductions in toxicity.

Table 3 presents the results of calculations of the PEEP index from the data. In all instances except one, the PEEP index was determined to be less than 3, which is considered acceptable by Environment Canada.¹⁷ In the case of the schoolyard material, which was freshly installed and kept in place for three months, the PEEP index was only marginally greater than 3 (3.2). With further aging in place or treatment before installation, this value should drop below 3.

DISCUSSION

An exposure assessment performed to address the potential health risks to children playing in facilities where tire crumb is used as ground cover concluded that there was

Table 2. Initial results of species-specific assays for aquatic toxicity potential of fresh tire crumb.

Test	Toxic Units (100/LC ₅₀ or EC ₅₀)		
	Alberta	Tire	Midwest
	Environmental Rubber Products No. 1	Recycling No. 2	Tire No. 3
Microtox	15.4	8.9	7.3
<i>D. magna</i>	22.6	10	13.5
<i>P. promelas</i>	12.2	14.7	6.4
<i>S. capricornutum</i>	22	22.3	17
Total	72.2	55.9	44.2

little potential for an exposure sufficient to cause adverse health effects in children. Genotoxicity testing of tire crumb samples following solvent extraction concluded that no DNA- or chromosome-damaging chemicals were present. This suggests that ingestion of small amounts of tire crumb by small children will not result in an unacceptable hazard of contracting cancer.

These findings indicate that chemicals leaching from relatively fresh tire crumb may present a moder-

ate toxic threat to aquatic species if the runoff is not diluted. However, this toxic activity is quickly degraded by natural processes, presumably by conversion of the chemicals responsible to nontoxic products. Conditions likely to produce runoff, such as rain and snowmelt, are also likely to dilute the runoff in receiving sewers, bodies of water, and groundwater by considerable volumes. Given that undiluted runoff is not likely and that three months is an outside estimate of the duration of toxicity, it is doubtful that tire crumb would present a significant risk of contamination in receiving surface waters or groundwater.

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Table 3. Results of species-specific assays and summary PEEP index for aquatic toxicity potential of tire crumb aged in place for three months.

Test	Alberta	Crumb Deployed in School
	Environmental Rubber Products No. 1	
Microtox	14.9	11.7
<i>D. magna</i>	16.0	8.0
<i>P. promelas</i>	43.5	22.6
<i>S. capricornutum</i>	1042	412
Cumulative toxicity	1120	454
PEEP index	—	3.2

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