National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Evaluation of *health risks* of playing sports on synthetic turf pitches with *rubber granulate*

Scientific background document

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Synopsis

Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate
Scientific background document

New research by the Dutch National Institute for Public Health and the Environment (RIVM) indicates that the health risk of playing sports on synthetic turf pitches with an infill of rubber granulate is virtually negligible. Therefore, it is considered safe for people to play sports on such pitches. The research was conducted following public concerns prompted by the Dutch TV programme *Zembla* called 'Dangerous Play' in October 2016. RIVM hopes that the results of the research will help to answer questions from ministries, municipalities, sports clubs and parents.

To evaluate the health risks of playing sports on rubber granulate, it is important to determine which hazardous substances are contained in the granulate and to what extent they may be released. Subsequently, it should be examined how people playing sports can come into contact with these substances and whether this can lead to health effects. Rubber granulate contains numerous substances, such as polycyclic aromatic hydrocarbons (PAHs), metals, plasticisers (phthalates) and bisphenol A (BPA). These substances were found to be released from the granulate in very low amounts. This is because the substances are more or less 'enclosed' in the granulate, which means that the effect of these substances on human health is virtually negligible.

What did RIVM investigate?
RIVM determined the substances in rubber granulate from 100 sports pitches that are representative of the synthetic turf pitches in the Netherlands. The institute further performed three types of laboratory tests to examine the release of substances from the granulate if a person playing sport comes into contact with them. These 'migration studies' were used to assess to which extent substances can enter the human body via the skin, via the gastrointestinal tract or via the lungs. This was used to calculate human exposure to the released substances and how this can affect health. In addition, RIVM studied the information available in the scientific literature on substances in rubber granulate, their properties and their health effects.

Is there a link with leukaemia?
No indications were found in the available literature of a link between playing sports on synthetic turf pitches with an infill of rubber granulate and the incidence of leukaemia and lymphoma. No international research has demonstrated this connection. Moreover, it is clear from the composition of the rubber granulate that the chemical substances that are capable of causing leukaemia or lymphoma are either not present (benzene, styrene and 1,3-butadiene) or are present in a very low amount (2-mercaptobenzothiazole). Since the 1980s, a slight rise has been observed in the number of people aged between 10 and 29 who get leukaemia. This trend has not changed since pitches made of synthetic

turf were first used in the Netherlands in 2001. Nor does research conducted in the U.S. reveal any increase in the number of new cases of lymphoma in areas where there are relatively many pitches with synthetic turf with an infill of rubber granulate.

Information from new American research will be available early 2017. As rubber granulate has been used on football pitches in the United States for a longer period of time (since 1997), it will be possible to analyse over a longer period whether a link exists between playing sports on synthetic turf pitches and getting leukaemia. RIVM is in contact with the researchers and is keeping a sharp eye on the research.

Rubber granulate in the environment
This research focuses on potential health risks for people who play sports on synthetic turf pitches with an infill of rubber granulate. The research confirms earlier insights showing that the rubber granulate contains metals capable of entering the environment. In particular, zinc was found to be released from the granulate. This metal is not hazardous to humans, but can have consequences for organisms in the soil or surface water.

Does rubber granulate meet requirements?
Rubber granulate needs to fulfil the regulatory requirements for 'mixtures'. This concentration limit prescribes the maximum permissible amount of certain substances allowed in rubber granulate (there is no limit for how much may be released). This concentration limit concerns substances that are carcinogenic (such as PAHs), hazardous for reproduction or that damage DNA. The amount of PAHs in rubber granulate easily satisfies this concentration limit. The concentration limit for consumer products is far more stringent: it allows far lower amounts of PAHs (100 to 1000 times lower) compared with the concentration limit for mixtures. The amount of PAH in rubber granulate is slightly higher than the concentration limit for consumer products. The European Chemicals Agency (ECHA) is currently conducting research to determine a suitable concentration limit for rubber granulate. RIVM recommends adjusting the concentration limit for rubber granulate to one that is closer to the concentration limit applicable to consumer products.

Why is rubber granulate used for football pitches?
Rubber granulate is finely crushed rubber particles that are usually made from old car tyres. When used as infill on pitches of synthetic turf, it gives the pitch properties similar to normal turf. It means the ball does not roll too fast and does not bounce too high, and makes the synthetic turf better suited to sliding tackles than it would be without the granulate. Synthetic turf pitches can be used intensively all year around and need less maintenance.

A lot is invested nowadays in order to reuse old products as a raw material for new products. This also applies to car tyres. The questions that have arisen about the safety of rubber granulate show that tension may exist between the reuse of materials and concerns about the health risks of new products.

Keywords: rubber granulate, synthetic turf, PAHs, metals, phthalates, risk evaluation, leukaemia

Publiekssamenvatting

Beoordeling gezondheidsrisico's door sporten op kunstgrasvelden met rubbergranulaat
Wetenschappelijk achtergrondrapport

Uit nieuw onderzoek van het RIVM blijkt dat het risico voor de gezondheid van sporten op kunstgrasvelden die zijn ingestrooid met rubbergranulaat, praktisch verwaarloosbaar is. Dat betekent dat het verantwoord is om op deze velden te sporten. Aanleiding voor het onderzoek is de maatschappelijke bezorgdheid die ontstond na de televisie-uitzending van *Zembla* 'Gevaarlijk spel' in oktober 2016. Het RIVM hoopt met de resultaten bij te dragen aan de beantwoording van de vragen van ministeries, gemeenten, sportclubs en ouders.

Om te kunnen beoordelen in hoeverre sporten op granulaat een risico voor de gezondheid vormt, is het belangrijk om eerst te bepalen welke schadelijke stoffen in het granulaat zitten en in welke mate ze eruit kunnen vrijkomen. Vervolgens moet worden gekeken op welke manieren sporters in contact komen met deze stoffen en of dat gevolgen voor de gezondheid heeft. In rubbergranulaat zitten heel veel verschillende stoffen, zoals polycyclische aromatische koolwaterstoffen (PAK's), metalen, weekmakers (ftalaten) en bisfenol A (BPA). De stoffen blijken in zeer lage hoeveelheden uit de korrels vrij te komen. Dat komt doordat de stoffen min of meer in het granulaat zijn 'opgesloten'. Hierdoor is het schadelijke effect op de gezondheid praktisch verwaarloosbaar.

Wat heeft het RIVM onderzocht?
Het RIVM heeft de stoffen onderzocht in rubbergranulaat van 100 sportvelden die representatief zijn voor de kunstgrasvelden in Nederland. Daarnaast zijn drie soorten laboratoriumproeven uitgevoerd om te onderzoeken welke stoffen uit de korrels vrijkomen als de sporter ermee in aanraking komt. Met deze zogeheten migratiestudies is uitgezocht in welke mate stoffen via de huid in het lichaam kunnen terechtkomen, via het spijsverteringskanaal of via de longen. Vervolgens is berekend in hoeverre mensen aan de vrijgekomen stoffen blootstaan en wat dat betekent voor de gezondheid. Verder is de beschikbare informatie in de wetenschappelijke literatuur bestudeerd over de stoffen in rubbergranulaat, de eigenschappen en de gezondheidseffecten ervan.

Is er een verband met leukemie?
In de beschikbare informatie zijn geen signalen aangetroffen die duiden op een verband tussen sporten op kunstgras met rubbergranulaat en het ontstaan van leukemie en lymfeklierkanker. Dit verband is in geen enkel internationaal onderzoek aangetoond. Bovendien blijkt uit de samenstelling van de rubberkorrels dat de chemische stoffen die leukemie of lymfeklierkanker kunnen veroorzaken er niet (benzeen, styreen en 1,3-butadieen) of in heel lage hoeveelheid (2-mercaptobenzothiazol) in zitten. Sinds eind jaren tachtig van de vorige eeuw is er in het algemeen een lichte stijging te zien in het aantal mensen tussen 10 en 29 jaar dat leukemie krijgt. Deze ontwikkeling is

niet veranderd sinds de kunstgrasvelden in 2001 in Nederland in gebruik zijn genomen. Onderzoek in Amerika laat ook geen verhoging zien in het aantal nieuwe gevallen van lymfeklierkanker in gebieden waar relatief veel kunstgrasvelden liggen die zijn ingestrooid met rubbergranulaat.

Begin 2017 komt informatie uit nieuw Amerikaans onderzoek beschikbaar. Omdat rubbergranulaat in de Verenigde Staten langer (sinds 1997) op voetbalvelden wordt gebruikt, kan over een langere periode worden geanalyseerd of er een verband is tussen sporten op kunstgras en het krijgen van leukemie. Het RIVM heeft contact met de onderzoekers en volgt dit onderzoek op de voet.

Rubbergranulaat in het milieu
De focus in dit onderzoek ligt op mogelijke gezondheidsrisico's voor mensen die sporten op velden met ingestrooid rubbergranulaat. Het onderzoek bevestigt eerdere inzichten dat het rubbergranulaat metalen bevat die in de omgeving terecht kunnen komen. Er blijkt vooral zink uit het rubbergranulaat vrij te komen. Dit metaal is niet schadelijk voor de mens, maar kan wel gevolgen hebben voor organismen in de bodem en het oppervlaktewater.

Voldoet het rubbergranulaat aan de norm?
Rubbergranulaat moet voldoen aan de norm voor zogenoemde mengsels. Deze norm schrijft voor hoeveel er maximaal van bepaalde stoffen in mag zitten (er bestaat geen norm voor wat eruit mag komen). Het gaat daarbij om stoffen die kankerverwekkend zijn (zoals PAK's), schadelijk zijn voor het nageslacht of het DNA beschadigen. De hoeveelheid PAK's in het rubbergranulaat voldoet ruim aan deze norm. De norm voor consumentenproducten is aanzienlijk strenger: deze staat veel lagere (100 tot 1000 maal minder) gehalten aan PAK's toe dan de mengselnorm. Het gehalte PAK's ligt iets boven de norm voor consumentenproducten. Momenteel doet het Europese Agentschap voor Chemische Stoffen (ECHA) onderzoek om te bezien welke norm voor rubbergranulaat wenselijk is. Het RIVM adviseert om de norm voor rubbergranulaat bij te stellen naar een norm die dichter in de buurt ligt van de norm voor consumentenproducten.

Waarom wordt rubbergranulaat gebruikt voor voetbalvelden?
Rubbergranulaat is fijngemalen rubber en wordt meestal gemaakt van oude autobanden. Als instrooimateriaal op kunstgrasvelden zorgt het ervoor dat het veld vergelijkbare eigenschappen krijgt als een gewoon grasveld. Dat betekent dat de bal niet te snel rolt, niet te hoog stuitert en het kunstgras beter geschikt is om slidings te maken dan zonder granulaat. Kunstgrasvelden kunnen het hele jaar door intensief gebruikt worden en vergen minder onderhoud.

Tegenwoordig wordt veel geïnvesteerd om oude producten te hergebruiken als grondstof voor nieuwe producten. Dat geldt ook voor autobanden. De vragen over de veiligheid van rubbergranulaat maken duidelijk dat er een spanningsveld kan bestaan tussen het hergebruik van materialen en de zorgen om de gezondheidsrisico's van nieuwe producten.

Kernwoorden: rubbergranulaat, kunstgras, PAK, metalen, ftalaten, risicobeoordeling, leukemie

Contents

Introduction

Football[1] is a very popular sport in the Netherlands: the Royal Dutch Football Association (KNVB) is by far the largest sports association, with more than 1.2 million members. Every weekend, more than 63,000 football teams play their matches on the pitch. Nearly one out of three football pitches is a synthetic turf pitch. In total, the Netherlands has about 2,000 synthetic turf football pitches, of which 90 percent have rubber granulate infill. There is also a relatively small number of rugby pitches, korfball pitches and Cruyff Courts with rubber granulate.

In recent years, questions have been raised in the Netherlands and other countries about the potential health risks of hazardous substances in rubber granulate on synthetic turf pitches. Recently, concerns about hazardous substances in rubber granulate have increased dramatically in the Netherlands due to a broadcast by the television programme *Zembla* on 5 October 2016 entitled, 'Gevaarlijk spel' (Dangerous game). That broadcast reported that rubber granulate contains high concentrations of hazardous substances, including carcinogenic substances. Subsequently, a relationship was established between playing sports on these synthetic turf pitches and the incidence of leukaemia in children. It was also claimed that there has been insufficient research on the health risks of playing sports on synthetic turf pitches with rubber granulate to determine that playing sports on these pitches is safe.

Concerns about the potential health risks of rubber granulate are clearly noticeable. Some parents do not want their children to play on pitches with rubber granulate any longer. Therefore, some organisations have decided to implement precautionary measures such as having the youngest members play on grass pitches, cancel keeper training on synthetic turf and adjusting competition schedules. If it is a question of installing or replacing a synthetic turf pitch, this is sometimes postponed or the set-up is adjusted.

On 7 October 2016, the Minister of Health, Welfare and Sport commissioned RIVM to conduct a research in the short term on health risks from playing sports on synthetic turf pitches with an infill of rubber granulate. The main question is whether playing sports on synthetic turf pitches with rubber granulate is safe. This comprehensive scientific report includes the scientific background information for the design and results of the research that includes sampling and chemical analyses of rubber granulate, an evaluation of the international scientific literature and the assessment of health risks.

For this research, RIVM was advised by a specially appointed scientific advisory group consisting of experts from universities, knowledge institutes and Municipal Public Health Services. The reports from the meetings with the advisory groups can be found on RIVM's website.

[1] In this report 'football' refers to the European understanding of football, which correlates to the American game of soccer. In the American publications used in this report, the term 'soccer' is maintained.

In addition, RIVM set up a social advisory group for this research. This advisory group consisted of representatives from organisations that are involved in various ways in the use of rubber granulate on synthetic turf pitches: the Ministry of Health, Welfare and Sport (VWS), the Ministry of Infrastructure and the Environment (IenM), the Human Environment and Transport Inspectorate (ILT), the Office for Risk Assessment and Research of the Netherlands Food and Consumer Product Safety Authority (NVWA), The Association of GGDs (Community Health Services), Royal Dutch Football Association (KNVB), Trade Association Sports and Culture Technique (BSNC), Association of Sports and Municipalities (VSG) and the (trade) associations of tyre companies and tyre recycling VACO and RecyBEM. This social advisory group met four times during the research.

RIVM prepared a survey among a representative group of citizens and held two group meetings with people who had approached RIVM with questions and concerns about rubber granulate on synthetic turf pitches. Additionally, an analysis of media coverage ('discourse analysis') and of the questions that people asked directly to RIVM provided insights on the social perception and discussion on rubber granulate.

RIVM also contacted several people who had been given a chance to speak during the *Zembla* broadcast. Mr Maguire provided his literature references and Mrs Griffin gave access to the database. Professor Watterson was contacted about the scientific literature and Professor Van den Berg was a member of the scientific advisory group for this research.

Finally, RIVM consulted various international agencies that are also currently investigating the potential health risks of rubber granulate, such as the European Chemicals Agency (ECHA), the U.S. Environmental Protection Agency (EPA) and the Ministry of Health of the State of Washington. The results from this international research are expected in the course of 2017.

1. Context and background information

1.1 What is rubber granulate?

Rubber granulate is finely ground rubber. It is mainly made from old car tyres. Various products are made from rubber granulate such as rubber tiles and infill material for synthetic turf pitches. Rubber granulate on synthetic turf pitches ensures that the pitch has similar characteristics to conventional grass pitches, making sure that balls do not roll too fast or bounce too high. In addition, synthetic turf is suitable for making slidings. Synthetic turf pitches require less maintenance than sports pitches with natural grass and can be used intensively throughout the year.

Figure 1 Rubber granulate as infill material on a synthetic turf pitch

The Netherlands has nearly two thousand synthetic turf football pitches of which approximately 1,800 have rubber granulate infill (see Figure 2; Source: KNVB). About 120 tonnes of rubber granulate, derived from approximately 20,000 used car tyres, fill one football pitch. In addition to synthetic turf football pitches, there is also a relatively small number of other synthetic turf pitches with rubber granulate, such as korfball pitches, rugby pitches and 'Cruyff Courts' (small playing fields of synthetic turf in neighbourhoods). Rubber granulate is not used for hockey pitches.

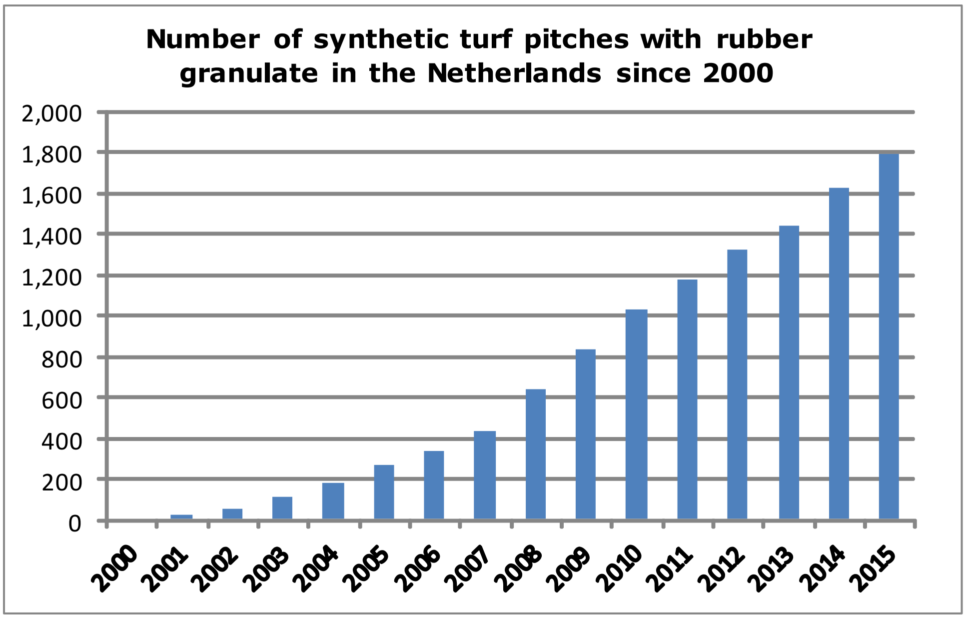

Figure 2 Estimate of the number of synthetic turf pitches with rubber granulate in the Netherlands since 2000 (Source: KNVB)

More than 90 percent of the synthetic turf football pitches in the Netherlands have infill with rubber granulate made from old car tyres (Source: KNVB). It concerns so-called SBR rubber. SBR is an abbreviation for styrene-butadiene rubber. The other 10 percent of the synthetic turf football pitches are filled in with coated SBR rubber or another infill material such as EPDM rubber (ethylene-propylene-diene monomer), TPE (thermoplastic elastomer), cork, or mixtures of SBR rubber, various synthetic and natural materials.
Rubber granulate must be added several times as part of the maintenance of a synthetic turf pitch.

1.2 Previous research by RIVM

In 2006 RIVM performed a risk assessment of rubber granulate on synthetic turf pitches based on existing knowledge and literature. It included a report by the Danish Environmental Protection Agency. Based on the data available at the time and the selected exposure scenario, it was concluded that the health risk due to exposure to polycyclic aromatic hydrocarbons (PAHs) in rubber granulate is negligible.
At that time, Intron was commissioned by various parties to conduct research on the environmental and health risks of rubber granulate. The research report was published in 2007. Part of this research was a study by Industox during which degradation products of PAHs were measured in the urine of seven people playing sports after they had been in contact with rubber granulate. In 2007, RIVM assessed this information and advised the Ministry of Infrastructure and the Environment on this matter. Although the research on degradation products in the urine of the people playing sports was limited, the findings were consistent with the earlier conclusion from the literature research from 2006. RIVM therefore saw no reason for further action or recommendations for PAHs. However, recommendations to further investigate hypersensitivity reactions induced by aromatic amines were supported. Since information on other substances was lacking, no definitive conclusion could be made on the health risks of rubber granulate on synthetic turf pitches.
In addition, in 2007, RIVM performed measurements on evaporation of nitrosamines from rubber granulate at four football pitches. Nitrosamines are chemical compounds that are known to cause cancer. In none of the measurements nitrosamines were detected in the air above the pitches. Additional research revealed that only very limited amounts of nitrosamines were released from rubber granulate.
In early 2016, in response to questions, RIVM re-examined the Industox research from 2007. RIVM then concluded once again that no adverse health effects are to be expected. Because much new research on PAHs in rubber granulate has been conducted since 2006, RIVM also advised to evaluate the new information this research has provided.

1.3 Other ongoing research

Research is also being done outside the Netherlands on hazardous substances in rubber granulate and the potential health risks. In Europe, the European Chemicals Agency (ECHA) is currently working on a literature research of the health risks of substances in granulate, the results of which are expected to be published in early 2017 (ECHA 2016). Based on this, ECHA shall determine whether further risk management measures are necessary. Based on the results of ECHAs

research, the European Commission may decide whether specific concentration limits for rubber granulate need to be developed.
The U.S. EPA is also doing research on the health risks of rubber granulate in which the granulate from dozens of pitches will be analysed (EPA 2016; OEHHA 2016). In addition, the results of two American studies on the relationship between leukaemia and synthetic turf pitches are expected in 2017.
Given the current concern in the Netherlands, the Minister of Health, Welfare and Sport has decided not to wait until this research has been completed.

1.4 Aim of the present research

The aim of the present research is to answer the question whether playing sports on synthetic turf pitches with rubber granulate poses health risks. Therefore, the following questions were investigated:

1. Which hazardous substances are present in rubber granulate and in what amounts? (Chapter 2 and Part A and B of the scientific background information in this report).
2. To what extent can people playing sports on synthetic turf pitches be exposed to these substances and what are the resulting health risks? (Chapter 3 and Part C of the scientific background information in this report).
3. What is known about the relationship between playing sports on synthetic turf with rubber granulate and leukaemia and lymphoma? (Chapter 4 and part D of the scientific background information in this report).
4. How do the concentrations of substances found relate to regulatory and other limits? (Chapter 5 and Part C of the scientific background information in this report).

How has RIVM examined the health risks of rubber granulate?

- Rubber granulate from 100 synthetic turf fields in the Netherlands was tested for the presence of hazardous substances.
- Tests were performed to determine the extent to which substances are released from rubber granulate after ingestion, contact with the skin and through evaporation in hot weather.
- Estimates were made on how and how long different age groups and categories of people playing sports come in contact with rubber granulate.
- The calculated exposure to hazardous substances was compared with toxicological information on these substances. Based on this, a health risk assessment was performed.
- In addition, signals on the relationship between leukaemia and lymphoma and playing sports on synthetic turf fields with rubber granulate in the Netherlands were examined.

The following diagram shows the various research activities and their interrelationships.

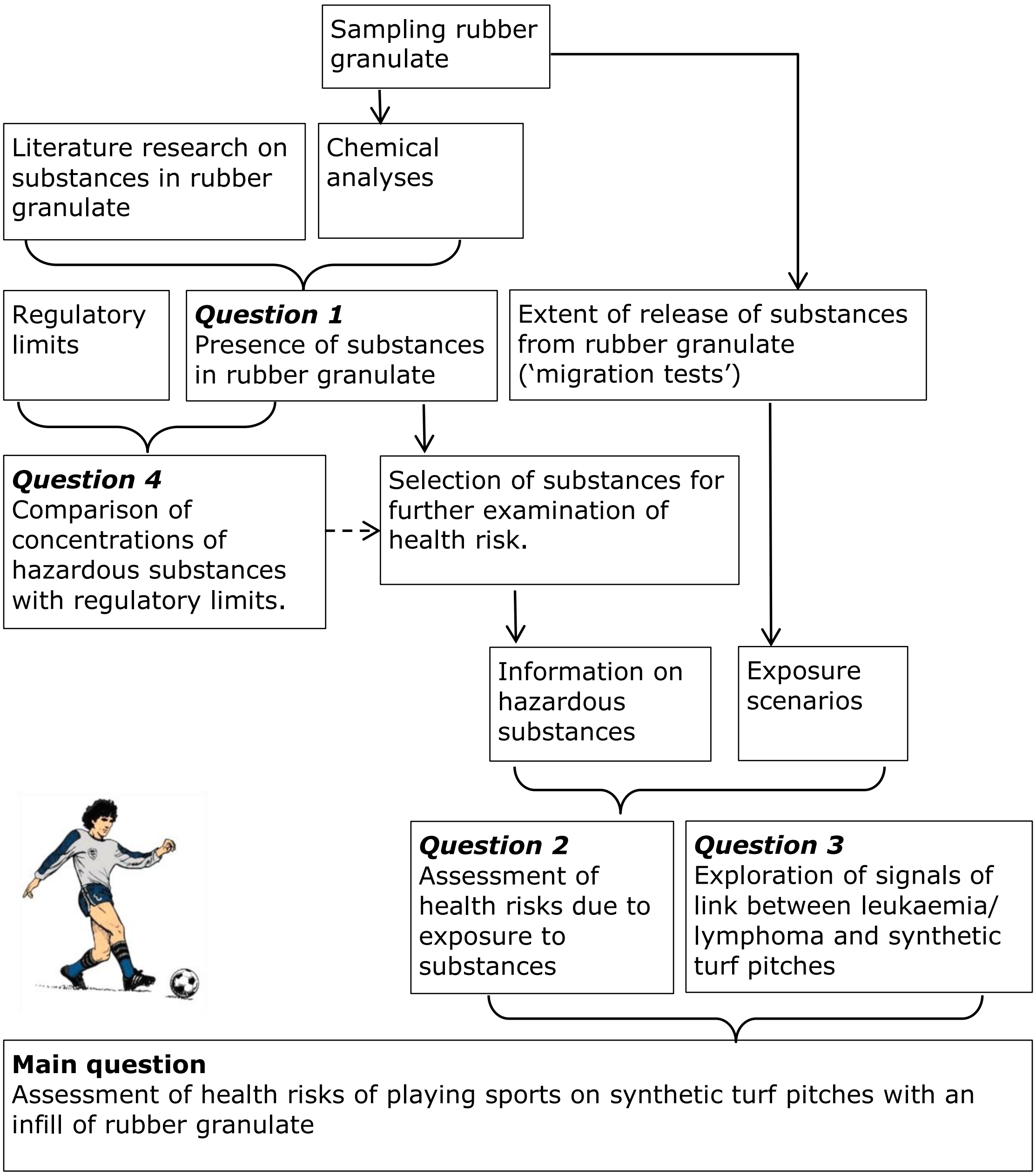

Figure 3 Schematic overview of the research

2. Substances in rubber granulate

In addition to a combination of synthetic rubber and natural rubber, rubber in car tyres consists of various substances that give the rubber the desired properties. These include fillers (such as carbon black and silica), plasticisers (such as mineral oils), substances for the vulcanisation process of rubber (such as sulphur, zinc oxide and benzothiazoles) and antidegradants that give the rubber better resistance to oxygen, ozone and high temperatures. In addition to substances that are intentionally added during the manufacture of car tyres, there are also impurities in the rubber and the excipients. In addition, substances are formed during the production process. All in all, a large number of substances are present in rubber and rubber granulate.

Previous research on rubber granulate has shown that it contains various substances that can pose a health risk. These include PAHs, metals, phthalates and (volatile) organic compounds such as phenols and benzothiazoles. Several of these substances can cause cancer and/or are reprotoxic with a certain level of exposure. In Chapter 3 a calculation is made of the exposure to hazardous substances by playing sports on synthetic turf pitches with rubber granulate.

2.1 Sampling and analysis of rubber granulate

To acquire a good, up-to-date picture of the concentrations of hazardous substances in rubber granulate, samples were taken of the rubber granulate present in 100 synthetic turf pitches throughout the Netherlands. To do so, a random sample was drawn from a database of synthetic turf football pitches from the KNVB, supplemented with korfball pitches, rugby pitches and 'Cruyff Courts' (small playing fields of synthetic turf in neighbourhoods). The pitches known to use a type of infill material other than rubber granulate from old car tyres were beforehand excluded. Six different sites were sampled on each pitch. Detailed information on the sampling can be found in Part A of the scientific background information in this report.

Figure 4 Sampling of rubber granulate with a vacuum cleaner (left) and infill of a glass pot with the sampled material (right)

600 granulate samples (100 pitches x 6 samples) were analysed for 45 substances, including PAHs, phthalates and volatile organic compounds. In these samples, leaching of metals was also determined using a batch leaching test with water. Additionally, samples from 10 pitches were examined for benzothiazoles, phenols, PCBs and other volatile organic compounds.

In addition, migration tests were conducted on a number of samples that investigated which substances are released from rubber granulate after ingestion, upon contact with the skin and through evaporation in hot, sunny weather. More information about this can be found in Chapter 3 and in Part B of the scientific background information in this report.

The results proved that in nine of the 100 sampled pitches the infill material partly came from materials other than rubber granulate from car tyres. Since these nine pitches are not representative of synthetic turf pitches with rubber granulate from car tyres, the results from these pitches are not included in the overview tables with measurement results.

2.2 Substances in rubber granulate from Dutch synthetic turf pitches

The chemical analyses of rubber granulate samples show that rubber granulate has several PAHs, metals, phthalates, benzothiazoles and phenols. Some of the samples also have low concentrations of PCBs. With regard to leaching of metals to water, this is mainly the case for zinc, copper and cobalt. Various substances tested, including benzene, were not found in any sample. Table 1 on the following page presents an overview of the substances that are detected in at least five percent of the samples. More details on the analyses can be found in Part B of the scientific background information in this report.

Table 1 Concentrations of substances in rubber granulate samples. The concentrations are average values of each pitch. Reported are the substances present in more than 5% of the samples (except for the eight ECHA PAHs[1], they are all reported).

Substance/Substance group	Percentage of samples above the detection limit	Concentration in mg/kg dry matter	
		Median[2]	Maximum
PAHs			
phenanthrene	38[3]	<0.6	7.1
anthracene	5[3]	<0.5	1.1
fluoranthene	93[3]	3.4	20.3
pyrene	98[3]	7.5	28.7
benzo(ghi)perylene	62[3]	4.1	7.7
benzo(c)fluorene	43[4]	0.2	0.7
cyclopenta(cd)pyrene	100[4]	1.5	2.5
benzo(a)anthracene[1]	27[3]	<0.9	2.2
benzo(b) + benzo(j)fluoranthene[1]	48[3]	<1.2	3.0
benzo(k)fluoranthene[1]	1[3]	<0.5	0.5
benzo(a)pyrene[1]	25[3]	<1.1	2.2
benzo(e)pyrene[1]	57[4]	2.8	7.8
chrysene[1]	57[3]	1.3	3.5
dibenzo(a,h)anthracene[1]	0[3]	<0.5	<0.5
Sum PAH (ECHA 8)[1]		5.8	19.8
Phthalates			
di-2-ethylhexylphthalate	100[3]	7.6	27.2
di-isobutylphthalate	17[3]	<0.5	2.3
di-isononylphthalate	77[5]	35	61
dicyclohexylphthalate	47[5]	0.1	0.2
di-n-nonylphthalate	37[5]	0.5	0.8
diphenylphthalate	7[5]	<0.1	0.1
bis(2-ethylhexyl)adipate	63[5]	0.3	1.1
Benzothiazoles			
benzothiazole	100[4]	2.7	6.3
2-hydroxybenzothiazole	100[4]	1.6	13.8
2-mercaptobenzothiazole	100[4]	2.6	7.6
2-methoxybenzothiazole	100[4]	2.6	10.2
2-aminobenzothiazole	100[4]	0.1	0.4
N-cyclohexyl-1,3-benzothiazole-2-amine	100[4]	1.5	3.9

[1] These are the eight PAHs for which separate concentration limits are determined for mixtures, consumer products such as toys, namely benzo(a)pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, benzo(j)fluoranthene, benzo(e)pyrene. Benzo(b) and benzo(j)fluoranthene cannot be quantified separately due to overlapping peaks in the chromatogram.
[2] The median means that 50% of the average values of each pitch lie below the median and 50% above it.
[3] Analyses of 546 samples from 91 fields.
[4] Analyses of seven mixed samples derived from seven fields.
[5] Analyses of 43 samples from seven fields.
[6] Sum of PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180.

Substance/Substance group	Percentage of samples above the detection limit	Concentration in mg/kg dry matter	
		Median[2]	Maximum
2,2-dithiobis-(benzothiazole)	71[4]	0.2	0.3
N-cyclohexyl-2-benzothiazole sulphenamide	43[4]	<0.02	0.04
Phenols			
4-tert-octylphenol	100[4]	4.8	22.4
Bisphenol A	100[4]	0.5	2.5
Polychlorobiphenyls			
PCBs[6]	29[4]	<0.035	0.074

The footnotes of the above table can be found on previous page.

Table 2 Leaching of metals from rubber granulate to water. Reported are the metals in so far as they have been detected in at least 5% of the samples.

Substance group	Percentage of samples above the detection limit	Concentration in mg/kg dry matter (average values of each pitch)	
		Median	Maximum
Zinc	100	21	129
Copper	78	0.09	0.9
Cobalt	66	0.06	0.4
Barium	16	<0.05	0.2

Table 2 provides information on leaching of metals from the granulate samples to water. These concentrations mainly give an indication of the possible leaching of metals from rubber granulate to the *environment* (soil and ground water). For the assessment of the *health risks* of metals in rubber granulate, Chapter 3 presents the migration of metals to artificial gastro-intestinal juices and sweat. The most relevant metals considered for human health are: cadmium, lead and cobalt.

There was little variation in the concentrations of substances between the pitches and between the measuring points per pitch. The concentrations in the samples of the nine pitches with different infill material do not substantially differ from those from the samples with SBR rubber, except in the samples from two of the nine pitches. In the samples from these two pitches, high concentrations of phthalates were found[1]. Additional research shows that the granulate on these two pitches not only consists of SBR rubber from car tyres but from a mixture of car tyre rubber and another material, presumably EPDM rubber.
It also appears that usually somewhat higher PAH and zinc concentrations in the rubber granulate were measured in newer pitches than in older pitches. Substances from the rubber granulate may have leached away with rain water, may have evaporated or may be chemically degraded. Another possibility is that more sand is present in

[1] This will be briefly discussed in the chapter on the assessment of the health risks (see section 3.4).

older pitches, which, as if it were, has diluted the amount of rubber granulate.

The literature research shows that the measured concentrations of PAHs, phthalates, benzothiazoles and phenols in rubber granulate are largely consistent with the concentrations measured in other research on rubber granulate. The maximum concentrations measured in this research are usually somewhat lower than the maximum concentrations from other research (see Part C of the scientific background information in this report).

3. Assessment of health risks posed by substances in rubber granulate

This chapter presents an assessment of the health risks posed by playing sports on synthetic turf pitches with rubber granulate resulting from exposure to hazardous substances in the rubber granulate. First, the substances that are described in the scientific literature as being hazardous to human health were selected. The potential exposure to these substances was calculated based on exposure scenarios and information on the release of substances from rubber granulate. Subsequently, an assessment was made of what this exposure means for the health risk of playing sports on a synthetic turf pitch with an infill of rubber granulate.
Detailed information on the risk assessment can be found in Part C of the scientific background information in this report.

3.1 Which substances were further investigated?

Chapter 2 shows that a large number of substances are present in rubber granulate. To select the substances that could pose a health risk, it was first determined which substances might exceed one or more regulatory limits. The comparison with these limits was done with the results from the chemical analyses and with the composition of rubber granulate as described in the scientific literature. The measured or described concentrations of substances in rubber granulate were compared with the concentration limits for mixtures, the concentration limit for consumer products, the limit for toys, the limit from the Building Materials Decree and the soil limit (Chapter 5 provides more information on these limits). After that, an assessment was made of which of these substances appear on the list of 'Substances of very high concern' (SVHC)[1]. The substances on the SVHC list are hazardous for people and/or the environment because, for example, they are carcinogenic, reprotoxic or accumulate in the food chain. The substances on the SVHC list that are only of concern for the environment were not included. In this way, the following substances were selected for further assessment of health risks: PAHs, bisphenol A (BPA), several metals (cadmium, cobalt and lead), the phthalates and 2-MBT.

While zinc and PCBs exceed one or more limits in rubber granulate, they were not included in the further assessment of the health risk (see Chapter 5). The leaching of zinc to water is above the limit of the Building Materials Decree, which is based on effects on the environment. For zinc, this excess means that there could be an environmental risk. The total concentration of the seven different PCBs[2] is above the soil limit for residential classification. Since these PCBs belong to the 'non-dioxin-like' PCBs, they do not appear on the SVHC list and are not included in the subsequent risk assessment. Other PCBs were not found.

[1] More information on the list with SVHC substances:
www.rivm.nl/rvs/Stoffenlijsten/Zeer_Zorgwekkende_Stoffen
[2] PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180.

3.2 Exposure scenarios

To calculate the potential exposure to substances in rubber granulate of people playing amateur sports, five exposure scenarios were detailed. The scenarios were elaborated in such a way that they calculate a *realistic worst case* exposure for a substance or a group of substances in rubber granulate. This means that, based on actual situations, the exposure is calculated for the highest exposed people playing sports. Thus, the majority of the people playing sports will be less exposed. In the scenarios, a distinction was made between playing sports for recreational purposes and performance-oriented sports. To overcome differences in exposure, a further distinction was made by age, based on categories as they are now used by the KNVB. A total of five scenarios were detailed:

1. Children aged 4 to 11 years
   This scenario is based on a 4-year-old football player and is a worst case scenario for children aged 4 to 11 years. Children aged 4 to 6 years start playing football in a playful manner. Due to hand-mouth behaviour, ingestion of rubber granules is included.
2. Goalkeepers starting at 7 years of age
   This scenario is for goalkeepers of all age groups. In football, the goalkeeper is introduced in the age group starting at 7 years. In this goalkeeper scenario, ingestion of rubber granules and increased skin exposure is included.
3. Children aged 11 to 18 years, performance-oriented sports
   This scenario applies to children aged 11 to 18 years, and is a worst case scenario based on an 11-year-old football player. With the aim of including performance-oriented sports, a higher frequency of training was chosen.
4. Adults (18 to 35 years of age), performance-oriented sports
   This scenario is for all adults. Performance-oriented sports with a higher frequency of training was also chosen for adults.
5. Lifelong exposure
   Lifelong exposure was also calculated for both an outfield player and a goalkeeper. This is based on the above-mentioned four scenarios and a scenario for veterans who play football recreationally until the age of 50. This is important for substances for which the risk assessment is based on lifelong exposure.

The above scenarios provide a picture of possible ways of coming into contact with rubber granulate while playing football. For each scenario, values were chosen for factors such as body weight and the frequency and duration of playing sports. In addition, for each route of exposure, the relevant values were selected such as body surface area in contact with granulate, amount of granulate in contact with the skin, respiratory rate and amount of granulate that might be ingested.

For exposure after ingestion, it was assumed that 0.2 g granulate is ingested each time while playing sports in scenarios 1 and 2, and 0.05 g in scenarios 3 and 4. For scenario 5, the lifelong exposure was calculated based on the amount of rubber granulate ingested in the above-mentioned age groups.

Figure 5 0.2 grams of rubber granulate

The inhalation exposure of rubber granulate dust is based on the literature. Based on the amount of particles of rubber granulate found in the air of a sports hall (NIPH, 2006), it is assumed that 12 µg/m^3 in the form of small particles (smaller than 10 µm) is present in the air and can be inhaled.
Part C of the scientific background information presents more details on the exposure scenarios. The inhalation exposure to vapours arising from rubber granulate is described in section 3.3 and Part B of the scientific background information.

Although not assessed in detail, it is assumed that the above-mentioned scenarios can also be used for korfball and rugby. For korfball, less contact via the skin is expected. For rugby, more contact via the skin is expected since the game is often played on the ground. It is also conceivable that the mouth guard of rugby players can fall to the ground and can bring in rubber granulates upon re-insertion. Therefore, the goalkeeper scenario is most suitable for rugby players.

3.3 Release of substances from rubber granulate

Rubber granulate generally consists of particles of 0.5 to 3 millimetres. It is unlikely that the substances are released completely from the particles and absorbed by the skin and in the gastrointestinal system. The substances within the particles are more or less ‘enclosed’ in the molecular structure of the rubber. In order to assess what percentage of the substances can effectively be released from the rubber granulate and come in contact with the body, so-called **migration tests** were carried out. Experiments on the extent to which substances from the granulate are released into artificial sweat and gastro-intestinal juices were performed. In addition, the extent to which substances from rubber granulate evaporate into the air in hot conditions was analysed.

A limited number of samples were examined for migration to air, sweat and gastro-intestinal juices. The results of these tests provide a consistent picture. For the calculation of the exposure, the maximum detected migration was assumed for each substance.

For substances for which no migration data are available, such as BPA and benzothiazoles (including 2-MBT), it was assumed that the total amount of this substance in the granulate comes in contact with the skin or enters the gastro-intestinal juices upon dermal exposure or ingestion.

Via the skin

To more accurately assess dermal exposure, the extent to which substances from rubber granulate dissolve in artificial sweat was examined. The amount of substances released from rubber granulate in two hours at 37 °C was measured. This was done for samples from seven pitches with SBR rubber.
Phthalates were not found in concentrations above the detection limit. Only five of the PAHs, including chrysene and benzo(e)pyrene, could be detected. Of the total amount of the five PAHs in the rubber granulate samples, approximately 0.02 percent were released in artificial sweat. This percentage is used to calculate the dermal exposure to PAHs.
For the metals cadmium, cobalt and lead, no information on the concentration in rubber granulate is available and therefore the percentage released in artificial sweat could not be calculated. Therefore, the maximum amount of metal released in artificial sweat per gram of rubber granulate was determined. Per gram of rubber granulate, a maximum of 0.07 μg lead, 0.48 μg cobalt and 0.02 μg cadmium is released in artificial sweat. These values were used for the exposure calculation.

After ingestion

To better assess exposure after ingestion, the amount of a substance released in a simulated gastrointestinal system was examined (Verwei et al., 2016). Figure 6 is an illustration of this artificial gastrointestinal system. Five samples of SBR granulate were exposed to conditions similar to those in the human stomach, and then in the intestines. Subsequently, the fraction of the substances released from the granulate was determined. The fraction of the substances that remains in the granulate cannot be absorbed by the body and will be excreted via the stool.
About 20 percent of the phthalates and 9 percent of the PAHs present in the rubber granulate samples are released in the gastro-intestinal juices after ingestion. These percentages are used to calculate exposure after ingestion. For the metals cadmium, cobalt and lead, no information on the concentration in rubber granulate is available and therefore the percentage released in the gastro-intestinal juices could not be derived. Therefore, the maximum amount of metal that per gram of rubber granulate is released in gastro-intestinal juices was determined. For lead, a maximum of 9 μg per gram rubber granulate is released, and for cobalt this is 2 μg per gram. Cadmium is not detected in gastro-intestinal juices.

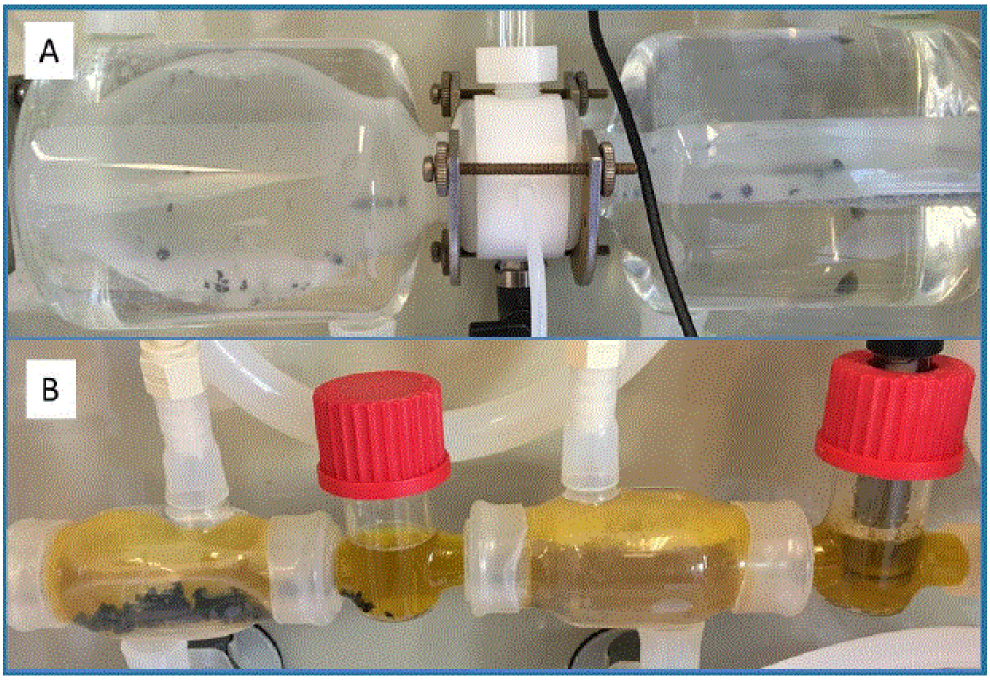

Figure 6 Photos of rubber granulate in the tiny TIM system during the experiment
A. Rubber granulate in the artificial stomach compartment.
B. Rubber granulate in the artificial intestines compartment

By inhalation
On sunny summer days, the rubber granulate can heat up considerably, causing substances from the granulate to evaporate. To simulate this, and thus to estimate exposure by inhalation, experiments were performed to determine the extent to which substances from the rubber granulate evaporate into the air at 60 °C. The high temperature ensures conditions in which substances can evaporate more easily. If the substances do not evaporate at these high temperatures, these substances will not be released at lower temperatures.
Benzene, toluene, ethylbenzene, xylene, styrene or 1,3-butadiene were not detected in the evaporated air. The following substances were detected to a limited extent: ethanol, acetone, acetaldehyde, carbon disulfide, methyl ethyl ketone and methyl isobutyl ketone. In addition, various other substances were found in low concentrations.
Subsequently, calculations were made to determine the air concentration at a height of one metre. These calculations were performed using a validated dispersion model (model NUMDIF).
Since the substances are released into the air to a very limited extent or not at all, and since the calculated concentrations in the air above the synthetic turf pitch are low, it is concluded that inhaling substances derived from rubber granulate does not contribute to a relevant extent to the exposure to substances of people playing sports, and therefore does not form any health risk. However, via the release of substances on hot days with little wind, an unpleasant odour can be detected.

3.4 Health risk assessment

Concerns about rubber granulate are mainly about the carcinogenic properties of some substances in rubber granulate, and about the possible relationship with **leukaemia and lymphoma** in particular. Benzene and styrene are substances that are associated with this type of cancer. However, benzene and styrene were not found in rubber granulate samples during the chemical analyses. 2-MBT is also suspected of this type of cancer (among others). The health risk assessment for 2-MBT indicates that the exposure is so low that no risk is expected. For PAHs, no clear link with leukaemia and lymphoma is known.

In calculating the risks, a number of worst case assumptions were made. The highest average concentration of each pitch of substances found on Dutch synthetic turf pitches was assumed and the highest migration values of the various substances were used. The assumption was also made that all training and games take place on synthetic turf pitches with rubber granulate.

In addition, for **PAHs,** the generally accepted method of calculation (linear extrapolation) as applied for carcinogenic substances (non-threshold) was used. Realistic worst case exposure scenarios were assumed, which include information on the release of substances from the granulate for inhalation and absorption by the skin and the gastrointestinal system (see section 3.2).

Exposure to PAHs is mainly caused by the ingestion of pieces of rubber granulate. The risk assessment shows that inhalation of rubber granulate dust that is present in the air hardly contributes to the total exposure. PAHs appear to migrate to sweat only to a very limited extent. Dermal exposure contributes little to the total exposure.

With this approach, an additional cancer risk of 0.8 to 1.2 per million exposed people is calculated for PAHs in rubber granulate, for someone who is a lifelong outfield player. This additional cancer risk is 2.2-3.0 per million for someone who has been a goalkeeper from ages 7 to 50. The calculated additional cancer risks are around the 'negligible risk', a policy-based risk limit of one additional case of cancer per million exposed individuals upon lifelong exposure, and are therefore virtually negligible.

Although dermal exposure contributes little to the total exposure, it must be noted that migration tests with artificial sweat for lipophilic substances such as PAHs give an underestimate of the amount of PAHs to which the skin is exposed. In the event that the exposure of the skin is 10 times higher, the additional cancer risk is still comparable, namely 3.1-4.2 per one million for someone who is a goalkeeper from ages 7 to 50.

Aside from a comparison of the additional cancer risk associated with the negligible risk, this can also be compared with the 'maximum permissible risk'. The maximum permissible risk is a policy-based risk limit of one additional case of cancer per ten thousand exposed individuals for lifelong exposure. The maximum permissible risk limit can help to determine whether drastic measures (e.g. decontamination, product recalls) are needed to reduce the risk. The calculated additional cancer risks of playing sports on synthetic turf pitches with rubber granulate are much lower than the maximum permissible risk.

The group of PAHs consists of hundreds of substances. The PAHs as investigated here are representative of the entire PAH mixture.

The contribution of exposure to PAHs by rubber granulate (37-98 ng/day) is small relative to the normal exposure for adults via food (1,800-4,900 ng/day) (EFSA, 2008). This comparison is made for the total concentrations of eight different PAHs, which are representative of all PAHs taken together. The daily exposure to PAHs via food may be substantially higher due to consumption of barbecued meat. In addition to food, exposure to PAHs via air, drinking water and soil is limited in the Netherlands.

In assessing the health risk, safety factors are used to compensate for any differences in sensitivity between humans and animals. After all, information on the toxicity of a substance is often based on animal studies but must be protective for sensitive groups such as children. Internationally, there is no scientific consensus on the need for and the level of a possible additional factor to protect children. In the US, for the linear extrapolation method, which is applicable for PAHs, an additional factor of 3 is applied for children between the ages of 2 and 16 (EPA 2005, OEHHA 2009). Even if this factor were to be applied in the risk assessment of PAHs, the calculated cancer risk would remain well below the maximum permissible risk.

For **BPA**, there is no data on the release to sweat and gastro-intestinal juices. Therefore, it is assumed that the amount of BPA in the rubber granulate is available for absorption by the body after exposure to the skin and after ingestion. With these conservative assumptions, the year average exposure of BPA for the scenario of a 7-year-old goalkeeper is well below (26 percent of) the exposure-level regarded as safe. The exposure is lower in the remaining scenarios. A year average exposure is assumed since high exposure on some days is compensated by low exposure on other days. There is no information on the release of BPA into the air, but given the low vapour pressure of the substance, this route is unlikely. For BPA, total exposure is determined almost entirely by exposure via the skin. Since it is likely that not all the BPA from the rubber granulate can be released and is available for absorption by the skin, the health risk is probably lower than calculated here. This result gives no reason for concern for BPA.

For the metals **cadmium** and **cobalt,** no risk was found under the selected conditions.
The metal **lead** has a very low safe exposure limit. This exposure limit is not exceeded by the year average exposure from rubber granulate. The calculated exposure to lead from rubber granulate is largely caused by the ingestion of pieces of rubber granulate.

For **phthalates,** the substances are combined within the substance group since they can cause an effect in the same way. No risk was found for the phthalates: the calculated exposure is many times smaller than the exposure limit regarded as safe. This is also true for the two samples that presumably partly consisted of EPDM rubber and in which high concentrations of phthalates were found.

For the **benzothiazoles** (which includes **2-MBT**), the substances in the substance group were combined as well and the calculated exposure was many times smaller than the exposure limit regarded as safe.

3.5 Conclusion

In this chapter an assessment was made of the health risks posed by playing sports on synthetic turf pitches with rubber granulate resulting from exposure to hazardous substances in the rubber granulate.

For PAHs, the additional cancer risk is 2.2-3.0 per million for someone who has been a goalkeeper from ages 7 to 50. This additional cancer risk is virtually negligible. It is much smaller than the so-called maximum permissible risk and is slightly higher than the negligible risk. The negligible risk is a policy-based risk limit of one additional case of cancer per million exposed individuals during lifelong exposure.

The metal lead has a very low safe exposure limit. This exposure limit is not exceeded by the year average exposure from rubber granulate.

For the remaining substances -- BPA, phthalates, the metals cadmium and cobalt and the benzothiazoles (including 2-MBT) -- the exposure is substantially lower than the exposure regarded as safe, and there is no health risk.

4. Rubber granulate, leukaemia and lymphoma

In the *Zembla* broadcast, attention was paid to the possible relationship between playing sports on synthetic turf pitches with rubber granulate and the development of leukaemia and lymphoma. The American football trainer Amy Griffin was among those interviewed. Since she saw several young football goalkeepers with cancer, she kept a record of cancer patients who had played sports on synthetic turf with rubber granulate. Following the information provided by Amy Griffin, RIVM investigated what is known about a potential link between playing football on synthetic turf and the development of leukaemia and lymphoma.
Detailed information can be found in Part D of the scientific background information in this report.

4.1 Risk factors for leukaemia and lymphoma in children and adolescents

According to the literature research, genetic factors play an important role in the development of leukaemia and lymphoma in children and adolescents. These factors make some more susceptible to risk factors than others.

So far, exposure to ionising radiation is the only environmental factor that is scientifically proven to have a causal link with childhood *leukaemia*. Other factors that are likely to play a role in the development of childhood leukaemia are exposure to high concentrations of specific carcinogenic substances such as benzene, various pesticides and cigarette smoke.

Some autoimmune disorders can increase the risk of certain subtypes of *lymphoma* as well as high exposure to carcinogenic substances such as cigarette smoke or, for example, intensive domestic use of insecticides.

4.2 New cases of leukaemia and lymphoma in the Netherlands among children and young adults

Data from the Netherlands Cancer Registry shows that in the period 2006-2015 nearly 2,300 children under the age of 18 had a diagnosis of leukaemia or lymphoma. In children under the age of 15, it usually involves (lymphocytic) leukaemia. Starting from the age of 15, lymphoma is more common, particularly Hodgkin's lymphoma and non-Hodgkin's lymphoma. In total, it constitutes almost 40 percent of all new cases of cancer in children under the age of 18 (NKR, 2016).

Figures from the Netherlands Cancer Registry (Source: IKNL) show that the number of new cases of leukaemia and lymphoma has gradually increased since the 1990s: from 6.4 to 8.8 per 100,000 children and young adults between the ages of 10 and 29 (see figure 7). This corresponds with approximately 200 boys and men and 160 girls and women in 2015. Over the entire period there is a slight but statistically

significant increase demonstrated in the incidence for the age group 10-29 years.
Due to the relatively small numbers, there is always some variation from year to year. Therefore, in addition to the figures for each year (red dots in figure 7), a three-year moving average is also given and included in the graph (blue line).

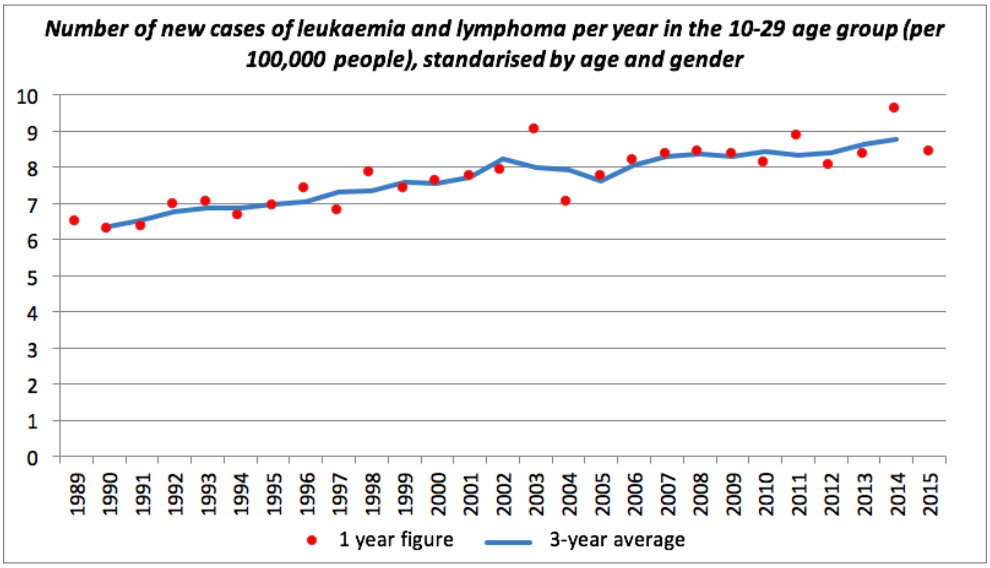

Figure 7 Number of new cases of leukaemia or lymphoma per year in the 10-29 age group (per 100,000 people), standardised by age and gender.

It was then determined whether any changes in the trend in the number of new cases of leukaemia and lymphoma could be demonstrated for the period 1989-2015. That was not the case. Synthetic turf with rubber granulate was introduced in the Netherlands starting in 2001. There is no indication for an *additional* increase during the period 2001-2015.

On the one hand, this trend analysis is fairly sensitive: any change of some additional cases of leukaemia and lymphoma per year in the Netherlands was already picked up in this way. On the other hand, the relevance of this analysis is limited since, for example, changes in the well-known risk factors for leukaemia and lymphoma cannot be taken into account.

4.3 Research in the US

Since the data from the dataset from Amy Griffin, the American football trainer, was collected based on self-reporting, it is difficult to say how representative they are. Currently in the US, the Ministry of Health of the State of Washington is investigating how the figures from her database, together with data over the total number of leukaemia and lymphoma cases from the American Cancer Registry, can be interpreted. These results are expected in early 2017[1].

[1] Update: the results have been published in January 2017 (http://www.doh.wa.gov/Portals/1/Documents/Pubs/210-091.pdf). There was no increased number of cancer diagnoses among football players compared to what would be expected if football players experienced the same cancer rates as Washington residents of the same ages.

Other American research[1] examined the link between the incidence of leukaemia/lymphoma and areas with more or fewer synthetic turf pitches with rubber granulate. No increase was seen in new cases of leukaemia/lymphoma in areas with relatively more synthetic turf. There is also no trend in the number of people getting lymphoma in areas of California where there are many synthetic turf pitches. The first synthetic turf pitches were installed there in 1997.

4.4 Other research

Inquiry into the European network of environmental epidemiologists has not revealed any other data collections or research based on which the indication of an increased risk of leukaemia/lymphoma due to playing sports on synthetic turf (with rubber granulate) can be verified. No research on the relationship between playing football on synthetic turf (with rubber granulate infill) and leukaemia or lymphoma in children and adolescents was found in scientific literature.

4.5 Conclusion

Based on this investigation, there are no indications that playing football on synthetic turf results in an additional risk of leukaemia and lymphoma. There are various underlying reasons for this:

1. In the previous chapters, attention was also paid to carcinogenic substances that may be associated with the development of leukaemia or lymphoma. Chapter 2 shows that benzene, styrene and 1,3-butadiene were not found in rubber granulate samples. The risk assessment for 2-mercaptobenzothiazole indicates that the exposure is so low that no risk should be expected (see Chapter 3).
2. Research in the US shows no increase in the number of people getting lymphoma in those areas where there are relatively more synthetic turf pitches. There is also no trend in the number of people getting lymphoma in those areas of California with most of the synthetic turf pitches.
3. Figures from the Netherlands Cancer Registry show that there are no significant changes in the trend in the number of new cases of people aged 10-29 who developed leukaemia or lymphoma during the past 27 years. This trend analysis would pick up changes of several additional cases per year.

[1] It involves as yet unpublished research by Bleyer and Keegan. http://comedsoc.org/images/Incid%20Lymph%201974-2013%201992-2013%202000-2013%20Highest%20Field%20Density%20Counties%20Sex.pdf

5. Concentrations of substances in rubber granulate as compared to regulatory limits

5.1 Measurements as compared to regulatory limits

Detailed information on the comparison to regulatory limits can be found in Part C of the scientific background information in this report.
The concentrations of hazardous substances measured in rubber granulate are well below the general European concentration limits for mixtures. According to the European substances regulations, rubber granulate is a 'mixture'. Other examples of 'mixtures' (of substances) are cleaning products, paint and glue. For mixtures[1], concentration limits apply for substances that are carcinogenic, mutagenic or toxic for reproduction. These include certain PAHs, metals, phthalates and organic compounds such as benzene.

For consumer products made from rubber, much more stringent concentration limits[2] apply for the PAH content (a factor of 100 to 1,000 lower) than for mixtures. For toys, the concentration limits[3] for carcinogenic PAHs are more stringent than those for consumer products by a factor of 2.
The concentrations of PAHs in rubber granulate measured in this research are (slightly) above the concentration limit for consumer products and also above the concentration limit for toys (see Table 3).

In practice, the major difference between the concentration limits for PAHs in mixtures on the one hand and consumer products on the other results in the situation that the concentration limit for PAHs for rubber shock-absorbing tiles (for which the concentration limit for consumer products is applicable) is 100 to 1,000 times more stringent than the concentration limit for rubber granulate. When we compare the use of rubber tiles at playgrounds with playing sports on pitches with rubber granulate infill, this major difference between these concentration limits cannot be properly justified. In Europe, a debate is currently underway as to whether it is desirable to have more stringent concentration limits for rubber granulate, particularly with respect to carcinogenic PAHs (e.g. EC 2015; RIVM, 2016). As mentioned earlier, the European Chemicals Agency (ECHA) is conducting research that, among other things, will determine whether indeed more stringent, specific concentration limits for rubber granulate are needed from a health perspective.

Since rubber granulate is applied on the soil and substances from rubber granulate may leach into the soil and groundwater, an indicative[4]

[1] These concentration limits only apply for 'mixtures intended for supply to the general public', i.e. not exclusively intended for the professional user. Although rubber granulate is not sold to consumers, rubber granulate falls under the category of mixtures intended for supply to the general public. See Annex XVII, entry 28 in the European REACH regulation (1907/2006).
[2] See Annex XVII, entry 50.5 in the European REACH regulation (1907/2006) on PAH in articles with rubber or plastic parts.
[3] See Annex XVII, entry 50.6 in the European REACH regulation (1907/2006) on PAHs in toys.
[4] For many limits, specific test methods apply, which may vary per substance group. The test methods used in this research do not always correspond with the test method prescribed for that limit.

comparison can also be made of the leaching concentrations of the metals with the limit for building materials that are used in or on the soil. This indicative comparison (see Table 4) shows that the leaching concentrations of zinc in rubber granulate do not meet the emission limits for granular building materials[1]. The measured leaching concentrations for zinc are not relevant for human health but for the environment. This is however not examined further in the current research on human health risks.

[1] Soil quality regulation, Annex A, Table 1.

Table 3 Comparison[1] of concentrations of substances in rubber granulate with the concentration limit for mixtures and with other regulatory limits. Reported are substances that have been detected in at least 5% of the samples and for which limits are available. Limits that are exceeded are in red, with the percentage of pitches that exceeds the limit in parentheses.

	Concentration in mg/kg dry matter (average values of each pitch)			Concentration limit for mixtures	Other limits (in mg/kg dry matter)			
Substance/Substance group	Median (P50)	P90	Max.		Consumer products[2]	Toys[2]	Building materials	Soil (residential classification)
PAHs								
benzo(a)pyrene	<1.1	1.3	2.2	100[3]	**1** (43%)	**0.5** (71%)	10	n.a.
benzo(a)anthracene	<0.9	1.2	2.2	1,000	**1** (23%)	**0.5** (29%)	40	n.a.
chrysene	1.3	1.9	3.5	1,000	**1** (62%)	**0.5** (86%)	10	n.a.
benzo(k)fluoranthene	<0.9	1.8	3.0	1,000	**1** (57%)	**0.5** (86%)	n.a.	n.a.
phenanthrene	<0.5	2.0	7.1	n.a.	n.a.	n.a.	20	n.a.
anthracene	<0.5	<0.5	1.1	n.a.	n.a.	n.a.	10	n.a.
fluoranthene	3.4	8.3	20.3	n.a.	n.a.	n.a.	35	n.a.
benzo(ghi)perylene	4.1	6.5	7.7	n.a.	n.a.	n.a.	40	n.a.
Sum PAH (VROM10)	9.6	17.7	35.5	n.a.	n.a.	n.a.	50	**6.8** (59%)
Phthalates								
di-2-ethylhexylphthalate	7.6	14.2	27.2	3,000	1,000	n.a.	n.a.	**8.3** (38%)
di-isobutylphthalate	<0.5	0.8	2.3	250,000	n.a.	n.a.	n.a.	**1.3** (5%)
Phenols				n.a.	n.a.	n.a.	n.a.	n.a.
Bisphenol A	0.5	2.0	2.5	3,000	n.a.	0.1 mg/L	n.a.	n.a.
Polychlorobiphenyls								
PCBs[4]	<0.035	0.06	0.074	n.a.	n.a.	n.a.	0.5	**0.04** (29%[5])

[1] For many limits, specific test methods apply, which may vary per substance group. The test methods used in this research do not always correspond with the test method prescribed for that limit.
[2] For certain consumer products and toys, limits also apply with respect to various metals but a comparison with the measured values from this research is not possible since in this research only the leaching of metals to water has been determined.
[3] The lowest of the three concentration limits applicable for BaP.
[4] Sum of PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180.
[5] Two of the seven mixed samples.

Table 4 Comparison[1] of the leaching values of metals in rubber granulate with the limit for granular building materials[2]. Reported are the metals that in more than 5% of the samples are detected with the percentage of samples that exceed the limit in parentheses.

	Leaching concentration in mg/kg dry matter		Limit for building materials[2]
Metals	Median	Max	
Zinc	21	129	**4.5** (100%)
Copper	0.09	0.9	0.9
Cobalt	0.06	0.4	0.54
Barium	<0.05	0.2	22

5.2 Conclusion

The concentrations of substances in rubber granulate meet the general European concentration limits for mixtures of substances. If the concentration limits for consumer products and toys were to be applied to rubber granulate, a large number of the samples would not meet these concentration limits because of the concentration of PAHs. There is a debate in Europe as to whether a specific concentration limit for rubber granulate is desirable.

[1] For many limits, specific test methods apply, which may vary per substance group. The test methods used in this research do not always correspond with the test method prescribed for that limit. Therefore, it is an indicative comparison.
[2] This refers to the maximum emission value for granular building materials.

6. Conclusions and recommendations

6.1 Conclusions

Various substances in rubber granulate
Chemical analyses of rubber granulate from 100 Dutch synthetic turf pitches show that various substances such as PAHs, metals, phthalates, benzothiazoles and phenols are present in rubber granulate. The concentrations are in general consistent with the concentrations found in previous research.

Health risk virtually negligible
The so-called migration tests show that substances present in rubber granulate are only to a (very) limited extent released from the granulate when ingested, upon contact with the skin or through evaporation in hot weather.
Exposure calculations show that for PAHs, the additional cancer risk is virtually negligible. Exposure to PAHs by rubber granulate is small relative to the normal exposure to PAHs via diet.
The metal lead has a very low safe exposure limit. This exposure limit is not exceeded by the year average exposure from rubber granulate.
For the remaining substances -- BPA, phthalates, the metals cadmium and cobalt and the benzothiazoles (including 2-MBT) -- the exposure is substantially lower than the exposure level regarded as safe, and the health risk is negligible.

No indications of a relationship between leukaemia and playing sports on synthetic turf
Of the carcinogenic substances that could be associated with leukaemia and lymphoma, benzene, styrene and 1,3-butadiene were not found in the tested rubber granulate.
The health risk assessment for benzothiazoles, including 2-MBT, indicates that the exposure is so low that no risk of leukaemia or lymphoma can be expected. No clear link with leukaemia or lymphoma is known for PAHs.

Research conducted in the U.S. does not reveal any increase in the number of new cases of lymphoma in areas where there are relatively many synthetic turf pitches. There is also no trend in the number of people getting lymphoma in those areas of California with most of the synthetic turf pitches. Figures from the Netherlands Cancer Registry show that since the 1980s a slight rise has been observed in the number of people aged between 10 and 29 who get leukaemia. This trend has not changed since pitches made of synthetic turf were first used in the Netherlands in 2001.

Different concentration limits
The concentrations of substances in rubber granulate meet the general European concentration limits for mixtures of substances. If the concentration limits for consumer products and toys were to be applied to rubber granulate, a large number of the samples would not meet these concentration limits because of the concentration of PAHs. There

is a debate in Europe as to whether a specific concentration limit for rubber granulate is desirable.

6.2 Recommendations

Playing sports on synthetic turf pitches
The results of this research indicate that playing sports on synthetic turf pitches with rubber granulate is safe. The health risk from playing sports on these synthetic turf pitches is virtually negligible. While rubber granulate contains hazardous substances, these substances are only released from the rubber granulate to a limited extent after ingestion, contact with the skin or evaporation in hot weather.

Concentration limit for rubber granulate
RIVM recommends adjusting the concentration limit for rubber granulate to one that is closer to the concentration limit for consumer products.
In view of the use of synthetic turf pitches, even by young children, there is a need for sound health-based limits for rubber granulate. At this time, there is a big difference (factor 100 to 1,000) between the concentration limit for PAHs in rubber consumer products (such as rubber shock-absorbing tiles) and the concentration limit for rubber granulate, for which the concentration limit for mixtures applies. When we compare the use of rubber tiles at playgrounds with playing sports on pitches with rubber granulate infill, this major difference between these concentration limits does not appear to be well justified.
With the research currently being conducted by the European Chemicals Agency (ECHA), work is currently underway here in Europe on the health risks of rubber granulate. RIVM will actively contribute the results of the present research to ECHA.
Better supported and more stringent limits for rubber granulate may contribute over time towards reducing current concerns on health risks due to playing sports on synthetic turf.

7. Discussion

About this research
For this research, a large amount of information was collected in a short period of time, based on extensive laboratory testing and scientific literature. In the literature, very little is known about the release of substances from rubber granulate. Therefore, for this research, a number of so-called migration tests were conducted to investigate the extent to which hazardous substances are released in artificial sweat, artificial gastro-intestinal juices and through evaporation at high temperatures. Although a limited number of tests were involved, the results give a consistent picture.
As is common practice in the assessment of health risks of substances, assumptions are also made in this research in assessing exposure and health risk. Well-substantiated assumptions were made in assessing the actual exposure that occurred and the extrapolation of experimental animal data to human beings. These assumptions were presented to a scientific advisory board, appointed specially for this purpose.

What was not investigated?
This report was not about the question of whether the use of rubber granulate from old car tyres on synthetic turf pitches is desirable. Discussions conducted by RIVM during this research period and meetings of the scientific advisory board reveal that there may be tension between the ambition to increase recycling of materials (such as car tyres) and concerns about the potential exposure of humans and the environment to hazardous substances in new products. This research only concerns human health effects: environmental impact was not considered. The research also did not consider the advantages and disadvantages of alternative materials for synthetic turf pitches.
In accordance with the question from the Minister of Health, Welfare and Sport, this research investigated whether health risks can be expected from playing sports on synthetic turf pitches with rubber granulate. Other uses of synthetic turf pitches do not fall within the scope of this research.

Current research
Research is also currently being conducted abroad on the potential health risks of rubber granulate. The results from this research will become available in the course of 2017. RIVM shall continue to pay very close attention to research in this area.

Health risks from substances
Every day, we are exposed to substances that can cause health risks. Consider inhaling polluted air along highways, in inner cities, in agricultural areas, but also eating roasted meat or inhaling substances when painting a house. The amount of substances around us says very little about the health risks. The extent in which substances enter the body through different routes may be important for that as well as the effects that these substances may or may not have in the body.
People perceive health risks very differently, which was revealed in the discussions conducted by RIVM with those playing sports, parents of

those playing sports, with the members of the scientific advisory board, media reports and a survey.

Finally
Decisions on the use of synthetic turf pitches are now primarily up to sports clubs, municipalities, the KNVB and suppliers of synthetic turf pitches. RIVM hopes that the results of this research shall provide a useful contribution in this decision-making process and for the answer to questions from governments, associations, people playing sports and parents of children playing sports.

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- Municipal Public Health Services
- Association of Sports and Municipalities (VSG)
- Association of Dutch Municipalities (VNG)
- VACO (trade association for the tyre and wheel industry)
- RecyBEM (management company for Dutch legislation on waste management for end of life tyres)
- Trade Association Sports and Culture Technique (BSNC)
- Netherlands Comprehensive Cancer Centre (iKNL)
- Netherlands Cancer Institute (NKI)
- Princess Maxima Centre
- Participants in the group discussions
- Netherlands Food and Consumer Product Safety Authority (NVWA), Office for Risk Assessment and Research (BuRO)
- Ministry of Health, Welfare and Sport (VWS), Food, Health Protection and Prevention division (VGP) and Sport division
- Ministry of Infrastructure and the Environment (IenM), Safety and Risks division
- Human Environment and Transport Inspectorate (ILT)

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- Netherlands Food and Consumer Product Safety Authority (PV Lab Chemistry and Micro team, Groningen)
- TNO (Environmental Modelling, Sensing and Analysis, Utrecht)
- Triskelion (Zeist)

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- Prof. Dr. Jos Kleinjans
- Prof. Dr. Erik Lebret
- Nicole Nijhuis, MSc, ERT
- Dr. Paul Scheepers
- Dr. Irma de Vries
- Rik van de Weerdt, MSc, ERT

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Scientific background information

Part A: Sampling and analysis of infill of 100 synthetic turf pitches

Part B: Chemical analysis of rubber granulate

Part C: Literature research

Part D: Leukaemia and lymphoma

8. Part A: Sampling and analysis of infill of 100 synthetic turf pitches

8.1 Introduction

A key aspect in the RIVM study on possible health risks of playing sports on synthetic turf pitches with rubber granulate consisted of sampling and analysing infill from 100 randomly selected synthetic turf pitches in the Netherlands. Using standard methods, the infill material from all pitches was analysed for the presence of forty-five chemical substances. Ten pitches were sampled in triplicate. The additional samples were used for counterchecks and additional research.

8.2 Selection of pitches

Details about the number, type and location of synthetic turf pitches in the Netherlands were provided to RIVM directly by the Royal Dutch Football Association (KNVB) or obtained via mediation by the KNVB. The KNVB has compiled its own database of information on more than 1900 synthetic turf pitches. Although the database is extensive and includes significant quantities of technical information (e.g. date of completion, turf supplier, pitch type and the contractor who installed the pitch), it is not entirely up-to-date, since information is not always updated as it becomes obsolete. Moreover, the database does not contain a complete data set for each and every technical detail. For instance, incomplete data is an issue for the type of infill material used in the pitches, a detail which has not been specified for 58% of the pitches. SBR infill is used for 35% of pitches, while a different infill is used for 7% (such as EPDM, TPE, cork, or mixtures of a variety of synthetic and natural materials). It is assumed that the majority of pitches labelled as ‘infill unknown’ use SBR infill.

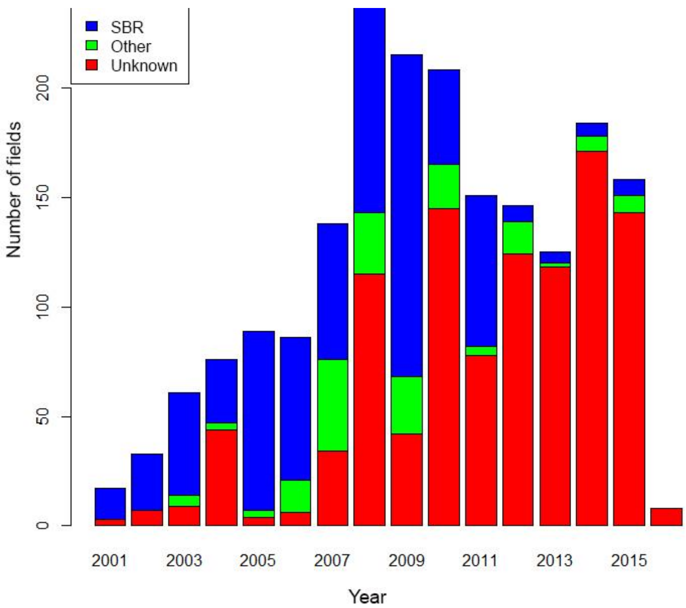


Figure 1 Classification of infill for synthetic turf pitches according to the KNVB database.

The KNVB data set was supplemented by additional information from the Mulier Institute and the Cruyff Foundation; the KNVB also arranged access to information on korfball pitches and, at a very late stage, information on rugby pitches. The Mulier file contains data on approx. 1400 synthetic turf pitches at about 950 locations. Although these pitches are very likely to be a subset of the pitches referenced in the KNVB data, direct comparison with the KNVB data set is difficult; the Mulier file uses a different structure and focuses on different aspects, primarily providing complementary information. A relatively low number of other pitches using SBR infill are represented in the data: 27 Cruyff Courts, 28 korfball pitches, and 7 rugby pitches.

Exactly 100 pitches were sampled for the purposes of this research. Since the sample needed to be representative of the entire group of synthetic turf pitches, and the KNVB database contained the most detailed data on such variables as the year the pitch was completed, the supplier and the contractor, this file was used as the primary source. After filtering for infill categories entered as 'SBR' and 'unknown', a random selection from the KNVB database was generated, supplemented by korfball pitches and Cruyff Courts, resulting in a list of 200 pitches that were expected to have SBR infill. The pitch managers of the first 100 pitches were then contacted. In some cases, the pitch in question did not fulfil the selection criteria, for example because it was no longer in use or because a different type of infill had been used. In such cases, the pitch was removed from the selection and replaced by the next pitch on the list. This process resulted in a random sample of 100 synthetic turf pitches, including two Cruyff Courts and two korfball pitches (Figure 2). The sample represents over 5% of the total number of synthetic turf pitches with SBR infill in the Netherlands.

Figure 2 Locations where rubber granulate was sampled for RIVM research (light blue dots). The black markers indicate sports facilities with one or more synthetic turf pitches. (Source: Mulier Institute)

Six positions were sampled per pitch. We used the same positions as required to assess the quality of the pitch according to FIFA regulations. This includes areas subject to intensive and less intensive play; the corner, the goal area, the middle of one half of the pitch, the centre spot, the edge of the pitch and the penalty mark (see Figure 3).

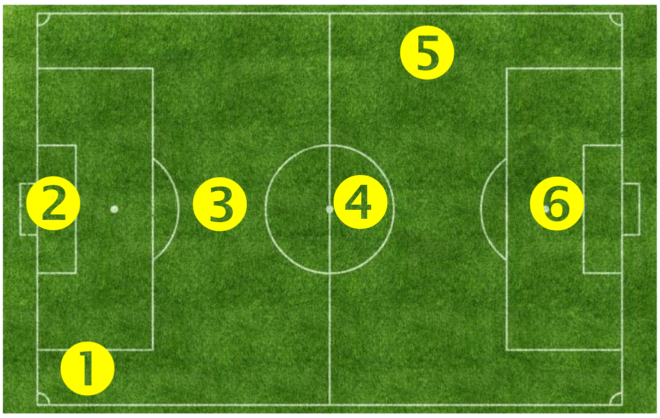


Figure 3 Sampling positions on the pitch.

After collecting the samples, the managers of the sampled pitches were asked to fill out a questionnaire which was used to check available information (the year the pitch was completed, supplier, type of turf, contractor) and add any missing information (maintenance schedule, presence of certificates). About 60% of the people who were contacted returned a completed questionnaire.

8.3 Sampling method

Rubber granulate was collected from within a circle with a surface area of about 380 cm^2 (the size of a bucket) using a vacuum cleaner (equipped with dust bag and filters) for two minutes. A test sample revealed that this method yields approximately one litre of rubber granulate (about 500 grams). The 'gaps' left after the sample was taken were filled in using rubber granulate lying alongside the pitch. On some pitches (generally the older ones) or in certain areas on the pitch (centre spot, penalty mark), the infill was often fairly sandy. In those cases, two adjacent areas were vacuumed for one minute each. The filters were replaced and the vacuum cleaner was cleaned out after each pitch.

Figure 4: Rubber granulate sampling using a vacuum cleaner (left) and filling a glass jar with the sampled material (right)

The collected material was stored in a glass jar, using a separate jar for each sample location, labelled with a bar code. Only RIVM can trace the combination of barcode, pitch and FIFA sampling position. The laboratories performing the analyses were not aware of the exact origins of the samples.

Triple samples of infill material were taken from 10 pitches for conducting additional measurements. The two additional samples collected per FIFA position were used for counterchecks, a general unknown screening and a number of ‘migration tests’ (see Figure 5). The migration tests examined which substances are released from rubber granulate and to what extent these substances are released during contact with the skin and when ingested. The migration tests also looked at the extent to which hazardous substances that could be inhaled might be released under highly unfavourable circumstances.

8.4 Sample analysis

A total of 720 samples were collected. The 600 samples from Batch 1 (100 synthetic turf pitches, 6 positions per pitch) were sent to Alcontrol Laboratories for standard analyses, testing for the presence of PAHs, phthalates and volatile compounds checking whether heavy metals were leaching from the sample material. Additionally, Alcontrol Laboratories performed an additional test on 60 samples to determine the amount of PAHs using *warm extraction*.

The 60 samples from Batch 2 (10 pitches, 6 positions per pitch) were sent to TNO for counterchecks for PAHs and phthalates. TNO took partial samples and sent them to the Netherlands Food and Consumer Product Safety Authority (NVWA) for counterchecks for heavy metals.

The 60 samples from Batch 3 (10 pitches, 6 positions per pitch) were sent to various laboratories for a series of additional experiments. This included:

- A *General Unknown Screening*. This series of tests is used to detect the presence of possible substances that could not be included in the targeted analyses already conducted, but may - based on other research - be found in the material, and to detect substances that have not been tested for during previous analyses of the material;

- *Migration Tests*. These are tests to determine the extent to which substances from rubber granulate are released under conditions that closely resemble those during and after playing sports. Three types of experiments were performed:
  a. Ingestion: tests to determine the substances released after swallowing rubber granulate that has ended up in the mouth in some way, and the extent to which these substances are released. In this experiment, rubber granulate was first exposed to saliva, then gastric juices, and finally intestinal juices.

b. Inhalation: tests to determine which substances are released in gaseous form when rubber granulate is heated to 60°C[1], and the extent to which these substances are released. These figures were used to calculate exposure to hazardous substances via vapour inhalation assuming a worst-case scenario. (Weather conditions: warm with a very stable atmosphere. This results in the highest air concentrations compared to normal weather conditions.)
c. Dermal contact: tests to determine which substances are released following skin contact with rubber granulate and the extent to which these substances are released.

The results of these analyses are described in Part B of the scientific background information of this report.

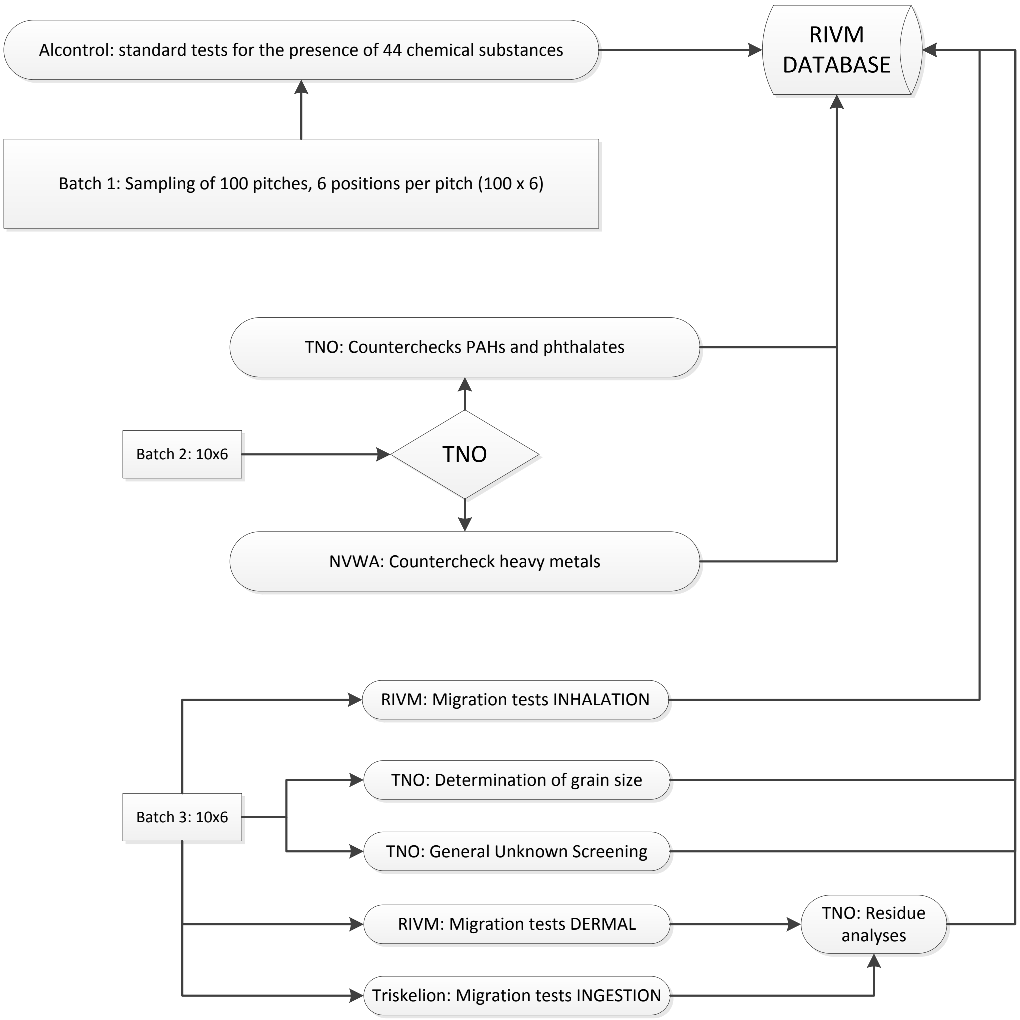


Figure 5 Flowchart for sampling and laboratory analyses of rubber granulate for the RIVM research project on "Evaluation of health risks of playing sports on synthetic turf pitches with rubber granulate"

[1] During warm summer days when outdoor temperatures exceed 25°C, the temperature of the rubber granulate on a synthetic turf pitch may reach 60°C.

9. Part B: Chemical analysis of rubber granulate

9.1 Description of tests and measuring methods

Blinded tests have been performed by several laboratories. The samples used in the tests described in this section are linked to a unique code. The laboratories did not know the meaning of the codes, so the origin of the samples was unknown to them. After the laboratories completed the analysis, RIVM combined the analytical results with information about the origins of the samples and field characteristics.

9.1.1 Composition of rubber granulate and leaching of metals

Based on literature review a list of substances was selected to be tested. The expertise of the laboratories involved and their possibilities to deliver at short notice also played a role in the selection of substances. (see also Figure 5 of Part A).

Standard tests were performed by Alcontrol and included:
Dry weight, metals, PAHs, phthalates and volatile organic compounds.

Table 1 Substances tested in all 600 samples

Metals (leaching)	**PAHs**	**phthalates**	**VOC**
antimony	acenaphtene	dihexyl phthalate	benzene
arsenic	acenaphtylenene	dimethyl phthalate	toluene
barium	anthracene	diethyl phthalate	ethylbenzene
cadmium	benzo(a)anthracene	di-n-butyl phthalate	o-xylene
chromium	benzo(a)pyrene	diisobutyl phthalate	p- and m-xylene
cobalt	benzo(b)fluoranthene	butyl benzyl phthalate	styrene
copper	benzo(k)fluoranthene	di(2-ethylhexyl) phthalate	
mercury	benzo(g,h,i)perylene		
lead	chrysene		
molybdenum	dibenz(a,h)antracene		
nickel	phenanthrene		
selenium	fluoranthene		
tin	fluorene		
titanium	indeno(1,2,3-cd)pyrene		
vanadium	naphthalene		
zinc	pyrene		

Additional substances of interest were tested by TNO, who also performed counterchecks on the PAH’s and phthalates mentioned in Table 1.

Table 2 Additional substances of interest tested in 10% of the samples

metals	**PAHs**	**phthalates**
-	benzo(c)fluorene benzo(e)pyrene cyclopenta(cd)pyrene 5-methylchrysene dibenzo[al]pyrene dibenzo[ae]pyrene dibenzo[ai]pyrene dibenzo[ah]pyrene	diphenyl phthalate diisononyl phthalate diisodecyl phthalate di-n-octyl phthalate di-n-nonyl phthalate dicyclohexyl phthalate bis (2-ethylhexyl) adipate
phenols	**PCBs**	**benzothiazoles**
4-t-octylphenol 4-nonylphenol bisphenol-A triclosan	PCB28 PCB52 PCB101 PCB118 PCB138 PCB153 PCB180	benzothiazole 2-hydroxybenzothiazole 2-mercaptobenzothiazole 2-methoxybenzothiazole 2-aminobenzothiazole N-cyclohexyl-1,3-benzothiazole-2-amine 2,2-dithiobis(benzothiazole) N-cyclohexyl-2-benzothiazole sulphenamide

Metals. The NEN-EN 12457-2 test was used to determine the leaching of metals into water. A mixture of rubber granulate and water (liquid to solid ratio (L/S) =10, pH approx. 7) was shaken for 24 hours; the test was conducted at room temperature. The concentrations of metals in the (filtered) water were determined by ICP/MS and have been converted into the amounts released per kilogram of sample material. The temperature, pH and electroconductivity were also determined. Analysis was performed with ICP-MS, conform NEN-EN-ISO 17294-2, except for mercury, which that analysed conform NEN-EN-ISO 17852.

PAHs and phthalates. PAHs and phthalates were extracted using an organic solvent. A mixture of rubber granulate and solvent was shaken at L/S=10. Extraction efficiency depends e.g. on the type of solvent and the temperature. For that reason, three methods were compared to determine which method would yield the highest concentrations; that method was used for the risk assessment.

Three methods for extracting PAHs and phthalates were compared:

1. Extraction of substances mentioned in Table 1 with petroleum ether, at room temperature (all 600 samples),
2. Extraction of substances mentioned in Table 1 with petroleum ether, at temperatures up to about 70°C (10% of the samples),
3. Extraction with hexane (Table 1 and Table 2), at room temperature (10% of the samples).

Volatile compounds. Rubber granulate (100 mg) was shaken for half an hour with 100 mL methanol at room temperature. The methanol was then heated so that the volatile compounds evaporated. The substances in the gaseous phase were analysed. The gaseous phase was analysed for benzene, ethyl benzene, toluene, xylenes and styrene.

PCBs and phenols. One gram of rubber granulate was shaken with 100 ml acetonitrile for five days. Analysis by LC/MS-MS.

General unknown screening. Tests were conducted to identify any unknown substances that were present in the rubber granulate or could be released from it by evaporation.

The substances that can be detected depend strongly on the solvents used. For that reason, extractions were performed with hexane. About 1.5 gram of rubber granulate was shaken at 20 rpm with 5 mL solvent for three hours at room temperature. Splitless analysis with GCxGC was employed.

In order to detect unknown volatile compounds, 30 grams of rubber granulate was heated to 40°C and kept overnight in a closed one-litre bottle. The substances released were tentatively identified by comparing the mass spectra against mass spectra in the substance library of the National Institute of Standards and Technology (NIST). This method gives a probable identification. Further research using reference compounds is needed to conclusively to determine the identity of the substances. However, this was not feasible within the available time frame.

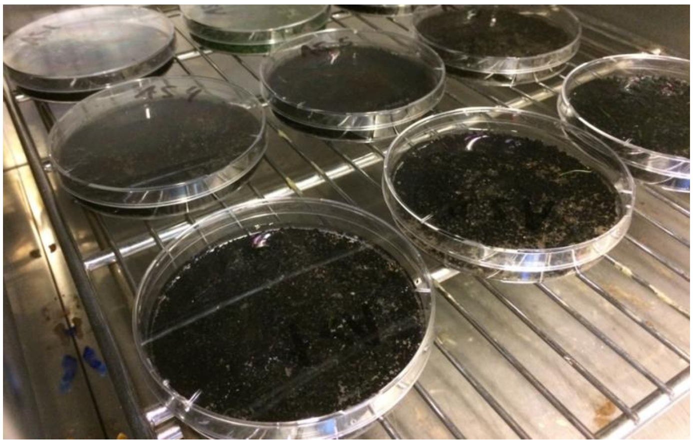
9.1.2 Migration tests

In order to estimate the fraction of substances in rubber granulate that is available for uptake after ingestion or dermal contact the concentrations determined in the migrations tests were compared with the composition as described in paragraph 9.1.1. Migration and composition were determined by different laboratories on blinded samples.

9.1.2.1 Migration into sweat

An experiment was set up following the example set by the Danish EPA using sections taken from car tyres (report no. 54 2005, page 27). The experimental setup is intended exclusively to obtain an impression of the migration of organic compounds and metals into sweat. In the current experimental setup, artificial sweat is exposed to rubber granulate in a Petri dish for two hours at 37°C.

The conditions chosen for this setup were somewhat more extreme than in the Danish study (one hour at 30°C). The amount of artificial sweat covered the entire bottom of the Petri dish (see picture on next page). The amount of rubber granulate (approximately 8±1 grams) was just sufficient to cover the bottom of a Petri dish with a single layer.



The rubber granulate was weighed, including any moisture and sand that was still clinging to it. Dry weight of the samples were adopted from parallel experiments (see paragraph 9.1.1). The scale of the experiment was determined by the number of samples and the amount of artificial sweat that was available in the very short term.

The experiment was carried out in duplicate in 10 cm Petri dishes made of polystyrene with 15 mL artificial sweat (Artificial Eccrine Perspiration, stabilised; LCTech GmbH, Dorfen, Germany) on 10 samples of rubber granulate and 2 blanks. The artificial sweat contained the 7 minerals, 19 amino acids and 4 metabolites that are most common in natural sweat. The pH was 4.5. The sweat extract was collected after two hours by means of decanting. PAHs, phthalates and metals were tested in the sweat extract.

9.1.2.2 Migration to saliva, stomach and intestinal juices.

To test the migration of substances from the rubber granulate into the gastrointestinal system, the Tiny-TIM setup from Triskelion[1] was used. Tiny-TIM is a system consisting of two compartments that simulate the conditions in the stomach and the small intestine.

Both the gastric compartment (Figure 1A) and the intestinal compartment (Figure 1B) consist of a glass exterior and a silicone inner wall. There is a water jacket between the glass and the silicone that keeps the stomach contents at 37°C. Peristalsis is simulated by pumping water in and out of the water jacket, pushing the stomach contents, kept within the silicone wall, from the left compartment to the right compartment. During the experiment, peristalsis was simulated for four hours in the gastric and intestinal compartments. Secretions of gastric acid, enzymes, water and simulated saliva were added to the gastric compartment throughout the experiment, while bicarbonate, bile, pancreatic enzymes and electrolyte were secreted into the intestinal compartment.

[1] Havenaar, R., Anneveld, B., Hanff, L.M., De Wildt, S.N., De Koning, B.A.E., Mooij, M.G., Lelieveld, J.P.A., Minekus, M. (2013). In vitro gastrointestinal model (TIM) with predictive power, even for infants and children? Internat. J. Pharm. 457: 327-332.

Figure 1. Photos of rubber granulate in the Tiny-TIM system during the experiment. A: Rubber granulate in the artificial gastric compartment. B: Rubber granulate in the artificial intestinal compartment.

The experiment was carried out under fasted conditions. This means that the test product is introduced with water (without food) into the stomach under acidic initial conditions. The acidity of the stomach drops over time from pH 3.0 to pH 1.8 as HCl is added. The pH of the intestinal compartment is 6.5 and kept constant throughout the experiment.

Water is added to the gastric compartment along with simulated saliva and the initial gastric residue (a total of 135 ml). Approximately one gram of rubber granulate was added to this, after which the four-hour experiment was started.

The gastric compartment starts to empty as soon as the experiment starts. Within about 30 minutes, half the stomach contents have been emptied into the intestinal compartment. The gastric compartment is completely emptied after 60 minutes.

Linked to the intestinal compartment, there is a membrane for separating water-soluble substances and lipophilic substances in micelles from precipitated, complexed and non-dissolved substances. The filter pore size is 50 nm and it has a surface of 0.3 m^2 (polysulfone plasma filter Plasma Flux P1 dry, Fresenius Medical Care, Bad Homburg, Germany). Filtration is a constant process that continues throughout the experiment. The filtrate is collected twice, after 120 and 240 minutes. This filtrate sample provides information about the fraction of dissolved substances after four hours in the gastrointestinal tract.

In addition to the filtrate samples, the remaining contents – the residue – were collected from the gastric and intestinal compartments. The two compartments were then flushed twice with water and the respective rinsings were combined with the residues from each compartment. This residue contained rubber grains that had remained in the Tiny TIM system. The rubber grains were removed from the residue sample before the samples were analysed for heavy metals, PAHs and phthalates. This means that only the heavy metals, PAHs and phthalates that had been released from the rubber granulate were measured. Research into the bioavailability of medicines has shown that the bioavailability in an empty stomach is greater than in a full stomach[1].

Although the filtrate normally provides a good representation of the bioavailable fraction, we have in this case used the sum of all released amounts of metals, PAHs and phthalates in the filtrate and residue[1,2,3]. Taking the sum of both types of sample means we are probably on the high side in terms of bioavailability, but that is a conservative choice for the risk analysis.

9.1.3 Migration into air

On a warm summer day (at least 25°C), with high solar irradiation, the temperature of black rubber granulate can rise as high as 60°C. Some chemical substances will then evaporate out of the granulate more quickly than normal. Under average weather conditions, these substances will be dispersed quickly by the wind. However, a few times per year, weather conditions are so stable that the evaporated substances will persist above the playing surface for a longer time. The evaporation of substances was determined after heating of rubber granulate at 60°C. The substances were tentatively identified and quantified. Assuming a worst-case scenario, this data was then used to estimate inhalation exposure to evaporated hazardous substances. The measurements and calculations performed are explained below.

Evaporation of substances from heated rubber granulate

In this test, the bottom of a glass bottle was covered with a 3-cm layer of rubber granulate and the bottle was sealed. This thickness is characteristic of how rubber granulate is applied on synthetic turf pitches. The amount of granulate used was weighed to measure its mass and corrected to the level of dry matter. The granulate in the bottle was heated to 60°C for several hours. The air containing the evaporated substances was then extracted from the bottle at least five times (every 45 minutes) and analysed to identify the substances using GC/MS[4], for which a standard mixture of 65 substances (EPA TO15) was used as a

[1] Verwei, M., Minekus, M., Zeijdner, E., Schilderink, R., Havenaar, R. (2016). Evaluation of two dynamic *in vitro* models simulating fasted and fed state conditions in the upper gastrointestinal tract (TIM-1 and Tiny-TIM) for investigating the bioaccessibility of pharmaceutical compounds from oral dosage forms. Int. J. Pharm. 498: 178-186.

[2] Van de Wiele, T., Oomen, A., Wragg, J., Cave, M., Minekus, M., Hack, A., Cornelis, C., Rompelberg, C., De Zwart, L., Klinck, B., Van Wijnen, J., Verstraete, W., Sips, A. (2007). Comparison of five *in vitro* digestion models to *in vivo* experimental results: Lead bioaccessibility in the human gastrointestinal tract. J. Experimental Sci. Health. Part A, 42: 1203-1211.

[3] Barker, R., Abrahamsson, B., Kruusmägi, M. (2014). Application and validation of an advanced gastro-intestinal in vitro model for evaluation of drug product performance in pharmaceutical development. J. Pharm. Sci. 103 (11): 3704-3712. DOI 10.1002/jps.24177

[4] GC/MS stands for gas chromatography/mass spectrometry. This is a combined analysis method that allows for simultaneous, highly sensitive detection of various substances in a mixture.

reference. The air in the bottle was replaced with fresh air during sampling.

The highest values have been reported. Assuming that saturation will not be achieved in 45 minutes[1], the evaporation rates in nanograms per second from one kilogram of rubber granulate at 60°C can be calculated for each substance and for each granulate sample. Ten granulate samples were analysed. In seven of the cases, the samples were SBR. Two of the three non-standard samples were coated or green SBR and one was recycled EPDM.

From evaporation rate to air concentration at a height of one metre
The NUMDIF[2] dispersion model was used to convert from the evaporation rate (per second per kg of granulate) to an air concentration at a height of one metre. The conversion was based on the following (unfavourable) situation:

- Given a group of eight synthetic turf pitches 200 m long and 200 m wide;
- We assume that 15 kg rubber granulate per square metre has been spread on the pitch;
- We assume that the wind is blowing across the pitch in a single direction, with negligible dispersion perpendicular to the wind direction.

The other input parameters are based on international research. Calculations were done for extremely stable weather, for stable weather and for unstable weather.

The calculations used a default substance emission of 1 $ng \cdot s^{-1} \cdot m^{-2}$ over the entire surface area of 200x200 metres. The concentrations calculated must therefore still be multiplied by the actual emission for each substance in order to derive the actual concentration of each substance in the air. For that calculation, we have assumed the results of the tests on granulate samples described above.

The results are shown in Figure 2. For the extremely stable meteorological conditions (black line, worst-case scenario), the maximum air concentration is 160 ng/m^3 at a distance of 240 m (i.e. 40 m beyond the edge of the pitch). At the edge of the pitch (200 m), the air concentration is 140 ng/m^3. These maximum concentrations are 6 to 10 times higher than the maximum concentrations calculated for stable (red) and unstable (green) meteorological conditions respectively.

[1] It was not possible to verify this assumption due to the urgent nature of the research.
[2] J.A. van Jaarsveld, A. Bleeker, J.W. Erisman, G.J. Monteny, J.H. Duyzer, D. Oudendag: Ammoniak emissie-concentratie-depositie relaties op lokale schaal, RIVM report 725601001 (July 2000).

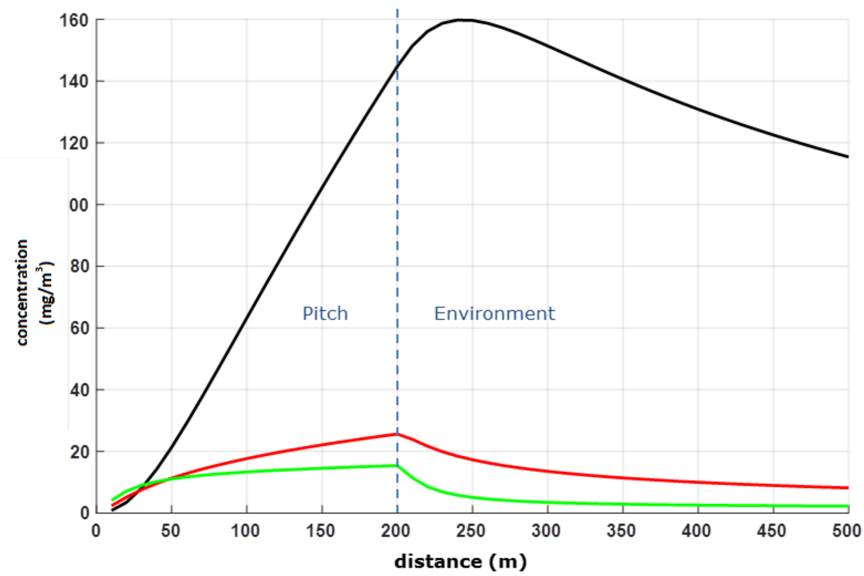


Figure 2: Air concentrations at a height of one metre, assuming a standard emission rate of 1 ng per m^2 per second over a surface area of 200x200 m^2, as a function of the distance for three sets of meteorological conditions. Black: very stable weather (worst-case scenario), red: stable weather, green: unstable weather.

9.2 Data analysis method

9.2.1 Data aggregation

Average concentrations for each pitch have been calculated from samples of the individual 6 FIFA-positions in order to determine the characteristics of the infill material used. The percentage of samples that were above the limit of detection is specified for each individual substance, as well as the median and maximum concentrations for the pitches.

9.2.2 Representativeness of the samples

Questionnaires, discussions with pitch managers and observations by the people taking the samples eventually revealed that the infill material on 9 pitches consisted entirely or partly of material other than car tyre rubber. These samples were eliminated from the data set, resulting in a data set of 546 samples taken from 91 different pitches.

Some of the analysis results relate to a smaller set of samples. It concerns the analysis of substances mentioned in Table 2, the counterchecks and the general unknown screening. The original plan was to use samples from 10 pitches for these additional experiments. Unfortunately, it became apparent after additional samples were taken from these pitches that the infill material used on three of them consisted partly or entirely of materials other than tyre rubber. As a result, the counterchecks of SBR samples were conducted on 42 samples (7 pitches x 6 FIFA positions), while the general unknown screening was conducted on 7 samples (7 mixed samples from the 6 FIFA positions on 7 pitches).

Figure 3 shows the age of the 91 pitches used for the characterisation. Approximately 10% of the pitches are more than 10 years old. This figure does not reflect the most recent date on which supplemental rubber granulate was used as infill.

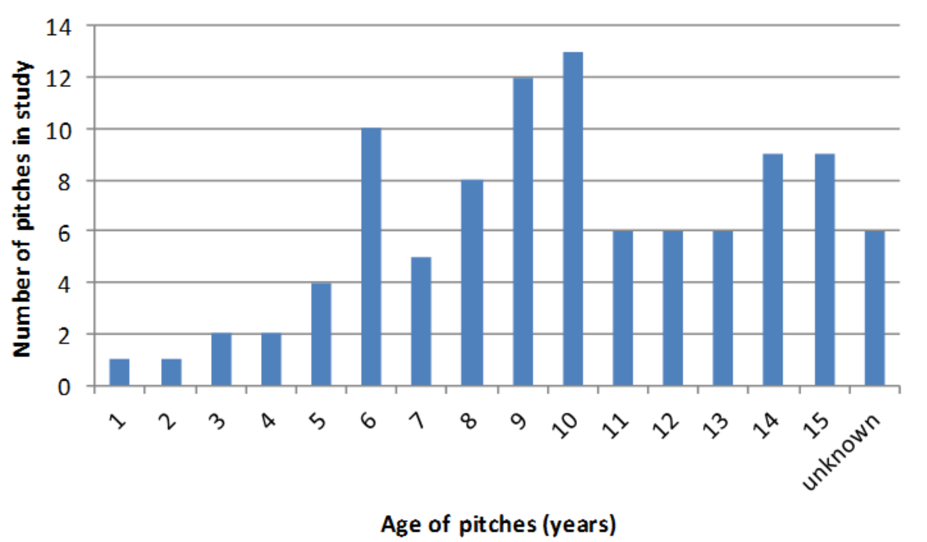


Figure 3 Distribution of pitch ages in the sample set.

9.2.3 *Limit of detection*

To calculate the average concentration on a pitch, values below the limit of detection (LOD) were handled as follows:

- If all samples on the pitch yielded values below the limit of detection, the average pitch concentration was shown as <LOD.
- Some samples on the pitch were below the limit of detection; a concentration equal to the limit was used for these samples.

Only the observations that were above the limit of detection were used to calculate the total PAH concentrations. If all substances in a sample were below the limit of detection, the total concentration is shown as <LOD. The total concentrations for individual samples were calculated, followed by the average per pitch.

9.3 Content of rubber granulate - organic compounds

9.3.1 *Cold and hot petroleum extraction for PAHs*

ALcontrol subjected 60 samples to both hot and cold extractions with petroleum ether. For the statistical data processing, 18 samples (from 3 pitches) were removed from the data set because they turned out not to be SBR rubber. The extraction yields of the 3 methods were therefore compared for 42 samples from 7 pitches. A comparison was made of the concentrations for samples that yielded results above the limit of detection (see Figure 4). The gradient of the regression line indicates the ratio between the hot and cold extractions. This gradient was used as a correction factor for the cold extraction, as shown in Tables 4 through 6.

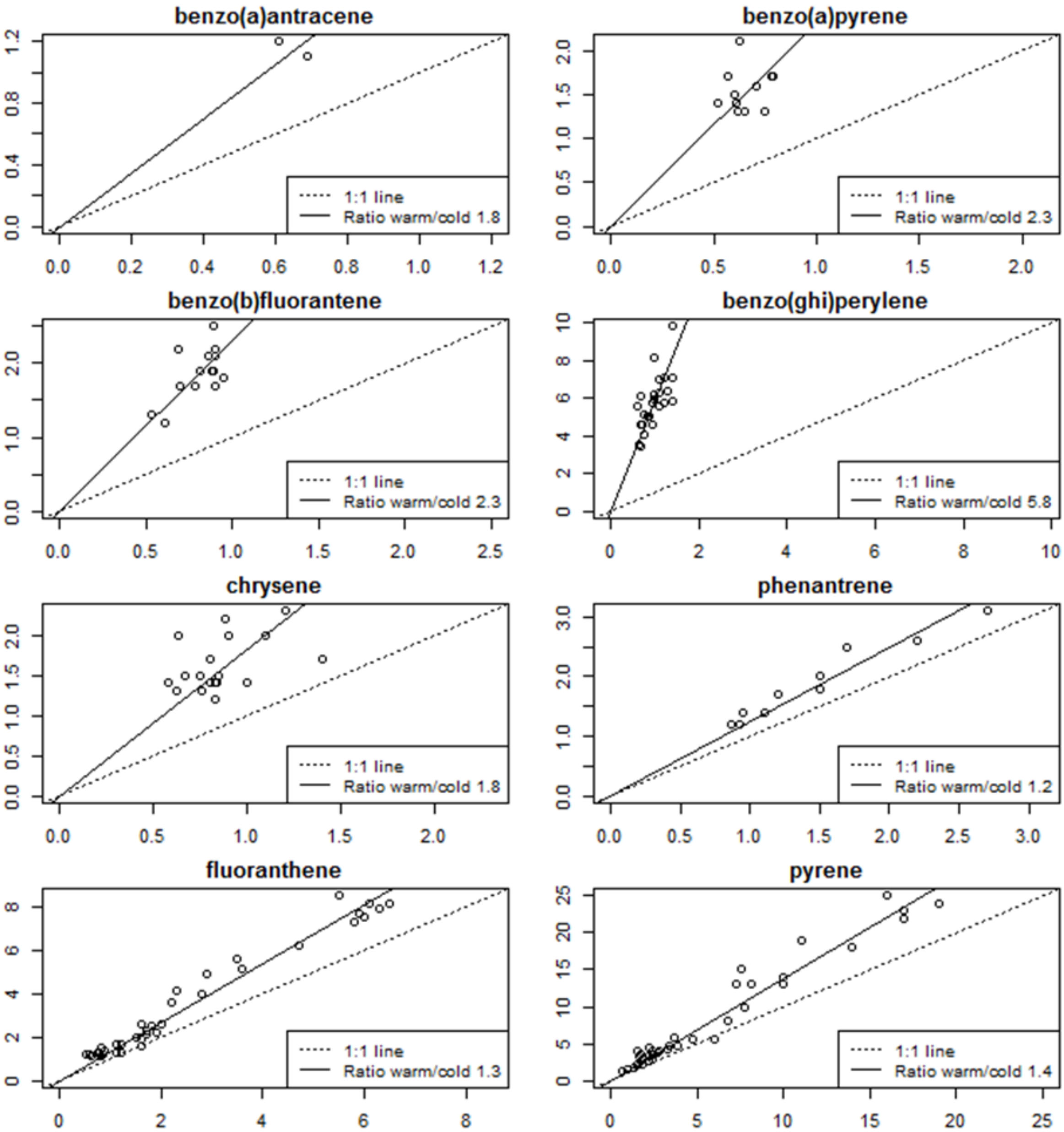


Figure 4 Comparison of hot and cold petroleumether-extraction methods for determination of PAHs (Tests performed by ALcontrol).

For most PAHs, the ratio between hot and cold extractions gives a factor of between 1.3 and 2.3, although the gradient for the ALcontrol analyses is 5.7 for benzo(g,h,i)perylene (see Figure 4). The ratio between the hot and cold extractions increases proportionate to the molecular mass of the PAHs (see Figure 5).

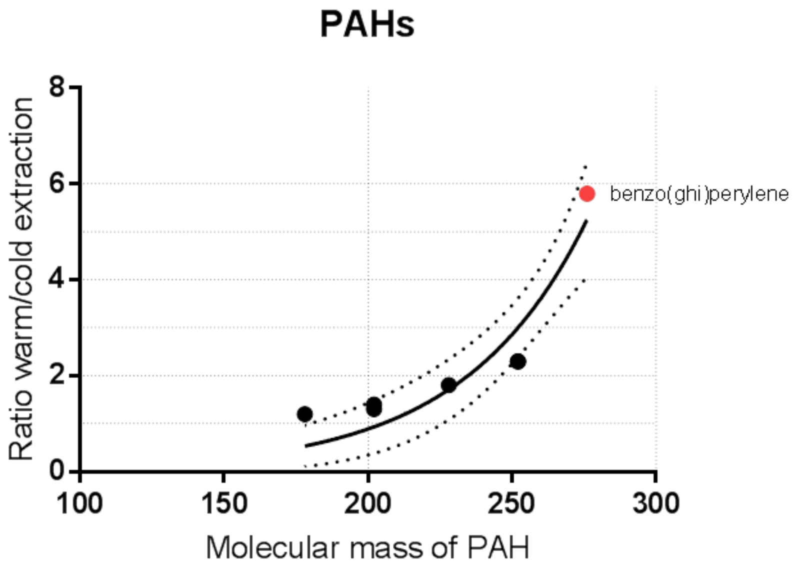


Figure 5 Relationship between the molecular mass of PAHs and the hot/cold extraction yield ratio. The line represents a statistical fit with an exponential model.

The yield of the hot extraction performed by ALcontrol seems to be on the high side for benzo(g,h,i)perylene, which raises the question of whether this might be an artefact.

In order to be certain that no other substances are involved, the sample was subjected to identification according to NEN-EN-ISO 22892. The identification of a compound is determined by two criteria:

1. Gas chromatographic criterion: The relative retention time of the compound in the chromatogram of the sample may not differ by more than 0.2% from that of the compound in the chromatogram of the calibration standard.
2. Mass spectrometric criterion: The areas under the curves for the peaks at three masses have a specific ratio in the mass spectrum of the calibration standard. If benzo(g,h,i)perylene is present in a sample, these ratios must be virtually identical. If there is disruption because the matrix shows peaks at 1 or more specific masses, the ratio may therefore differ. The ratio determined may not differ by more than +/- (0.1*(standard ratio)+ 10) %.

Both criteria were fulfilled, although experts suggest that conclusive confirmation of the identity of the PAHs would require additional reference substances to exclude artefacts.

9.3.2 *Counterchecks with hexane extraction for PAHs*

TNO performed a cold extraction with hexane on part of the samples (see paragraph 9.2.2). The extraction yields of hexane could be compared with the extraction yields of PE (as described in paragraph 9.3.1) for 42 samples from 7 pitches. The concentrations were compared for samples that were above the limit of detection (see Figure 6).

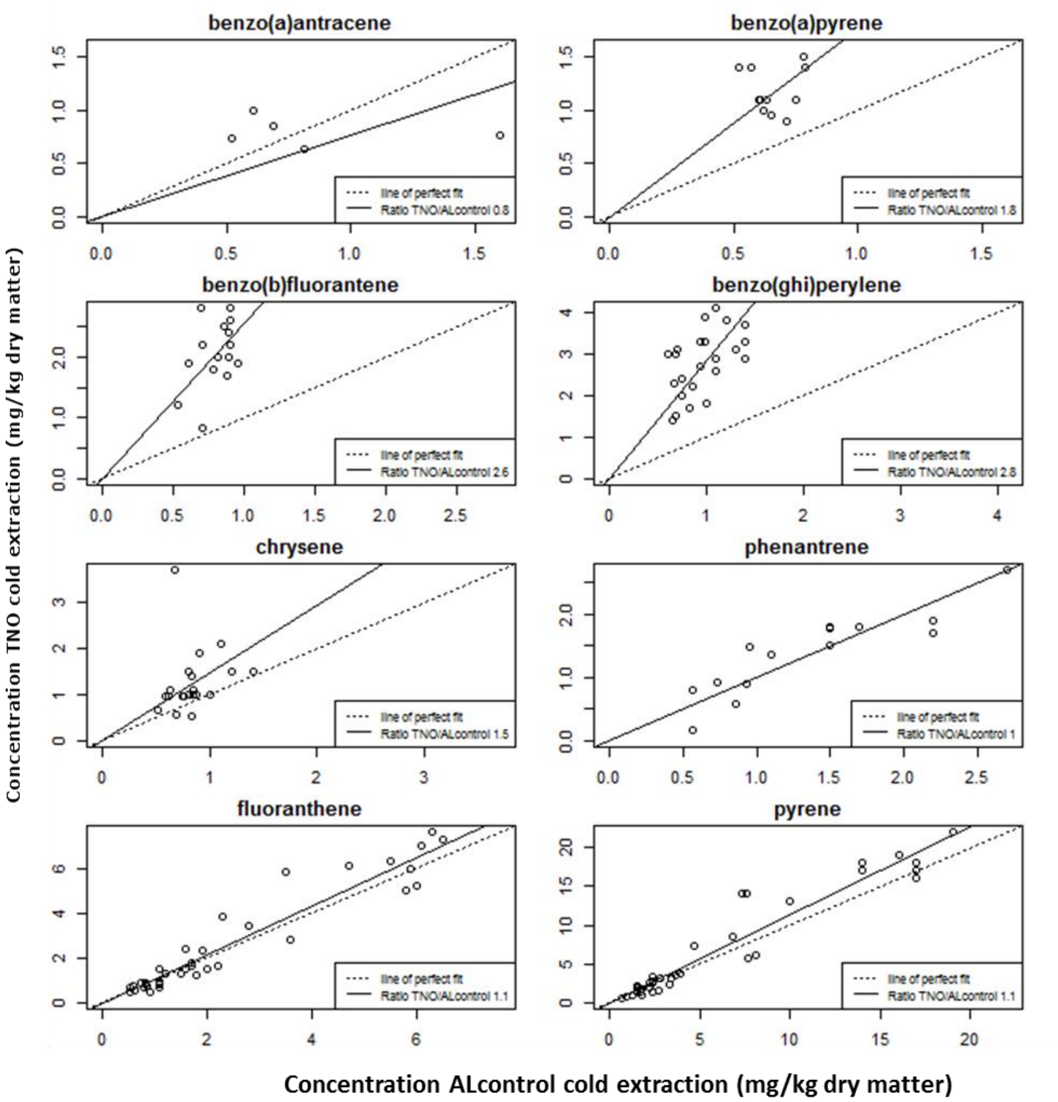


Figure 6 Comparison of the countercheck (TNO) for cold PAH extraction.

For a number of substances, the extraction yield was higher in the countercheck. As seen in the comparison between hot and cold extraction, there appears to be a correlation with the molecular mass of the PAHs.

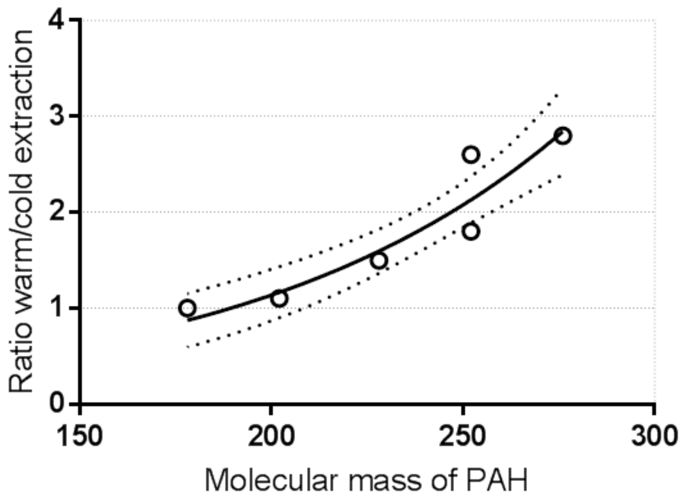


Figure 7 Relationship between molecular mass and extraction yield ratio from TNO (hexane extraction) and ALcontrol (cold petroleum ether extraction).

9.3.3 *Countercheck on phthalates*

A countercheck of the findings for phthalates was done on 42 samples. The DEHP concentrations determined by TNO (hexane-extraction) were on average 0.6 times lower than the ALcontrol concentrations (petroleumether extraction). For the time being, the concentrations as determined by ALcontrol are being used. There were not enough samples available to establish a reliable comparison for other phthalates.

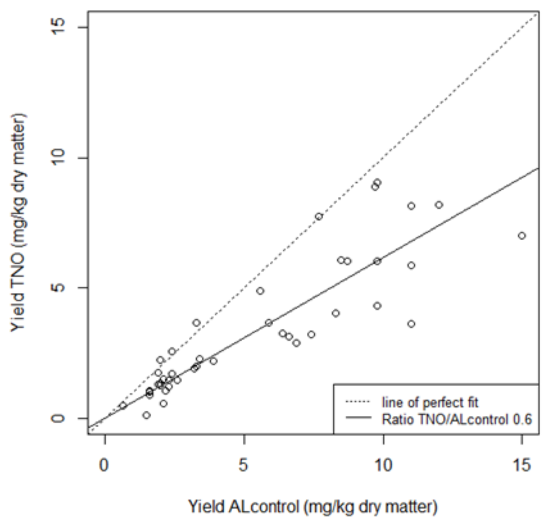


Figure 8. Comparison of DEHP concentrations by ALcontrol and the countercheck by TNO.

TNO used a lower limit of detection and was therefore capable of determining concentrations for a number of samples that ALcontrol had reported as <LOD. Conversely, ALcontrol found DEHP in two samples that remained below the limit of detection for TNO.

Table 3 Comparison of analysis results by ALcontrol and the countercheck by TNO for phthalates.

	n < LOD ALcontrol		TNO		Δn	concentrations in < LOD samples
DEHP	0	< 0.5	2	< 0.5	2	0.67-1.5
DIBP	39	< 0.5	22	< 0.1	17	0.11-0.41
DBP	42	< 0.5	39	< 0.1	3	0.13-0.16
BBP	42	< 0.5	40	< 0.1	2	0.12-0.13
DEP	42	< 0.5	42	< 1	0	
DMP	42	< 0.5	42	< 0.1	0	

9.3.4 *Overview of concentrations for the risk assessment*

The analysis results regarding the content are summarised in the following tables. The results of the counterchecks were only used if they warranted adjusting the results of the routine analyses. This was the case in comparing PAH concentrations analysed after cold and hot extractions. The results showed higher concentrations from hot extractions than from cold extractions. The PAH concentrations in the overview tables show the concentrations that were obtained by the hot extraction or were extrapolated to that level using a correction factor. Correction factors are mentioned in Figure 4.

Table 4 Concentrations of substances that were found in more than 5% of the samples. The median (P50), the ninetieth percentile (P90) and the maximum are shown for the 91 pitches.

			Pitch concentration			
				mg/kg dry matter		
Abbreviation	**Substance / Substance group**	**% samples > LOD**	**P50**	**P90**	**Maxi-mum**	**Note**
PAH	**polycyclic aromatic hydrocarbons**					
Ant	anthracene	5	< 0.5	< 0.5	1.1	a
BaA	benzo(a)anthracene	27	< 0.5	1.2	2.2	a
BaP	benzo(a)pyrene	25	< 0.5	1.3	2.2	a
BbF	benzo(b)fluoranthene	48	< 0.5	3.0	3.0	a
BcF	benzo(c)fluorene	43	0.2	0.6	0.7	c
BeP	benzo(e)pyrene	57	2.8	4.2	7.8	d
BghiP	benzo(ghi)perylene	62	2.0	6.5	7.7	a
Chr	chrysene	57	1.3	1.9	3.5	a
CpP	cyclopenta(cd)pyrene	100	1.5	2.3	2.5	c
Phen	phenanthrene	38	< 0.5	2.0	7.1	a
FluA	fluoranthene	93	3.4	8.3	20.3	a
Pyr	pyrene	98	7.5	23.6	28.7	a
	phthalates					
DEHP	di-2-ethylhexyl phthalate	100	7.6	14.2	27.2	a
DINP	diisononyl phthalate	77	35	53	61	b
DEHA	bis (2-ethylhexyl) adipate	63	0.3	0.7	1.1	b
DIBP	diisobutyl phthalate	17	< 0.5	0.8	2.3	a
DCHP	dicyclohexyl phthalate	47	0.1	0.2	0.2	b
DNNP	di-n-nonyl phthalate	37	0.5	0.8	0.8	b
DPP	diphenyl phthalate	7	< 0.1	< 0.1	0.11	b

			Pitch concentration			
				mg/kg dry matter		
Abbreviation	**Substance / Substance group**	**% samples > LOD**	**P50**	**P90**	**Maxi-mum**	**Note**
	benzothiazoles					
BT	benzothiazole	100	2.7	5.7	6.3	c
OHBT	2-hydroxybenzothiazole	100	1.6	8.1	13.8	c
MBT	2-mercaptobenzothiazole	100	2.6	6.3	7.6	c
MTBT	2-methoxybenzothiazole	100	2.6	9.7	10.2	c
ABT	2-aminobenzothiazole	100	0.10	0.29	0.38	c
NCBA	N-cyclohexyl-1,3-benzothiazole-2-amine	100	1.5	3.6	3.9	c
MBTS	2,2-dithiobis(benzothiazole)	71	0.28	0.3	0.33	c
CBS	N-cyclohexyl-2-benzothiazole sulphenamide	43	< 0.02	0.04	0.04	c
	phenols					
	4-t-octylphenol	100	4.8	19.6	22.4	c
	bisphenol A	100	0.5	2.0	2.5	c
	polychlorobiphenyls					
PCB28		14	< 0.005	0.012	0.015	c
PCB101		29	< 0.005	0.017	0.020	c
PCB153		29	< 0.005	0.023	0.030	c
PCB138		14	< 0.005	0.012	0.014	c
PCB180		14	< 0.005	0.011	0.012	c
tot PCB		29	< 0.035	0.060	0.074	

a. Analysis of 546 samples from 91 pitches
b. Analysis of 43 samples from 7 pitches. Additional substances that were analysed in the counterchecks.
c. Analyses of 7 mixed samples from 7 pitches. Additional substances requiring separate (more time-consuming) analysis, which could possibly be quantified during the general unknown screening.
d. Analyses of 7 mixed samples from 7 pitches. Because of the strong correlation with chrysene (r^2=0.98), estimates were made for all pitches using the formula [BeP] = 2.2467 x [Chr]. See section 9.3.5.

In various regulatory contexts, sum-concentrations are used to address mixture toxicity of PAHs. PAHs are used. The sum-concentrations of various combinations are shown in Table 5.

Table 5 Total concentrations for various combinations of PAHs.

		pitch concentration mg/kg dry matter)		
Total of the parameters	**separate substances**	**P50**	**P90**	**Maximum**
EFSA 4 total	BaA+BaP+BbF+Chr	2.0	5.5	10.1
EFSA 8 total	BaA+BaP+BbF+Chr+BkF+dBahA+IP+BghiP	5.9	10.9	16.2
ECHA 8 total	BaA+BaP+BbF+Chr+BkF+dBahA+BjF+BeP[1]	5.8	10.9	19.8
VROM10 total	BaA+BaP+Chr+BkF+IP+BghiP+Naph+Ant+Phen+FluA	9.6	17.7	35.5
EPA16 total	VROM10+BbF,dBahA+Fl+AcNy+AcN+Pyr	18.3	42.0	62.2
GS18 total	PAH7+ECHA8[1]+Naph+IP+BghiP	24.8	81.6	81.6

[1] BjF (benzo(j)fluoranthene) is not measured as an individual substance, but its peak coincides with that of benzo(b)fluoranthene and benzo(k)fluoranthene. BjF is therefore implicitly included in the total.

Substances which were detected in concentrations above the limit of detection in fewer than 5% of the samples, are shown in Table 6. In all cases, the median of the concentrations on the pitch is below the limit of detection, so Table 6 only shows the maximum concentrations.

Table 6 Concentrations of substances that were found in fewer than 5% of the rubber granulate samples or that were not shown to be present in concentrations above the limit of detection.

Abbreviation	Substance / Substance group	LOD mg/kg dry matter	% samples > LOD	maximum pitch concentration (mg/kg dry matter)	Note
	polycyclic aromatic hydrocarbons				
	fluorene	0.5	3	0.9	a
	acenaphthene	0.5	2	1.0	a
BkF	benzo(k)fluoranthene	0.5	0.2	0.5	a
IP	indeno(1,2,3-cd)pyrene	0.5	0.2	0.5	a
	acenaphthylene	0.5	0		a
diBahA	dibenz(a,h)anthracene	0.5	0		a
	naphthalene	0.5	0		a
	5-methylchrysene	0.2	0		c
	dibenzo[al]pyrene	0.2	0		c
	dibenzo[ae]pyrene	0.2	0		c
	dibenzo[ai]pyrene	0.2	0		c
	dibenzo[ah]pyrene	0.2	0		c
	phthalates				
DBP	di-n-butyl phthalate	0.5	2	0.9	a
BBP	butyl benzyl phthalate	0.5	1	1.0	a
DEP	diethyl phthalate	0.5	1	2.9	a
DHP	dihexyl phthalate	0.5	0		a
DMP	dimethyl phthalate	0.5	0		a
DNOP	di-n-octyl phthalate	0.1	0		b
DIDP	diisodecyl phthalate	10	0		b
	phenols				
	4-nonylphenol	0.5	0		c
	triclosan	0.02	0		c
	volatile compounds				
	benzene	0.05	0		a
	toluene	0.05	0.4	0.06	a
	ethyl benzene	0.05	0		a
	o-xylene	0.05	0		a
	p and m-xylene	0.05	0.4	0.06	a
	styrene	0.05	0.2	0.053	a
	polychlorobiphenyls				
PCB52		0.005	0		c
PCB118		0.005	0		c

a. Analysis of 546 samples from 91 pitches
b. Analysis of 43 samples from 7 pitches. Additional substances that were analysed in the counterchecks.
c. Analyses of 7 mixed samples from 7 pitches. Additional substances requiring separate (more time-consuming) analysis, which could possibly be quantified during the general unknown screening.

9.3.5 *Correlations between substances*

In order to be able to accurately assess the risks for people playing sports, it is important to know whether various substances are present in high concentrations at the same time. A rule of thumb is that there is a 'significant' relationship if the correlation coefficient *r* is greater than 0.6. This is a conservative assumption: in view of the large number of samples in RIVM's data set, the actual significance (p value of < 0.05) occurs at lower *r* values.

Significant correlations were found between the log-transformed concentrations of:

- fluorene and anthracene (*r*=0.87)
- pyrene and fluoranthene (*r*=0.91) and between both of these substances and phenanthrene (*r*=0.74)
- benzo(b)fluoranthene, benzo(g,h,i)perylene and chrysene (*r*= 0.81-0.87), and between all three and DEHP (*r*= 0.71-0.76) and benzo(a)pyrene PAHs (*r*= 0.61-0.76)
- copper and cobalt (*r*=0.67)
- benzo(e)pyrene and chrysene (*r*=0.98) and benzo(g,h,i)perylene (*r*=0.93)

It is striking that DEHP is not correlated to the other phthalates. DIBP and DNBP are correlated (r^2=0.62). Various total concentrations are used in order to take into account the fact that some substances occur simultaneously (see Table 5).

Benzo(e)pyrene is an important component in the ECHA8 total parameter for PAHs in process oils for car tyres and for the GS18 total parameter for PAHs in consumer products in Germany. However, BeP was not included in the standard analysis package for the 600 samples, although it was detected in 7 mixed samples. Other PAHs were also detected in the same samples. The results show a strong relationship between the presence of chrysene and BeP. This relationship has been used for estimating the BeP concentration in all the individual samples using the regression function [BeP] = 2.2467 x [Chrysene].

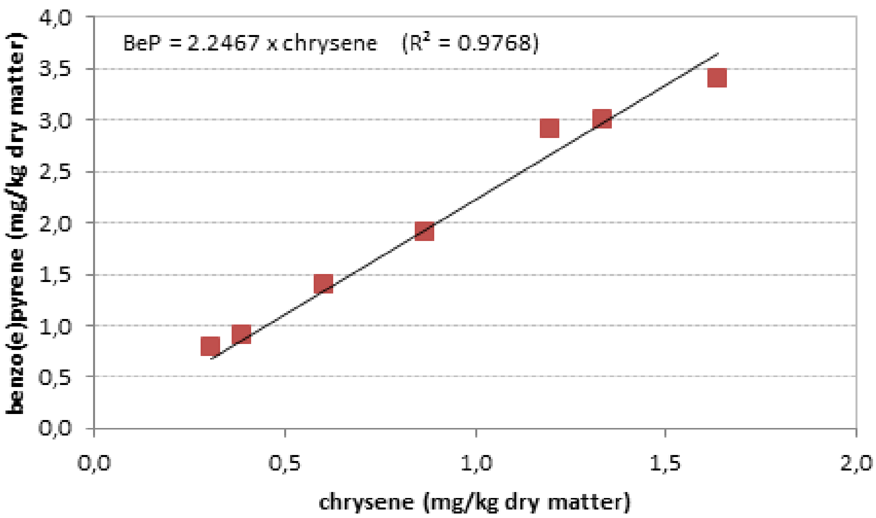


Figure 9 Relationship between chrysene and benzo(e)pyrene concentrations in rubber granulate samples.

9.4 Leaching of metals into water

9.4.1 Overview of concentrations

Tests were done to determine the extent to which inorganic components leach into water. Leaching indicates the possible distribution of substances into groundwater and surface waters, as well as exposure levels for the skin of people playing sports. Amounts are expressed in mg of leachate per kilogram of rubber granulate. Data from the tyre industry and from the literature shows leaching of metals at much lower levels than the total amount of metals present in the rubber granulate.

Table 7 Leaching of metals that were found in more than 5% of the samples.

		% samples	mg/kg dry matter		
Abbreviation	**Substance / Substance group**	**> LOD**	**Median**	**Maximum**	**Note**
Zn	zinc	100	21	129	a
Cu	copper	78	0.09	0.87	a
Co	cobalt	66	0.06	0.38	a
Ba	barium	16	< 0.05	0.17	a

a. Analysis of 546 samples from 91 pitches

Table 8 Leaching of metals that were found in fewer than 5% of the samples.

Abbreviation	**Substance / Substance group**	**% samples > LOD**	**Median mg/kg dry matter**	**Maxi-mum mg/kg dry matter**	**Note**
Cr	chromium	3	< LOD	0.02	a
Ti	titanium	2	< LOD	0.18	a
Hg	mercury	0.4	< LOD	0.0006	a
Pb	lead	0.2	< LOD	0.10	a
Ni	nickel	0.4	< LOD	0.11	a
Se	selenium	0.5	< LOD	0.04	a
Sb	antimony	0			a
As	arsenic	0			a
Cd	cadmium	0			a
Mo	molybdenum	0			a
Sn	tin	0			a
V	vanadium	0			a

a. Analysis of 546 samples from 91 pitches

9.4.2 Countercheck

A countercheck of the leaching of metals was done on 60 samples. The limit of detection was somewhat lower for the lab that did the countercheck, resulting in fewer samples remaining below the limit of detection. In addition, a number of additional substances were included in the analysis package: boron, aluminium, manganese and strontium. The laboratory that did the countercheck found concentrations that were 1.1 to 1.7 times higher. No good explanation was found for this. The highest concentrations found in the tests and the countercheck are shown in Table 7.

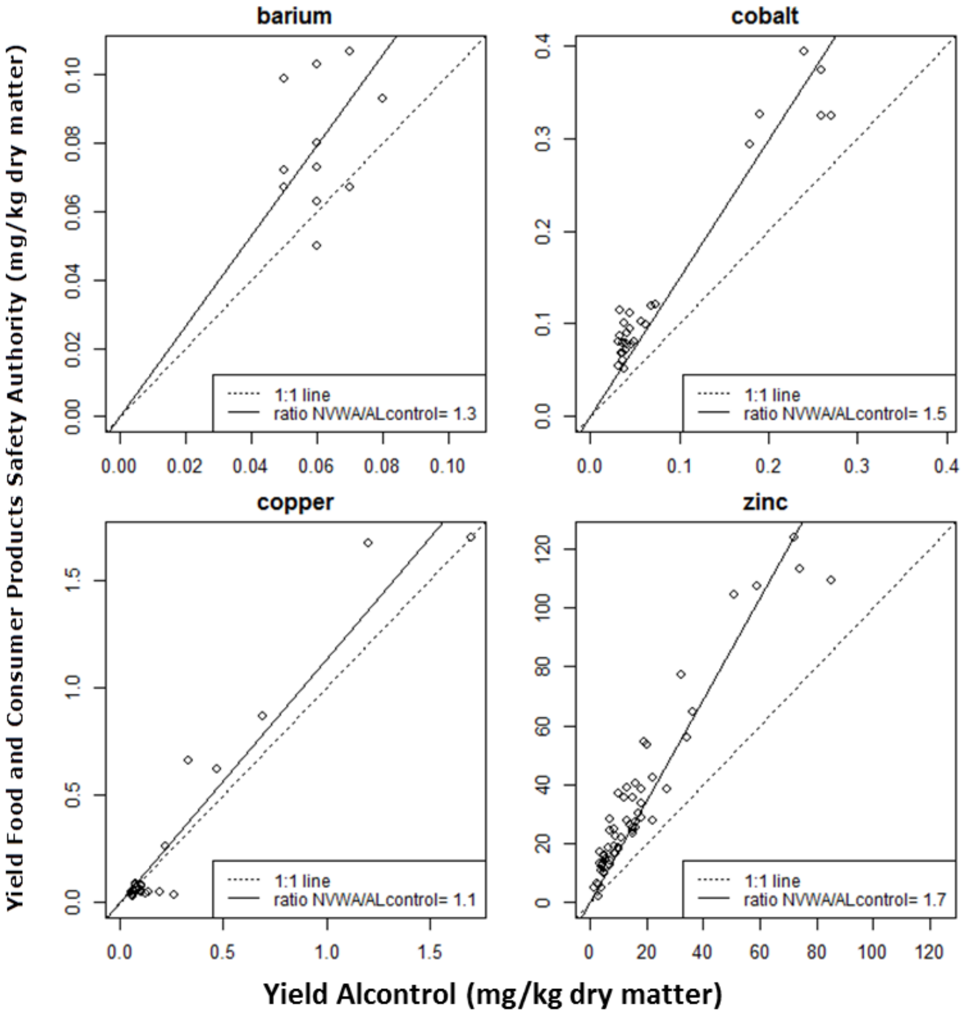


Figure 10 Countercheck of leaching of metals into water.

Moreover, measurable amounts of lead were found in the countercheck, whereas this substance remained below the limit of detection in the ALcontrol series.

Table 9 Overview of concentrations in the eluate of the leaching test – metals that were not quantified by ALcontrol. Results of 42 samples from 7 locations with SBR rubber.

Abbreviation	Substance / Substance group	% samples > LOD	Median	Maximum	Note
			mg/kg dry matter		
Al	aluminium	100	0.50	2.0	c
B	boron	0	< LOD	< LOD	c
Pb	lead	46	0.009	0.017	c
Mn	manganese	100	0.11	0.96	c
Sr	strontium	64	0.041	0.063	c

c. Analyses of 7 mixed samples from 7 pitches.

9.5 Migration tests

9.5.1 Migration into sweat

Metals

Based on earlier research on the content of rubber granulate, three metals were selected that could potentially be relevant for absorption via the skin: cadmium, cobalt and lead. The following concentration ranges were found in seven SBR samples. It was not possible to define a clear relationship with the concentrations in the elution tests that were done using water, since these tests did not yield any measurements above the limit of detection for cadmium or lead. A poor relationship was found for cobalt, but it is not reliable enough for use as a general rule for extrapolation.

Table 10 Migration of metals (in nanograms per gram of rubber granulate) into artificial sweat, after two hours' exposure at 37°C.

	n > LOD (out of 7)	median	max
cadmium	1	< 0.03	20
cobalt	7	280	480
lead	7	30	70

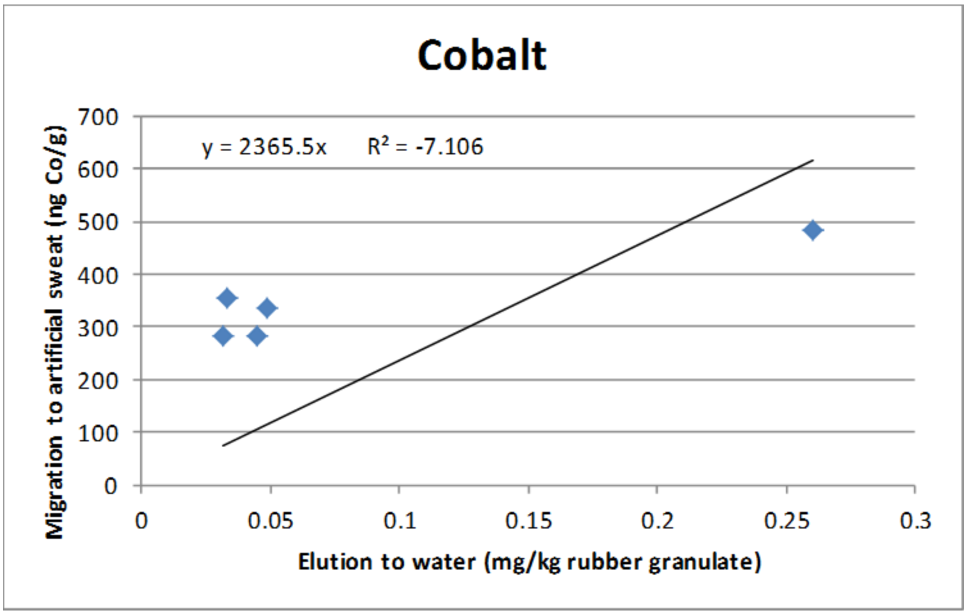


Figure 11 Relationship between elution of cobalt to water and migration of cobalt into artificial sweat.

PAHs and phthalates

It was possible to demonstrate the presence of naphthalene, fluoranthene, pyrene, chrysene and benzo(g,h,i)perylene in seven SBR samples. Phthalates were not present in concentrations above the limit of detection. The following concentration ranges were found in seven SBR samples:

Table 11 Migration of PAHs (in nanograms per gram of rubber granulate) into artificial sweat, after two hours' exposure at 37°C. For phthalates, the limit of detection for the analysis of the sweat has been stated.

	n > LOD (out of 7)	P50	max			max (µg/L)
PAH				**phthalates**		
naphthalene	3	< LOD	0.39	dimethyl phthalate	DMP	< 0.10
acenaphthylene	0		< 0.4	diethyl phthalate	DEP	< 0.10
acenaphthene	0		< 0.5	diisobutyl phthalate	DIBP	< 0.10
fluorene	0		< 0.4	dibutyl phthalate	DBP	< 0.10
phenanthrene	0		< 0.3	butyl benzyl phthalate	BBP	< 0.10
anthracene	0		< 0.3	dicyclohexyl phthalate	DCHP	< 0.10
fluoranthene	3	< 0.3	0.61	di(2-ethylhexyl) phthalate	DEHP	< 1.0
pyrene	4	0.20	1.76	diphenyl phthalate	DPP	< 0.10
benzo[a]anthracene	0		< 0.3	di-n-octyl phthalate	DNOP	< 0.10
chrysene	2	< 0.2	0.31	diisononyl phthalate	DINP	< 10
benzo[b]fluoranthene	0		< 0.3	diisodecyl phthalate	DIDP	< 10
benzo[k]fluoranthene	0		< 0.3	di-n-nonyl phthalate	DNNP	< 0.10
benzo[a]pyrene	0		< 0.4	bis (2-ethylhexyl) adipate	DEHA	< 0.10
indeno[1,2,3-cd]pyrene	0		< 0.5			
dibenzo[a,h]anthracene	1		1.08			
benzo[g,h,i]perylene	5	0.47	1.02			
EFSA4 total	2	< LOD	0.28			
EFSA8 total	5	0.56	1.55			
ECHA 8 total	3	< LOD	1.08			

[1] estimated as 2.2467 x [Chrysene]

The migration data above are only from seven samples and therefore only offer a preliminary impression of the range of bioavailable concentrations.

The migration of pyrene, fluoranthene and benzo(g,h,i)perylene from the rubber granulate of 7 pitches to sweat was compared against the total content of these substances in the rubber granulate based on the hexane extraction (see Figure 12). If the migration fraction is reasonably constant, that figure can be used to estimate the migration of those PAHs into sweat for all the other pitches in this research study.

There turned out to be a linear relationship for pyrene, fluoranthene and benzo(g,h,i)perylene between the concentration in the rubber granulate and the amount that can be released by contact with sweat. The fraction of these PAHs that is available for transdermal absorption is equal to the gradient of the regression line/1000, and varies between 0.0001 and 0.0002.

It is possible that the bioavailable fraction is related to the physical/chemical properties of the PAH, for example the molecular weight. Pyrene, fluoranthene and benzo(g,h,i)perylene have molecular masses of 202 to 276 g/mol. The molecular masses of most of the PAHs in this research are between those extremes. We assume that the migration that was measured for pyrene, fluoranthene and benzo(g,h,i)perylene is therefore representative of the other PAHs in this research.

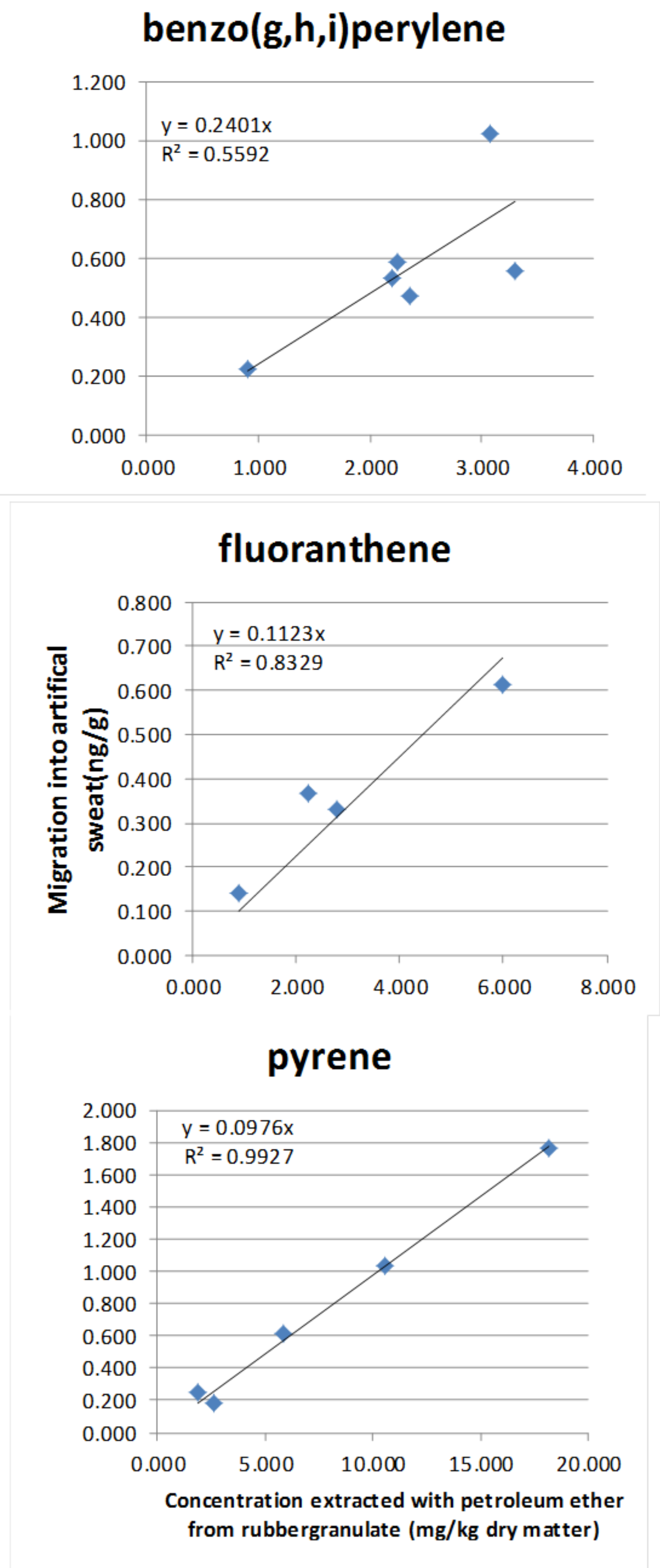


Figure 12 Relationship between PAH concentrations in rubber granulate and the concentrations in sweat.

9.5.2 *Migration in the gastrointestinal tract*

After a contact time of four hours between the rubber granulate and artificial gastro-intestinal juices, the following metals, PAHs and phthalates were detected (total levels in filtrate and residue). Many of the concentrations are just above the limit of detection, so there is a relatively high degree of uncertainty in the values measured here.

Table 12 Migration of phthalates, PAHs and metals from rubber granulate in a gastrointestinal simulation. Total migration into the gastro-intestinal juices in µg/g rubber granulate.

maximum concentration (µg/g rubber granulate)			
	SBR (n=5)		
acenaphthene	0.02	BBP	0.29
acenaphthylene	< LOD	DBP	0.08
anthracene	< LOD	DCHP	0.27
benzo[a]anthracene	0.01	DEHA	< LOD
benzo[a]pyrene	0.03	DEHP	1.84
benzo[b]fluoranthene	0.05	DEP	0.26
benzo[g,h,i]perylene	0.29	DIBP	0.18
benzo[k]fluoranthene	< LOD	DIDP	0.28
chrysene	0.15	DINP	< LOD
dibenzo[a,h]anthracene	0.02	DMP	0.05
phenanthrene	0.13	DNNP	0.06
fluoranthene	1.02	DNOP	< LOD
fluorene	< LOD	DPP	0.09
indeno[1,2,3-cd]pyrene	0.03		
naphthalene	0.37		
pyrene	1.13		
	(n=2)		
barium	6		
chromium	1		
cobalt	2		
copper	78		
lead	9		
nickel	2		
selenium	1		
titanium	1		
zinc	419		

Arsenic, cadmium, molybdenum, antimony, tin, vanadium and mercury were not found in the gastro-intestinal juices.

The fractions of PAHs and phthalates that are then available are equal to the gradient of the regression line between the total PAH and the migrated PAH (see Figure 13). The individual PAHs and phthalates have been grouped together because there were too few points to do a regression for each individual substance. It was estimated that approximately 20% is available for phthalates and an average of 9% for PAHs.

A good gradient could not conclusively be determined for the metals, since only three samples were in fact tested. Estimation of metal migration for all pitches was therefore not possible. For the risk assessment maximum measured migrated metal concentrations have been used instead.

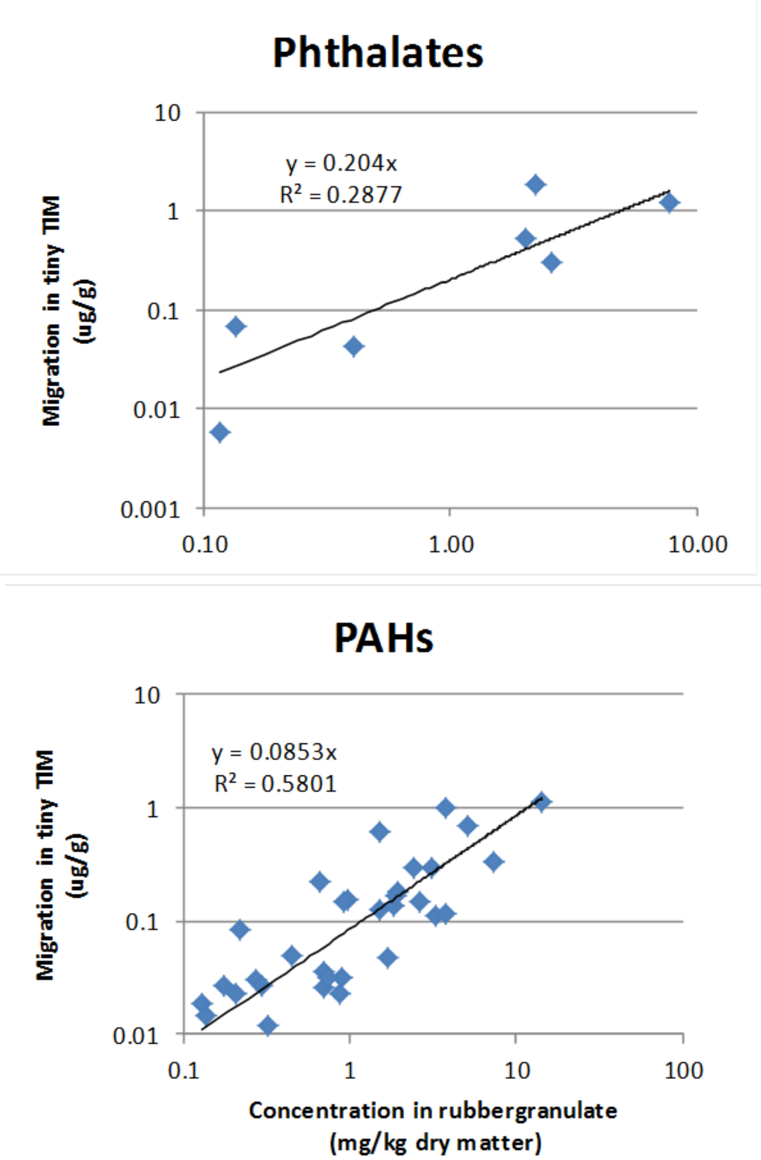


Figure 13 Ratio between PAHs measured by hexane extraction and the migration into artificial gastro-intestinal juices (Tiny-TIM). PAHs: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, chrysene, phenanthrene, fluoranthene, indeno(1,2,3-cd)pyrene and pyrene. Phthalates: DEHP, DBP, DCHP and DIBP. The points are individual samples in which both the hexane measurement and the Tiny-TIM measurement were above the limit of detection.

9.5.3 *Migration into air*

The results of the measurements and model calculations are shown in Table 13. The first data column shows the average evaporated amount measured for each substance (determined from seven SBR samples), while the second column shows the highest evaporated amount. The third column shows the resulting calculated maximum concentration of each substance in the air at a height of 1 m. Quantifications of the first

five substances are based on calibrated measurements. The concentrations of the remaining 17 substances were determined semi-quantitatively (indicative). Note that BTEX, styrene and 1,3-butadiene were not detected. This is consistent with the analyses performed by ALcontrol on 600 samples.
The calculation method results in worst-case concentrations. The combination of high solar radiation, high temperature and high wind speed occurs no more than a few times per year at most.

Table 13 Nature and concentration of substances after evaporation from rubber granulate at 60°C.

CAS no.	Substance name	**Emission** 45 min, 60°C Average **nanograms/g**	**Emission** 45 min, 60°C Maximum **nanograms/g**	**Air concentration** at a height of 1 metre Maximum **micrograms/m^3**
	Calibrated data			
64-17-5	Ethanol	29.8	149.2	133
67-64-1	Acetone	180.9	934.0	830
75-15-0	Carbon disulphide (CS_2)	4.9	7.9	7
78-93-3	Methyl ethyl ketone (MEK)	12.6	62.5	56
108-10-1	Methyl isobutyl ketone (MIK)	167.5	542.0	482
	Indicative data			
463-58-1	Carbon oxide sulphide (COS)	3.5	8.1	7
115-11-7	2-methylpropene	3.9	6.3	6
067-56-1	Methanol	8.6	17.1	15
075-07-0	Acetaldehyde	15.3	19.5	17
075-65-0	2-methyl-2-propanol	2.0	4.5	4
078-83-1	2-methyl-1-propanol	3.2	3.2	3
078-84-2	2-methylpropanal	6.4	11.7	10
078-85-3	Methacrolein	5.5	8.1	7
078-94-4	Methyl vinyl ketone (MVK)	6.0	7.9	7
534-22-5	2-methylfuran	10.3	15.2	13
930-27-8	3-methylfuran	3.8	5.5	5
590-86-3	3-methylbutanal	4.0	5.8	5
107-87-9	Methyl propyl ketone (MPK)	2.5	2.5	2
066-25-1	Hexanal	2.0	2.5	2
110-12-3	5-methyl-2-hexanone	3.5	9.3	8
108-94-1	Cyclohexanone	3.8	9.0	8
100-52-7	Benzaldehyde	1.6	1.6	1

10. Part C: Literature research

10.1 Introduction

The Dutch TV programme *Zembla* aired an episode on 5 October 2016 entitled 'Gevaarlijk spel' (Dangerous Play) that raised questions about the safety of playing sports on synthetic turf pitches with an infill of rubber granulate made from recycled car tyres. The rubber granulate is added to give synthetic turf pitches the same characteristics and playability as conventional grass pitches.

Rubber granulate is finely ground rubber, also known as 'rubber crumb', which is often made from scrap rubber products, in particular shredded car tyres. The use of scrap rubber for this purpose results from a European directive banning car tyres from landfills and mandating recycling [1]. The rubber granulate is used to make a variety of products, such as rubber tiles and rubber carpeting, but is also used in its granular form as infill material on synthetic turf pitches.

The Netherlands currently has approximately 2,000 synthetic turf sports fields (mostly football pitches), around 90% of which have an infill of rubber granulate made from ground car tyres. Approximately 120 tons of rubber granulate, made from 20,000 car tyres, are used on a single football pitch. Another name for this type of infill material is styrene butadiene rubber granulate, or SBR. Although SBR granulate is generally assumed to be made exclusively from vehicle tyres, there is no mandatory verification system, so the end product may also include other types of rubber. The tyre sector uses the term SBR granulate in the strict sense, making an explicit distinction between SBR granulate and other granulate which may be made e.g. from scrap rubber tubes from the chemical industry [2].

In addition to rubber (whether natural and/or synthetic), car tyres also contain a multitude of chemical additives (such as plasticisers, fillers, anti-degradants, vulcanisation substances and reinforcing agents) which give the tyres the desired characteristics. These include a number of *substances of very high concern* (SVHC). SVHCs are substances that are considered hazardous to people and the environment, e.g. because they are carcinogenic, reprotoxic or accumulate in the food chain [3]. For example, tyres contain various polycyclic aromatic hydrocarbons (PAHs), a number of which are proven carcinogens, as well as a variety of heavy metals, plasticisers and volatile and semi-volatile compounds. Since these substances may be released from rubber granulate over time, concerns have arisen about the potential health risks for both children and adults who play sports on synthetic turf pitches with an infill of rubber granulate made from car tyres.

Based on the national and international knowledge available in 2006 and 2007, RIVM had previously concluded that exposure to PAHs, plasticisers and nitrosamines is not expected to pose a health risk to people playing sports on synthetic sports pitches with an infill of rubber granulate [4-6]. In response to public concerns following the Zembla broadcast, the Dutch Minister of Health, Welfare and Sport (Minister Schippers) requested RIVM to urgently carry out additional research, specifically taking into account information that had become available in recent years.

Given the short period of time available for this new research, it was not possible to conduct a comprehensive study addressing all aspects. Nor was a full scientific risk assessment possible, which would normally be done when setting, for example, limit values. Consequently, prioritisation was necessary; on that basis, it is only possible to offer an indicative risk assessment.

The research approach is described in Section 10.2. Section 10.3 discusses regulatory limit values with possible relevance for substances found in rubber granulate. Section 10.4 describes the prioritisation of the substances to be selected based on literature data. This prioritisation is adapted further in Section 10.5, based on data on the content of the rubber granulate sampled from Dutch pitches. The results of the migration tests are described in Section 10.6. The toxicity of the prioritised substances is described in Section 10.7, while Section 10.8 covers the exposure assessment and Section 10.9 provides the indicative risk assessment. Finally, Section 10.10 presents a short discussion of the research findings and uncertainties therein.

10.2 Approach

The underlying question posed by the public and the Minister is, “Is it possible to play sports on pitches with a rubber granulate infill without health risks?” The Netherlands is not the only country that is having to deal with this issue. The same question has been asked in other European countries and in the USA; studies are currently being conducted in these countries to find answers. One of the most extensive studies is currently being undertaken in the USA, as a joint initiative of the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (ATSDR), and the U.S. Consumer Product Safety Commission (CPSC). This multi-agency action plan is known as the ‘Federal Research Action Plan (FRAP) on Recycled Tire Crumb Used on Playing Fields and Playgrounds’ [7]. This FRAP will pursue four objectives. Firstly, it is intended to identify and characterise the chemical constituents of rubber granulate. Secondly, it is intended to identify ways in which people may be exposed to rubber granulate based on their activities on the pitches. Thirdly, the action plan is intended to help identify and fill the most significant gaps in current data and knowledge, and fourthly, to specify any follow-up activities which could be carried out in order to obtain more insight into the possible risks. The research protocol includes a very detailed description of how the research will be structured and when the initial results will be reported (scheduled for the end of 2016, but reporting has been delayed by several months) [8]. An extensive literature research will also be part of the study.

Besides the above-mentioned research, the Californian Office of Environmental Health Hazard Assessment (OEHHA) has also launched a long-term research study on the possible health risks of rubber granulate [9]. This study not only includes literature research and chemical characterisation of rubber granulate, but will also develop exposure scenarios and will include biomonitoring of sports players as part of the exposure assessment.

In Europe, the European Chemicals Agency (ECHA) launched a preliminary investigation with a view to informing the European Commission no later than February 2017 as to whether the presence of certain substances in rubber granulate made from scrap tyres could lead to health risks that are not adequately controlled and require additional measures [10]. ECHA will base its research on the results of previous studies in this field carried out in EU member states and elsewhere. ECHA has also approached relevant parties to obtain information about the content of rubber granulate and synthetic turf, the numbers of synthetic turf pitches, the type of infill material, etc. ECHA is also partnering with EPA and OEHHA to exchange information about developments and results from their current studies.

In order to properly address the ministerial request for a technical literature study, RIVM contacted EPA for information about relevant literature; the short time frame did not allow for our own systematic search for all the relevant literature, and EPA had recently already conducted this for its own research. With a view to exploring any additional relevant literature, RIVM consulted with ECHA and with the experts who spoke during the Zembla TV programme (Professor Watterson and Mr McGuire). RIVM also contacted its Belgian counterparts, since they had also announced an intention to research rubber granulate. However, enquiries revealed that the Belgian research is currently limited to an enforcement-related study. There are plans though to conduct supplementary research, including sampling of pitches and an analysis of samples for toxicologically relevant substances.

The basis for the technical literature study therefore consists of the bibliography as published in Annex B of the EPA/ATSDR research protocol [7], supplemented by a number of additional references as supplied by ECHA and the two experts (Watterson and McGuire), as well as references from the bibliography provided by the European tyre sector (ETRMA) and the Dutch tyre sector (VACO/RecyBEM) [11]. All relevant references from these sources have been included in the list of references at the end of this part of the scientific background information.

To answer the question posed by the public and the Minister, it is first of all important to identify the substances that people playing sports on synthetic turf pitches with rubber granulate are exposed to and, subsequently, the amounts involved in such exposure. This information has to be combined with information about the hazardous properties of these substances. However, car tyres contain a wide range of chemical substances. To use the available time and resources as efficiently as possible, the risk assessment focuses on those substances having hazardous properties of the highest concern. In order to prioritise these substances, it is not only necessary to know which substances are present in rubber granulate but, more importantly, which of these substances could be released in significant amounts (leaching/migration). After all, people will only be exposed to substances that have been released. Prioritisation was initially based on literature data on the content of rubber granulate and on leaching/migration, since the results of the analyses from the sampling study of the 100 Dutch pitches only became available during the course of the research.

Regulatory limit values with possible relevance for rubber granulate and its constituent substances were used as a prioritisation tool by comparing these limit values to the literature data on content and leaching. Only substances whose levels exceeded the limit values were initially selected for health risk assessment, insofar as they were also an SVHC from a human health perspective. Once the results of the analyses of the sampling study were available, they were reviewed to determine whether the list of prioritised substances needed adaptation to the situation on the Dutch fields. The resulting prioritised substances were subsequently reviewed to provide a brief outline of their most significant SVHC properties, and to present toxicological reference values, where available.

In view of the question posed, the exposure assessment focuses primarily on people playing sports on synthetic turf pitches with rubber granulate infill. It is not possible to investigate the exposure by using biomonitoring, since the short time available does not allow such complex research. For that reason, literature data were used to develop possible exposure scenarios. In combination with the results of the analyses these exposure scenarios provided the exposure estimates. Other users/exposed populations than people playing sports have also been identified, but no exposure scenarios have been detailed for these groups due to a lack of time.

Lastly, an indicative risk assessment for people playing sports has been provided, based on the estimated exposure and the toxicological reference values for the prioritised SVHCs. Where necessary and possible in connection with these substances, indirect (or background) exposure and direct exposure to sources other than rubber granulate were also considered. The result of the risk assessment was compared with previous studies. Unfortunately, it is not possible to incorporate findings from the recent studies by EPA, OEHHA and ECHA, since those research results are not available yet.

10.3 Overview of regulatory limit values with possible relevance for substances found in rubber granulate

The regulatory limit values which are applicable to, or could be relevant for, rubber granulate and substances in rubber granulate were chosen as the prioritisation tool for substances to be selected for the health risk assessment. These limit values for all substances analysed in the present study are listed in Table I in Annex I of this part of the scientific background information.

No legislation exists in the Netherlands or Europe that specifically applies to rubber granulate. However, because rubber granulate is a mixture, companies that market it are required to apply the rules and criteria of the CLP Regulation to their commodity in terms of the hazard classification, labelling and packaging of substances and mixtures. Moreover, in Europe, the REACH Regulation dictates that the manufacturer and/or importer of mixtures of substances, such as rubber granulate, is responsible for safe use of the product. These statutory regulations are briefly outlined below, as are the Toy Safety Directive and the Soil Quality Decree. Despite the fact that not all the regulations described are formally applicable to rubber granulate, the limit values may still be relevant given the comparable material or field of application.

Due to the lack of specific legislation, the end product is not subject to any mandatory verification system. However, certification schemes may exist at the national level which allow companies to apply voluntarily to have their product certified. The Netherlands offers an eco-label certification scheme for rubber granulate as infill material for synthetic turf pitches [12]. If evidence can be provided that the rubber granulate fulfils the eco-label requirements in this certification scheme, the eco-label can be awarded. Looking at the substances in rubber granulate, PAHs have to meet the limit values for granular building materials from the Soil Quality Decree, while metals are assessed based on the European Toy Standard EN 71 [13].

REACH Regulation (EC) 1907/2006
REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) is a European regulation that ensures that more information is available about chemicals and requires those substances to be used safely. The purpose of REACH is to more effectively protect human health and the environment from the potential risks posed by chemical substances, while enhancing the competitiveness of the EU chemicals industry. REACH also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. In principle, REACH applies to all chemicals, although there are exceptions (such as radioactive substances). REACH also covers mixtures and articles and substances in articles, even if those articles are made from recycled material. It therefore relates not only to substances used in industrial processes, but also to substances used in daily life, for example chemicals in cleaning products, paint and household goods like clothing, furniture and electrical devices.

The fact that the REACH regulation focuses on generating data on the hazardous properties of chemical substances means there is an overlap with the Classification, Labelling and Packaging (CLP) Regulation (EC) 1272/2008. This regulation guarantees that employees and consumers in Europe have clear information about the hazards of chemicals in the EU by mandating the classification and labelling of chemical substances and mixtures. The information collected and assessed on chemical substances under REACH can be used to classify substances and mixtures according to the CLP criteria, based on the hazards related to the substance. This can be done at EU level (for example primarily for substances which are carcinogenic, mutagenic or reprotoxic (CMR) or are respiratory sensitisers) or at the level of self-classification by companies.

REACH places the burden of proof for safe use of chemicals on the companies. In order to comply with REACH requirements, companies must identify and manage the risks related to the substances which they manufacture or market in the EU. They have to show ECHA how the substance can be used safely and, where necessary, inform users of risk management measures (for example via safety data sheets). Companies also have to register the classification of the substance with ECHA, which then adds it to the C&L Inventory. This public database contains all the harmonised (European Community) classifications and self-classifications.

If the risks cannot be managed, the authorities can limit the use of substances in various ways, for example by imposing a restriction. Restrictions limit or ban the manufacture, sale or use of substances (or groups of substances) which constitute a risk to human health or the environment. This can take the form of a total or partial ban (in this context, a total ban means that all possible sources of exposure to a substance are addressed simultaneously), or a condition, such as imposing a concentration or migration limit. These limit values may be defined based on health considerations (the maximum content or emission at which an estimated exposure is not expected to result in an unacceptable risk related to the substance), but may e.g. also be based on the detection limit of the analytical method. Annex XVII to the REACH Regulation contains a list of substances which are subject to restrictions, applicable to the substance on its own, or in a mixture or article.

There is one restriction which is directly applicable to rubber granulate. The fact that rubber granulate is considered a mixture in the EU (and not an article) means that it has to meet the restriction which applies to mixtures under REACH entry 28-30. This means that, if a mixture contains a substance which is classified as CMR category 1A/1B in Annex VI of the CLP regulation, the mixture may not be supplied to the general public if it contains a substance in a concentration greater or equal to the generic or specific concentration limits applicable to that substance. Table I in Annex I of this part of the scientific background information indicates the concentration limits which apply to the CMR category 1A/1B substances in rubber granulate.

Other restrictions which are not directly applicable to rubber granulate, but which could be relevant with a view to certain substances present in rubber granulate, are also included in Table I in Annex I of this part of the scientific background information. These are:

- 8 PAHs (entry 50): concentration limits for extender oils for processing rubber in tyre production and for articles and toys which may come into contact with the human skin or the oral cavity
- Cadmium (entry 23): concentration limits for mixtures and specific plastic articles, paints and brazing fillers
- Nickel (entry 27): migration limits for piercings and jewellery
- 6 phthalates (entries 51 and 52): concentration limits for toys
- Benzene (entry 5): concentration limits for toys and for mixtures
- Toluene (entry 48): concentration limits for adhesives and spray paint
- Lead (entry 63): concentration limit for jewels/jewellery and concentration limit and migration limit for articles or parts thereof which children can place in their mouths

References used: [14-17]

Toy Safety Directive 2009/48/EC
The European safety requirements for toys are set out in the Toy Safety Directive. This includes regulations on e.g. mechanical, chemical and electrical safety. The objective of the regulation is that toys should not present a hazard to child health and safety in the event of normal, reasonable use. Toys may not potentially cause physical injury due to swallowing, inhaling or contact via the skin and eyes. This means, for example, that components which can be removed from the material by sucking or biting may not constitute a health hazard.

In the field of chemical safety, toys have to comply with general laws on chemical substances, in particular REACH. Where necessary, additional legislation exists to guarantee safe use by children, who represent a vulnerable group of consumers. This applies, in particular, to CMR category 1A/1B/2 substances, which are not allowed to be present in toys, barring a few exceptions (for example nickel). The presence of certain CMR substances (such as phthalates, PAHs and benzene) is subject to restrictions. These substances are included in Annex XVII of REACH, which lists specific concentration limits for toys containing these substances. The Toy Safety Directive contains migration limits for the release of metals (such as arsenic, mercury, cadmium, lead, chromium(VI) and (organic) tin) from dry, liquid and scraped-off toy material. The release of nitrosamines and nitrosable substances is specifically regulated using migration limits, and rules exist for allergenic fragrances in toys.
These migration limits are based on the health-based limit values for these substances, at the levels not expected to cause any effects in the event of lifelong exposure (TDI, Tolerable Daily Intake). A 10% fraction of the TDI is taken as the limit to leave room for exposure from other sources. Oral exposure of children aged 0-3 years is based on 100, 400 and 8 mg/day of dry, liquid and scraped-off toy material respectively.

Toys are defined as products which, whether exclusively or otherwise, have been designed or are intended to be used during play by children under 14 years old. Rubber granulate does not fulfil this definition but, due to the sometimes similar way it is used (which is in effect inappropriate for rubber granulate), the concentration limits and migration limits for some substances present in rubber granulate as stated in Annex II to the Toy Safety Directive for dry toy material and in REACH Annex XVII might be relevant. For that reason, they have been included in Table I in Annex I of this part of the scientific background information.

References used: [3, 18, 19]

Soil Quality Decree

The Soil Quality Decree [*Besluit bodemkwaliteit*] defines the preconditions for using building materials on or in the soil or in surface water, with the aim of preventing the undesirable release of substances into the environment. A building material is defined as material in which the total levels of silicon, calcium or aluminium jointly amount to more than 10 percent by weight of the material in question. The Soil Quality Decree defines three categories of building materials: monolithic building materials, granular building materials and secondary building materials applied in the context of insulation, management and control measures. With regard to quality, the Soil Quality Decree requires all building materials in the entire building materials chain to comply with the limit values set for maximum content and emissions. Inorganic parameters (for example metals) are subject to emission limit values, which differ for the three categories of building materials. Organic parameters (for example benzene, PAHs and mineral oil) are subject to content limit values, since there are no suitable leaching tests for a number of these substances, and there is not enough leaching data available to set emission limit values. The content limit values are the same for all three categories of building materials.

Rubber granulate from car and commercial vehicle tyres (SBR rubber) is not covered by the Soil Quality Decree because the total levels of silicon, calcium or aluminium combined do not generally exceed 10 percent by weight. However, if they are used, the duty of care specified in Article 13 of the Soil Protection Act [*Wet bodembescherming*] has to be fulfilled in order to ensure that the soil is not contaminated.

Granulates which do fall within the scope of the Soil Quality Decree (such as rubber granulate based on thermoplastic elastomers (TPE) and rubber granulate based on elastomers (EPDM)) usually fall into the category of granular building materials. These are building materials of which the smallest unit has a volume of less than 50 cm^3, or building materials which do not retain their shape permanently in normal circumstances. In the event that SBR rubber were to fall within the scope of the Soil Quality Decree, the content and emission limit values for granular building materials would be most relevant. These can be found in Table 2 and Table 1 respectively, in Annex A of the Soil Quality Regulation [*Regeling bodemkwaliteit*], and are also included in Table I in Annex I of this part of the scientific background information for the substances in rubber granulate. The emission requirements for granular building materials have been derived from the regulatory limit values which apply to substances in groundwater, surface water, drinking water and soil. These requirements also take into account the gradual release of substances from building materials over a period of 100 years in conjunction with a layer of building material which is 20 cm thick. Another aspect which is taken into account is adsorption to three different soil types (sand, clay and peat), rinsing off into surface water, and flushing into groundwater at a depth of 1 m.

The Soil Quality Decree also establishes rules and quality requirements for soil used elsewhere on or in the ground. In this context, a distinction is made according to land use class (reference value, 'residential' or 'industrial'). The limit values are largely based on knowledge about the risks that substances present to people and the environment and are intended to ensure that the quality of the receiving location does not deteriorate to an unacceptable extent. If the soil quality limit values were to be applicable to rubber granulate, the limit values for 'residential' quality appear to be the most relevant, although they are fairly stringent, meaning that many urban locations will be unable to meet such requirements. Soil which fulfils the requirements for this class can be used for homes with a garden, locations where children play, and green spaces that have environmental significance. The applicable limit values are lower than the limit values for the 'industrial' quality class (use for other green areas, buildings, infrastructure and industry), but are higher than the reference values. The limit values for the 'residential' quality class in Table 1 in Annex B of the Soil Quality Regulation are included for the substances in rubber granulate in Table I in Annex I of this part of the scientific background information, performing a soil type adjustment on the limit values for the metals according to Annex G of the Regulation. The limit values in the Regulation are derived from the maximum limit for acceptable risk in the event of lifelong exposure, the MPR-human (Maximum Permissible Risk level for humans) for threshold substances and the 'Negligible Risk' ($1*10^6$ per life) for non-threshold substances. The RIVM CSOIL model was used to calculate human exposure. This included exposure via different routes. For instance, the calculations were carried out based on oral exposure of children and adults to 100 and 50 mg of soil respectively per day and exposure via plants cultivated in a person's own garden. Based on these exposure levels, calculations were made to determine the concentration of the substances in the soil at which the maximum permissible risk is not exceeded. The end result is the limit values as stated in the Regulation.

References used: [3, 20-25]

As shown in Table I in Annex I of this part of the scientific background information, one or more limit values from the statutory regulations could be relevant to the majority of the substances for routine analysis in rubber granulate. The only exceptions are titanium and 4 of the 16 EPA PAHs (acenaphthene, acenaphthylene, fluorene and pyrene). The prioritisation tool may be less effective for the additional substances requiring separate, more time-consuming analysis, since the statutory regulations do not specify limit values for approximately two-thirds of these substances. Substances without a specified limit were prioritised based on whether or not they are considered substances of very high concern (see section 10.4).

10.4 Prioritisation of substances – literature data

Rubber granulate can contain a huge variety of substances. Besides the rubber itself, it may include plasticisers, fillers, anti-degradants, vulcanisation substances and reinforcing agents. Consequently, given the available time and resources, it is essential to focus the risk assessment on those substances having hazardous properties of the highest concern. The prioritisation of these substances was initially based on literature data, since the results of the analyses from the sampling study of the 100 Dutch pitches were not yet available when the research started.

A literature search was performed to find studies in which pitches had been sampled and results were reported for the content of the rubber granulate on these pitches. Only studies in which the SBR type was investigated were selected; other types of rubber granulate and rubber tiles were disregarded. The search also focused on finding studies of the migration/leaching of substances from rubber granulate, since such data are more relevant for the risk assessment than content data. However, there were so few studies on migration/leaching, and the studies were so different in design (e.g. different migration times or extraction methods), that the data could not easily be compared. That is why, in the end, only the content data from the literature was used to prioritise the substances. Although more studies are available on content, also these are not all equivalent in terms of number of measurements, analytical method, etc. This lack of comparable parameters makes it quite difficult to present a range of the levels observed for the various substances, or even a median or 90th percentile. Consequently, the maximum levels reported for each substance were used as the worst-case scenario for prioritisation purposes.

The result of the prioritisation is shown in Table II in Annex II. Listing all the substances analysed in the present study, the table indicates whether the maximum concentration reported in literature for the substance in question exceeds one or more possibly relevant regulatory limit values (blue colour). Only these substances were initially selected for the health risk assessment. It should be noted that this is a fairly rough approach to prioritisation: levels below a limit value are not automatically safe, whereas levels above a limit value do not automatically present a health risk. However, it is judged that if the concentration of a substance in rubber granulate does not exceed the limit value(s) which are considered acceptable for the substance in question in products/media other than rubber granulate, this concentration should also be acceptable for rubber granulate. Therefore, those substances are not considered a priority. For the substances which were initially prioritised it was subsequently assessed whether they were an SVHC from a human health perspective – i.e, whether they have a harmonised classification or self-classification as CMR category 1A/1B. The choice for these hazardous properties rather than others is due in part to the fact that these were the main focus of concern following the Zembla TV programme.

The list of substances for which a regulatory limit value exists was narrowed down to the substances which exceed a limit value ánd are SVHC. For the substances without regulatory limit values available, the only prioritisation criterion was whether they are SVHC. The substances which were prioritised according to this method are shown shaded grey in Table II in Annex II. Once the results of the analyses from the Dutch pitch samples were available, the list of prioritised substances was reviewed to see if it needed to be adapted (see section 10.5).

10.5 Content of rubber granulate from Dutch pitches and further prioritisation

The chemical analyses results from the present study were used to verify the literature data for the rubber granulate used on synthetic turf pitches in the Netherlands. In order to assess the relationship between the content of that rubber granulate and the limit values, both were compared in Table III in Annex III. The comparison was based on the maximum pitch concentrations found. It should be noted that the analysis data for the metals does not represent content, but leaching (to water). Therefore, data from the Dutch environmental quality label for sustainable products and services ('Milieukeur') was used; these data consist of content data from batches of rubber granulate which were submitted for certification in the period 2010-2016 [26]. In all likelihood, this content data is more representative of the rubber granulate on the Dutch pitches than the content data from the literature.

The comparison shows that the maximum pitch concentrations of the analysed substances in rubber granulate are lower than the maximum concentrations reported for those substances in the literature. The rubber granulate on all tested pitches is below the concentration limits applicable to mixtures. Several other limit values were exceeded, although they are not directly applicable:

- The level of five of the eight PAHs that are subject to limits in consumer articles and toys under REACH (entry 50) exceed both limits (benzo[a]pyrene (BaP), benzo[a]anthracene (BaA), chrysene (CHR), benzo[b]fluoranthene (BbFA) and benzo[e]pyrene (BeP)). The limit values for consumer articles is exceeded by 2.2, 2.2, 3.45, 2.95 and 7.75x respectively, and the limit value for toys by 4.4, 4.4, 6.9, 5.9 and 15.5x respectively.
- Two phthalates (DEHP and DIBP) exceed the 'residential' soil limit, but none of the six phthalates that are subject to REACH entry 51/52 exceeds the limit value for toys.
- Two metals (cadmium and lead) exceed the limit value specified by the Toy Safety Directive. However, this concerns a migration limit and the comparison with the content is a worst-case scenario, since it is unlikely that 100% will migrate. The leaching data for cadmium and lead show that migration into water is negligible (levels at or below the limit of detection of 0.004 and 0.10 mg/kg respectively; see Table IV in Annex IV).

For further prioritisation for the indicative risk assessment, the content data was compared with the regulatory limit values (see Table III in Annex III). This eventually resulted in the prioritised substances presented in Table 1. This list of prioritised substances was not further adapted in response to the results of the leaching/migration tests (see section 10.6), even though these results seem to suggest that some substances should no longer be a priority.

Table 1. Prioritised substances for the indicative risk assessment

Substances	Abbreviation	Cas no.	Why SVHC	
			CLP Annex VI	**Notified**
Cadmium		7440-43-9	Carc. 1B	
Cobalt		7440-48-4		Carc. 1B Repr. 1B
Lead		7439-92-1	Repr. 1A	
PAHs, in particular:				
Benzo[a]pyrene	BaP	50-32-8	Carc. 1B; Muta. 1B; Repr.1B	
Benzo[a]anthracene	BaA	56-55-3	Carc. 1B	
Chrysene	CHR	218-01-9	Carc. 1B	
Benzo[b]fluoranthene	BbFA	205-99-2	Carc. 1B	
Benzo[e]pyrene	BeP	192-97-2	Carc. 1B	
Phthalates, in particular:				
Bis(2-ethylhexyl) phthalate	DEHP	117-81-7	Repr. 1B	
Diisobutyl phthalate	DIBP	84-69-5	Repr. 1B	
Dicyclohexyl phthalate [#]	DCHP	84-61-7	Repr. 1B	
2-Mercaptobenzothiazole	2-MBT	149-30-4		Carc. 1B
Bisphenol A [*]	BPA	80-05-7	Repr. 1B	

[#] Additionally prioritised based on the findings from the counterchecks
[*] Additionally prioritised based on the 'general unknown' screening

Benzene was initially also considered for prioritisation, since this carcinogen is associated with leukaemia and lymphoma. However, benzene was not found in any pitch sample (limit of detection 0.05 mg/kg) and is therefore not relevant to the risk assessment.

10.6 Results of migration tests on rubber granulate from Dutch pitches

As described in sections 10.4 and 10.5, the content data was used to select the substances that appear to be of highest priority for the indicative risk assessment. The initial selection was based first on exceedance of regulatory limit values and second on the substance being an SVHC. It should be noted that concentrations higher than a limit value do not automatically represent a health risk. For these levels to present a health risk, the substance in question must be released from the rubber granulate to such an extent (by means of leaching/migration) that the toxicological reference value for this substance is exceeded in a specific exposure scenario. That is why the results of the leaching/migration tests are so important for the risk assessment: they show which substances are actually available for exposure. The results of these tests are described in detail in Part B of the scientific background information. A short summary is presented below, primarily focusing on the prioritised substances.

Headspace analysis
The headspace analysis looked at which substances evaporate from rubber granulate at 60°C and to what extent. The volatile compounds benzene, toluene, ethylbenzene, xylene, styrene and 1,3-butadiene were not found in levels above the limit of detection in the evaporated air. Other volatile substances, such as ethanol, acetone, carbon disulfide, acetaldehyde, methyl ethyl ketone and methyl isobutyl ketone, were found to a limited extent but will only be present in the air above a synthetic turf pitch in relatively low concentrations (see Part B of the scientific background information). Although only a limited number of samples were tested, it can tentatively be concluded that inhalation of vapour from rubber granulate does not contribute significantly to the exposure of people playing sports to the abovementioned substances. No headspace analyses were performed for the prioritised substances.

Leaching into water
Tests were conducted (at 20°C; see Annex IV) on all pitch samples to determine the extent to which metals leach into water, e.g. to establish potential skin exposure via rainwater for people playing sports. Three prioritised metals (cadmium, cobalt and lead) were tested, but it was only possible to demonstrate the presence of a small amount of cobalt (over 25x less than the amount of cobalt which is permitted to migrate according to the Toy Safety Directive). The leaching route via rainwater therefore does not play a significant role for these three metals in the context of people playing sports who come into contact with rubber granulate.

Migration into artificial sweat (skin migration)
Seven SBR samples were tested to determine the migration of metals, phthalates and PAHs from rubber granulate into artificial sweat (over two hours, at 37°C) in a simulation of what could be released after contact with the skin. For people playing sports, the route via sweat is regarded as a relevant exposure route. The results are listed in Annex V. Phthalates were not found in concentrations above the limit of detection. The three prioritised metals were detected (although cadmium was only found in a single sample), but at much lower levels (20-200x) than the amount which is permitted to migrate according to the Toy Safety Directive. Looking at the PAHs, only naphthalene, fluoranthene, pyrene, chrysene, benzo[g,h,i]perylene and benzo[e]pyrene were found to migrate in levels above the limit of detection. Of these PAHs, only chrysene and benzo[e]pyrene are considered SVHCs. The maximum migration level of chrysene and benzo[e]pyrene in these samples is 0.31 and 0.70 µg/kg respectively.

Since the results of the migration tests relate only to a limited number of samples, the concentrations found do not provide a comprehensive overview of the range of concentrations that can possibly be found for all Dutch pitches sampled. However, in these seven samples, there appears to be a fairly constant relationship between the total PAH concentration in the rubber granulate and the migration into sweat. When related to the total amount of these five PAHs in the rubber granulate samples, approximately 0.02% is released in sweat, meaning 5000x lower than the amount contained in rubber granulate. This fixed ratio is used to estimate the migration into sweat for all PAHs, and in all samples not tested for migration. It can be tentatively concluded that the fraction of PAH that appears to migrate from rubber granulate into sweat is small to minimal, meaning that actual exposure to these substances will be limited.

Migration into artificial saliva/gastric juice/intestinal juice (in vitro digestion)
Five of the seven SBR samples which were analysed for migration into artificial sweat were also analysed for migration into artificial saliva/gastric juice/intestinal juice, in order to simulate how much of the metals, phthalates and PAHs is released from rubber granulate following ingestion of the grains. The results are stated in Annex V, presented as 'total amount released'. This represents the worst-case scenario, given that the substances may still be bound to suspended matter or lipids, which could reduce absorption through the intestinal wall.
Looking at the metals, cadmium was not detected at all, while the migration of cobalt and lead in the worst-case scenario ('total amount released') is below the migration limit for these metals according to the Toy Safety Directive.
Looking at the various phthalates present in the rubber granulate samples, it is estimated that after ingestion approximately 20% is released into the gastrointestinal tract (worst-case scenario). That figure is approximately 9% for the PAHs (worst-case scenario).
Since the results of the migration test relate only to a limited number of samples, the concentrations found do not provide a comprehensive overview of the range of concentrations that can possibly be found for all Dutch pitches sampled. They are therefore primarily used to see whether a fixed fraction appears to become available. This cannot be established for the metals, given the very small number of samples and the lack of content data. However, there appears to be a reasonably robust correlation for the PAHs and phthalates. It can therefore be tentatively concluded that 9% of the PAHs and 20% of the phthalates migrate from the rubber granulate into the gastrointestinal tract.

10.7 Toxicity of the prioritised substances

Toxicological reference values were identified for the prioritised substances in Table 1 by means of a quick scan of the available toxicological literature on these substances. It should be explicitly noted that only a limited assessment of the data was possible due to the short time available for the present study. The toxicological reference values used for the indicative risk assessment are shown in Table 2. A group approach was used for the PAHs, with the sum total of four or eight PAHs being used as a marker for the total PAH mixture in rubber granulate. All other substances were assessed on an individual basis. For the phthalates in addition also a total risk was estimated; since the toxicological reference value for many phthalates is based on the same effect/mode of action, combined toxicity may occur.

It should also be noted that the toxicological reference values generally apply to the total exposure to a substance, meaning exposure via all sources in which the substance is present. This report only examines a single source of exposure, namely exposure to rubber granulate. When exposure via that source remains below the toxicological reference value, it does not present a health risk as such. If, however, there are other sources of exposure, that particular source may still contribute to a possible health risk when the total exposure via all sources exceeds the toxicological reference value. Where necessary and possible, an attempt has been made to consider any (background) exposure to sources of the prioritised substances other than rubber granulate.

Annex VI briefly outlines the toxicological profiles that form the basis for the toxicological reference values for each substance. The main focus was on the hazardous properties that warrant SVHC status: the CMR properties. Other effects were therefore not specifically examined.

Table 2. Overview of the selected toxicological reference values

Substances	**Abbreviation**	**Cas no.**	**Reference value**		
			Oral (mg/kg bw/d)	**Dermal** (mg/kg bw/d)	**Inhalation** (mg/m^3)
Metals					
Cadmium		7440-43-9	2.5×10^{-3} mg/kg bw/wk		5×10^{-6}
Cobalt		7440-48-4	1.4×10^{-3}		0.5×10^{-3}
Lead		7439-92-1	0.05×10^{-3} $		0.5×10^{-3}
PAHs					
Benzo[a]pyrene	BaP	50-32-8			1×10^{-6} #
Benzo[a]anthracene	BaA	56-55-3			
Chrysene	CHR	218-01-9			
Benzo[b]fluoranthene	BbFA	205-99-2			
	= EFSA PAH4		0.34 *	0.51 *	
Benzo[a]pyrene	BaP	50-32-8			1×10^{-6} #
Benzo[a]anthracene	BaA	56-55-3			
Chrysene	CHR	218-01-9			
Benzo[b]fluoranthene	BbFA	205-99-2			
Benzo[k]fluoranthene	BkFA	207-08-9			
Dibenz[a,h]anthracene	DBahA	53-70-3			
Benzo[ghi]perylene	BghiP	191-24-2			
Indeno[1,2,3-cd]pyrene	I123cdP	193-39-5			
	= EFSA PAH8		0.49 *	0.74 *	
Benzo[a]pyrene	BaP	50-32-8			1×10^{-6} #
Benzo[a]anthracene	BaA	56-55-3			
Chrysene	CHR	218-01-9			
Benzo[b]fluoranthene	BbFA	205-99-2			
Benzo[k]fluoranthene	BkFA	207-08-9			
Dibenz[a,h]anthracene	DBahA	53-70-3			
Benzo[e]pyrene	BeP	192-97-2			
Benzo[j]fluoranthene	BjFA	205-82-3			
	= ECHA PAH8		0.49 *	0.74 *	
Phthalates					
Bis(2-ethylhexyl) phthalate	DEHP	117-81-7	0.034	0.672	0.12 (child) 0.16 (adult)
Diisobutyl phthalate	DIBP	84-69-5	0.0083	0.08	0.025
Dibutyl phthalate	DBP	84-74-2	0.0067	0.07	0.02
Benzyl butyl phthalate	BBP	85-68-7	0.5	10	1.7

Substances	Abbreviation	Cas no.	Reference value		
			Oral (mg/kg bw/d)	**Dermal** (mg/kg bw/d)	**Inhalation** (mg/m^3)
Diisononyl phthalate	DINP	28553-12-0	0.25	6.25	0.87 (child) 1.16 (adult)
Diisodecyl phthalate	DIDP	26761-40-0	0.26 (child) 0.08 (adult)	6.50 (child) 2.06 (adult)	0.90 (child) 0.38 (adult)
Dicyclohexyl phthalate	DCHP	84-61-7	0.18	1.8	0.63
Other					
2-Mercapto-benzothiazole	2-MBT	149-30-4	0.31	0.94	1.09
Bisphenol A	BPA	80-05-7	4×10^{-3} @	0.1×10^{-3}	0.2

[$] This is a maximum exposure value

* This is a $BMDL_{10}$, as a marker for PAH mixture

[#] For BaP, as a marker for PAH mixture

[@] Based on new scientific evidence, RIVM in 2016 suggested to European authorities to lower the toxicological reference value for BPA [RIVM-report 2015-0192. Bisphenol A Part 2. Recommendations for risk management]. This suggestion has had no follow-up yet, so the reference value as presented still stands.

10.8 Exposure assessment

The exposure assessment focuses primarily on people, in particular football players, playing sports on synthetic turf pitches with rubber granulate infill. Other users/exposed populations have been identified, but no exposure scenarios have been developed in more detail in view of the specific concerns that prompted the request for a recommendation, as well as the available time.

It is not possible to investigate exposure through biomonitoring, since the available time frame was too limited to carry out such complex research. Biomonitoring involves assessing the total physical impact of a substance on the body by measuring the substance (or a marker) in e.g. the blood or urine of test subjects. This indicates the total exposure to a substance; total exposure is what should ideally be compared with a toxicological reference value intended to cover all sources of exposure. However, it is a complex undertaking to organise blood and/or urine tests on any significant scale in a very short space of time, not to mention identifying potential past and present sources of exposure, other than rubber granulate. This additional information would reveal the extent to which each individual source contributes to the total exposure and also, therefore, how much or little of that exposure comes from the rubber granulate. Also, due to the short time available for the research, it was impossible to carry out an observational study to obtain activity patterns and information on contact with rubber granules during play.

For that reason, literature data was used to describe possible exposure scenarios, which were then combined with the analysis results to arrive at exposure estimates.

Exposure scenarios

The exposure scenarios for people playing sports were based on recreational sport (amateurs, not professionals) on synthetic turf pitches by both children and adults. For this purpose, recreational sports were categorised into two groups: sport as a leisure activity and more performance-oriented sport. This distinction is relevant because performance-oriented sport have more frequent activity, which could also be expected to increase the intensity of exposure. Possible differences in exposure were mitigated by differentiating according to age, based on categories now used by the Royal Netherlands Football Association (KNVB), although not all age categories have been used in the scenarios. This results in the following scenarios:

1. Children under 6 years old
   The 'under 6' category in the Netherlands is for children aged 4-6 years who are just starting to play football. The way the game is organised for these young children differs considerably per club. However, it is clear that there is no competitive element in this category and that these children only play within their own club. A scenario has been drawn up for a 4-year-old child as a worst-case scenario for children up to 11 years old, based on recreational play on the pitches.
2. Goalkeepers aged 7 years old
   Goalkeepers are introduced into the game in the 'under 8' group. A separate goalkeeper's scenario has been included due to the higher frequency of sport (separate goalkeepers' training in addition to training with the team) and due to the possible ingestion of rubber grains (oral route) and increased dermal exposure for a goalkeeper who is 7 years old. This goalkeeper's scenario is also considered a worst-case scenario for teenage and adult goalkeepers.
3. Children aged 11-18 years old, performance-oriented sport
   From age 11 (which is still in the 'under 12' category), children generally start playing on a full-size pitch. From this age, children are also selected to play in teams that train more often than recreational teams. A scenario for performance-oriented sport which corresponds with the elite amateur level was therefore selected as the worst case for this age group. This category applies as the worst-case scenario for children up to 18 years old.
4. Adults, performance-oriented sport
   Performance-oriented sport was also selected as the worst-case scenario for adults due to the higher training frequency.

In addition to these four scenarios, there is also a fifth scenario, based on 'lifelong' exposure for an outfield player and a goalkeeper. For this scenario, assumptions were made about the number of years that an adult person engages in performance-oriented sport (up to the age of 35), after which the person continues to play with the veterans until reaching the age of 50. 'Veteran' football (age 35-50) is regarded as recreational in nature. The 'lifelong' exposure is then averaged out over 70 years, based on the assumed exposure from age 4 to age 50. This scenario is primarily relevant for those substances that have a toxicological reference value, which is based on lifelong exposure (as is the case for non-threshold substances, including the PAHs).

The five scenarios are described in more detail in Annex VII.

The scenarios have been drawn up in such a way that they calculate a realistic worst-case scenario for exposure to a substance (or group of substances) in rubber granulate. This means that actual situations are used to calculate the exposure for people playing sports who are most exposed to the substance(s). Exposure will be lower for the majority of people playing sports in their daily lives.

The exposure calculations are based on input parameters obtained from the chemical analyses of the rubber granulate samples, input parameters needed to describe the sport scenario, and equations (models). The chemical analyses look at content and physiological availability in migration studies. Content analyses indicate which substances are present in the rubber granulate samples (characterisation) and the total levels of those substances in the granulate. Physiological availability analyses give an impression, in simulation circumstances, of which substances may migrate into receptor fluids (which simulate the gastrointestinal tract or the skin) or evaporate into the air, and in what amounts; this represents the amount of substances that people may be exposed to. The migration tests did not include any experiments on inhalation of rubber granulate dust or substances released from granulate dust into the lungs, because sampling of particulate matter is not feasible in the period set aside for the research. This route was therefore taken into account by using PM10 values (= particulate matter of which the particles smaller than 10 µm in diameter) from the literature, as measured at SBR synthetic turf pitches in indoor environments.

Describing the sport scenarios requires assumptions about the type of contact (via ingestion, inhalation, and skin), behaviour, intensity, contact surface area, frequency and duration of the actual or potential exposure. The assumptions are therefore largely based on findings during sports activities as reported in the literature. It should be noted that no studies were found which investigated the exact oral ingestion of grains of rubber granulate, or analysed the effective skin exposure (either for intact skin, or damaged skin) while playing sports. For that reason, the figures are largely based on contact with the ground (soil).

In calculating exposure to the prioritised substances, the maximum levels of the substances from the migration tests were used for the oral and dermal routes (see Annex V). In the absence of migration data, the maximum content value (a very worst-case scenario) was used to calculate the route via inhalation of particulate matter. Evaporation as an exposure route was not calculated due to the lack of the prioritised substances in the headspace analysis.

The input parameters relating to the exposure were not set to their maximum values; using maximum values for all input parameters results in a very unrealistic worst-case scenario for estimated exposure. It is, in fact, not plausible for an individual player or goalkeeper to be in the 'worst-case' group for all input parameters. Where possible, distributions were used for the input parameters that show the variation in the parameters. A certain percentile of those parameters was then selected. The chosen parameters were selected for the following reasons:

- Body weight and body surface area: 25th percentile [27], so relatively small children and/or adults are protected. The ratio between surface area and weight (which are related to each other) represents a higher exposure in young children than in older children and adults; a lower body weight actually results in a higher exposure per kg of body weight;
- Respiratory rate: 75th percentile of the exposed group of people playing sports [27];
- PM10 value: the value from a Norwegian study was chosen based on PM10 concentrations in a sports hall with synthetic turf containing SBR granulate [28]. This is the only study which determined not only the PM10, but also the corresponding fraction rubber granulates. Using an ‘indoor’ PM10 value also minimises the effect of the outside air, representing a worst case for outdoor activities;
- Ingestion of rubber grains by children aged up to 11: 0.2 g per training activity or match. Ingestion of grains in the other scenarios was calculated based on an estimated 0.05 g per training activity or match. These soil ingestion values represent the 95th percentile [29].
- Dermal exposure of outfield players: an estimate was made based on literature data. Based on the Pavilonis (2013) study a ‘rubber granulate load on the skin’ of between 0.5–0.8 grams were derived, with the 16–19-year-olds being the group with the highest exposure [30]. Based on the Norwegian NIPH study values varying between 1 gram (children aged 7–11) and 6 grams (adults) were derived, which are based on a skin adherence factor of 1 mg/cm^2 body surface area [31]. The US EPA (2011) [29]reports skin adherence factors for exposure to soil during football, with major variations observed up to values well above the Norwegian study. In view of this variation, the ‘load of rubber granulate on the skin’ was chosen as reported in the Norwegian study, because that study is based on a realistic skin adherence factor of 1 mg/cm^2, this case relates specifically to rubber granulate, and approximates a high percentile, but lower than the 95^{th} percentile, in the US EPA study.
- Dermal exposure of goalkeepers: no specific data is reported in the literature. Accordingly, an arbitrary choice was made to use a 10-fold higher exposure than the exposure in the 4-year-old child scenario, given the much more frequent contact with the pitch. The US EPA reports an extremely large spread in dermal exposure for football players, with a 95th percentile of up to 10.6 grams [29].

In addition to these parameters, the frequency and duration of the training sessions and matches used to calculate each scenario are based on clubs’ training schedules and have been discussed with the KNVB. The frequency and duration of intensive sport are representative of the activity level at elite amateur clubs, so they offer protection for other amateur clubs.

Lastly, it was assumed that each and every training session and match take place on a synthetic turf pitch with rubber granulate, which is a worst-case assumption.

Table 3 presents a summary of the input parameters for the four scenarios. None of the scenarios makes a distinction between boys/girls or men/women.

Table 3. Input parameters for estimated exposure for the four scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Reference**
General					
Body weight (kg)	15.7	24.3	44.8	68.8	[27]
Frequency (times per week)	2	3	5	5	Based on training schedule
Duration (hours per event)	1x 1 hour, 1x 1.5 hour	1x 1 hour, 2x 1.5 hour	1.5	2	Based on training schedule
Duration (months per year)	7 (all routes)	7 (dermal) 10 (inhalation and oral)	7 (dermal) 10 (inhalation and oral)	7 (dermal) 10 (inhalation and oral)	Based on training schedule
Dermal					
Body surface area in contact (cm^2)	1260 (¼ legs, ½ arms, hands)	1290 (¼ legs, ½ arms)	2680 (¼ legs, ½ arms, hands)	3680 (¼ legs, ½ arms, hands)	[27]
Amount of granulate (g) [1]	1 (according to literature)	10 (estimate, literature x factor 10)	3.3 (according to literature)	6 (according to literature)	[31]
Inhalation					
Respiratory rate (m^3/hour; with intensive activity)	1.58	1.92	2.53	3.07	[27]
PM10 (μg/m^3) rubber granulate	12	12	12	12	[31]
Oral					
Direct ingestion (g)	0.2	0.2	0.05	0.05	[29,31]

The exposure calculations are then based on the following equations:

- Daily dermal exposure = mass of granulate in dermal contact (per sport occasion) x migration fraction / body weight [1]
- Air concentration of chemical substance in PM10 = air concentration PM10 x weight fraction in granulate
- Daily oral exposure = mass of ingested granulate (per sport occasion) x migration fraction / body weight

[1] This calculation implicitly includes period of contact. The result of the migration test states the amount of a substance that migrates into sweat from rubber granulate in two hours. Two hours corresponds quite closely to the total time a player spends on the pitch before, during and after a training session/match.

To calculate the year average exposure, daily exposure is multiplied by the weekly frequency of the activity and the number of months per year. To calculate 'lifelong' exposure, the year average exposure is multiplied by the number of years of exposure per scenario relative to the total of 70 years (e.g. the 4-year-old scenario lasts 7 years: factor 0.1) and the scenarios, including the veterans' scenario, are added up.

In analysing substances that have a threshold a tiered approach has been followed. If the calculated daily exposure to a substance in rubber granulate does not result in an unacceptable risk, further calculations are not needed. At that point, year average exposure or lifelong exposure does not have to be calculated, since the estimated daily exposure is already the worst-case scenario.

These calculations yield an estimated dose of the chemical substance (or group of substances) which is on or in the body (external exposure), but has not yet been absorbed into the bloodstream (internal exposure). Since the external exposure will be compared with the external toxicological reference values for the risk assessment, there is no need to convert the external exposure into an internal one (by adjusting for absorption). The only exception is the estimated dermal exposure to BPA, in which case the external exposure is indeed converted into an internal exposure because the toxicological reference value applies to the absorbed BPA.

Results
Although limited from the point of view of the number of samples tested, the migration tests (in vitro digestion, skin migration, headspace analysis) provide an indication of the substances that are released/evaporated, as well as the amounts. The results of the in vitro digestion and skin migration tests were used to calculate the exposure for the oral and dermal route, respectively. However, no migration data was available for BPA and 2-MBT, so instead the content values were used to calculate the exposure. Exposure to vapours is not included in the estimated exposure, since the prioritised substances were not included in the headspace analysis. What remains for the inhalation route is exposure to rubber dust; content data was used in these calculations, since there is no data on migration of rubber dust into artificial lung fluid. The worst-case scenario was used here: the assumption that the total amount of chemical substance in the inhaled rubber dust present in PM10 also becomes available for exposure via the airways.

The results of the exposure calculations for the various scenarios and prioritised substances are shown in Tables 4 through 8 in Section 10.9. These estimates are considered worst-case because they are based on maximum migration or content values for the prioritised substances. On average, therefore, these values will be lower.

As stated previously, a group approach was used for the PAHs. Consequently, the exposures stated in Table 4 represent the sum of the four or eight PAHs included in the EFSA4 or EFSA8/ECHA8.
The calculated exposure to PAHs via particulate matter is 0.027 ng/m^3, based on BaP as a marker for the PAHs, which is well below the

reference value of 1 ng/m^3. This exposure is not included in Table 4, because the air reference value is based on a different marker and effect than the oral and dermal reference values. As a result, the additional risks of cancer from the inhalation route of exposure cannot be added up for the risk assessment.

Other users/exposed populations

- People playing sports other than football:
  Besides people playing sports on football pitches with synthetic turf and rubber granulate made from SBR rubber, there are other people who play sports, for example korfball and rugby, who come into contact with rubber granulate. The scenarios for football players are realistic worst-case scenarios. It can reasonably be assumed that these scenarios are also representative of korfball and rugby.

  However, the intensity of exposure would vary. The scenarios can be considered a more extreme worst-case scenario for korfball, since less dermal contact is expected in that sport. The opposite is true for rugby; there is more contact with the soil during rugby than during football, since rugby plays often take place on the ground. This is also supported by the skin adherence factors which the US EPA (2011) reports for rugby players. It is also feasible that rugby players' mouth guard may fall onto the ground and convey rubber granulates into the mouth upon re-insertion. The goalkeeper scenario would be most appropriate for rugby players.

  It is possible that people playing sports in scenarios 1 through 3 will also engage in games/sports on the same pitches during physical education classes at school, which could lead to higher exposures. Based on two extra hours of contact (and therefore two extra sport occasions) on the pitches per week, the exposure per scenario could be as much as 1.4 to 2 times higher via the dermal and oral route and as much as 1.2 to 1.8 higher via inhalation (under the same intensive contact conditions, although such conditions are unlikely to occur in this context).
- Employees/volunteers who install/maintain pitches
  Such activities as producing rubber granulate production or spreading and refilling rubber granulate on the pitches fall outside the scope of this study. However, it is likely that these employees and/or volunteers are exposed to more rubber dust in the air during these activities.
- Professional football players
  Professional football players play on the pitches more often and more intensively. The scenario is comparable to scenario 4 above, although the frequency and amount of time spent on the pitches will be higher.
- Sports teachers, coaches
  Like professional football players, the coaches and teachers may spend more hours a week on the pitch. In principle, however, they would receive little to no dermal exposure and no oral exposure.
- Spectators

Spectators on the sideline will, in principle, not have any direct contact with the rubber granulate, although they may be exposed to vapours and possibly rubber dust. Partly due to a lower level of activity, the inhalation exposure for spectators on the sidelines is expected to be lower than for people playing sports.
More exposure is expected if spectators stay on or near the pitch for longer, for example during tournaments. Athletes may also be present near the pitch as spectators on the same day.

- Small children at play
  Small children may have intensive contact with rubber granulate if they are allowed to play on synthetic turf pitches with rubber granulate, for example while at a daycare centre, after-school club or playing on the sideline as spectator. For children under 4 years old, oral exposure from ingestion and hand-mouth contact will be the main route to consider. The frequency and duration of play will be equal to or slightly higher than scenario 1 above, depending on how frequently the child goes to a daycare centre or after-school club.

10.9 Indicative risk assessment

An initial, indicative risk assessment was made by calculating the exposure estimates for the various scenarios and prioritised substances (based on migration or content analysis) and then comparing those estimates to the toxicological reference values for the prioritised substances. Please note that this is an ‘external' comparison (with the exception of dermal BPA, see clarification in Section 10.8). The external exposure for each exposure route is compared with the external toxicological reference value. The risk per exposure route can then be summed in order to make an estimate of the combined risk over all routes.

The toxicological reference values for the genotoxic carcinogenic PAHs are related to a non-threshold effect. The Dutch policy on genotoxic carcinogenic substances is to aim at achieving a negligible or maximum permissible risk level. The negligible risk level is one in a million (i.e. , one additional case of cancer per million exposed individuals), while the maximum permissible risk level is one in ten thousand (one additional case of cancer per ten thousand exposed individuals). These risk levels are all based on lifelong exposure, and constitute a generic risk approach.

The additional cancer risk can be calculated in different ways. One way is for instance by linear extrapolation: the lowest dosage which leads to a statistically significant increase in tumours in laboratory animals compared to the controls serves as point of departure for a linear extrapolation to the non-observable, low-dose area that is associated with a negligible risk (10^{-6}) or maximum permissible risk (10^{-4}). Another method is the margin of exposure (MOE) approach, with the MOE being defined as the quotient of that lowest dosage in laboratory animals and the exposure estimate for humans [32]. As point of departure for the tumorigenic dosage in this approach, EFSA prefers to use the BMDL10 (95 percent lower confidence level of the dosage resulting in a 10% additional cancer risk in laboratory animals upon lifelong exposure). The

MOE approach does not lead to explicit conclusions about the additional cancer risk. However, EFSA does assert that an MOE of 10,000 or higher would indicate a 'low concern from a public health point of view' [32].

In order to assess the risk of the mixture of PAHs in rubber granulate via the oral and dermal route, the $BMDL_{10}$ values for PAH4 and PAH8 as derived by EFSA were taken (see Annex VI). Linear extrapolation was used to express the estimated exposure in terms of additional cancer risk. This was done in accordance with the REACH Guidance [33], as follows. First the $BMDL_{10}$ is converted into a 'human' $BMDL_{10}$ (by adjusting for allometric scaling), which is then divided by a high-to-low dosage factor, in order to reach a low risk level (e.g. dividing the 'human' $BMDL_{10}$ by 100,000 results in the dosage at which the additional cancer risk is one in a million (10^{-6})). As an example: the $BMDL_{10}$ of 0.34 mg/kg bw/d for PAH4 has been derived from an oral carcinogenicity study with mice. The allometric scaling factor is 7 for mouse-human extrapolation. The additional cancer risk from PAH4 at 1 in 10^{-6} is therefore 0.34 : 7 : 100,000 is 0.00049 µg/kg bw/d. In other words, the additional cancer risk per µg/kg bw/d is 2.06×10^{-3}.

Linear extrapolation is not required for the inhalation route, since the reference value for air (for BaP as a marker for PAH mixtures) already relates to an additional cancer risk (see Annex VI).

The toxicological reference value for lead is based on developmental neurotoxicity. Children are the most sensitive to these effects, since their brain and central nervous system are still developing. The reference value is extremely low because it is a non-threshold effect; lead exposure should therefore be kept as low as possible. For the risk assessment, the estimated exposure was compared with the maximum tolerable exposure value for lead from a toxicological perspective.

For all other substances for which a risk assessment was performed (phthalates, cadmium, cobalt, 2-MBT and BPA), the toxicological reference values are related to a threshold effect. It is assumed that lifelong exposure to the reference value, such as an acceptable or tolerable daily intake (ADI or TDI) or a derived no-effect level (DNEL), does not pose any health risks. A Risk Characterisation Ratio (RCR) was calculated for the threshold substances, which is the quotient between the exposure and the toxicological reference value. If the RCR is lower than or equal to one, there is no cause for concern.

The results of the indicative risk assessments for the PAHs, phthalates, metals, 2-MBT and BPA are shown in Tables 4 through 8 and in Figures 1 through 3. These tables and charts show that exposure to rubber dust via inhalation hardly, if at all, contributes to the total exposure to these prioritised substances. The oral route is the most important exposure route for PAHs and phthalates in rubber granulate, while the dermal route is the most important for BPA.

Looking at PAHs in rubber granulate, the dermal route (with a very low migration to sweat, 0.02%) and inhalation route (with a dust exposure well below the air reference value) do not appear to be relevant exposure routes. Due to the lack of headspace measurements for the

PAHs, evaporation has been calculated based on the concentration in the granulate (see Annex V). The calculated maximum concentration in the air immediately above the synthetic turf pitch (0.03 ng/m^3 at 60°C) is well below the air reference value of 1 ng/m^3. Exposure to PAHs via inhalation of vapour will therefore not play any relevant role for people playing sports.

Assuming that 9% of the maximum pitch levels for the sum of PAHs migrates into the gastrointestinal tract, the oral exposure to PAHs in rubber granulate for a 'lifelong' outfield player or goalkeeper is associated with additional cancer risks of 0.8-1.1x10^{-6} (outfield player) and 2.1-2.8x10^{-6} (goalkeeper) (Table 4, Figure 1). The same kind of calculation based on 9% migration of the P90 pitch levels results in additional cancer risks of 4.4-6.0x10^{-7} (outfield player) and 1.1-1.6x10^{-6} (goalkeeper) for the oral route (see Table VIII.1 and Figure I in Annex VIII). These risks range from just below to very slightly above the risk level that is considered negligible in the Netherlands (1x10^{-6}).

The additional cancer risks may have been overestimated here. First, the linear extrapolation method is generally regarded as conservative. Second, it has been assumed that during their life each person plays every training session and every match on synthetic turf with rubber granulate from which the highest levels of PAHs are released. Further, 0.2 g of rubber grains would have to be ingested during each training session or match during the person's entire football career, which is difficult to imagine (see photo in Annex VII).

On the other hand, there are also uncertainties which may have the opposite effect on the cancer risks, such as the fact that the basis for the toxicological reference value (a standard carcinogenicity study in mice) does not cover exposure during the first few years of life, and the fact that lipophilic substances such as PAHs do not pass readily into aqueous solutions such as sweat (see discussion). In addition, rubber granulate is only one source of exposure to PAHs.

Under worst-case conditions (estimated exposure based on maximum migration values, not averaged out over the year/lifetime, all training sessions and matches on synthetic turf with rubber granulate), the indicative risk assessment for the metals cadmium, cobalt and lead in rubber granulate does not reveal a risk for this source of exposure for cadmium and cobalt (see Table 6), nor for lead in the scenarios for players aged 11 and up (see Figure 2). For children under the age of 11, if these worst-case conditions occur on the day they play their sport, the maximum tolerable exposure value for lead is exceeded. The year average exposure for these children however remains below that value (see Figure 2).
As stated, the toxicological reference value for lead is extremely low. For example, the exposure to lead via food (0.53-0.76 µg/kg bw/d for children aged 2-6) is already higher than what is tolerable from a toxicological perspective (maximum 0.05 µg/kg bw/d). Compared to food, the contribution from rubber granulate (primarily via the oral route) appears to be fairly limited, certainly as regards the year average exposure. We should also not forget that, in order to achieve that exposure, children would have to ingest 0.2 g of rubber grains during

each training/match (which is difficult to imagine), and that all of the 'total amount released' is indeed available for absorption via the intestinal wall (which is unlikely).
For all three metals analysed here, although migration was only tested in a small number of samples, the results appear to show that migration into sweat and saliva/gastric juice/intestinal juice does not exceed the amount which is permitted to migrate for these metals according to the Toy Safety Directive. In the absence of a dermal toxicological reference value for the metals, the dermal exposure was compared with the oral reference value, assuming equal absorption via both routes. This is a worst-case assumption, as for metals dermal absorption is generally lower than oral absorption.
Although metals were not included in the headspace analysis, no additional contribution to the exposure via inhalation of vapour is expected for the prioritised metals, given their very low vapour pressure.

The results also reveal that, in worst-case conditions (estimated exposure based on maximum migration values, not averaged out over the year/lifetime, all training sessions and matches on synthetic turf with rubber granulate), the exposure to various phthalates is many times lower than the toxicological reference values for these phthalates. Even when accounting for simultaneous exposure to multiple phthalates (because of their similar toxicological profile), this combined exposure does not reveal a risk (see Table 5).
The same applies for 2-MBT (see Table 7). The worst-case scenario for this substance can be considered even more extreme, because in the absence of migration data for this substance the calculations were based on maximum content data. The combination of all benzothiazoles also does not appear to be a problem. In case they are all converted into the same toxicological metabolite, and the toxicological reference value for 2-MBT were to be compared with the sum total of benzothiazoles, the total RCR is well below 1 for all four scenarios (0.012, 0.024, 0.003 and 0.004 for scenarios 1 through 4 respectively).
Consequently, exposure to phthalates and benzothiazoles from this source is not a cause for concern, even if the inhalation route would contribute as well to the total exposure (after evaporation from rubber granulate; not established in the headspace analysis). The RCRs are so low that other sources of exposure to these substances (which will be numerous, certainly in the case of the phthalates) can still contribute significantly to total exposure before the toxicological reference values are exceeded.

Looking at BPA, the risk is almost solely determined by dermal exposure. In worst-case conditions (estimated exposure based on maximum content values, not averaged out over the year/lifetime, all training sessions and matches on synthetic turf with rubber granulate), there is only one scenario for which the RCR is not below 1 for the exposure on the day of playing sport. This is scenario 2 (7-year-old goalkeeper), for which the RCR equals 1. The other scenarios offer no cause for concern (Table 8A, Figure 3A).
Since the reference value for BPA is based on lifelong average exposure, the year average exposure for scenario 2 was also examined. In addition, a more realistic goalkeeper scenario was developed. This

scenario includes adjustments for age (see Section 10.8), since a person will not be a 7-year-old goalkeeper for his or her entire life. The resulting exposure for the 7-year-old goalkeeper scenario is in that case no longer a cause for concern (Table 8B, Figure 3B). This is partly because synthetic turf with rubber granulate will not be the playing surface for every single training session or match, as has been assumed in the worst-case scenario.
BPA was not in the standard package of substances to be analysed, but came to light in the 'general unknown' screening. As a result, a skin migration test has not yet taken place for BPA. Even so, it is unlikely that 100% of the BPA present in rubber granulate will migrate into sweat. Consequently, the true RCRs will, in all likelihood, be lower than currently calculated. In addition, no additional risk is expected via inhalation of vapour (not determined for BPA in the headspace analysis), given the low vapour pressure of BPA in combination with the reference value for air.

*Table 4. Results of the indicative risk assessment for the PAHs * (A: EFSA4, B: EFSA8, C: ECHA8) according to the linear extrapolation method; based on maximum migration values*

A

EFSA - 4		max. migration level (mg/kg rubber granulate)	lifelong exposure (µg/kg bw/d)	$BMDL_{10}$ (µg/kg bw/d)	Additional risk per µg/kg bw/d	Additional risk
Outfield player	**oral**	0.91	3.89E-04	340	2.06E-03	8.00E-07
	dermal	0.00202	3.35E-05	510	1.37E-03	4.60E-08
	total					*8.46E-07*
Goalkeeper	**oral**	0.91	1.02E-03	340	2.06E-03	2.09E-06
	dermal	0.00202	7.35E-05	510	1.37E-03	1.01E-07
	total					*2.20E-06*

B

EFSA - 8		max. migration level (mg/kg rubber granulate)	lifelong exposure (µg/kg bw/d)	$BMDL_{10}$ (µg/kg bw/d)	Additional risk per µg/kg bw/d	Additional risk
Outfield player	**oral**	1.46	6.24E-04	490	1.43E-03	8.91E-07
	dermal	0.00324	5.37E-05	740	9.46E-04	5.08E-08
	total					*9.42E-07*
Goalkeeper	**oral**	1.46	1.63E-03	490	1.43E-03	2.33E-06
	dermal	0.00324	1.18E-04	740	9.46E-04	1.12E-07
	total					*2.44E-06*

Table 4 – continued
C

ECHA - 8		**max. migration level (mg/kg rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	1.78	7.60E-04	490	1.43E-03	1.09E-06
	dermal	0.00396	6.57E-05	740	9.46E-04	6.21E-08
	total					*1.15E-06*
Goalkeeper	**oral**	1.78	1.99E-03	490	1.43E-03	2.84E-06
	dermal	0.00396	1.44E-04	740	9.46E-04	1.36E-07
	total					*2.98E-06*

* The toxicological reference value for PAHs is based on lifelong exposure. Instead of the four separate scenarios based on different age groups, a 'lifelong' scenario was therefore developed, one for an outfield player and one for a goalkeeper (see section 10.8).

Table 5.Results of the indicative risk assessment for the phthalates (A: 4-year-old child, B: 7-year-old goalkeeper, C: 11-year-old child, D: performance-oriented sport); based on maximum migration (oral, dermal) or pitch values (inhalation)

A

Scenario	**Oral**			**Dermal ***			**Inhalation**			**Total**
4-year-old child	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**DNEL (µg/m^3)**	**RCR**	**RCR**
DBP	2.19E-03	6.7	3.27E-04	1.08E-05	70	1.55E-07	1.03E-05	20	5.16E-07	3.28E-04
BBP	2.52E-03	500	5.04E-06	1.08E-05	10000	1.08E-09	1.19E-05	1700	6.99E-09	5.05E-06
DEHP	6.93E-02	34	2.04E-03	1.06E-04	672	1.58E-07	3.26E-04	120	2.72E-06	2.04E-03
DIBP	5.91E-03	8.3	7.12E-04	1.08E-05	80	1.35E-07	2.78E-05	25	1.11E-06	7.13E-04
DINP	0.1554	250	0.000622	1.06E-03	6250	1.70E-07	7.32E-04	870	8.41E-07	6.23E-04
DCHP	5.35E-04	180	2.97E-06	1.08E-05	1800	6.02E-09	2.52E-06	630	4.00E-09	2.98E-06
Total			*3.71E-03*			*6.25E-07*			*5.20E-06*	*3.71E-03*

B

Scenario	**Oral**			**Dermal ***			**Inhalation**			**Total**
7-year-old goal-keeper	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**DNEL (µg/m^3)**	**RCR**	**RCR**
DBP	1.42E-03	6.7	2.11E-04	7.00E-05	70	9.99E-07	1.03E-05	20	5.16E-07	2.13E-04
BBP	1.63E-03	500	3.26E-06	7.00E-05	10000	7.00E-09	1.19E-05	1700	6.99E-09	3.27E-06
DEHP	4.48E-02	34	1.32E-03	6.87E-04	672	1.02E-06	3.26E-04	120	2.72E-06	1.32E-03
DIBP	3.82E-03	8.3	4.60E-04	7.00E-05	80	8.74E-07	2.78E-05	25	1.11E-06	4.62E-04
DINP	0.1004	250	0.0004016	6.86E-03	6250	1.10E-06	7.32E-04	870	8.41E-07	4.04E-04
DCHP	3.46E-04	180	1.92E-06	7.00E-05	1800	3.89E-08	2.52E-06	630	4.00E-09	1.96E-06
Sum			*2.40E-03*			*4.04E-06*			*5.20E-06*	*2.40E-03*

Table 5 – continued

C

Scenario	Oral			Dermal *			Inhalation			Total
11-year-old child	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m³)**	**DNEL (µg/m³)**	**RCR**	**RCR**
DBP	1.92E-04	6.7	2.87E-05	1.25E-05	70	1.79E-07	1.03E-05	20	5.16E-07	2.93E-05
BBP	2.21E-04	500	4.42E-07	1.25E-05	10000	1.25E-09	1.19E-05	1700	6.99E-09	4.50E-07
DEHP	6.07E-03	34	1.79E-04	1.23E-04	672	1.83E-07	3.26E-04	120	2.72E-06	1.81E-04
DIBP	5.18E-04	8.3	6.24E-05	1.25E-05	80	1.57E-07	2.78E-05	25	1.11E-06	6.37E-05
DINP	0.01362	250	5.45E-05	1.23E-03	6250	1.96E-07	7.32E-04	870	8.41E-07	5.55E-05
DCHP	4.69E-05	180	2.60E-07	1.25E-05	1800	6.96E-09	2.52E-06	630	4.00E-09	2.71E-07
Sum			*3.25E-04*			*7.23E-07*			*5.20E-06*	*3.31E-04*

D

Scenario	Oral			Dermal *			Inhalation			Total
Performance-oriented sport	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m³)**	**DNEL (µg/m³)**	**RCR**	**RCR**
DBP	1.25E-04	6.7	1.87E-05	1.48E-05	70	2.12E-07	1.03E-05	20	5.16E-07	1.94E-05
BBP	1.44E-04	500	2.88E-07	1.48E-05	10000	1.48E-09	1.19E-05	1700	6.99E-09	2.96E-07
DEHP	3.95E-03	34	1.16E-04	1.46E-04	672	2.17E-07	3.32E-04	120	2.04E-06	1.19E-04
DIBP	3.37E-04	8.3	4.06E-05	1.48E-05	80	1.85E-07	2.78E-05	25	1.11E-06	4.19E-05
DINP	0.008866	250	3.55E-05	1.45E-03	6250	2.33E-07	7.32E-04	870	6.31E-07	3.63E-05
DCHP	3.05E-05	180	1.70E-07	1.48E-05	1800	8.24E-09	2.52E-06	630	4.00E-09	1.82E-07
Sum			*2.11E-04*			*8.56E-07*			*4.31E-06*	*2.17E-04*

* No phthalates were found above the limit of detection in artificial sweat. The limit of detection was taken as the worst case in calculating dermal exposure.

Table 6.Results of the indicative risk assessment for cadmium and cobalt (A: 4-year-old child, B: 7-year-old goalkeeper, C: 11-year-old child, D: performance-oriented sport); based on maximum migration (oral, dermal) or content values (inhalation)

A

Scenario	**Oral**			**Dermal ***			**Inhalation #**			**Total**
4-year-old child	**Exposure (µg/kg bw/d)**	**TDI$ (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**TDI (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**air limit (µg/m^3)**	**RCR**	**RCR**
Cadmium	0	0.36	0	0.001	0.36	0.004	2.52E-05	0.005	5.04E-03	8.58E-03
Cobalt	0.025	1.4	0.018	0.031	1.4	0.022	1.20E-03	0.5	8.40E-04	0.042

B

Scenario	**Oral**			**Dermal ***			**Inhalation #**			**Total**
7-year-old goalkeeper	**Exposure (µg/kg bw/d)**	**TDI$ (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**TDI (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**air limit (µg/m^3)**	**RCR**	**RCR**
Cadmium	0	0.36	0	0.008	0.36	0.023	2.52E-05	0.005	5.04E-03	0.028
Cobalt	0.016	1.4	0.012	0.198	1.4	0.141	1.20E-03	0.5	8.40E-04	0.155

C

Scenario	**Oral**			**Dermal ***			**Inhalation #**			**Total**
11-year-old child	**Exposure (µg/kg bw/d)**	**TDI$ (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**TDI (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**air limit (µg/m^3)**	**RCR**	**RCR**
Cadmium	0	0.36	0	0.001	0.36	0.004	2.52E-05	0.005	5.04E-03	9.13E-03
Cobalt	0.002	1.4	0.002	0.035	1.4	0.025	1.20E-03	0.5	8.40E-04	0.029

Table 6 – continued
D

Scenario	Oral			Dermal *			Inhalation #			Total
Performance -oriented sport	**Exposure (µg/kg bw/d)**	**TDI[$] (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**TDI (µg/kg bw/d)**	**RCR**	**Exposure (µg/m³)**	**air limit (µg/m³)**	**RCR**	**RCR**
Cadmium	0	0.36	0	0.002	0.36	0.005	2.52E-05	0.005	5.04E-03	9.88E-03
Cobalt	0.001	1.4	0.001	0.042	1.4	0.030	1.20E-03	0.5	8.40E-04	0.033

* In the absence of a dermal toxicological reference value, the oral TDI was taken.

In the absence of content data from own research, the Dutch environmental quality label for sustainable products and services ('Milieukeur') content values were taken for cadmium [26]. Since that source offers no content values for cobalt, a fictitious level of 100 mg/kg was chosen.

$ The toxicological reference value for cadmium is a TWI of 2.5 µg/kg bw/wk (see Annex VI); for the indicative risk assessment, this has been converted into a reference value for daily exposure (0.36 µg/kg bw/d).

Table 7. Results of the indicative risk assessment for 2-mercaptobenzothiazole; based on maximum pitch values

2-MBT		**Oral**			**Dermal**			**Inhalation**			**Total**
	max level rubber granulate (mg/kg)	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**DNEL (µg/m^3)**	**RCR**	**RCR**
4-year-old child	7.6	0.10	310	3.12E-04	0.48	940	5.15E-04	0.000091	1090	8.37E-08	8.27E-04
7-year-old goalkeeper	7.6	0.06	310	2.02E-04	3.13	940	3.33E-03	0.000091	1090	8.37E-08	3.53E-03
11-year-old child	7.6	0.01	310	2.74E-05	0.56	940	5.96E-04	0.000091	1090	8.37E-08	6.23E-04
Performance-oriented sport	7.6	0.01	310	1.78E-05	0.66	940	7.05E-04	0.000091	1090	8.37E-08	7.23E-04

Table 8. Results of the indicative risk assessment for bisphenol A (A: day exposure; B: year average exposure); based on maximum pitch values

A

		Oral			Dermal			Inhalation			Total
Bisphenol A	**max level rubber granulate (mg/kg)**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Exposure (µg/m^3)**	**DNEL (µg/m^3)**	**RCR**	**RCR**
4-year-old child	2.5	0.032	4	7.96E-03	0.016	0.1	0.16	0.00003	200	1.50E-07	0.17
7-year-old goalkeeper	2.5	0.021	4	5.14E-03	0.103	0.1	1.03	0.00003	200	1.50E-07	1.03
11-year-old child	2.5	0.003	4	6.98E-04	0.018	0.1	0.18	0.00003	200	1.50E-07	0.18
Performance-oriented sport	2.5	0.002	4	4.54E-04	0.022	0.1	0.22	0.00003	200	1.50E-07	0.22

B

		Oral			Dermal			Inhalation			Total
Bisphenol A	**max level rubber granulate (mg/kg)**	**Year average exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Year average exposure (µg/kg bw/d)**	**DNEL (µg/kg bw/d)**	**RCR**	**Year average exposure (µg/m^3)**	**DNEL (µg/m^3)**	**RCR**	**RCR**
4-year-old child	2.5	0.005	4	1.33E-03	0.003	0.1	0.03	0.00003	200	1.50E-07	0.03
7-year-old goalkeeper	2.5	0.007	4	1.84E-03	0.026	0.1	0.26	0.00003	200	1.50E-07	0.26
11-year-old child	2.5	0.002	4	4.15E-04	0.008	0.1	0.08	0.00003	200	1.50E-07	0.08
Performance-oriented sport	2.5	0.001	4	2.70E-04	0.009	0.1	0.09	0.00003	200	1.50E-07	0.09
Lifelong goalkeeper*	2.5	0.003	4	6.99E-04	0.009	0.1	0.09	0.00003	200	1.50E-07	0.09

* Estimate assumes lifelong exposure of an outfield player/goalkeeper who starts out playing football from age four to age seven and then becomes a goalkeeper.

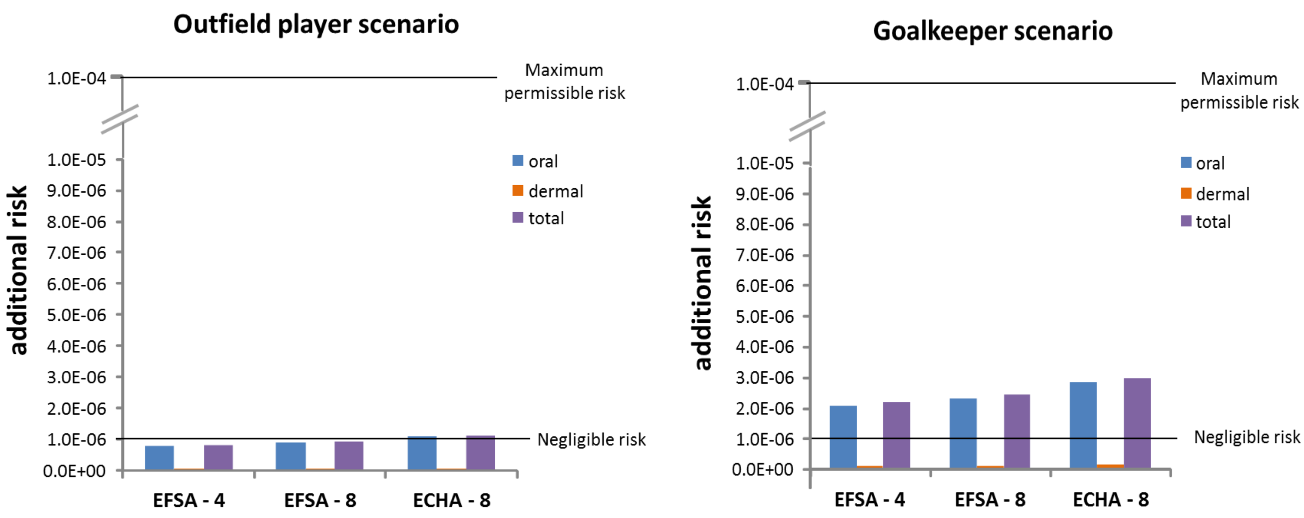


Figure 1. Results of the indicative risk assessment for the PAHs according to the linear extrapolation method; based on maximum migration values. Horizontal lines represent additional cancer risk of one in a million (negligible risk) or one in ten thousand (maximum permissible risk).

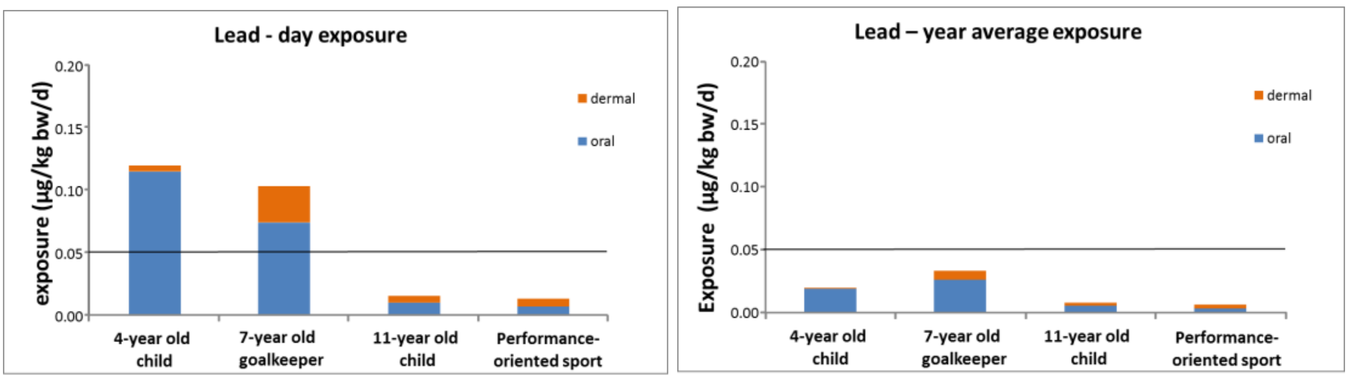
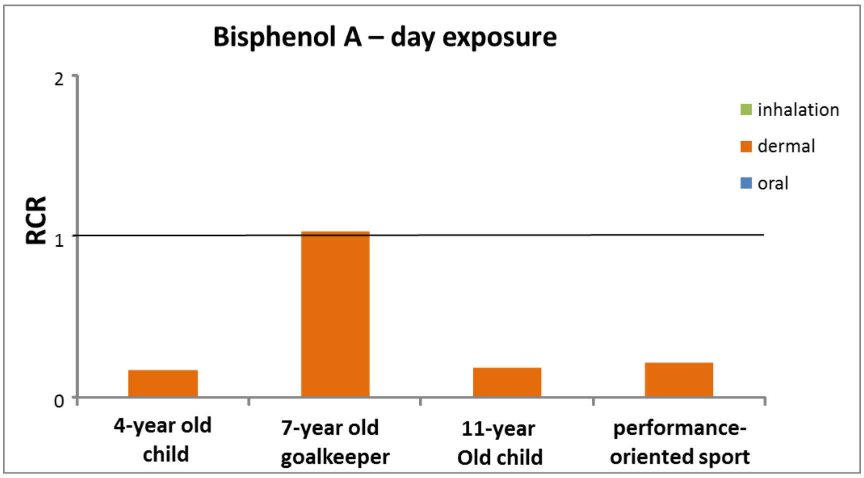


Figure 2. Results of the indicative risk assessment for lead (left: day exposure; right: year average exposure) based on maximum migration values (oral, dermal). Horizontal line is the maximum tolerable exposure value.

A



B

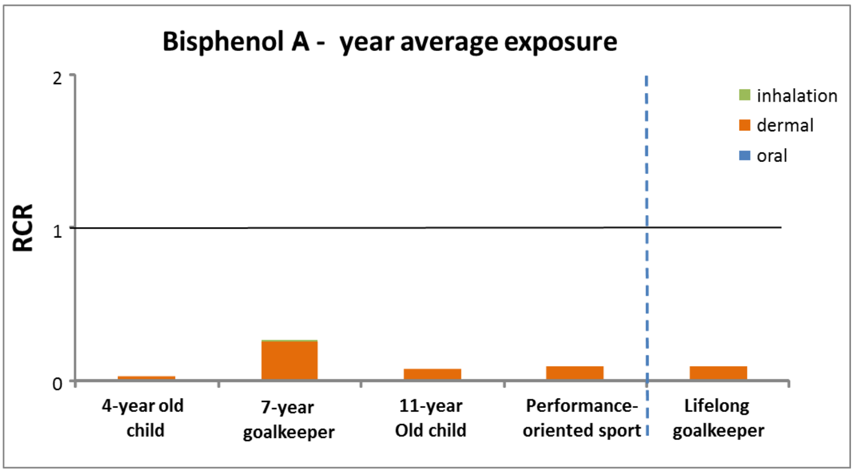


Figure 3. Results of the indicative risk assessment for Bisphenol A (A: day exposure; B: year average exposure); based on maximum pitch values. Horizontal line is RCR=1

Other studies

Before discussing these results, a number of findings from other research are presented for the purposes of comparison with the current research. (See also Annex IX for summaries of the most important studies.)

Inhalation

The results show that the inhalation route for the prioritised substances does not contribute significantly to a potential risk. This concurs with the findings from other studies. For example, RIVM found no detectable levels of nitrosamines in the air above synthetic turf pitches, nor in evaporated air after heating to 70°C [6]. Exposure measurements carried out during the construction and maintenance of synthetic turf pitches revealed increased dust concentrations when the pitch was being filled, but not during maintenance. There was no clear increase in exposure to PAHs and the concentrations of volatile organic compounds (VOCs) were below the limit of detection [34].

In an Italian study, stationary and personal air measurements were performed during football matches on a synthetic turf pitch. The additional cancer risk calculated for PAHs based on worst-case assumptions (30 years of football, at the highest measured concentration) was one in a million, which is generally regarded as a negligible risk [35]. Other Italian research found comparable or lower risks for PAHs, based on measurements and calculations during football matches on the pitches, as well as during their construction [36, 37]. Measurements of PM10, PM2.5, and PAHs above a synthetic turf pitch in the city of Turin indicated that the air concentrations were not higher than in background measurements elsewhere in the city [38]. In relation to both carcinogenic and non-carcinogenic substances, the risk from playing sports on synthetic turf was approximately one order of magnitude lower than the risks from inhaling exhaust fumes from the traffic in Turin [39].

In Norway, exposure to various rubber granulate components, as well as the associated risk, was assessed in sport halls with synthetic turf. Although VOCs, PAHs, phthalates, semi-volatile compounds, benzothiazoles and aromatic amines were measured, no increased health risk was ascertained [28, 31]. French research that detected emissions of VOCs and formaldehyde from granulates also revealed that the concentrations above a synthetic turf pitch are not higher than the background levels, and that there is no cause for concern if there is sufficient ventilation [40].

Based on air measurements, US EPA concluded that the concentrations of chemical substances, metals and VOCs above synthetic turf pitches do not appear to give any cause for concern, although they did note that the findings are based on a limited data set [41]. OEHHA/Californian EPA also failed to find any increase in the concentrations of VOCs in the air on warm summer days [42]. Two studies in Connecticut examined the air concentrations of VOCs and SVOCs (including PAHs) for indoor and outdoor synthetic turf pitches. The concentrations of VOCs and SVOCs above indoor synthetic turf pitches were higher, as a result of which the calculated cancer risk was approximately twice as high. However, the risks for both types of pitches were so low (around one in a million) that there was no cause for concern [43-46].

Dermal exposure
The dermal exposure route is more relevant for the substances in rubber granulate, despite the fact that the results of the skin migration tests reveal that phthalates are not released at all and PAHs are only released to a very limited extent. In a Dutch study, 1-hydroxypyrene (as a marker for PAHs) was detected in the urine of football players after playing football on synthetic turf pitches with an infill of rubber granulate. It was concluded that the absorption of PAHs via contact with the skin with rubber granulate was minimal [47].

A very recent Italian study assessed the migration of PAHs from granulate into artificial sweat, showing that migration is well below 0.1% and therefore very low. As a consequence, the authors argue that significant exposure to PAHs via the skin is very unlikely [36].

Two studies by the Danish EPA (2005 and 2008) not only assessed intake via the mouth but also exposure via skin contact with car tyres or with rubber granulate [48, 49]. The results of the assessment of the migration into artificial sweat from car tyres revealed the presence of only the most water-soluble PAHs and aromatic amines. However, the concentrations were so low (for example fluoranthene 0.03-0.3 ng/cm^2, pyrene 0.03-0.5 ng/cm^2) that there was no significant risk. Calculations of skin absorption due to exposure to rubber granulate also revealed no health risk, except possibly for people who are allergic to benzothiazole and amines [48, 49].

An American study (conducted in New Jersey) included research on migration from rubber granulate into artificial sweat. The levels were very low for all substances and the concentrations of PAHs were below the limit of detection [50].

Oral exposure
Oral exposure is also relevant, primarily for children up to ten years old. Only a small number of studies have examined the health risks of ingesting grains of rubber granulate based on analyses. In RIVM research from 2007, the migration of nitrosamines to artificial saliva was determined for a limited number of samples. A very limited amount of nitrosamines was released [6].

In two studies by the Danish EPA (2005 and 2008), measurements of car tyres and rubber granulate respectively were used to calculate children's exposure based on ingestion via the mouth and via skin contact. Although the analyses revealed PAHs, aromatic amines and phthalates and 100% oral absorption was assumed, the safety margins were so large that the risk was regarded by the authors as insignificant [48, 49].

OEHHA was commissioned by the California EPA and an institute in New Jersey to carry out digestion tests with both rubber shreds and rubber granulate. Both studies conclude that the additional risk based on the analyses is minimal. It should be noted, however, that the number of analysed samples was limited (respectively three and two) and the OEHHA study did not detect any PAHs [50, 51].

PAHs
Looking at the various substance groups in rubber granulate, it can be stated that, in general, the concentrations of PAHs in rubber granulate in the present research are of the same order of magnitude as found in previous studies [30, 35, 37, 39, 48, 52-54]. However, the levels of (fluor)antracenes and anthenes in a number of studies were a factor of 2-10 higher than detected now [37, 39, 54] and two studies report a clearly higher concentration of BaP with maximum values of 8.58 and 11 mg/kg [35, 54].

Some of the studies included leaching tests using artificial lung fluid, sweat and/or gastric acid. These tests found little to no concentrations of PAHs. In case of PAHs being detected, these were the more water-soluble PAHs, such as fluoranthene and pyrene [30, 39, 48, 52, 54].

To summarise, the results of other studies correspond closely with the results of this study, showing concentrations of PAHs which are generally in the low mg/kg range and involve very limited migration to bodily fluids. Accordingly, these other studies generally concluded that the risk for the players is small, although it was pointed out that the limitations of the studies do mean there are still uncertainties.

Metals
Looking at the metals found in rubber granulate, the literature presents a reasonably clear overall impression. A number of metals are relevant from the perspective of human toxicology; the metal found in the highest concentrations in rubber granulate was lead. The highest measured concentrations were generally between 20 and 60 mg/kg [35, 37, 41, 52-54], with a peak of 308 mg/kg [39]. The lowest measured concentrations varied from a few mg/kg to approximately 10 mg/kg. Other human toxic compounds such as arsenic, cadmium and mercury were often not present above the limit of detection or were only present in low concentrations (a few mg/kg for arsenic and cadmium). Leaching and migration were determined less frequently; since different media were used, it is more difficult to compare these studies.

The amount of lead that leached into water or aqueous body fluids (sweat, lung fluid) was generally below or just above the limit of detection, regardless of the concentration of lead in the rubber granulate [30, 39, 53]. Higher migration values were found in acidic liquids: 48-140 µg/L [51] and 2.5–260 mg/kg [30] in digestion tests.
Just as in the present research, other studies also revealed lead as being the most relevant metal in rubber granulate in terms of human health risks.

VOCs
Volatile organic compounds (VOCs) were not detected in the present study, or only in very low concentrations. Benzene and ethylbenzene were not detected in any samples, while toluene, xylene and styrene were detected up to 0.057, 0.103 and 0.053 mg/kg. Only a few studies were found in the literature in which VOCs were detected in the rubber granulate.

During air measurements on a synthetic turf pitch with SBR granulate infill in Arnhem, 'Hulpverlening Gelderland Midden' (2006) did not detect any benzene, toluene, ethylbenzene, xylenes or naphthalene (or in other words BTEXN) [55]. The INTRON study found VOC levels in the rubber granulate on the pitch which were comparable to those in the present research. However, the levels of toluene, xylene and styrene were higher in production samples (up to 0.15, 1.9 and 0.47 mg/kg respectively) [53]. The highest levels of benzene, toluene and xylene were found in an Italian study: 0.64 µg/kg, 0.45 mg/kg and 0.98 mg/kg [39].

In addition to measurements in the rubber granulate, other studies also examined concentrations of VOCs in air above the pitches. These generally offered no cause for concern, although studies in sports halls did advise proper ventilation [28, 38-43, 45, 56, 57].

Phthalates
Only a few previous studies were found which had also determined the levels of phthalates in rubber granulate. A number of Norwegian studies found concentrations which are comparable to the results of our analyses [28, 31, 52]. The Danish EPA found relatively high concentrations of phthalates and relatively significant leaching, with a much higher level of diisobutyl phthalate in particular than the levels found in the current research (up to 175 mg/kg). Nevertheless, this Danish study concluded that the safety margin was large enough and that there is no risk [49].

10.10 Discussion and conclusion

The results of the sampling study show that the rubber granulate on all tested pitches is within the concentration limits set for mixtures. Although they are not directly applicable to rubber granulate, several other regulatory limit values were exceeded, in particular the limit values under REACH for levels of eight PAHs in consumer products and toys. These eight PAHs are each allowed to be present in a consumer product up to a maximum of 1 mg/kg, or up to a maximum of 0.5 mg/kg in the case of toys. The maximum pitch levels for five of the eight PAHs are 2.2 to 7.75x higher than the concentration limit of 1 mg/kg (P90 1.2-4.2x), and 4.4 to 15.5x higher than the concentration limit of 0.5 mg/kg (P90 2.4-8.4x).

Exceeding these limit values does not automatically mean that the PAHs in rubber granulate pose an additional cancer risk above the negligible or maximum permissible risk level. For that to be the case, a sufficient amount of the PAHs would need to be released from the rubber granulate; exposure is only possible if the PAHs are released. A risk assessment based on leaching/migration/evaporation data is therefore the most relevant approach. This shows that the additional cancer risk for the PAHs in rubber granulate is around the negligible risk level of $1x10^{-6}$ ($0.8-1.2x10^{-6}$ for an outfield player and $2.2-3.0x10^{-6}$ for a goalkeeper).

This risk assessment includes a number of uncertainties. One of the uncertainties is the use of the derived BMDL10 values based on a study with coal tar to assess the risk of PAH mixtures in rubber. This is inherently inaccurate due to the difference in content and perhaps potency between the tested coal tar mixture and the PAH mixture present in rubber granulate. It is not clear what the exact effect of this difference is and whether it results in an underestimation or overestimation of the risk. Another uncertainty is associated with the fact that the limited data set on migration levels has been extrapolated to all pitch samples. However, within the limited number of samples, there appears to be a fairly constant relationship between the total PAH concentration in the rubber granulate and the migration into both sweat and gastric juice/intestinal juice, so the uncertainty introduced by the small data set may well be minor.

There is also uncertainty associated with the use of sweat migration data. PAHs are lipophilic compounds, so migration in a more lipophilic medium than aqueous artificial sweat will be higher. So, whereas migration into sweat appears to offer the best representation of PAH exposure in relation to the sweat-covered skin of an athlete, it will be less accurate for non-sweaty skin which contains natural skin oil and sebum and is therefore greasy (and may well be covered with skin care products that may have lipophilic characteristics, such as body lotion or sun cream). It is not easy to determine the extent to which more PAHs migrate from rubber granulate into a lipophilic migration medium than into sweat, because no studies have been performed in which PAH migration from rubber granulate into both sweat and a lipophilic medium have been tested under the same conditions.

Recently, however, the migration of PAHs from a piece of rubber into sweat (in 24 hours) was compared with the migration to 20% ethanol (also hydrophilic in nature), and with the migration of PAHs to, and their permeation through, the skin (in an in vitro and ex vivo model). The migration into sweat was considered to underestimate permeation into skin by one to two orders of magnitude [58]. However, other studies using a potent adsorbent with a large specific surface area as a model for skin revealed that PAHs from rubber granulate do not migrate to the medium within a single day [59]. As a result, these data cannot be used to make a quantitative estimate of the migration to a lipophilic medium. Moreover, migration and skin absorption are very slow processes in relation to the relatively short contact time with rubber granulate when playing sports. In addition, the skin surface area that is in direct contact with the rubber grains is minimal and thus limits absorption. All in all, the expectation is that dermal absorption will make a limited contribution to total absorption, even if migration is higher. Assuming that migration into a lipophilic medium is 10x higher than into sweat, this would result in additional cancer risks which are comparable to the previously calculated additional cancer risks: $1.3\text{-}1.7 \times 10^{-6}$ (outfield player) and $3.1\text{-}4.2 \times 10^{-6}$ (goalkeeper) (see Table VIII.2 and Figure II in Annex VIII).

A complicating factor when using an animal study to calculate cancer risks for young children is that a standard carcinogenicity study only exposes the laboratory animals to the substance starting from the age of around 6-8 weeks. This corresponds approximately to the period of adolescence in the case of humans. The consequence is that such a study does not provide any information about exposure in the preceding period. In the US, EPA and OEHHA apply an 'age-dependent adjustment factor' (ADAF) to calculate the cancer risk when using linear extrapolation based on a standard animal study [60, 61]. The value of the ADAF should preferably be determined based on substance-specific information; otherwise it is, by default, 10 for the 0 to 2 years old group and 3 for the 2 to 16 years old group. The default ADAF for people aged 16 and up is 1 [60, 61].
The Netherlands and Europe do not currently offer guidance or guidelines (based on any regulatory framework) on how to deal with the issue of 'early-life exposure' in the risk assessment of carcinogenic substances based on an animal study. For that reason, it was decided that this report would use the standard linear extrapolation method to assess the risks of PAHs in rubber granulate – i.e. without an additional factor to account for any intraspecies differences as a consequence of 'early-life exposure' (in accordance with standard practice). When using

the linear extrapolation method, it is generally assumed that applying the high-to-low dosage factor results in an assessment which is sufficiently conservative to cover intraspecies differences as well. From a scientific perspective, some doubts have been expressed on this assumption. For example, the high-to-low dosage factor is argued to only correct for a 10% risk in animals to e.g. a 0.0001% risk in animals. Recommendations have therefore been made to apply the interspecies and intraspecies factors to carcinogenic substances by default, similarly to the risk assessment of non-carcinogenic substances, in addition to the high-to-low dosage factor [62]. As is the case for non-carcinogenic substances, the default intraspecies factor of 10 should in that case be sufficient to cover also any differences in sensitivity as a consequence of 'early-life exposure'.
The application of an extra factor for age-dependent differences in sensitivity (for example a factor of 3, as proposed by EPA [61] and used by Ginsberg and Toal (2010) in their risk assessment of PAHs in rubber crumb infill on artificial turf fields in Connecticut [44]) would lead to calculated risks which are higher than those currently calculated, though the additional cancer risk for exposure to the PAHs in rubber granulate would still be below the maximum permissible risk.

In addition to the above-mentioned uncertainty, which would result in a higher additional cancer risk, there are other factors or uncertainties which could have an opposite effect. For example, the linear extrapolation of a 10% risk to a low percentage risk in animals is indeed conservative, as shown by (probabilistic) modelling. When probabilistically addressing the uncertainties in the toxicological data in the risk calculation, the confidence interval around the additional cancer risk reveals that the cancer risk calculated with the linear method is a worst-case scenario and corresponds to the upper boundary of the confidence interval. The cancer risk at the lower boundary of the confidence interval is one order of magnitude lower [63].

There is also uncertainty in the assumptions made regarding the input parameters in the exposure scenarios. This applies not only for the PAHs but for all substances. Reliable data for these parameters are not available. It may be that the EPA research into exposure characteristics will generate interesting and relevant data in the near future [8]. The present research is based on an extreme worst-case scenario, given the assumption that a single person all his/her life will play every training session and every match on synthetic turf with rubber granulate, which, on top of all that, releases the highest levels of PAHs. Moreover, this release is based on the 'total amount released'. This is very much a worst-case scenario, given that the PAHs may still be bound to suspended matter or lipids, which could reduce absorption through the intestinal wall. Last but not least, this research assumes that the person in question will ingest 0.2 g of rubber grains during each and every training session/match throughout their entire football career, which is another worst-case scenario.

Taking into account all the uncertainties related to the indicative risk assessment, it is not expected that the additional cancer risks for PAHs in rubber granulate will be higher than what has currently been estimated (around the negligible risk of one in a million). Nevertheless, rubber granulate is only one of the many sources of exposure to PAHs. Others include, for example, exhaust fumes, tyre particulates, cigarette smoke, burned wood (open fire) and meat (barbecue) (see Annex VI). Compared to food as the most important source of PAHs for the general population (non-smokers), the estimated exposure via rubber granulate (23-60 ng/day versus 1200-3300 ng/day via food for PAH4, 37-98 ng/day versus 1800-4900 ng/day via food for PAH8) is, however, marginal. Exposure via food may even be significantly higher when the person eats large amounts of barbecued meat on a regular basis [64].

In a previous report on PAHs in rubber granulate, RIVM concluded in 2006 that the risk associated with oral and dermal exposure is negligible. Given that specific data on the release of PAHs from rubber granulate and on exposure to rubber granulate was not available, the dermal and oral exposure were estimated at the time using worst-case assumptions and data reported in the literature. The risk assessment from 2006 is not easy to compare with the present risk assessment due to the use of a different marker for the mixture of PAHs (BaP), a different toxicological reference value (100 µg BaP/kg bw/d), and different exposure scenarios. For oral exposure, an ingestion of 100 mg rubber granulate/day was assumed, as an average oral ingestion for children via hand-mouth contact while playing. Based on a concentration of 3 mg/kg BaP in rubber granulate, and based on the assumption that 10% of this entered the body, the internal exposure was estimated as being 0.5 ng/kg bw/d for a person weighing 60 kg. For dermal exposure, the assumptions were an exposed skin surface area of 200 cm^2, 1 hour skin contact/day, and a skin migration of 0.001 ng/cm^2 (based on Danish research on migration of BaP from car tyres). The internal exposure via the dermal route was estimated as being 1-2 ng/kg bw/d. A comparison with the toxicological reference value resulted in additional cancer risks of 1 in a million in the case of dermal exposure and 0.5 in a million in the case of oral exposure [4].

In addition to the PAHs, rubber granulate also contains other substances of high concern. Of these, the phthalates, several metals (cadmium, cobalt and lead), 2-MBT and BPA were prioritised for the current risk assessment. The phthalates and 2-MBT, as well as cadmium and cobalt, appear not to be any cause for concern, even in worst-case conditions. Even the combined toxicity due to simultaneous exposure to several phthalates or several benzothiazoles does not appear to be any cause for concern. Given the low toxicological reference value for lead, any exposure easily becomes too high. Even the background exposure via food exceeds the reference value. Compared to food, however, the contribution by rubber granulate appears to be fairly limited, certainly in terms of the year average exposure.

The RCRs calculated for BPA in worst-case conditions are not as extremely low as for e.g. the phthalates or 2-MBT. Nevertheless, there does not appear to be cause for concern for the various scenarios (including the 7-year-old goalkeeper scenario with the highest RCR) as regards rubber granulate as source of exposure. The RCRs have now been calculated based on content, but it is unlikely that 100% of the BPA present in rubber granulate will migrate to sweat. The true RCRs will therefore, in all likelihood, be lower. So, even if the toxicological reference value for BPA should be adjusted downwards (see footnote under Table 2), there will most probably still be no cause for concern. This is relevant in relation to BPA because rubber granulate is not the only source; there are various other sources of BPA which contribute to exposure and potential health risks.

Nitrosamines were not included in the headspace analysis. In previous research carried out by RIVM, no nitrosamines were detected in air samples taken from above a variety of synthetic turf pitches. At the time, the release of nitrosamines from different types of rubber granulate was also investigated under laboratory conditions by means of headspace analysis (heating to 70°C) and by means of chemical extraction. In both sets of conditions, no measurable amounts of nitrosamines were released. Migration tests with saliva simulant revealed that, in a number of samples, a very limited amount of nitrosamines could be released [6].

Substances of high concern other than those referred to above were not considered immediate priorities due to the low levels found in the rubber granulate samples. For that reason, they are not expected to offer cause for concern, given the conclusions reached in the indicative risk assessment of the prioritised substances. However, it should be noted that the focus in the present research was on substances which have CMR 1A/1B characteristics (and therefore fall under the definition of substance of very high concern, SVHC). Other characteristics, such as for example (respiratory) sensitising characteristics, were therefore not included.

The concerns expressed following the Zembla TV programme relate primarily to the carcinogenic characteristics of some substances in rubber granulate and, in particular, to a possible link with leukaemia and lymphoma. Benzene is a substance associated with those types of cancer. However, benzene was not detected in any of the rubber granulate samples. IARC also suspects 2-MBT of causing this type of cancer, among other types. However, the indicative risk assessment for 2-MBT showed that the exposure to this non-genotoxic carcinogen is so low that no risk can be expected. For the time being, therefore, it is primarily the PAHs in rubber granulate which may potentially lead to an increased cancer risk. However, a clear link has not been established between the PAHs and leukaemia and lymphoma [65, 66].

Conclusion
The sampling study of the Dutch pitches show that the rubber granulate on all tested pitches is within the concentration limits set for mixtures. Although they are not directly applicable to rubber granulate, several other regulatory limit values were exceeded. However, the indicative risk assessment suggests that these concentrations of phthalates, benzothiazoles, BPA and the metals cadmium and cobalt in the rubber granulate do not result in a health risk.
Given the low toxicological reference value for lead, the exposure to lead should be very low. Compared to lead ingested via food, the exposure to lead via rubber granulate is fairly limited. Based on the indicative risk assessment, PAHs appear to be the substances of the highest concern. For this group of substances, the estimated additional cancer risk is

around the negligible risk level of one in a million. Taking into account all the uncertainties relating to this risk assessment, it is not expected that the cancer risks will be higher than current estimates.
Several carcinogenic substances are specifically associated with the two types of cancer about which concern was expressed after the Zembla TV programme: leukaemia and lymphoma. These carcinogens – benzene, styrene and 1,3-butadiene – were not detected in the rubber granulate samples. Although 2-mercaptobenzothiazole was detected, the levels were so low that no risk can be expected.
The present research examined the health risks for people playing sports from exposure to substances in rubber granulate on synthetic turf pitches. Based on the findings, it can be concluded that the health risks are virtually negligible. Our findings and conclusion are in line with previous national and international research into the health risks of rubber granulate.

10.11 List of abbreviations

ADI	Acceptable Daily Intake
BaP	Benzo[a]pyrene
$BMDL_{10}$	95 percent lower confidence level of the dosage resulting in a 10% additional cancer risk in laboratory animals upon lifelong exposure
CLP	Classification, Labelling and Packaging
CMR	carcinogenic, mutagenic, reprotoxic
DNEL	derived no-effect level
GM	geometric mean
GSD	geometric standard deviation
LOD	limit of detection
MOE	Margin of Exposure
LOAEL	Lowest Observed Adverse Effect Level
NOAEL	No Observed Adverse Effect Level
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorobiphenyl
PM10	particulate matter in which the particles are smaller than 10 µm in diameter
RCR	Risk Characterisation Ratio
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SBR	styrene-butadiene-rubber
TCA	Tolerable Concentration in Air
TDI	Tolerable Daily Intake
(s)VOC	(semi-)Volatile Organic Compounds
SVHC	Substance of Very High Concern

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10.13 Annex I - Overview of regulatory limit values with possible relevance for substances found in rubber granulate

Table I shows the regulatory limit values which are applicable to, or could be relevant for, rubber granulate and its constituent substances. The substances are subdivided into substances for routine analysis and additional substances requiring separate, more time-consuming analysis.

Table I Overview of regulatory limit values with possible relevance for substances found in rubber granulate

Substances [a]	**CLP Annex VI** [b]	**REACH Annex XVII**		**Toy Safety Directive** [e f]	**Soil Quality Decree**	
		entry 28-30 [c]	**other entries**		**building materials** [g]	**soil** [h]
		[mg/kg]	**[mg/kg]** [d]	**[mg/kg]**	**[mg/kg]**	**[mg/kg]**
SUBSTANCES FOR ROUTINE ANALYSIS						
METALS						
Antimony	-	-	-	45	0.32	*15*
Arsenic	-	-	-	3.8	0.9	*14*
Barium	-	-	-	1500	22	-
Cadmium	Carc. 1B	1000	100 [i] 100 or 1000 [j]	1.3	0.04	*0.4*
Chromium	[Carc. 1B] [k]	[1000] [l]	[2-3] [m]	Cr-3: 37.5 Cr-6: 0.02	0.63	*115*
Cobalt	-	-	-	10.5	0.54	*123*
Copper	-	-	-	622.5	0.9	*26*
Mercury	Repr. 1B	3000	-	7.5	0.02	*0.7*
Lead	Repr. 1A	300 (Dev) 3000 (Fert)	500 [n o]	13.5	2.3	*119*
Molybdenum	-	-	-	-	1	*88*
Nickel	-	-	0.2 [p] 0.5 [q]	75	0.44	*114*
Selenium	-	-	-	37.5	0.15	-
Tin	-	-	-	15000 [r]	0.4	*658*
Titanium	-	-	-	-	-	-
Vanadium	-	-	-		1.8	*283*
Zinc	-	-	-	3750	4.5	*138*

Substances [a]	CLP Annex VI [b]	REACH Annex XVII		Toy Safety Directive [e f]	Soil Quality Decree	
		entry 28-30 [c]	other entries		building materials [g]	soil [h]
		[mg/kg]	[mg/kg] [d]	[mg/kg]	[mg/kg]	[mg/kg]
PAHs						
Benzo[a]pyrene (BaP)	Carc. 1B Muta. 1B Repr. 1B	100 1000 3000	1 [s t] 0.5 [u]	-	10	-
Benzo[a]anthracene (BaA)	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	40	-
Chrysene (CHR)	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	10	-
Benzo[b]fluoranthene (BbFA)	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	-	-
Benzo[k]fluoranthene (BkFA)	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	40	-
Dibenz[a,h]antracene (DBahA)	Carc. 1B	100	1 [s t] 0.5 [u]	-	-	-
Benzo[ghi]perylene	-	-	-	-	40	-
Indeno[1,2,3-cd]pyrene	-	-	-	-	40	-
Acenaphthene	-	-	-	-	-	-
Acenaphthylene	-	-	-	-	-	-
Anthracene	-	-	-	-	10	-
Fluoranthene	-	-	-	-	35	-
Fluorene	-	-	-	-	-	-
Naphthalene	-	-	-	-	5	-
Phenanthrene	-	-	-	-	20	-
Pyrene	-	-	-	-	-	-
Sum PAH	-	-			50 [v]	6.8 [v]
Volatile compounds						

Substances [a]	CLP Annex VI [b]	REACH Annex XVII		Toy Safety Directive [e f]	Soil Quality Decree	
		entry 28-30 [c]	other entries		building materials [g]	soil [h]
		[mg/kg]	[mg/kg] [d]	[mg/kg]	[mg/kg]	[mg/kg]
Benzene	Carc. 1A Muta. 1B	1000 1000	5 [w]	-	1	0.2
Toluene	-	-	1000 [x]	-	1.25	0.2
Ethylbenzene	-	-	-	-	1.25	0.2
Xylenes	-	-	-	-	1.25 (sum) [y]	0. 45 (sum) [y]
o-xylene	-	-	-	-	-	see xylenes
m- and p-xylene	-	-	-	-	-	see xylenes
Styrene	-	-	-	-	-	0.25
<u>PHTHALATES</u>						
Dimethyl phthalate	-	-	-	-	-	9.2
Diethyl phthalate	-	-	-	-	-	5.3
Di-n-butylphthalate	Repr. 1B	3000	1000 [z]	-	-	5.0
Benzyl butyl phthalate	Repr. 1B	3000	1000 [z]	-	-	2.6
Bis(2-ethylhexyl) phthalate	Repr. 1B	3000	1000 [z]	-	-	8.3
Diisobutyl phthalate	Repr. 1B	250000	-	-	-	1.3
Dihexyl phthalate	Repr. 1B	3000	-	-	-	18
ADDITIONAL SUBSTANCES REQUIRING SEPARATE, MORE TIME-CONSUMING ANALYSIS						
<u>PAHs</u>						
Benzo[j]fluoranthene (BjFA)	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	-	-
Benzo[e]pyrene BeP	Carc. 1B	1000 *	1 [s t] 0.5 [u]	-	-	-
Cyclopenta[cd]pyrene	-	-	-	-	-	-

Substances [a]	CLP Annex VI [b]	REACH Annex XVII		Toy Safety Directive [e f]	Soil Quality Decree	
		entry 28-30 [c]	other entries		building materials [g]	soil [h]
		[mg/kg]	[mg/kg] [d]	[mg/kg]	[mg/kg]	[mg/kg]
Dibenzo[a,e]pyrene	-	-	-	-	-	-
Dibenzo[a,h]pyrene	-	-	-	-	-	-
Dibenzo[a,i]pyrene	-	-	-	-	-	-
Dibenzo[a,l]pyrene	-	-	-	-	-	-
5-Methylchrysene	-	-	-	-	-	-
Benzo[*c*]fluorene	-	-	-	-	-	-
PHTHALATES						
Di-n-octylphthalate	-	-	1000 [z]	-	-	-
Di-isononylphthalate	-	-	1000 [z]	-	-	-
(semi)Volatile compounds/OTHER						
4-t-Octylphenol	-	-	-	-	-	-
4-n-Nonylphenol	-	-	-	-	-	-
Iso-nonylphenol	-	-	-	-	-	-
2-Mercaptobenzothiazole (MBT)	-	-	-	-	-	-
2-4(-Morpholinothio)-benzothiazole	-	-	-	-	-	-
N-cyclohexyl-2-benzothiazole sulphenamide (CBS)	-	-	-	-	-	-
2.2'–Dithiobisbenzothiazole (MBTS)	-	-	-	-	-	-
2-Methylthiobenzothiazole (MTBT)	-	-	-	-	-	-

Substances [a]	CLP Annex VI [b]	REACH Annex XVII		Toy Safety Directive [e f]	Soil Quality Decree	
		entry 28-30 [c]	other entries		building materials [g]	soil [h]
		[mg/kg]	[mg/kg] [d]	[mg/kg]	[mg/kg]	[mg/kg]
Benzothiazole (BT)	-	-	-	-	-	-
o-Toluidine	Carc. 1B	1000	-	-	-	-
Aniline	-	-	-	-	-	-
Cyclohexylamine	-	-	-	-	-	-
1,3-Butadiene	Carc. 1A Muta. 1B	1000 1000	-	-	-	-
Vinyl chloride	Carc. 1A	1000	-	-	-	0.1
Ethylene oxide	Carc. 1B Muta. 1B	1000 1000	-	-	-	-
PCBs		-	-	-	0.5 (sum) #	0.04 (sum) #
Volatile mineral oils				-	-	190
Nitrosamines				0.05 @		

[a] The limit values presented here for the metals refer to the element, unless indicated otherwise
[b] The harmonised classification reported in this column is limited to categories 1A and 1B of the CMR endpoints
[c] The concentration limit presented in this column is linked to the classification for Carc. 1A/B (entry 28), Muta. 1A/B (entry 29) and Repr. 1A/B (entry 30)
[d] The unit for these entries is mg/kg unless indicated otherwise
[e] Toy limit values for dry, brittle, powder-like or pliable toy material
[f] The toy limit values as recorded in 2009/48/EC represent migration limits
[g] For metals, this is the maximum emissions value for granular building materials. For other substances, this is the maximum content value.
[h] The maximum content value for residential quality, which is based on a standard soil (25% lutite, 10% organic compounds). For the metals, these limit values have been adjusted for soil type (in accordance with Annex G of the Soil Quality Regulation), based on 2% lutite and 98% organic compounds. The adjusted limit values are shown in italics.
[i] For mixtures and articles made from specific plastic material, or brazing fillers (entry 23)
[j] Specific cadmium-containing paints (excluding paints with a zinc content >10%, which are subject to a limit value of 1000 mg/kg; or for painted articles which also have a limit value of 1000 mg/kg) (entry 23)
[k] Cr-6 compounds have a harmonised classification as Carc. 1B H350i
[l] Mixtures which contain Cr-6 compounds are subject to a concentration limit of 1000 mg/kg (entry 28)

[m] REACH Annex XVII entry 47 applies specifically to Cr-6: 2 mg/kg (0,0002%) for cement and cement-containing mixtures (hydrated); 3 mg/kg for leather products or articles which contain leather and come into contact with the skin
[n] Jewellery (entry 63)
[o] All or parts of articles which children can put into their mouths, unless migration is lower than 0.05 µg/cm² per hour (equivalent to 0.05 µg/g/hour) (entry 63)
[p] Migration limit in µg/cm^2/week for piercings (entry 27)
[q] Migration limit in µg/cm^2/week for jewellery (entry 27)
[r] Migration limit for organic tin: 0.9 mg/kg
[s] Article (consumer product) (entry 50)
[t] Extender oils for rubber processing in tyre production (entry 50); also subject to a limit value of 10 mg/kg for the sum of the 8 PAHs in REACH Annex XVII entry 50
[u] Toys (entry 50)
[v] Sum total of naphthalene, phenanthrene, anthracene, fluoranthene, chrysene, benzo(a)anthracene, benzo(a)pyrene, benzo(k)fluoranthene, indeno(1,2,3,cd)pyrene, benzo(ghi)perylene
[w] (Parts) of toys (entry 5)
[x] Adhesives and spray paint (entry 48)
[y] Sum total of o-xylene, p-xylene and m-xylene
[z] Toys and childcare products (entry 51/52)
*This concentration limit for mixtures applies for the sum of the PAHs with a Carc. 1A/B harmonised classification (with the exception of benzo[a]pyrene and dibenzo[a,h]anthracene)
[#] Sum total of PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180
[@] Sum total of the nitrosamines, but without specifying which nitrosamines

10.14 Annex II – Prioritisation of substances based on exceeded limit value(s) and SVHC status – LITERATURE DATA

The substances for routine analysis and the additional substances requiring separate, more-time consuming analysis were reviewed and prioritised. The aim was to determine whether the maximum concentrations as reported in literature for the substance in question exceed one or more regulatory limit values imposed by legislative frameworks that may be relevant in this context. For those substances for which that was the case, **the exceeded limit value** is indicated in blue. After that, the substances that exceeded one or more limit values were reviewed to determine whether the substance is considered an SVHC, i.e. whether it has properties that could pose a risk to human health. The assessment criterion was whether the substance has a harmonised classification or self-classification as CMR category 1A/1B. Those substances are shaded in grey and received top priority, unless the following step (see Annex III) showed that these substances were not found in the Dutch pitch samples, or were only found in negligible amounts. SVHC status is also used as the initial prioritisation criterion for the substances for which no limit values have been provided in the legislative frameworks.

Table II Prioritisation of substances based on exceeded limit value(s) (one or more) and SVHC status [prioritised substances are shaded grey]

Substances	Content data literature [a]	REACH Annex XVII		Toy Safety Directive [b]	Soil Quality Decree		Ref.:
		entry 28-30	other entries		building materials [c]	soil [d]	
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	
SUBSTANCES FOR ROUTINE ANALYSIS							
METALS [e]							
Antimony	7.7	-	-	45		*15*	[35, 67]
Arsenic	3.55	-	-	3.8		*14*	[35, 39, 52-54, 67]
Barium	4778	-	-	**1500**		-	[35, 39, 67]
Cadmium	2.68	1000	100 100 or 1000	**1.3**		***0.4***	[35, 37, 39, 52-54, 67]
Chromium	56 [f]	-	-	Cr-3: 37.5 [g] Cr-6: 0.02 [g]		*115*	[35, 37, 39, 41, 52-54, 67]
Cobalt	234	-	-	**10.5**		***123***	[35, 39, 67]
Copper	260	-	-	622.5		***26***	[35, 37, 39,

Substances	**Content data literature [a]**	**REACH Annex XVII**		**Toy Safety Directive [b]**	**Soil Quality Decree**		**Ref.:**
		entry 28-30	**other entries**		**building materials [c]**	**soil [d]**	
	[mg/kg]	**[mg/kg]**	**[mg/kg]**	**[mg/kg]**	**[mg/kg]**	**[mg/kg]**	
							52, 53, 67]
Mercury	0.16	3000	-	7.5		*0.7*	[35, 52, 53, 67]
Lead	308	**300** [h]	500	**13.5**		***119***	[35, 37, 39, 41, 52-54, 67, 68]
Molybdenum	6.6	-	-	-		*88*	[35, 67]
Nickel	26.12	-	[i]	75		*114*	[35, 37, 39, 52, 53, 67]
Selenium	< LOD	-	-	37.5		-	[35, 67]
Tin	390	-	-	15000		*658*	[35, 39, 67]
Titanium	48.5	-	-	-	-	-	[35, 39, 67]
Vanadium	22	-	-			*283*	[35, 67]
Zinc	21000	-	-	**3750**		***138***	[35, 37, 39, 41, 49, 52-54, 67]
<u>PAHs</u>							
Benzo[a]pyrene (BaP)	10.7	100 [j]	**1** **0.5**	-	**10**	-	[35, 37, 39, 52-54, 59, 69, 70]
Benzo[a]anthracene (BaA)	15.3	1000	**1** **0.5**	-	40	-	[35, 37, 39, 52-54, 59, 69, 70]
Chrysene (CHR)	7.55	1000	**1** **0.5**	-	10	-	[35, 37, 39, 52-54, 59, 69, 70]
Benzo[b]fluoranthene (BbFA)	15.7	1000	**1** **0.5**	-	-	-	[35, 37, 39, 52-54, 59, 69, 70]

Substances	Content data literature [a]	REACH Annex XVII		Toy Safety Directive [b]	Soil Quality Decree		Ref.:
		entry 28-30	other entries		building materials [c]	soil [d]	
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	
Benzo[k]fluoranthene (BkFA)	7.29	1000	**1** **0.5**	-	40	-	[37, 39, 52-54, 59, 69]
Dibenz[a,h]antracene (DBahA)	8.13	100	**1** **0.5**	-	-	-	[35, 37, 39, 52-54, 59, 69, 70]
Benzo[ghi]perylene	29.2	-	-	-	40	-	[35, 37, 39, 52-54, 70]
Indeno[1,2,3-cd]pyrene	3.73	-	-	-	40	-	[35, 52-54, 69, 70]
Acenaphthene	10.15	-	-	-	-	-	[37, 52, 53, 69, 70]
Acenaphthylene	1	-	-	-	-	-	[52-54, 69, 70]
Anthracene	11.9	-	-	-	**10**	-	[37, 52-54, 69, 70]
Fluoranthene	11.3	-	-	-	35	-	[37, 52-54, 69, 70]
Fluorene	11.03	-	-	-	-	-	[37, 52-54, 69, 70]
Naphthalene	2.4	-	-	-	5	-	[37, 52-54, 69, 70]
Phenanthrene	12.3	-	-	-	20	-	[37, 52-54, 69, 70]
Pyrene	37	-	-	-	-	-	[35, 37, 39, 52-54, 69, 70]
<u>Volatile compounds</u>							
Benzene	0.064	1000 1000	5	-	1	0.2	[39, 53]

Substances	Content data literature [a]	REACH Annex XVII		Toy Safety Directive [b]	Soil Quality Decree		Ref.:
		entry 28-30	other entries		building materials [c]	soil [d]	
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	
Toluene	0.45	-	1000	-	1.25	**0.2**	[39, 53]
Ethylbenzene	no data	-	-	-	1.25	0.2	
Xylenes	1.9 [k]	-	-	-	**1.25** [k]	**0.45** [k]	[39, 53]
o-xylene	1.0	-	-	-	-	see xylenes	
m- and p-xylene	0.94	-	-	-	-	see xylenes	
Styrene	0.47	-	-	-	-	**0.25**	[53]
PHTHALATES							
Dimethyl phthalate	3.4	-	-	-	-	9.2	[31, 52]
Diethyl phthalate	1.5	-	-	-	-	5.3	[31, 52]
Di-n-butylphthalate	50	3000	1000	-	-	**5.0**	[31, 49, 52]
Benzyl butyl phthalate	2.8	3000	1000	-	-	**2.6**	[31, 52]
Bis(2-ethylhexyl) phthalate	62	3000	1000	-	-	**8.3**	[31, 49, 52]
Diisobutyl phthalate	175	250000	-	-	-	**1.3**	[49]
Dihexyl phthalate	no data	3000	-	-	-	18	
ADDITIONAL SUBSTANCES REQUIRING SEPARATE, MORE TIME-CONSUMING ANALYSIS							
PAHs							
Benzo[j]fluoranthene (BjFA)	0.08	1000	1 0.5	-	-	-	[59, 70]
Benzo[e]pyrene BeP	1.61	1000	**1** **0.5**	-	-	-	[59, 69]
Cyclopenta[cd]pyrene	no data	-	-	-	-	-	
Dibenzo[a,e]pyrene	no data	-	-	-	-	-	
Dibenzo[a,h]pyrene	no data	-	-	-	-	-	
Dibenzo[a,i]pyrene	no data	-	-	-	-	-	
Dibenzo[a,l]pyrene	no data	-	-	-	-	-	

Substances	Content data literature [a]	REACH Annex XVII		Toy Safety Directive [b]	Soil Quality Decree		Ref.:
		entry 28-30	other entries		building materials [c]	soil [d]	
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	
5-Methylchrysene	no data	-	-	-	-	-	
Benzo[*c*]fluorene	no data	-	-	-	-	-	
<u>PHTHALATES</u>							
Di-n-octylphthalate	< LOD	-	1000	-	-	-	[31]
Di-isononylphthalate	78	-	1000	-	-	-	[31]
<u>(semi)Volatile compounds/OTHER</u>							
4-t-Octylphenol	33.7	-	-	-	-	-	[31, 52]
4-n-Nonylphenol	< LOD	-	-	-	-	-	[31, 52]
Iso-nonylphenol	21.6	-	-	-	-	-	[31, 52]
2-Mercaptobenzothiazole (MBT)	no data	-	-	-	-	-	
2-4(-Morpholinothio)-benzothiazole	3.76	-	-	-	-	-	[71]
N-cyclohexyl-2-benzothiazole sulphenamide (CBS)	no data	-	-	-	-	-	
2.2’–Dithiobisbenzothiazole (MBTS)	no data	-	-	-	-	-	
2-Methylthiobenzothiazole (MTBT)	no data	-	-	-	-	-	
Benzothiazole (BT)	171	-	-	-	-	-	[49, 71]
o-Toluidine	no data	1000	-	-	-	-	
Aniline	249	-	-	-	-	-	[49]
Cyclohexylamine	no data	-	-	-	-	-	

Substances	Content data literature [a]	REACH Annex XVII		Toy Safety Directive [b]	Soil Quality Decree		Ref.:
		entry 28-30	other entries		building materials [c]	soil [d]	
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	
1,3-Butadiene	no data	1000	-	-	-	-	
Vinyl chloride	no data	1000	-	-	-	0.1	
Ethylene oxide	no data	1000	-	-	-	-	
PCBs	0.202 [l]	-	-	-	0.5 [l]	**0.04** [l]	[31, 35, 52]
Volatile mineral oils	no data			-	500	190	
Nitrosamines	< LOD			0.05 [m]			[6]

[a] The maximum value as found in the literature

[b] This toy limit value is a migration limit. The comparison with the maximum content value reported in the literature is therefore a worst case.

[c] The limit value stated for the metals is not a content value but an emission value (based on leaching). Given that this is difficult to compare with the maximum content value reported in the literature, this limit value for the metals is not included in the table.

[d] The maximum content value for residential quality, which is based on a standard soil (25% lutite, 10% organic compounds). For the metals, these limit values have been adjusted for soil type (in accordance with Annex G of the Soil Quality Regulation), based on 2% lutite and 98% organic compounds. The adjusted limit values are shown in italics.

[e] The content values and limit values presented here for the metals refer to the element, unless indicated otherwise.

[f] Total chromium (i.e. not Cr-6)

[g] The toy limit value for chromium is specified for Cr-3 and Cr-6, meaning that the comparison with the maximum content value (for total chromium) reported in the literature does not apply. Given that the Dutch pitch samples were not analysed for the presence of Cr-6 and the assumption that the measured total chromium is entirely Cr-6 is too extreme, chromium has not been prioritised.

[h] The lowest of the two concentration limit values applicable for lead

[i] This limit value for nickel concerns a migration limit in $\mu g/cm^2$/week, which cannot be compared with the maximum content value in mg/kg reported in the literature. As a result, this limit value is not presented in the table above.

[j] The lowest of the three concentration limit values applicable for BaP

[k] Sum total of o-xylene, p-xylene and m-xylene

[l] Sum total of PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180

[m] Sum total of the nitrosamines, but without specifying which nitrosamines

10.15 Annex III – Further prioritisation of substances based on analysis data from Dutch pitch samples and on SVHC status

For the purpose of further prioritisation, the results of the analyses of the Dutch pitch samples were examined. This was done first to see how the rubber granulate on the Dutch pitches relates to the regulatory limit values, and secondly to see whether the list of prioritised substances in Annex II requires any adjustment: do any substances need to be added, for example from the general unknown screening (as performed on 10 mixed samples) or counterchecks (as performed on PAHs and phthalates for one-tenth of the 600 samples), or are the levels of the previously prioritised substances so low (around or below the limit of detection) that they are no longer an immediate priority for the indicative risk assessment? As in Table II in Annex II, each **exceeded limit value** is indicated in blue, while SVHCs among the substances with one or more exceeded limit values, and among the substances without a defined limit value, are shaded grey.

Looking at the **metals**, it is important to note that the analysis of the pitch samples does not represent the content; instead, this value represents leaching (into water). This data cannot, therefore, be compared with the limit values based on content, but it can be compared with the emission limits for granular building materials from the Soil Quality Decree (see Table IV in Annex IV). Data from 'Milieukeur', the Dutch environmental quality label for sustainable products and services, was used to arrive at a comparison for metals based on content. The 'Milieukeur' data consists of content data from batches of rubber granulate which were submitted for certification in 2010-2016 [26]. In all likelihood, this content data is more representative of the rubber granulate on the Dutch pitches than the content data from the literature.

Table III Prioritisation of substances based on analysis data from Dutch pitch samples and SVHC status [prioritised substances are shaded grey]

Substances	Content data from Dutch pitch samples[a]	Milieukeur content data on metals[b]	REACH Annex XVII		Toy Safety Directive [c]	Soil Quality Decree	
			entry 28-30	other entries		Building materials [d]	soil [e]
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
SUBSTANCES FOR ROUTINE ANALYSIS							
METALS [f]							
Antimony		< LOD	-	-	45		*15*
Arsenic		< LOD	-	-	3.8		*14*
Barium		5.7	-	-	1500		-
Cadmium		2.1	1000	100 100 or 1000	**1.3**		***0.4***
Chromium		2.6 [g]	-	-	Cr-3: 37.5 [h] Cr-6: 0.02 [h]		*115*
Cobalt *		no data	-	-	10.5		*123*
Copper		no data	-	-	622.5		*26*
Mercury		< LOD	3000	-	7.5		*0.7*
Lead		35	300 [i]	500	**13.5**		*119*
Molybdenum		no data	-	-	-		*88*
Nickel		no data	-	[j]	75		*114*
Selenium		< LOD	-	-	37.5		-
Tin		no data	-	-	15000		*658*
Titanium		no data	-	-	-		-
Vanadium		no data	-	-			*283*
Zinc		17700	-	-	**3750**		***138***
PAHs [k]							
Benzo[a]pyrene (BaP)	2.21		100 [l]	**1** **0.5**	-	10	-
Benzo[a]anthracene (BaA)	2.19		1000	**1** **0.5**	-	40	-

Substances	Content data from Dutch pitch samples[a]	Milieukeur content data on metals[b]	REACH Annex XVII		Toy Safety Directive [c]	Soil Quality Decree	
			entry 28-30	other entries		Building materials [d]	soil [e]
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
Chrysene (CHR)	3.45		1000	**1** **0.5**	-	10	-
Benzo[b]fluoranthene (BbFA)	2.95		1000	**1** **0.5**	-	-	-
Benzo[k]fluoranthene (BkFA) #	0.52		1000	1 **0.5**	-	40	-
Dibenz[a,h]antracene (DBahA)	< LOD		100	1 0.5	-	-	-
Benzo[ghi]perylene	7.70		-	-	-	40	-
Indeno[1,2,3-cd]pyrene	0.54		-	-	-	40	-
Acenaphthene	1.03		-	-	-	-	-
Acenaphthylene	< LOD		-	-	-	-	-
Anthracene	1.10		-	-	-	10	-
Fluoranthene	20.3		-	-	-	35	-
Fluorene	0.95		-	-	-	-	-
Naphthalene	< LOD		-	-	-	5	-
Phenanthrene	7.08		-	-	-	20	-
Pyrene	28.7		-	-	-	-	-
Volatile compounds							
Benzene	< LOD		1000 1000	5	-	1	0.2
Toluene	0.057		-	1000	-	1.25	0.2
Ethylbenzene	< LOD		-	-	-	1.25	0.2
Xylenes	0.103 [m]		-	-	-	1.25 [m]	0.45 [m]
o-xylene	< LOD		-	-	-	-	see xylenes
m- and p-xylene	0.057		-	-	-	-	see xylenes
Styrene	0.053		-	-	-	-	0.25

Substances	Content data from Dutch pitch samples[a]	Milieukeur content data on metals[b]	REACH Annex XVII		Toy Safety Directive [c]	Soil Quality Decree	
			entry 28-30	other entries		Building materials [d]	soil [e]
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
PHTHALATES							
Dimethyl phthalate	< LOD		-	-	-	-	9.2
Diethyl phthalate	2.92		-	-	-	-	5.3
Di-n-butylphthalate	0.86		3000	1000	-	-	5.0
Benzyl butyl phthalate	0.99		3000	1000	-	-	2.6
Bis(2-ethylhexyl) phthalate	27		3000	1000	-	-	**8.3**
Diisobutyl phthalate	2.32		250000	-	-	-	**1.3**
Dihexyl phthalate	< LOD		3000	-	-	-	18
GENERAL UNKNOWN SCREENING [n] **/ COUNTERCHECK** [o]							
PAHs							
Benzo[j]fluoranthene (BjFA)	[in peak BbFA]		1000	1 0.5	-	-	-
Benzo[e]pyrene (BeP)	7.75		1000	**1** **0.5**	-	-	-
Cyclopenta[cd]pyrene	2.5		-	-	-	-	-
Dibenzo[a,e]pyrene	< LOD		-	-	-	-	-
Dibenzo[a,h]pyrene	< LOD		-	-	-	-	-
Dibenzo[a,i]pyrene	< LOD		-	-	-	-	-
Dibenzo[a,l]pyrene	< LOD		-	-	-	-	-
5-Methylchrysene	< LOD		-	-	-	-	-
Benzo[*c*]fluorene	0.7		-	-	-	-	-
PHTHALATES							
Di-n-octylphthalate	0.1		-	1000	-	-	-

Substances	Content data from Dutch pitch samples[a]	Milieukeur content data on metals[b]	REACH Annex XVII		Toy Safety Directive [c]	Soil Quality Decree	
			entry 28-30	other entries		Building materials [d]	soil [e]
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
Di-isononylphthalate	61		-	1000	-	-	-
Diisodecyl phthalate	10		-	1000 [p]	-	-	-
Di-n-nonylphthalate	0.8		-	-	-	-	-
Dicyclohexyl phthalate	0.21		3000 [q]	-	-	-	-
Diphenyl phthalate	0.11		-	-	-	-	-
Bis (2-etylhexyl)adipate	1.1		-	-	-	-	-
PHENOLS							
4-t-Octylphenol	22.4		-	-	-	-	-
4-n-Nonylphenol	< LOD		-	-	-	-	-
Triclosan	< LOD		-	-	-	-	-
Bisphenol A	2.5		3000 [r]	[s]	0.1 mg/L [t]	-	-
BENZOTHIAZOLES							
2-Mercaptobenzothiazole (2-MBT)	7.6		-	-	-	-	-
2-Methoxybenzothiazole	10.2		-	-	-	-	-
N-cyclohexyl-2-benzothiazole sulphenamide (CBS)	0.041		-	-	-	-	-
2.2'–Dithiobisbenzothiazole (MBTS)	0.3		-	-	-	-	-
2-Hydroxybenzothiazole	13.8		-	-	-	-	-
Benzothiazole (BT)	6.3		-	-	-	-	-
2-Aminobenzothiazole	0.38		-	-	-	-	-
N-cyclohexyl-1,3-	3.9		-	-	-	-	-

Substances	Content data from Dutch pitch samples[a]	Milieukeur content data on metals[b]	REACH Annex XVII		Toy Safety Directive [c]	Soil Quality Decree	
			entry 28-30	other entries		Building materials [d]	soil [e]
	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]
benzothiazole-2-amine							
1-Hydroxybenzotriazole	< LOD		-	-	-	-	-
Benzotriazole	< LOD		-	-	-	-	-
Tolyltriazole	< LOD		-	-	-	-	-
5,6-Dimethyl-1H-benzotriazole	< LOD		-	-	-	-	-
<u>OTHER</u>							
PCBs [@]	0.074 [u]		-	-	-	0.5 [u]	**0.04** [u]

[a] The maximum value found for a pitch

[b] Content data for metals in rubber granulate as submitted for eco-label certification in 2010-2016

[c] This toy limit value is a migration limit. The comparison with the maximum content value is therefore a worst case.

[d] The limit value stated for the metals is not a content value but an emission value (based on leaching). Given that this is difficult to compare with the maximum content value found for eco-label certification in 2010-2016, this limit value for the metals is not included in the table.

[e] The maximum content value for residential quality, which is based on a standard soil (25% lutite, 10% organic compounds). For the metals, these limit values have been adjusted for soil type (in accordance with Annex G of the Soil Quality Regulation), based on 2% lutite and 98% organic compounds. The adjusted limit values are shown in italics.

[f] The figures presented here for the metals refer to the element, unless indicated otherwise

[g] Total chromium (i.e. not Cr-6)

[h] The toy limit value for chromium is specified for Cr-3 and Cr-6, meaning that the comparison with the maximum content value (for total chromium) does not apply. Given that the Dutch pitch samples were not analysed for the presence of Cr-6 and the assumption that the measured total chromium is entirely Cr-6 is too extreme, chromium has not been prioritised.

[i] The lowest of the two concentration limits applicable for lead

[j] This limit value for nickel concerns a migration limit in µg/cm^2/week, which cannot be compared with the maximum content value in mg/kg reported in the literature. As a result, this limit value is not presented in the table above.

[k] The content values as presented for the PAHs concern the values adjusted for warm extraction

[l] The lowest of the three concentration limit values applicable for BaP

[m] Sum total of o-xylene, p-xylene and m-xylene

[n] As performed on 10 mixed samples

[o] As performed for PAHs and phthalates on one-tenth of the 600 samples
[p] Concerns toys and childcare products (entry 52)
[q] Dicyclohexyl phthalate is classified as Repr. 1B
[r] Bisphenol A is classified as Repr. 1B
[s] A restriction is being prepared for bisphenol A, regarding its use in thermal paper; the restriction will apply above a concentration limit of 0.02%.
[t] Migration limit in accordance with the methods in EN 71-10:2005 and EN 71-11:2005
[u] Sum total of PCB28, PCB52, PCB101, PCB118, PCB138, PCB153, PCB180

* Cobalt was prioritised based on literature data (see Table II in Annex II) because it exceeded the limit value under the Toy Safety Directive and the 'residential' soil limit. Moreover, although cobalt is not classified as an SVHC, it has been notified as such (Carc. 1B and Repr. 1B) by a number of companies. However, this limit value based on the Toy Safety Directive is a migration limit and the comparison with the content is a worst case, since it is unlikely that 100% will migrate. The leaching data for cobalt shows minor migration into water (see Table IV in Annex IV), meaning that cobalt meets the emission limit for granular building materials.
[#] Benzo[k]fluoranthene (BkFA) is not shaded grey because it was only found in a single pitch sample in a level just above the limit of detection (0.52 mg/kg). In all other pitch samples, the substance was undetectable (< LOD 0.5 mg/kg). Although this PAH itself is not, therefore, an immediate priority for the indicative risk assessment, it is included in this assessment because a group approach is used for the indicative risk assessment for the PAHs.
[@] PCBs were found in two (of seven) mixed samples. This concerns five of the seven PCBs for which there is a combination limit value in the Soil Quality Decree. No other PCBs than these five were found. The five PCBs (PCB28, PCB101, PCB138, PCB153 and PCB180) belong to the 'non-doxin like' PCBs. None of the five are SVHCs, so they are not considered to be an immediate priority for the indicative risk assessment.

10.16 Annex IV – Further prioritisation of metals based on leaching data from Dutch pitch samples and based on SVHC status

Table IV contains the leaching data generated for the **metals** from the analysis of the pitch samples compared with the emission limit values for granular building materials from the Soil Quality Decree. Only zinc exceeds the limit value (coloured blue), but this substance is not an SVHC in terms of properties that present a hazard to human health, so it is not an immediate priority for the indicative risk assessment.

Table IV Prioritisation of substances based on leaching data for metals

Substances	Leaching data from pitch samples[a]	Soil Quality Decree
		building materials[b]
	[mg/kg]	[mg/kg]
METALS [c]		
Antimony	0.039 (LOD)	0.32
Arsenic	0.05 (LOD)	0.9
Barium	0.23	22
Cadmium	0.004 (LOD)	0.04
Chromium	0.018	0.63
Cobalt	0.38	0.54
Copper	0.87	0.9
Mercury	0.0005 (LOD)	0.02
Lead	0.10 (LOD)	2.3
Molybdenum	0.05 (LOD)	1
Nickel	0.11	0.44
Selenium	0.041	0.15
Tin	0.10 (LOD)	0.4
Titanium	0.18	-
Vanadium	0.05 (LOD)	1.8
Zinc	129	**4.5**

LOD = limit of detection

[a] The maximum value as found for a pitch

[b] This limit value concerns an emission value for the metals (based on leaching)

[c] The figures presented here for the metals concern the element, unless indicated otherwise

10.17 Annex V – Results of migration tests

Skin migration

Table V.1 Migration (in ng/g rubber granulate) into artificial sweat, after two hours of exposure at 37°C

	n>LOD (out of seven)	median	max
Metals			
cadmium	1	<0.03	20
cobalt	7	280	480
lead	7	30	70
PAHs #			
naphthalene	3	< LOD	0.39
acenaphthylene	0		<0.4
acenaphthene	0		<0.5
fluorene	0		<0.4
phenanthrene	0		<0.3
anthracene	0		<0.3
fluoranthene	3	<0.3	0.61
pyrene	4	0.20	1.76
benzo[a]anthracene	0		<0.3
chrysene	2	<0.2	0.31
benzo[b]fluoranthene	0		<0.3
benzo[k]fluoranthene	0		<0.3
benzo[a]pyrene	0		<0.4
indeno[1,2,3-cd]pyrene	0		<0.5
dibenzo[a,h]anthracene	1		1.08
benzo[g,h,i]perylene	5	0.47	1.02
benzo[e]pyrene[1]	2	< LOD	0.70

LOD = limit of detection

[1] estimated from 2.2467 x [Chrysene]

The exposure calculation applies a percentage of 0.02% for the sum total of PAHs to the maximum (or the P90) content values (see section 10.6), resulting in the following maximum migration levels:

	Content (maximum pitch value)		Migration level (maximum)	Content (P90 pitch value)		Migration level (maximum)
EFSA4	10.1 mg/kg	* 0.02% =	2.02 µg/kg	5.5 mg/kg	* 0.02% =	1.10 µg/kg
EFSA8	16.2 mg/kg	* 0.02% =	3.24 µg/kg	10.9 mg/kg	* 0.02% =	2.18 µg/kg
ECHA8	19.8 mg/kg	* 0.02% =	3.96 µg/kg	10.9 mg/kg	* 0.02% =	2.18 µg/kg

The phthalates were not found in concentrations above the limit of detection.

Table V.2 Phthalates, limit of detection

Phthalate		LOD (µg/L)
dimethyl phthalate	DMP	0.10
diethyl phthalate	DEP	0.10
diisobutyl phthalate	DIBP	0.10
dibutyl phthalate	DBP	0.10
butylbenzyl phthalate	BBP	0.10
dicyclohexyl phthalate	DCHP	0.10
bis (2-n-ethylhexyl) phthalate	DEHP	1.0
diphenyl phthalate	DPP	0.10
di-n-octyl phthalate	DNOP	0.10
diisononyl phthalate	DINP	10
diisodecyl phthalate	DIDP	10
di-n-nonyl phthalate	DNNP	0.10
bis (2-ethylhexyl) adipate	DEHA	0.10

In vitro digestion

Table V.3 Migration (in µg/g rubber granulate) into gastric/intestinal juices (after four hours of exposure)

	Total amount released* (max)
Phthalates (n=5 samples) $	
BBP	0.29
DBP	0.08
DCHP	0.27
DEHA	< LOD
DEHP	1.84
DEP	0.26
DIBP	0.18
DIDP	0.28
DINP	< LOD
DMP	0.05
DNNP	0.06
DNOP	< LOD
DPP	0.09
PAHs (n=5 samples) #	
acenaphthene	0.02
acenaphthylene	< LOD
anthracene	< LOD
benzo[a]anthracene	0.01
benzo[a]pyrene	0.03
benzo[b]fluoranthene	0.05
benzo[g,h,i]perylene	0.29
benzo[k]fluoranthene	< LOD
chrysene	0.15
dibenzo[a,h]anthracene	0.02
phenanthrene	0.13
fluoranthene	1.02
fluorene	< LOD
indeno[1,2,3-cd]pyrene	0.03
naphthalene	0.37

	Total amount released* (max)
pyrene	1.13
Metals (n=2 samples) [1]	
Barium	6
chromium	1
cobalt	2
copper	78
lead	9
nickel	2
selenium	1
titanium	1
zinc	419

LOD = limit of detection

[1] Arsenic, cadmium, molybdenum, antimony, tin, vanadium and mercury were not found in the gastro-intestinal juices

* 'Total amount released' is the sum total of the amount in filtrate and in the liquid part of the residue

[$] The exposure calculation applies a percentage of 20% for the phthalates to the maximum content values (see section 10.6), resulting in the following maximum migration levels:

	Content (maximum pitch value)		Migration level (maximum)
DBP	0.86 mg/kg	* 20% =	0.172 mg/kg
BBP	0.99 mg/kg	* 20% =	0.198 mg/kg
DEHP	27.2 mg/kg	* 20% =	5.44 mg/kg
DIBP	2.32 mg/kg	* 20% =	0.464 mg/kg
DINP	61 mg/kg	* 20% =	12.2 mg/kg
DCHP	0.21 mg/kg	* 20% =	0.042 mg/kg

[#] The exposure calculation applies a percentage of 9% for the sum of PAHs to the maximum (or the P90) content values (see section 10.6), resulting in the following maximum migration levels:

	Content (maximum pitch value)		Migration level (maximum)	Content (P90 pitch value)		Migration level (maximum)
EFSA4	10.1 mg/kg	* 9% =	0.91 mg/kg	5.5 mg/kg	* 9% =	0.495 mg/kg
EFSA8	16.2 mg/kg	* 9% =	1.46 mg/kg	10.9 mg/kg	* 9% =	0.981 mg/kg
ECHA8	19.8 mg/kg	* 9% =	1.78 mg/kg	10.9 mg/kg	* 9% =	0.981 mg/kg

Headspace extraction – PAHs

Because no headspace analysis was performed for the PAHs, evaporation is calculated based on the concentration in the granulate compared to the air concentrations found in the literature.

Most PAHs have a fairly low vapour pressure and show a considerable tendency towards adsorption into particulate matter. For that reason, airborne PAHs will primarily be present in dust. Based on a vapour pressure of BaP of 7.3×10^{-10} Pa at 25°C [72] and a concentration of 2.5 mg BaP/kg rubber granulate, the Murray and Pottie method (1974) [73] can be used to calculate that the maximum concentration in the air immediately above the synthetic turf pitch is 0.03 ng/m^3 at 60°C. This is a worst-case situation; in actual practice, air temperatures that high do not occur very often and the wind would disperse some of the substance. This maximum concentration is well below the European limit value of 1 ng/m^3 and is also under the guidance value of 0.12 ng/m^3 proposed by the WHO. The measured year average background concentrations of BaP in the outside air in the Netherlands were between 0.04 and 0.11 ng/m^3 in 2013 [74].

Measurements of BaP vapour in the air above synthetic turf pitches in previous studies revealed concentrations which are comparable to the calculated concentration of BaP. The maximum concentrations of BaP were 0.02 ng/m^3 in Norway, 0.19 ng/m^3 in the US and 0.86 ng/m^3 in Italy [28, 36, 43]. In the case of the latter study by Ecopneus (2016) the higher concentration can be explained because the sample also contained particulate matter [36].
Measurements of PAHs in particulate matter in Italy revealed concentrations of BaP of up to 1.75 ng/m^3 (these measurements were taken in November, but all measurements in June were below the limit of detection) and 0.5 ng/m^3 [35, 38]. The concentrations of PAHs above the pitches in these studies were not higher than at other locations in the city. Three studies found no SVHC PAHs in the air above the limit of detection [39, 56, 75].
All studies conclude that there is no increased health risk due to exposure to PAHs via inhalation.

10.18 Annex VI – Toxicological profiles

2-Mercaptobenzothiazole

2-Mercaptobenzothiazole (2-MBT) is used as an accelerator in the process of making vulcanised rubber. The substance is classified in Europe for skin sensitisation (Skin Sens. 1, H317: May cause an allergic skin reaction) [15]. This substance is also notified as Carc. 1B (H350: May cause cancer) in the C&L inventory, although this self-classification was only performed by 3 of the 1139 companies (November 2016) [76].

IARC recently classified 2-MBT in group 2a ('Probably carcinogenic to humans'). This is based on limited evidence that this substance causes bladder cancer in humans and sufficient evidence of carcinogenicity in laboratory animals [77]. During the REACH substance evaluation process, it was assessed based on the same data that there is insufficient evidence of carcinogenicity [78], for example because a clear dose response relationship was not observed for all types of tumours in the NTP carcinogenicity studies in rats and mice [79]. Various types of tumours were observed in those NTP studies (for example, rat: mononuclear cell leukaemia, pancreatic tumours, pituitary tumours, pheochromocytomas; mouse: only liver tumours). NTP concludes that the results in these studies provide 'some evidence' of a carcinogenic effect in male and female rats, 'no evidence' in male mice and 'equivocal evidence' in female mice [79]. The available data does not refer to a genotoxic potential of the substance in vivo [80], so the development of the tumours is assumed to take place via a non-genotoxic mechanism.

In an ad hoc-assessment of this substance in 2003, RIVM derived a human MTR_{oral} of 94 µg/kg bw/d, based on a lowest NOAEL found of 94 mg/kg bw/d from a 90-d oral study of mice [79] and a total uncertainty factor of 1000. At the time, this value was designated as provisional due to the limited data available [80].

In the substance evaluation process under REACH, the German BAuA judged that the NOAEL for the 90-d oral study of mice was not 94 but 188 mg/kg bw/d, and that the lowest observed adverse effect level (LOAEL) of 188 mg/kg bw/d from a 90-day oral study of rats [79] would be used as the point of departure for DNEL derivation. This resulted in an oral DNEL of 0.31 mg/kg bw/d and, after route-to-route extrapolation, a dermal DNEL of 0.94 mg/kg bw/d and an inhalation DNEL of 1.09 mg/m^3 [78]. In 2015, this substance was also assessed by the German UBA; based on the NOAEL of 94 mg/kg bw/d from a 90-d oral study of mice, UBA also derived an oral reference value which is comparable to the oral reference value derived by BAuA [81].

Bisphenol A (BPA)

Bisphenol A (BPA) is a substance which can be found in many products, including store receipts, building materials (paint and coatings), food packaging, toys and medical devices.

BPA exposure in Europe via food intake was measured based on average and high exposure in children and in adolescents and adults. Average exposure is based on average concentration data and average consumption, while high exposure is based on average concentration data and high consumption. For children (babies aged 6-12 months, toddlers aged 12-36 months, and young children aged 3-10 years), average BPA exposure via food intake was measured at 0.290 – 0.375 µg/kg bw/d, while high exposure was measured at 0.813 – 0.857 µg/kg bw/d. For adolescents, adults and the elderly, average BPA intake via food was 0.116 – 0.159 µg/kg bw/d, while high exposure was 0.335 – 0.388 µg/kg bw/d [82].

BPA is almost completely absorbed into the body after oral exposure [82]. Limited absorption takes place following dermal exposure [83]. It is assumed that BPA can also be absorbed into the body after inhalation, although there is no relevant data [83].

BPA can cause damage to the kidneys and liver, mammary glands, fertility and immune system and has a negative impact on behaviour after in utero exposure [82, 84]. In Europe, BPA has a harmonised classification for the effects on human reproduction (Repro. 1B (H360F: May damage fertility)), in addition to a harmonised classification for the endpoints of human skin sensitisation (Skin sens. 1 (H317: May cause an allergic skin reaction), eye damage (Eye Dam. 1 (H318: Causes serious eye damage)) and specific target organ toxicity after single exposure (STOT SE 3 (H335: May cause respiratory irritation)) [15].

In 2015, EFSA derived a temporary TDI (t-TDI) of 4 µg/kg bw/d [82]. In addition, oral and dermal DNELs for consumer exposure to BPA were derived in 2015 under REACH: 4 µg/kg bw/d for oral and 0.1 µg/kg bw/d for dermal [84]. The dermal DNEL applies for absorbed BPA, based on a dermal absorption of 10% [84].

To assess inhalation exposure for the current report, RIVM derived an inhalation DNEL according to the method described in ECHA (2012) [33]. The DNEL is based on a 90-day inhalation study of rats (6 hour/d, 5d/week; 0, 10, 50 and 150 mg/m^3) [Nitschke (1988) as described in [83]]. In this study, mild inflammation of the olfactory epithelium was observed at 50 and 150 mg/m^3. There is no indication of possible systemic toxicity at this exposure. Application of the default assessment factors (2.5 for interspecies extrapolation, 10 for intraspecies extrapolation, 2 for extrapolation of subchronic to chronic) results in a DNEL of 0.2 mg/m^3.

Cadmium

Cadmium is a heavy metal that occurs naturally in the soil and is released during certain industrial processes. The main sources of exposure for the general public are food and smoking. The average cadmium intake in the Netherlands varies from 0.57 µg/kg bw/d at the age of 2 to approximately 0.20 µg/kg bw/d for adults [85]. In the Netherlands, the regional year average concentration of cadmium measured in the air was 0.16 ng/m^3 in 2013 [86].

The absorption of cadmium after exposure is relatively low: approximately 5% oral, <1% dermal and 10-30% after inhalation of dust. It is absorbed in the kidneys and liver and has a biological half-life of 10-30 years. Cadmium accumulates in the body due to its slow excretion rate, which may lead to kidney damage and osteoporosis. A link has also been demonstrated to various forms of cancer, primarily lung cancer in workers who have had frequent or intensive exposure to cadmium, as well as endometrial, bladder and breast cancer [87, 88]. In Europe, cadmium has a harmonised human classification for carcinogenicity (Carc. 1B (H350: May cause cancer)), mutagenicity (Muta. 2 (H341: Suspected of causing genetic defects)) and effects on reproduction (Repr. 2 (H361fd: Suspected of damaging fertility. Suspected of damaging the unborn child)) [15]. IARC has classified cadmium (and cadmium compounds) in group 1 ('carcinogenic to humans') [89].

EFSA derived a tolerable weekly intake for cadmium of 2.5 µg/kg bw/week based on effects on the kidneys as observed in various epidemiological studies [87].

The legal limit for air quality in Europe is 5 ng/m^3 for cadmium [90]. This value is based on kidney toxicity, but the respective EU working group also considered it sufficient protection for the endpoint carcinogenicity [91].

Phthalates
Phthalates are plasticisers which are used e.g. in plastic, furniture, toys and cosmetic products. Sources of exposure to phthalates include food, water and household dust.

After oral exposure, phthalates are generally absorbed fairly quickly via the gastrointestinal tract. Phthalates are also readily absorbed via the airways, but much less via the skin [92].

In Europe the phthalates dibutyl phthalate (DIBP), diethylhexyl phthalate (DHP), dibutyl phthalate (DBP), benzyl butyl phthalate (BBP), bis(2-ethylhexyl) phthalate (DEHP) and dicyclohexylphthalate (DCHP) have a harmonised classification for effects on the reproduction (Repro. 1B), for effects on the unborn child. Some also have a repro classification for effects on fertility [15]. An application for diisononyl phthalate (DINP) for Repr. 1B classification has been submitted to ECHA. IARC has classified benzyl butyl phthalate in group 3 ('Not classifiable as to its carcinogenicity to humans') and bis(2-ethylhexyl) phthalate in group 2B ('Possibly carcinogenic to humans') [93, 94].

Phthalates are endocrine disrupters that have an anti-androgenic effect. The primary target organ is the male reproductive organ. Exposure during pregnancy can have a negative effect on the development of the testes and on sperm production. Various organisations have derived toxicological limit values for phthalates, often specifying the anti-androgenic developmental effects as the most sensitive effect. The most recent are limit values derived under REACH; based on developmental effects, DNELs were derived for DEHP, DBP, DIBP and BBP [92, 95-97]. It was also noted that these DNELs are, in principle, applicable to the most sensitive groups (pregnant women and newborns/infants), and that application of the DNELs to older children and non-pregnant adults is conservative [92]. The DNELs are based on NOAELs or LOAELs from oral studies. Dermal and inhalation DNELs were derived by route-to-route extrapolation. Similarly, DNELs for the reprotoxicity endpoint were also proposed under REACH for diisononyl phthalate (DINP) and diisodecyl phthalate (DIDP) [98].

No toxicological reference value is known for DCHP. In the report on which the classification of DCHP as Repr. 1B is based [99], a NOAEL of 18 mg/kg bw/d was found in the oral 2-generation study by Hoshino et al. (2005) for development effects related to an anti-androgenic mechanism of action. This NOAEL can be used to derive a provisional oral DNEL (NOAEL/100 = 0.18 mg/kg bw/d). Although there is no kinetic information for DCHP, assuming that the absorption is of the same magnitude as for the other phthalates (almost completely (100%) for oral and inhalation, limited (up to 10%) for dermal), it is also possible to derive provisional dermal and inhalation DNELs after route-to-route extrapolation.

Phthalate	***DNEL oral (mg/kg bw/d)***	***DNEL dermal (mg/kg bw/d)***	***DNEL inhalation (mg/m^3)***
DEHP	0.034	0.672	0.12 (children) 0.16 (adults)
DBP	0.0067 (rounded off to 0.007)	0.07	0.02
DIBP	0.0083*	0.08	0.025
BBP	0.5	10	1.7
DINP	0.25	6.25	0.87 (children) 1.16 (adults)
DIDP	0.26 (children) 0.08 (adults)	6.50 (children) 2.06 (adults)	0.90 (children) 0.38 (adults)
DCHP	0.18	1.8	0.63

* Was 0.5 in 2012 opinion, but was adjusted in 2016 to 0.083 (in press)

Cobalt
Cobalt occurs naturally in rock, soil, water and plants. It is primarily used in alloys and, to a lesser extent, in paint and as a catalyst in the chemical industrial. It is also used as a growth promoter in animal feed.

Cobalt is essential to humans as a component of cobalamine (vitamin B12). The recommended daily intake of vitamin B12 in the US is 2.4 μg/day, which contains 0.1 μg of cobalt [100].

The toxicity database of cobalt is limited. There are no chronic oral toxicity studies. For subchronic exposure to humans (up to eight months) the lowest reported LOAEL is 0.04 mg/kg bw/d for cardiomyopathy and systemic effects in other organ systems. These effects were observed in people who drank beer in which cobalt sulphate was used as a foam stabiliser. However, the contribution of combined exposure to cobalt and alcohol cannot be ruled out [101]. In case of inhalation exposure to cobalt particles the respiratory tracts are the target organ. Occupational studies primarily found respiratory effects, including reduced pulmonary functioning, asthma, interstitial lung disease, wheezing and dyspnoea. Chronic animal studies revealed hyperplasia of the respiratory tracts, pulmonary fibrosis and emphysema as sensitive effects [102].

In Europe, cobalt has a harmonised classification for sensitisation of the skin (Skin Sens. 1 (H317: May cause an allergic skin reaction) and the airways (Resp. Sens. 1 (H334: May cause allergy or asthma symptoms or breathing difficulties if inhaled)) [15]. The substance has also been notified by the industry for, among other things, carcinogenicity (Carc. 1B (inhalation)) and effects on reproduction (Repr. 1B and 2 (effects on fertility)) [76]. IARC has classified cobalt (and cobalt compounds) and metallic cobalt particles in group 2B ('Possibly carcinogenic to humans') [103, 104].
The Netherlands recently submitted a proposal to ECHA to classify cobalt as Carc. 1B (H350: May cause cancer), Muta. 2 (H341: Suspected of causing genetic defects) and Repr. 1B (H360F: May damage fertility). This proposal still has to be assessed by RAC and is not yet legally binding.

In 2001 RIVM derived a TDI of 1.4 µg/kg bw/d based on a LOAEL for cardiomyopathy in humans. In addition, a TCA of 0.5 µg/m^3 was derived based on a LOAEL for interstitial lung diseases in humans [101].

Lead (element)
Lead is a heavy metal that occurs in the environment primarily in inorganic form. The most important human exposure sources for lead are food and water, as well as exposure via the air, household dust and soil. The average exposure via food in Europe is 0.36 – 1.24 µg/kg bw/d for adults; for persons with a high exposure, this is 0.73 – 2.43 µg/kg bw/d. For children, exposure to lead via food per kg body weight may be as much as 2-3x higher. In addition, exposure of two-year-old children to lead via household dust and soil is estimated at 0.18 – 0.80 µg/kg bw/d [105]. For the Netherlands, it has been calculated that the average exposure in children aged 2-6 years is 0.53 – 0.76 µg/kg bw/d [106, 107][1].

The average air concentrations for lead in non-urban areas are often less than 0.15 µg/m^3, while air concentrations for lead in most European cities is usually between 0.15 and 0.5 µg/m^3 [108]. The regional year average concentration of lead measured in the air in the Netherlands was 6.8 ng/m^3 in 2013 [86].

Lead is almost completely absorbed upon inhalation, but absorption via the skin is minimal and oral absorption varies from 10% in adults to 40-50% in children. After absorption, lead distributes in the blood, soft tissue and bone tissue. The bone tissue, in particular, easily absorbs lead and also partially releases it again over a longer period of time. The half-life for lead in blood and bone tissue is approximately 30 days and 10-30 years respectively [105, 109].

The most sensitive effect of lead is developmental neurotoxicity [105, 110, 111]. Other target organs are the cardiovascular system, the kidneys, the haematological system and male fertility [105, 109].

[1] New data will become available early in 2017.

In Europe, lead has a harmonised classification for the effects on reproduction (Repro. 1A (H360DF: May damage fertility and the unborn child)) and via breastfeeding (Lact. (H362: May cause harm to breast-fed children) [15]. IARC had initially classified lead (and lead compounds) in category 2b ('Possibly carcinogenic to humans') [112]. Following that, the inorganic lead compounds were re-evaluated in 2006 and classified in category 2A ('Probably carcinogenic to humans') [113].

Children are more at risk than adults due to their higher exposure, higher absorption, higher internal exposure of sensitive tissues (haematological and nervous system) and a higher sensitivity to the hazardous effects of lead [105, 108].
Limit values for exposure to lead are derived by means of dose-response analysis from epidemiological studies which correlate blood values with health effects. An exposure model is used to convert the blood values into the corresponding oral exposure levels.
In 2010 EFSA derived $BMDL_{01}$ values for blood lead concentrations in relation to three critical endpoints: 12 µg/L (corresponding to an oral exposure level of 0.50 µg/kg bw/d) for IQ decrease in children, 36 µg/L (corresponding to 1.50 µg/kg bw/d) for effects on systolic blood pressure and 15 µg/L (corresponding to 0.63 µg/kg bw/d) for prevalence of chronic kidney disease [105]. As shown by these $BMDL_{01}$ values, developmental neurotoxicity is the most sensitive effect. No threshold can be established for this effect. Given an MOE of 10 for this effect, EFSA expects there to be 'no appreciable risk' for children [105].
In line with these findings, ECHA applied a factor of 10 to the $BMDL_{01}$ for IQ decrease, resulting in a limit of 0.05 µg/kg bw/d, corresponding to 0.1 point IQ loss [110, 111]. This maximum exposure value of 0.05 µg/kg bw/d was adopted when assessing two restriction dossiers under REACH (for lead in jewellery and for lead in articles). Supposing that a child who weighs 10 kg sucks on 10 cm^2 (or 10 g) of (parts of) an article containing lead for 1 hour, this limit means that migration must not exceed 0.05 µg lead/cm^2/hour (or 0.05 µg lead/g/hour). Estimates indicate that migration at that level would result from a lead concentration of 0.05% (500 mg/kg). This has led to the conclusion that, if an article contains 0.05% lead or less, there is no additional risk for children [110, 111].

The legal limit for air quality in Europe is 0.5 µg/m^3 for lead [114]. This limit has been adopted from the WHO 'Air Quality Guideline' for lead [108]. This guideline is based on a critical level of lead in blood of 100 µg/litre that should not be exceeded by ≥98% of the exposed population. On this basis, the year average air concentration for lead should not exceed the 0.5 µg/m^3 limit [108].

Polycyclic aromatic hydrocarbons (PAHs)
Polycyclic aromatic hydrocarbons (PAHs) are a chemically diverse group of organic compounds, consisting of two of more six-membered aromatic rings. PAHs are created during combustion processes when organic compounds are heated to a high temperature. The PAHs released form a complex mixture of more than 200 different substances [115]. Benzo(a)pyrene is the best known and most studied of the PAHs.

It has long been known that PAH mixtures are carcinogenic. IARC concluded that benzo(a)pyrene is a human carcinogen. The carcinogenic effect of 13 other PAHs has been demonstrated in laboratory animals, while in the case of 16 other PAHs, there is limited evidence of a carcinogenic effect in laboratory animals. Animal testing data on various mixtures of PAHs has also revealed a carcinogenic effect. The carcinogenic effect has been proven for exposure to PAHs from tar products in various professions (e.g. roofing, paving) [65, 66].

PAHs in consumer products are subject to a restriction under REACH [116]. This restriction applies to each of the following eight PAHs and regulates a maximum of 0.5 mg/kg in toys and 1 mg/kg in articles: benzo[a]pyrene, benzo[e]pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene and dibenzo[a,h]anthracene.

In Europe, these eight PAHs have a harmonised classification for carcinogenicity (Carc. 1B (H350: May cause cancer) in Annex VI to Regulation (EC) 1272/2008, which also classifies benzo[a]pyrene and chrysene for mutagenicity (Muta 1B (H340: May cause genetic defects) and Muta 2 (H341: Suspected of causing genetic defects) respectively) [15]. The IARC classifications for these 8 PAHs are as follows:

Benzo[a]pyrene	Group 1 (human carcinogen)
Benzo[e]pyrene	Group 3 (inadequate evidence)
Benzo[a]anthracene	Group 2B (sufficient evidence in laboratory animals)
Chrysene	Group 2B (sufficient evidence in laboratory animals)
Benzo[b]fluoranthene	Group 2B (sufficient evidence in laboratory animals)
Benzo[j]fluoranthene	Group 2B (sufficient evidence in laboratory animals)
Benzo[k]fluoranthene	Group 2B (sufficient evidence in laboratory animals)
Dibenzo[a,h]anthracene	Group 2A (sufficient evidence in laboratory animals in combination with mechanistic data)

Epidemiological studies of populations with occupational exposure to mixtures of PAHs indicated that lung cancer was the most common effect. Certain studies also found cancer in other organs (kidneys, bladder, throat, scrotum, skin). In laboratory animals, numerous different types of tumours were found after administration of individual PAHs or mixtures of PAHs. In the animal study which EFSA (2008) used for the quantitative cancer risk assessment for PAHs, a study in mice with coal tar mixtures performed by Culp et al. (1998), tumours were found in liver, lungs, forestomach, intestines, blood vessels and connective tissue (sarcomas) following oral administration [64, 117].

Oral route:
EFSA (2008) performed a quantitative cancer risk assessment in relation to the presence of PAHs in food. The risk assessment was based on an oral experiment in mice during which coal tar mixtures were tested [64, 117]. EFSA also evaluated which dose metric was preferred for PAHs as

a mixture in order to characterise effects and exposure. The outcome was a preference for PAH4 (that is the sum of the levels of benzo(a)pyrene, chrysene, benz(a)anthracene and benzo(b)fluoranthene) and PAH8 (the sum of benzo(a)pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, dibenz(a,h)anthracene and indeno(1,2,3-cd)pyrene), without any difference between these two. EFSA derived a $BMDL_{10}$ of 0.34 mg/kg bw/day for the PAH4 and a $BMDL_{10}$ of 0.49 mg/kg bw/day for PAH8. In risk assessment for food, EFSA recommends calculating the 'margin of exposure' (MOE) between the estimated exposure and the $BMDL_{10}$. In the case of a MOE of 10,000 or higher, this would be a substance of low concern from a public health point of view [64].

If the derived $BMDL_{10}$ values based on a study with coal tar are used in the risk assessment of PAH mixtures from rubber, the result will only be an approximation of the actual situation. This is because the content may differ slightly, so the carcinogenic potential of these PAH mixtures may therefore also differ.

Both the EFSA PAH4 and the EFSA PAH8 can, in principle, be used to assess the risks of rubber granulate. However, it should be noted that the use of EFSA PAH4 in the risk assessment for rubber granulate implies the assumption that the relative contribution of EFSA PAH4 to the total effect due to rubber granulate exposure is equal to the relative contribution of the EFSA PAH4 to the carcinogenic effect as found in the mice tests with coal tar. The same applies when EFSA PAH8 is used.

In the case of the eight PAHs covered by the REACH restriction, the EFSA PAH4 are all present. With regard to the EFSA PAH8, however, there are two differences: instead of benzo(g,h,i)perylene and indeno-(1,2,3-cd)pyrene in the EFSA PAH8, benzo(e)pyrene and benzo(j)fluoranthene are present in the REACH PAH8. No $BMDL_{10}$ is available for these eight PAHs. The report by Culp et al. (1998) does not state the concentrations of benzo(e)pyrene and benzo(j)fluoranthene. Consequently, it is impossible to calculate a $BMDL_{10}$ for these eight PAHs. The $BMDL_{10}$ for the EFSA PAH8 could possibly be used for these eight PAHs, assuming a comparable contribution to the total effect by benzo(e)pyrene and benzo(j)fluoranthene on the one hand and benzo(g,h,i)perylene and indeno-(1,2,3-cd)pyrene on the other. The inaccuracy that would be introduced by this assumption is expected to be relatively minor.

In order to assess the entire mixture of PAH in rubber granulate, all three dose metrics will be used in the calculations. As described above, there will be an inevitable inaccuracy due to the difference in content and perhaps potency between the coal tar mixture that was tested and the PAH mixture present in rubber granulate.

Dermal route:
For the purpose of assessing dermal exposure to PAHs, the oral $BMDL_{10}$ values for PAH4 and PAH8 were converted to dermal $BMDL_{10}$ values. This was done by using absorption fractions for the oral route of 0.3 and for the dermal route of 0.2. See RIVM (2016) for details [63]. Using

these absorption fractions results in dermal $BMDL_{10}$ values of 0.51 mg/kg bw/d and 0.74 mg/kg bw/d for PAH4 and PAH8 respectively.

Inhalation route:
PAHs in air are subject to an EU limit value of 1 ng/m^3 expressed as benzo(a)pyrene [118]. This value corresponds to an estimated additional cancer risk of 1 in 10,000 per lifetime in case of lifelong exposure [118]. This figure represents the risk for the total mixture of PAHs in air. The EU value is based on an epidemiological study of the incidence of lung cancer in coke-oven workers in Pennsylvania, USA. Benzo(a)pyrene is used as a marker for the total mixture.
If the cancer risk of PAH mixtures present in the ambient air or above a synthetic turf pitch containing rubber granulate is assessed using the EU risk value, it implies the assumption that BaP in these mixtures contributes to the total carcinogenic effect of the mixture to the same extent as it did in the inhaled mixture in the critical coke-oven study. Although this assumption introduces some degree of inaccuracy in the assessment, it is unavoidable.

Background exposure to PAHs
Exposure to PAHs occurs via air, soil, water and food. Incidental exposure is also possible via the use of certain consumer products or via treatment with coal tar shampoo (medical application). In general, food is the main source for the general population. Smokers have a clearly increased exposure to PAHs and passive smoking can also lead to increased exposure. In developing countries, the practice of using fuel indoors, for example to prepare food, is an important source of exposure to PAHs.

Food
As stated, food is the most important source of PAHs for the general population (non-smokers). Food can be contaminated with PAHs from the air, soil or water or due to PAHs being formed during food production. For example, PAHs are formed when food is smoked to preserve it, and when certain cooking techniques such as grilling and barbecuing are used. Exposure calculations by EFSA (2008) show that cereal and cereal products contribute most to the average daily exposure to PAHs from food in Europe [64]. These EFSA data have not been specified for children. The reason for the higher exposure in this food category is not high concentrations in these products, but rather the substantial daily consumption of these products. The second biggest contributor is seafood and products derived from seafood. EFSA (2008) presents the following dietary exposure levels for the Netherlands for exposure to PAHs via food:

Calculated daily exposure to PAHs via diet in the Netherlands [64]

Total intake from food in ng/day					
Average for entire population			Population with high exposure*		
Benzo(a)pyrene	EFSA4	EFSA8	Benzo(a)pyrene	EFSA4	EFSA8
239	1197	1785	535	3318	4886

* Based on the 97.5th percentile for PAH intake via cereals and seafood (consumers only) in combination with the average PAH intake via the rest of the food for the entire population.

EFSA notes that PAH intake may be significantly higher compared to the values in the table in the event of increased consumption of barbecued meat that has a high fat content, which is therefore exposed to fumes from melting fat that drizzles into the barbecue flames.

Air
In 2010 through 2015, RIVM's National Air Quality Monitoring Network reported year average concentrations of benzo(a)pyrene in the air of 0.05-0.10 ng/m^3 (background station) and 0.07-0.14 ng/m^3 (urban background station, in an area with large numbers of residents but no busy streets or industry). In 2010-2013, year average concentrations of 0.15-0.21 ng/m^3 were reported for a traffic station (close to a street busy with traffic). Slightly higher year average concentrations were found at an industry station in Wijk aan Zee: 0.55-0.83 ng/m^3 [119]. This data indicates that air makes a limited contribution to the average daily exposure of the general population to PAHs (<<20 ng BaP/day).

The use of fuel to heat homes implies emissions of PAHs to air, particularly if wood or coal are used. The WHO (2010) emission factors are 2.0-114 mg PAH/kg for wood-based heating and 0.95-2.0 mg PAH/kg for coal-based heating [120]. These fuels are hardly used in the Netherlands anymore.

Smokers are clearly exposed to higher levels of PAHs. EFSA (2008) estimates the daily exposure from smoking 20 cigarettes to be 105 ng BaP/day [64].
WHO (2010) concludes that, in industrialised countries, second-hand tobacco smoke is the most important source of PAHs in the indoor air. WHO reports concentrations of 0.23 to 1.7 ng/m^3 in indoor air in homes contaminated with second-hand tobacco smoke, compared to 0.01 to 0.58 ng/m^3 in non-contaminated homes [120]. Higher concentrations are found in highly contaminated rooms (up to around 20 ng BaP/m^3) [64, 120]. WHO (2010) points out that concentrations in indoor air will have a significant impact on total exposure via air, because the average time spent indoors is much longer than the time spent outdoors (80-93% of the time). The total daily exposure to PAHs via indoor air in industrialised countries is estimated at 0.15-21 ng BaP/day [120].

Drinking water
According to the Drinking Water Decree [DrinkwaterBesluit] (2015), the Netherlands imposes a maximum limit of 10 ng/litre for benzo(a)pyrene and a limit of 100 ng/litre for total PAH (in other words the sum of 10 specified PAHs, excluding BaP) [121]. Regular checks of PAHs in drinking water reveal concentrations which are almost always below these limits [122-124]. The WHO (2003) estimates the average intake of PAHs via drinking water to be 1% of the intake via food [124].
Following an incident, KWR (2010) investigated increased PAH levels as a consequence of the use of bitumen and coal tar coatings in grey cast-iron pipes. Such coatings were used until approximately 1980 and are still present in an estimated 10% of the pipeline network. After migration out of the coatings, the PAHs are present in a solid state (attached to particles). KWR determined that under specific conditions (when rinsing the pipelines and after repairs) the PAHs concentrations in drinking water may be temporarily higher than the tolerable limits for

drinking water. In the case of rinsing, these conditions occur for a couple of days; in the case of repairs, the increased levels lasted for an average of 40 days [123].

Soil

The Soil Quality Regulation states that the background level for total PAH in the Netherlands is 1.5 mg/kg of soil [21]. Based on possible soil ingestion as the dominant route for the general population, this background level is accompanied by a maximum ingestion of 150 ng PAH/day[1] and an estimated maximum of 15 ng BaP/day[2].

[1] Based on the default soil ingestion of 100 mg/day

[2] Based on the assumption that the level of BaP is approximately one tenth of the total PAH (estimated on the basis of concentrations measured in agricultural soils as reported by Statistics Netherlands, Netherlands Environmental Assessment Agency, Wageningen UR, 2013 [125]

10.19 Annex VII – Exposure scenarios for people playing sports

Scenario 1: Children under 6 years old

This scenario of children aged from 4 to 6, the 'under 6' category, is based on a 4-year-old child who trains once per week (for 1 hour) and participates once per week in a number of mini-matches which last a total of 1.5 hours, with the exception of the two summer months and three winter months. This is based on a training schedule at an arbitrarily selected football club. The frequency and duration may differ per club, because the clubs themselves decide how the activities for children 'under 6' are structured. The assumption is that the children always play on synthetic turf with rubber granulate (this applies for all scenarios). The body weight of a 4-year-old child is estimated as being 15.7 kg, based on the 25th percentile of the body weight distributions among children aged between 3 and 6 [27].

A child can be exposed to chemical substances from the rubber granulate via three routes: skin contact, inhalation of chemical vapours or rubber dust (airborne particles), and/or ingestion. The accidental ingestion of rubber granulate is likely, certainly in the case of young children. For this reason, oral exposure was also taken into account.

Dermal exposure in a 4-year-old child

A child plays in football kit, so parts of his/her legs and arms are exposed. It is unrealistic to think that a child will also play with uncovered limbs in the winter period, meaning that direct contact with the skin will be limited to the person's hands in that season. The 'under 6' category usually stop playing in the winter months, or only play very infrequently. The older children aged up to 11 do continue playing during the winter months, but they too are very likely to wear extra clothing to cover their limbs. In this scenario, the 4-year-old child is seen as a worst-case scenario for children aged up to 11, because a child of 4 has a larger body surface area per kilogram of body weight than a child of 11 and therefore a higher exposure (expressed per kilogram body weight) in identical circumstances.

The exposure calculation is based on a 4-year-old child playing with uncovered limbs for seven months per year (with the exception of the three winter months and two months during summer break). The assumption is that a quarter of the leg area, all of the forearms and the hands can come into contact with the rubber granulate. Most literature also includes the scalp area. It cannot be ruled out that rubber granulate will end up on the player's head, although direct contact with the synthetic turf pitch is unlikely. For this reason, the scalp area has not been included. As a result, the estimated contact area is lower than in the literature [30, 31, 53]. Since no precise figures are available for a part of the limbs, the potentially contacted surface area has been calculated as follows: 0.176 m^2 x 0.25 (quarter of legs) + 0.098 m^2 x 0.5 (half of whole arms, without hands) + 0.033 m^2 (hands) = 0.126 m^2 (values of body surface areas from [27]; children aged 3 to 6 years old, 25th percentile values).

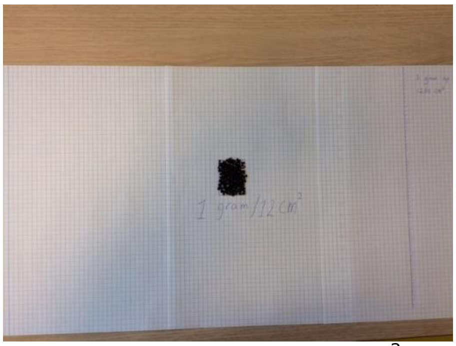
The actual skin contact with rubber granulate will not cover the entire contact area described above, nor will it do so continuously during the sport activity. However, when there is contact, it will be intensive. It is also possible for the rubber granulate to end up in the clothing of people playing sports and therefore be in constant contact with the skin. It is difficult to estimate what the exact contact area is that may lead to dermal exposure. The worst-case situation would be when the total surface area is covered with rubber granulate (0.126 m^2 for a 4-year-old child). No studies have been found in the literature (e.g. observation studies) which have investigated the exact period of contact and the exact contact area.

The migration analyses studied the amount of chemical substances available for dermal exposure. Since these studies generate an amount released of substance per gram of rubber granulate, it is important to determine the total amount of rubber granulate that may contact the skin per occasion of sport activity. This is an uncertain parameter; an estimate is provided below.

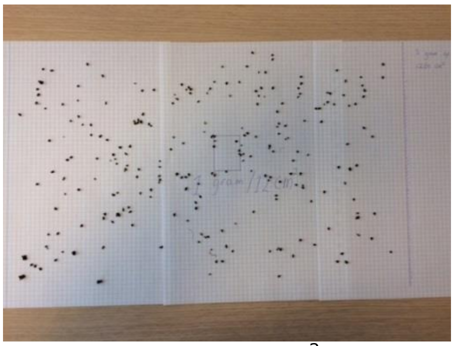
The amount of rubber granulate with which a child can come into contact via the skin depends on the type of sport activity, the uncovered skin, and any grains which end up in the clothing. The relevant estimates from the literature vary and are expressed in amounts per surface area (mg/cm^2) or in amounts per kilogram body weight per day (mg/kg bw/day). When converted into total amounts, the values vary between 0.45 g and 1.1 g of rubber granulate, although it should be noted that these amounts were calculated for the age category of 6-11 years ([30, 31]). No information is currently available for younger children.

Another theoretical approach for obtaining amounts is to use data from the US EPA on 'solid adherence to skin' (soil which remains on the skin after activities) [29]. US EPA (2011) reports skin adherence factors (mg/cm^2) for exposure to soil during football (geometric mean (GM):0,11; geometric standard deviation (GSD):1.8 to GM:0.014; GSD:5.3) and rugby (GM:0.4; GSD:1.7). In view of the wide range of values, it should be noted that much higher dermal exposures could occur if the calculations are based on the US EPA data. However, the question is whether dermal exposure to soil is not too extreme of a scenario for rubber granulate. Additionally, in view of the considerable range in skin adherence factors, it was decided to base the calculation on the 'dermal load of a substance' as reported in the Norwegian study (1.1 g for 1 mg/cm^2) [31]. This decision was made because the dermal load from that study specifically refers to rubber granulate and because the value falls within the spread of the values reported by the US EPA.

In view of the above considerations and based on the literature, 1 g of rubber granulate that can come into contact with the skin during a sport activity (training session or match) would appear to be a realistic estimate for a 4-year-old child. In order to get a better idea of the estimate, a weighted amount of rubber granulate of 10 g was spread out, after which the surface area was determined as being approximately 120 cm^2 and therefore 0.083 g/cm^2. The spread out layer was with little space between the grains and 1 grain deep. In the worst-case situation, where the skin would be covered in a layer of 1 grain, one could come into contact with (0.083 g/cm^2 x 1260 cm^2 =) 105 g of rubber granulate. In the literature, the assumption is that 1 g of rubber granulate leads to dermal exposure, which is approximately 1% of the absolute maximum estimate of the amount of rubber granulate. If the contact with rubber granulate were to be concentrated on one area of the body, 1 g of rubber granulate would represent 12 cm^2 of skin contact. These appear to be reasonable values. Calculations of the dermal exposure will therefore be based on 1 g of rubber granulate for the 4-year-old child.



grains on skin (1 g on 12 cm^2)



thinned out to 1% (12 cm^2 is approximately 1% of total exposed surface area of 1260 cm^2)

The migration analyses for determining the release of chemical substances from rubber granulate express the results in terms of amounts of chemical substance per gram of rubber granulate. The migrated amounts of chemical substance are determined by the sum of the extraction in the artificial sweat. For a description of the migration analysis, see Part B of the scientific background information in this report. Based on the amounts of chemical substance obtained per gram of rubber granulate, it was assumed that this is also the amount to which the child is dermally exposed (external value). To calculate the year average level of exposure, the dermal exposure per sport activity was adjusted for the frequency per week (2 x/week) and per year (7 months/year). It should be noted here that the year average level of exposure can only be used to assess the risk from genotoxic carcinogenic substances (non-threshold effects and for bisphenol A). Exposure during the sport activity will be calculated in order to assess the risks of threshold effects.

The dermal exposure on the day of exposure is calculated by:
Mass of granulate in dermal contact (per period of sport activity) x migration fraction / body weight

Inhalation exposure in a 4-year-old child
While playing on the synthetic turf pitch, the child may inhale chemical substances which have evaporated into the air or are present in rubber dust. The exposure to these substances is largely determined by the air concentrations of the emitted substances or rubber dust, and the amount of air which children inhale. It is assumed that the level of activity of children playing sport can be considered as ‘heavy exercise’. The respiratory rate is set at 1.58 m^3/h (children aged 3 to 6 years; [27]).

As described in Part B of the scientific background information in this report, the air concentration is based on headspace analyses of rubber granulate heated to 60°C in order to simulate a warm day. The results, shown in amounts of substance in vapour form per gram of rubber granulate, were used as input in air concentration simulations, as described in Part B of the scientific background information in this report. The calculated air concentration (in µg/m^3) is used for an estimate of the amount of chemical substance which can be inhaled as a consequence of evaporation (emission). Substances evaporate more at higher outdoor temperatures, which will primarily be relevant in the months of April to September. The grains are heated to 60 °C, ensuring that the calculation will be based on a worst-case scenario.

The Norwegian study revealed an air concentration of rubber dust (measured as PM10) of 12 µg/m^3 [31] in a sports hall with SBR rubber granulate. In this study, the influence of PM10 from the outside air can be assumed to be negligible, meaning that this value is relevant for determining the contribution of inhalable rubber dust to the total exposure. The air concentration of a chemical substance can be determined by multiplying the PM10 value by the weight fraction of the substance in the rubber granulate. Migration of substances into lung fluid was not determined. Consequently, the inhalation exposure estimate is based on the maximum concentration of a chemical substance in the rubber granulate. For this reason, the estimated exposure to chemical substances in PM10 is a worst-case estimate. The method used to calculate daily exposure per kilogram body weight is specified below. To calculate the year average exposure level the calculation has been adjusted for duration per week (2.5 x/week) and per year (7 months/year). to calculate. Again, it should be noted here that the year average exposure can only be used to assess the risk from genotoxic carcinogenic substances (non-threshold effects and for bisphenol A). Exposure during the activity will be calculated in order to assess the risks of threshold effects.

The air concentration of chemical substance in PM10 was determined by:
Air concentration of chemical substance in PM10 = air concentration PM10 x weight fraction in granulate

Oral exposure - ingestion by a 4-year-old child
While playing football, the child’s skin comes into contact with rubber granulate via his/her hands. Young children may have oral exposure as a consequence of hand-mouth contact with chemicals present on the skin. Little is known about hand-mouth contact of rubber granules and various approaches are used to calculate the exposure. The simplest way is to assume that a fixed amount of rubber granulate is ingested per occasion (training session or match) by hand-mouth contact. The literature contains a few figures, such as 1 gram of rubber granulate per match [31], as well as default assumptions based on the risk assessments for soil safety: 50 to 200 mg soil/day (E.g. [29, 30, 102]). It should be noted here that the estimate of 1 gram of rubber granulate ingestion per match also includes the placing of granulate in the mouth and is not limited to hand-mouth contact. An alternative calculation is

used in the context of biocides and plant protection products, based on the assumption is that 50% of the substance that ends up on the person's hands is available for oral ingestion. However, this assumption was made for younger children, aged between 1 and 3, who are more likely to show hand-mouth behaviour.

Children exhibiting pica (oral intake of mouthfuls of non-food substances such as sand, often assumed to be approximately 10 grams of the substance) is seen as too extreme of a scenario and will therefore not be included in the calculations. The assumption of 1 gram of rubber granulate ingestion per period of sport activity for a 4-year-old child was also estimated as being too extreme. Therefore, the default value for soil ingestion as used by the US EPA (2011) was selected for children. For a 4-year-old child, the assumption is that 0.2 grams of rubber granulate is available for oral ingestion during every occasion of sport activity, due both to hand-mouth contact and to 'eating' granulates. Digestion tests (migration test) reveal what amount from the rubber granulate migrates under simulation circumstances (see Part B of the scientific background information in this report), and is therefore available for oral exposure.


0.2 g of rubber granulate

The oral exposure on the day of exposure is calculated by:
Mass of ingested granulate (per period of sport activity) x migration fraction / body weight

Table 3 (Section 10.8) summarises the parameters for the estimated exposure for scenario 1.

Scenario 2: Goalkeepers aged 7-years old
In the 'under 8' category, the children play on half-size pitches with goalkeepers, who are introduced for the first time to the football game in this age category. This scenario assumes that there is a regular goalkeeper. However, in practice, this role may be assigned to a different child each match. In addition to dermal and inhalation exposure, this scenario also includes oral exposure, since rubber grains may end up in goalkeepers' mouths during training sessions and matches. Like the estimates for the 'under 6' category, the amount is estimated at 0.2 g of rubber granulate per period of sport activity (training session or match). The fact that gloves are worn means there is no dermal exposure via the hands.

The weight of a 7-year-old child is set at 24.3 kg, based on the category of children aged 6 to 11 years (25th percentile). The body surface area in contact with rubber granulate is 0.256 m^2 x 0.25 (quarter of the legs)

+ 0.130 m^2 x 0.5 (half of the arms) = 0.129 m^2 (25th percentile; [27]). No information is available about the skin contact goalkeepers have with rubber granulate although, compared to an outfield player, this will be more than only the arms and legs. The goalkeeper is assumed to be exposed to 10 g of rubber granulate per period of sport activity, which is 10-fold higher than exposure for an outfield player, which corresponds to approximately 10% of the total surface area of the skin that can effectively lead to exposure. This is a very uncertain estimate!

The goalkeeper is also exposed to substances via the air; the respiratory rate of a 7-year-old during intensive sport is 1.92 m^3/h. The frequency of sport is set at 3x per week (2x training sessions and a match) and the duration of training sessions (2x 1.5 hours) and matches (1 hour) is slightly higher than for younger children. The period is longer than seven months for the inhalation and oral exposure route, because these children continue training during the winter. Dermal exposure does not occur during the winter season because the skin is covered, inhalation and oral exposure do occur while playing on the pitches.


1 g of rubber granulate

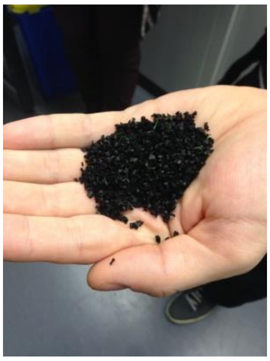

10 g of rubber granulate

Table 3 (Section 10.8) summarises the parameters for the exposure assessment for scenario 2. See scenario 1 for the equations used to calculate the exposure.

Scenario 3: children aged 11-18 years old, performance-oriented sport
This scenario considers children aged 11 and up (44.8 kg [27]), who have switched to playing on full-size pitches (starting with the 'category D' teams). One specific feature of this scenario is the performance-oriented players in the first team of this age group. This team places a strong emphasis on performance-oriented sport than would be the case in recreational sport. This primarily has an effect on the number of training sessions per week, which can be held as often as four times per week. The training sessions last at least 1 to 1.5 hours. A match lasting at least 2x30 minutes is also played. It can be assumed that children spend 1.5 hours on the pitch during match days. With the exception of the summer season, the children play throughout the entire year. They continue training during the winter break, in contrast to the younger 'under 6' children for whom this is not the case. This is based on a training schedule at an arbitrarily selected football club. The training schedule corresponds to that of an elite amateur club. It is therefore

possible that the frequency and duration may differ per club; in actual practice, both will be lower for most amateur clubs.

Dermal exposure of an 11-year-old child
A child plays in football kit, so parts of his/her legs and arms are exposed. The players will also wear shorts and shirt during the training sessions, with the exception of the winter season. The basic assumption is that children have skin contact via parts of the legs, lower arms and hands for seven months of the year. Since no precise figures are available for a part of the limbs, the possible contact area has been calculated as follows: 0.421 x 0.25 (quarter of legs) + 0.198 x 0.5 (half of whole arms, without hands) + 0.064 (hands) = 0.268 m^2 (values of body surface areas from [27], 2014; children aged 11 to 16 years old, 25th percentile).

The literature provides estimates for dermal exposure of children aged 11 and up between 0.65 g and 3.3 g of rubber granulate [30, 31]. In order to gauge whether these values could possibly be a reasonable estimate of the amount exposed, the figures were extrapolated back to a percentage that potentially and actually ends up on the skin, and to the amount of skin that would be covered if the granules ended up in just 1 connected area. As shown for scenario 1, it was calculated that 0.083 g of rubber granulate comes into contact with 1 cm^2. Potentially, the skin could come into contact with 0.083 g/cm^2 x 2680 m^2 = 222 g of rubber granulate. This is the worst-case estimate of the amount of rubber granulate. In the literature, the assumption is that 3.3 g of rubber granulate leads to exposure. This approximates 1.4% of the total contacted surface area. On the other hand, 3.3 g of rubber granulate represents 36 cm^2 skin contact during the training sessions or matches, on a single day. These appear to be reasonable values. For this reason, the assumption is that a child comes into contact with 3.3 g of rubber granulate per occasion of sport activity.

Inhalation exposure of an 11-year-old child
While playing on the synthetic turf pitch, the child may inhale chemical substances which have evaporated into the air or are present in rubber dust. The exposure to these substances is largely determined by the air concentrations of the emitted substances (see Part B of the scientific background information in this report) or the rubber dust, and the amount of air which children inhale. The assumption is that the level of activity of children playing sport can be considered as ‘heavy exercise’. The respiratory rate is set at 2.53 m^3/h ([27]; children aged 11 to 16 years). The period for inhalation is 10 months, since exposure via the air can also occur in the winter season.

Oral exposure - ingestion by a 11-year-old child
Oral exposure in the case of 11-year-old outfield players is no longer likely. They will no longer deliberately put rubber granules into their mouths and the hand-mouth contact will be substantially lower than in younger children. However, in line with the recommendations of the US EPA (2011) for oral exposure to soil, the assumption is that an oral ingestion of 0.05 grams will occur per occasion of sport activity.

In the case of older goalkeepers, it is considered likely that goalkeepers will ingest rubber granules during training sessions and matches. Since the oral exposure is included in the calculations for 7-year-old goalkeepers, and since this will generate a worst-case estimate for older goalkeepers, the 7-year-old goalkeeper's ingestion amount of 0.2 g is used as a starting point.

Table 3 (Section 10.8) summarises the parameters for the estimated exposure in scenario 3. See scenario 1 for the equations used to calculate the exposure.

Scenario 4: adults, performance-oriented sport
This scenario is based on adult men and women (18 years and older, 68.8 kg, 25th percentile [27]) who participate in performance-oriented sport. A specific factor in this scenario is the performance-oriented player in selection teams, where the number of training sessions each week can be as many as four times a week, with training sessions lasting up to two hours each time. A match lasting 2x 45 minutes is also played every week. It can be assumed that adults spend 2 hours on the pitch during match days. Consequently, the adults will spend 10 hours on the pitch per week. With the exception of the summer season, the adults play throughout the entire year. This is based on a training schedule at an arbitrarily selected football club, although it represents a training schedule of elite amateurs. It is therefore possible for the frequency and duration to differ per club.

Dermal exposure of adults
Parts of the legs and arms are exposed. The players will also wear shorts and shirt during the training sessions, with the exception of the winter season. The basic assumption is that adults have skin contact via parts of the legs, lower arms and hands for seven months of the year. Since no precise figures are available for a part of the limbs, the possible contact area has been calculated as follows: 0.59 x 0.25 (quarter of legs) + 0.26 x 0.5 (half of whole arms, without hands) + 0.09 (hands) = 0.368 m^2 (default values of body surface areas, adults, 25th percentile [27]).

The literature provides estimates for dermal exposure of adults aged 18 and up between 0.24 g and 7.5 g of rubber granulate [30, 31]. However, it should be noted that the highest value comes from the group of football players aged 16 to 19 years. The highest value for age 20 and older is 6 g of rubber granulate.

As shown for scenario 1, it was calculated that 0.083 g of rubber granulate comes into contact with 1 cm^2. Potentially, the skin could therefore come into contact with 0.083 g/cm^2 x 3680 cm^2 = 305 g of rubber granulate. This is the worst-case estimate of the amount of rubber granulate. In the literature, the assumption is that 6 g of rubber granulate leads to exposure. This corresponds to approximately 2% of the total contact surface area. On the other hand, 6 g of rubber granulate represents 72 cm^2 skin contact during the training sessions or matches, on a single day. These appear to be reasonable values. For this reason, the assumption is that an adult has skin contact with 6 g of rubber granulate per occasion of sport activity.

Inhalation exposure in an adult
While playing sports on a synthetic turf pitch, adults may inhale chemical substances which have evaporated into the air or are present in rubber dust. The exposure to these substances is largely determined by the air concentrations of the substances or the rubber dust, and the amount of air which adults inhale. The assumption is that the level of activity of adults playing sport can be considered as 'heavy exercise'. The respiratory rate is set at 3.07 m^3/h (adults [27]). The period for inhalation is 10 months, since exposure via the air can also occur in the winter season.

Oral exposure – ingestion by an adult
Oral exposure is no longer likely for adult outfield footballers. However, in line with the recommendations of the US EPA (2011) for oral exposure to soil, the assumption is that an oral ingestion of 0.05 grams will occur per occasion of sport activity.

Goalkeepers, however, are considered likely to ingest rubber granules during training sessions and matches. Accordingly, in the additional oral scenario for adult goalkeepers, the exposure derived from oral exposure in 7-year-old goalkeepers is included in the calculations. This will generate a worst-case estimate for older goalkeepers; the 7-year-old goalkeeper's scenario is used as a starting point.

Table 3 (Section 10.8) summarises the parameters for the estimated exposure for scenario 4. See scenario 1 for the equations used to calculate the exposure.

Scenario 5: 'lifelong exposure'
The 'lifelong' exposure is determined for the PAHs and several other substances. This exposure is determined by multiplying the year average exposure by the number of years that the year average exposure can take place, compared to a lifespan of 70 years. In other words, the 4-year-old scenario lasts for 7 years (covering the years up to the age of 10, in what is a worst-case approach), while the year average exposure for the 4-year-old scenario is multiplied by a factor of 0.1 (=7/70). The exposure is determined in the same way for the other scenarios and then added up. However, after playing performance-oriented sport, football players and goalkeepers often join the veterans. It is assumed that a player plays sport at a recreational level from age 36 to age 50. The frequency of sport is then 2x per week. The number of months per year is equated with adults playing performance-oriented sports.

To determine 'lifelong' exposure for goalkeepers, the assumption is that they have been an outfield player since age 4, and have played as a goalkeeper on the pitch from age 7. For that reason, goalkeepers' scenarios for 11-year-olds, adults and veterans were drawn up that are otherwise the same as for the outfield players, but with the higher dermal and oral exposure as described for the 7-year-old goalkeeper.

Calculation of 'lifelong' exposure for an outfield player:
Year average exposure scenario for 4-year-old x 7 years / 70 years +
Year average exposure scenario for 11-year-old x 7 years / 70 years +

Year average exposure scenario for adult x 18 years / 70 years +
Year average exposure scenario for veterans x 16 years / 70 years +
= 'lifelong' exposure for an outfield player

Calculation of 'lifelong' exposure for a goalkeeper:
Year average exposure scenario for 4-year-old x 3 years / 70 years +
Year average exposure scenario for 7-year-old goalkeeper x 4 years / 70 years +
Year average exposure scenario for 11-year-old goalkeeper x 7 years / 70 years +
Year average exposure scenario for adult goalkeeper x 18 years / 70 years +
Year average exposure scenario for veteran goalkeeper x 16 years / 70 years +
= 'lifelong' exposure for a goalkeeper

10.20 Annex VIII – Indicative risk assessment of PAHs based on P90 migration values and based on 10x the measured maximum migration values into sweat

Table VIII.1 Results of the indicative risk assessment for the PAHs (A: EFSA4, B: EFSA8, C: ECHA8) according to the linear extrapolation method; based on P90 migration values

A

EFSA - 4		**P90 migration value (mg/kg of rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	0.495	2.11E-04	340	2.06E-03	4.35E-07
	dermal	0.0011	1.82E-05	510	1.37E-03	2.50E-08
	total					*4.60E-07*
Goalkeeper	**oral**	0.495	5.53E-04	340	2.06E-03	1.14E-06
	dermal	0.0011	4.00E-05	510	1.37E-03	5.50E-08
	total					*1.19E-06*

B

EFSA - 8		**P90 migration value (mg/kg of rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	0.981	4.19E-04	490	1.43E-03	5.98E-07
	dermal	0.00218	3.62E-05	740	9.46E-04	3.42E-08
	Total					*6.33E-07*
Goalkeeper	**oral**	0.981	1.10E-03	490	1.43E-03	1.57E-06
	dermal	0.00218	7.93E-05	740	9.46E-04	7.51E-08
	total					*1.64E-06*

Table VIII.1 continued
C

ECHA - 8		P90 migration value (mg/kg of rubber granulate)	lifelong exposure (µg/kg bw/d)	$BMDL_{10}$ (µg/kg bw/d)	Additional risk per µg/kg bw/d	Additional risk
Outfield player	**oral**	0.981	4.19E-04	490	1.43E-03	5.98E-07
	dermal	0.00218	3.62E-05	740	9.46E-04	3.42E-08
	total					*6.33E-07*
Goalkeeper	**oral**	0.981	1.10E-03	490	1.43E-03	1.57E-06
	dermal	0.00218	7.93E-05	740	9.46E-04	7.51E-08
	total					*1.64E-06*

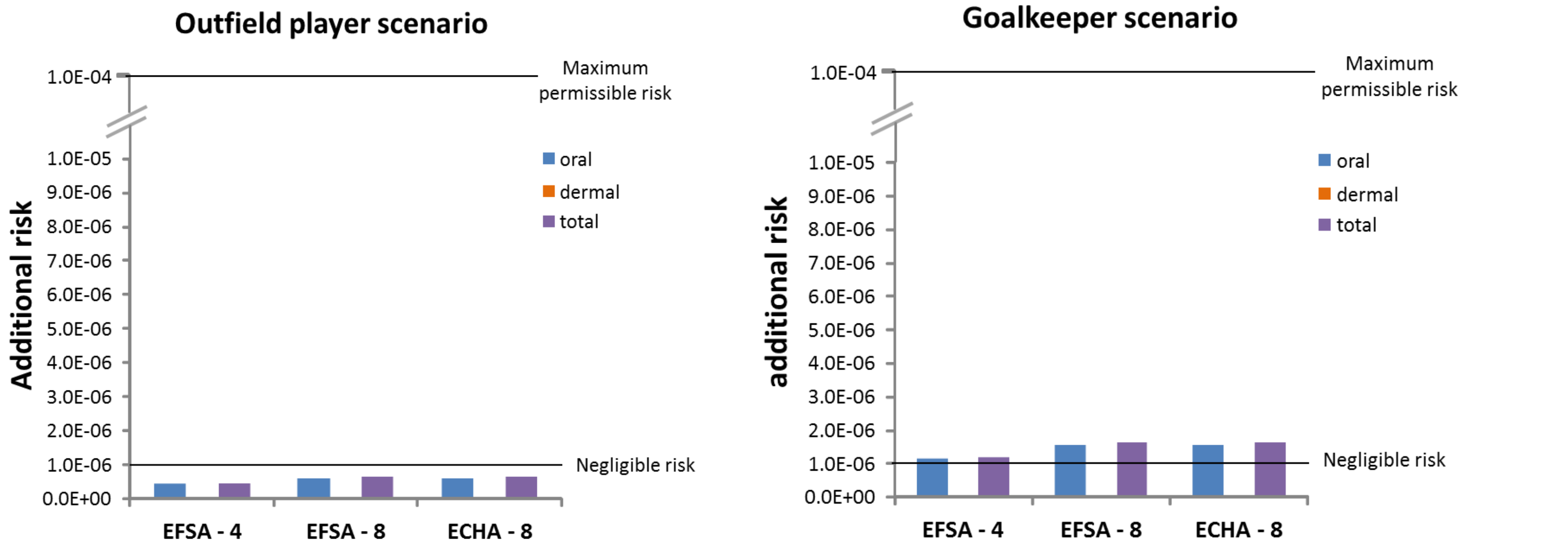


Figure I. Results of the indicative risk assessment for the PAHs according to the linear extrapolation method; based on P90 migration values. Horizontal lines represent additional cancer risk of one in a million (negligible risk) or one in ten thousand (maximum permissible risk).

Table VIII.2 Results of the indicative risk assessment for the PAHs (A: EFSA4, B: EFSA8, C: ECHA8) according to the linear extrapolation method; based on 10x the measured maximum migration values into sweat

A

EFSA - 4		**10x max migration value (mg/kg of rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	0.91	3.89E-04	340	2.06E-03	8.00E-07
	dermal	0.0202	3.35E-04	510	1.37E-03	4.60E-07
	total					*1.26E-06*
Goalkeeper	**oral**	0.91	1.02E-03	340	2.06E-03	2.09E-06
	dermal	0.0202	7.35E-04	510	1.37E-03	1.01E-06
	total					*3.10E-06*

B

EFSA - 8		**10x max migration value (mg/kg of rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	1.46	6.24E-04	490	1.43E-03	8.91E-07
	dermal	0.0324	5.37E-04	740	9.46E-04	5.08E-07
	Total					*1.40E-06*
Goalkeeper	**oral**	1.46	1.63E-03	490	1.43E-03	2.33E-06
	dermal	0.0324	1.18E-03	740	9.46E-04	1.12E-06
	total					*3.45E-06*

C

ECHA - 8		**10x max migration value (mg/kg of rubber granulate)**	**lifelong exposure (µg/kg bw/d)**	**$BMDL_{10}$ (µg/kg bw/d)**	**Additional risk per µg/kg bw/d**	**Additional risk**
Outfield player	**oral**	1.78	7.60E-04	490	1.43E-03	1.09E-06
	dermal	0.0396	6.57E-04	740	9.46E-04	6.21E-07
	total					*1.71E-06*
Goalkeeper	**oral**	1.78	1.99E-03	490	1.43E-03	2.84E-06
	dermal	0.0396	1.44E-03	740	9.46E-04	1.36E-06
	total					*4.21E-06*

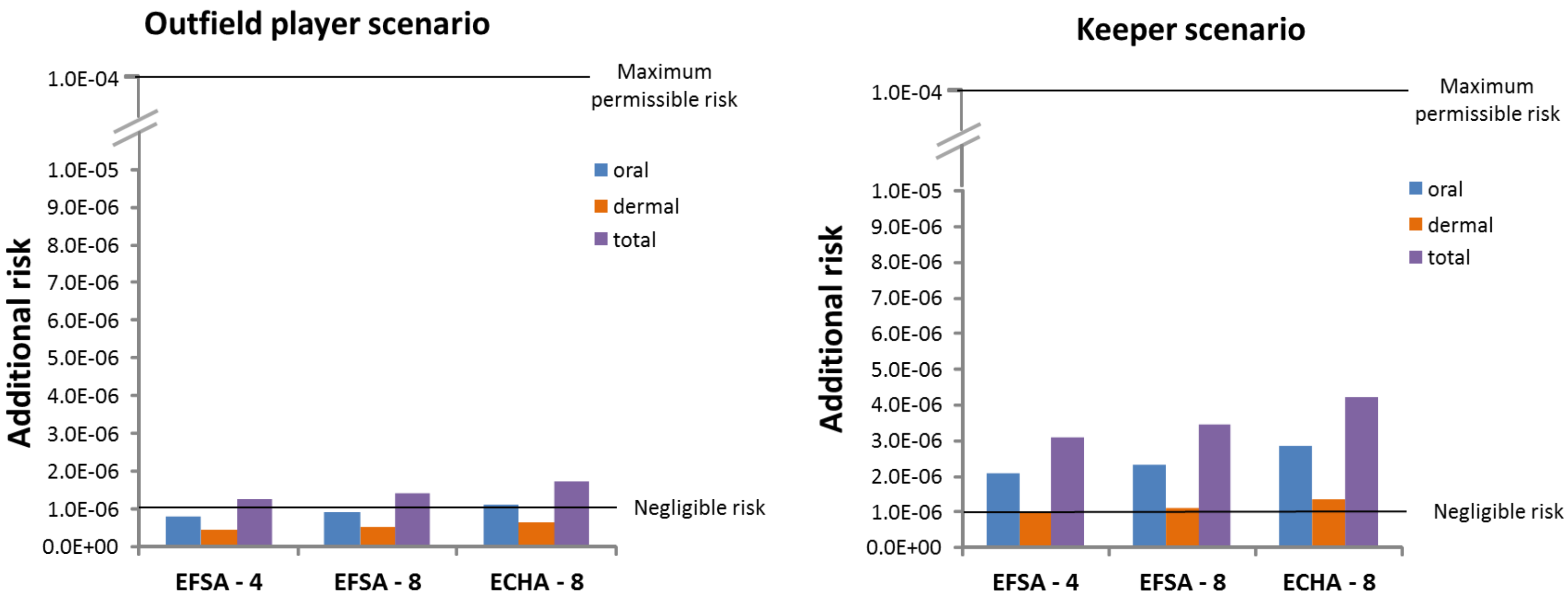


Figure II. Results of the indicative risk assessment for the PAHs according to the linear extrapolation method; based on 10x the measured maximum migration values into sweat. Horizontal lines represent additional cancer risk of one in a million (negligible risk) or one in ten thousand (maximum permissible risk).

10.21 Annex IX – Overview of international studies focusing on possible human health effects of rubber granulate

Reference	**INTRON (2007). Environmental and health aspects of infill rubber; shredded rubber from car tyres as infill material on synthetic turf pitches [Milieu- en gezondheidsaspecten van instrooirubber; gemalen rubber van autobanden als instrooimateriaal op kunstgrasvelden]; Hofstra U., final report 9 February 2007. [53]**
Research question	To generate independent data and to formulate conclusions based on these data on the potential environmental and health risks of the use of rubber infill from shredded car tyres on artificial turf.
Methodology	The investigation consists of a literature research supplemented with experimental research to fill the gaps in the knowledge and to verify already existent data. For the experimental investigation samples were taken on 3 production plants of rubber infill and samples were taken on 14 artificial turf pitches according to a FIFA protocol. For the experimental environmental investigation rubber infill samples were analyzed on the composition and also on the leaching of several parameters. The experimental investigation on health aspects was aimed at the uptake of polycyclic aromatic hydrocarbons (PAH's) through skin contact with rubber infill. A laboratory model migration test was performed on the migration of PAH's to massage oil and vaseline. Additionally with football players the presence of PAH metabolites (1-hydroxypyrene as marker) in the urine was measured after they had intensive skin contact with rubber crumb on an artificial turf pitch. The results from both tests have been compared with internationally accepted health limit values for PAH's.
Results	The content of heavy metals and phthalates in rubber infill complies with the European toy directive and is not expected to pose a health risk via ingestion. PAH levels were 20 to 40 mg/kg. In an exposure scenario for a professional football player a maximum average daily uptake was calculated of 0,12 ng/kg bw benzo[a]pyrene, which is below the advised limit value of 1 ng/kg bw. The uptake of PAH during the training on an artificial turf pitch could not be determined unambiguously in urine, although there had been an intensive skin contact with the rubber infill.
Conclusion	Based on the available literature on exposure to rubber crumb by swallowing, inhalation and skin contact and the experimental investigations on skin contact, there is not a significant health risk due to the presence of rubber infill for football players on artificial turf pitch with rubber infill from used car tyres.
Remarks	Inhalation was only assessed from literature review. No risk was found. The data concerning the urinary excretion of 1-hydroxypyrene were also separately published by van Rooij and Jongeneelen (2010) [47].

Reference	**van Rooij JG, Jongeneelen FJ. 2010: Hydroxypyrene in urine of football players after playing on artificial sports field with tire crumb infill [47].**
Research question	What is the exposure of football players to polycyclic aromatic hydrocarbons due to sporting on synthetic ground with rubber crumb infill?
Methodology	Seven male football players were trained and had a match on the artificial turf pitch. Total PAH concentrations in the rubber infill were 20-40 mg/kg. The total exposure time was 2.5 h. They had an intensive skin contact with rubber infill as confirmed by black staining of knees, hands, and elbows. All urine of seven non-smoking football players was collected over a 3-day period, the day before sporting, the day of sporting and the day after sporting. Urine samples were analyzed for 1-hydroxypyrene. Confounding exposure from environmental sources and diet was controlled for.
Results	Three players had relatively high background levels of 1-hydroxypyrene, which decreased after the match. Only one player showed a significant increase in elimination after the match; however he also consumed a fried hamburger directly after the match, which may also have caused the increase. The urinary elimination rates before the match ranged from 0.03-0.48 nmol/h, median 0.10 nmol/h and afterwards from 0.03-0.24 nmol/h, median 0.14 nmol/h
Conclusion	The uptake of PAH by football players active on artificial grounds with rubber crumb infill was minimal. If there is any exposure, than the uptake is very limited and within the range of uptake of PAH from environmental sources and/or diet.
Remarks	For more details on the rubber infill analyses, they refer to Hofstra 2007

Reference	**F.J. Jongeneelen and F. Kempeneers 2009: Research into health risks for workers due to rubber infill made from car tires for construction and maintenance of artificial turf [in Dutch - Onderzoek naar gezondheidsrisico's voor werknemers t.g.v. rubberinfill van autobanden bij aanleg en onderhoud van kunstgrasvelden] IndusTox rapport [34]**
Research question	Determine whether the installation and maintenance of rubber infill poses a health risk to workers
Methodology	Background and personal exposure levels were measured of rubber dust, PAHs and VOCs. Urinary 1-hydroxypyrene levels were determined in 9 workers of three locations.
Results	Inhalable dust levels had a geometric mean of 0.75 mg/m^3 and a 95th percentile of 3.7 mg/m^3 during construction. During maintenance, the geometric mean was 0.23 mg/m^3 and the 95th percentile 1.3 mg/m^3. Urinary 1-hydroxypyrene levels were clearly higher in smokers , but there was no clear relation between urinary 1-hydroxypyrene levels and construction/maintenance of rubber infills. VOC levels were all below LODs.
Conclusion	The inhalable dust concentrations are too high during the filling of the pitch, but not during maintenance. There was no clear (statistically significant) increase in exposure to PAHs during maintenance and filling. The concentrations of the VOCs were below the LODs.
Remarks	Report in Dutch

Reference	**Van den Hazel et al., 2006. Study of the health risks of SBR granulate in a synthetic turf pitch at Rijkerswoerd sports centre [Onderzoek gezondheidsrisico's SBR-granulaat in een kunstgrasveld van sportcentrum Rijkerswoerd]. Central Gelderland Health Services [Hulpverlening Gelderland Midden] (Municipal Public Health Services) [55]**
Research question	The aim of this study was to assess possible health risks associated with the use of rubber crumb on synthetic turf pitches, to aid in the decision of the sports club whether or not to use rubber crumb on their field. The sports club had requested the risk assessment in response to messages about health risks of rubber crumb in the media.
Methodology	Air samples were collected at 15 – 50 cm above an existing nearby turf field during soccer training. Reference air samples were taken at the same turf field when no training activities occurred. Samples were analyzed for inhalable dust (PM10) constituents (PAHs, metals), volatile nitrosamines, and VOCs (benzene, toluene, ethylbenzene, xylene, naphthalene). In addition, a crumb rubber sample taken from the field was analyzed for constituents.
Results	The following components were found in the crumb rubber sample: PAHs (antracene, chrysene, fenantrene, fluoranthene, pyrene), heavy metals (Cd, Cr, Fe, Co, Cu, Pb, Ni, Zn) and nitrosamines (NDEA, NDMA) (concentrations are displayed on page 10 of the report). Inhalable dust concentrations (4 samples) varied between 39 – 161 $\mu g/m^3$. Total PAH concentrations were 6,9 $\mu g/m^3$ without sports activities on the field, and 14 $\mu g/m^3$ during sports activities. Cr, Fe, Cu, Pb, Ni and Zn were detected in the air samples. For nitrosamines, only NDEA was detected in the air samples (concentration: 93 ng/m^3). Other nitrosamines and VOCs could not be detected. No elevated health risk was indicated in the risk assessment for PAHs (concentrations multiplied by carcinogenic potency factor) and metals in a realistic worst-case exposure scenario (35 year of playing for 3 days a week, 2 hours a day). For NDEA, a cancer risk of 4.5 per 10,000 was calculated, indicating that the maximum permissible cancer risk (1 per 10,000) is exceeded.
Conclusion	Based on a potential elevated cancer risk related to inhalation exposure to nitrosamines, it is recommended to postpone the use of crumb rubber infill on the new field until more data are available on the possible health risks of exposure to the rubber crumb. An additional health risk assessment was executed for short-term exposure at the measured turf field. This additional risk assessment concluded that, until more data are available on the possible health risks, the risk of continued use of the turf field is acceptable.
Remarks	It is stated that the results of this study cannot be extrapolated to other turf pitches, due to the low number of samples, effect of weather conditions, and sampling at only one turf field. Report in Dutch

Reference	**Schilirò et al 2013: Artificial Turf Football Fields: Environmental and Mutagenicity Assessment [38]**
Research question	To develop an environmental analysis drawing a comparison between artificial turf football pitches and urban areas relative to concentrations of particles (PM10 and PM2.5) and related polycyclic aromatic hydrocarbons (PAHs), aromatic hydrocarbons (BTXs), and mutagenicity

	of organic extracts from PM10 and PM2.5.
Methodology	The following parameters were determined in the presence and absence of artificial turf pitches: the concentration of particles (PM10 and PM2.5); the concentration of related PAHs; the concentration of aromatic hydrocarbons (benzene, toluene, and xylene [BTX]); and the mutagenicity of the organic extracts of the PM and PM2.5
Results	No significant differences were found between PM10 concentrations at an urban site and on a turf football field, both during warm and in cold seasons, either with or without on-field activity. PM2.5 concentrations were significantly greater at the urban site in the cold season as was the ratio of PM2.5 to PM10. BTXs were significantly greater at urban sites than on turf football pitches on both warm and cold days. The ratio of toluene to benzene (T/B ratio) was always comparable with that of normal urban conditions. The concentration of PAHs on the monitored football pitches was comparable with urban levels during the two different sampling periods, and the contribution of PAHs released from the granular material was negligible. PM10 organic extract mutagenicity for artificial turf football pitches was greater, whereas PM2.5 organic extract mutagenicity was lower, compared with the urban site studied. However, both organic extract mutagenicity values were comparable with the organic extract mutagenicity reported in the literature for urban sites.
Conclusion	On the basis of environmental monitoring, artificial turf football pitches present no more exposure risks than the rest of the city.
Remarks	Only air measurements were performed

Reference	**Menichini 2011: Artificial-turf playing fields: Contents of metals, PAHs, PCBs, PCDDs and PCDFs, inhalation exposure to PAHs and related preliminary risk assessment [35]**
Research question	To identify potential chemical risks of substances of concern in rubber granulates and to roughly assess the risk associated with inhalation exposure to PAHs.
Methodology	Rubber granulates were collected from 13 Italian pitches and analysed for 25 metals and nine PAHs. One further granulate was analysed for NDL-PCBs, PCDDs, PCDFs and 13 PAHs. Air samples were collected on filter at two pitches, using respectively a high volume static sampler close to the athletes and personal samplers worn by the athletes, and at background locations outside the pitches.
Results	Of the elements, only zinc occurred in concentrations above the (clean soil)standards (1.1 to 19 g/kg). Copper and tin exceeded the standards in ~half of the samples. The PAH values showed a high variation. The substance of most significant concern was BaP with concentrations ranging from 0.02 to 11 mg/kg. The variation in levels of PAHs and metals was high regardless of the origin of the samples. Aging of the field did result in lower PAH levels. Air measurements showed increases of BaP concentration in the field with respect to background concentration outside the field, varying from approximately < 0.01 ng/m^3, when measured using a static sampler close to the athletes, up to 0.4 ng/m^3 under the presumed worst case scenario, using personal samplers worn by the athletes.
Conclusion	Based on the 0.4 ng/m^3 concentration and using a conservative approach, the calculated excess lifetime cancer risk was 1 × 10− 6 for

	an athlete with an intense 30-year activity. The corresponding risk will be less relevant for discontinuous or amateur users.
Remarks	

Reference	**Bocca et al 2009: Metals contained and leached from rubber granulates used in synthetic turf areas. [67]**
Research question	To quantify metals contained in and leached from different types of rubber granulates used in synthetic turf areas.
Methodology	Leachates were prepared by extraction of about 5.0 g of material at room temperature for 24 h in an acidic environment (pH 5) and various metals were determined by HR-ICP-MS and ICP-OES
Results	The highest median values were found for Zn (10,229 mg/kg), Al (755 mg/kg), Mg (456 mg/kg), Fe (305 mg/kg), followed by Pb, Ba, Co, Cu and Sr. The other elements were present at few units of mg/kg. The highest leaching was observed for Zn (2300 µg/l) and Mg (2500 µg/l), followed by Fe, Sr, Al, Mn and Ba. Little As, Cd, Co, Cr, Cu, Li, Mo, Ni, Pb, Rb, Sb and V leached, and Be, Hg, Se, Sn, Tl and W were below quantification limits.
Conclusion	Data obtained were compared with the maximum tolerable amounts reported for similar materials, and only the concentration of Zn (total and leached) exceeded the expected values.
Remarks	

Reference	**Ruffino et al 2013: Environmental Sanitary Risk Analysis Procedure Applied to Artificial Turf Sports Fields [39]**
Research question	Do the chemicals released from rubber infill pose a risk to the users of artificial turf fields?
Methodology	A Tier 2 environmental–sanitary risk analysis on five artificial turf sports fields located in the city of Turin (Italy) was performed with the aid of RISC4 software. Two receptors (adult player and child player) and three routes of exposure (direct contact with crumb rubber, contact with rainwater soaking the rubber mat, inhalation of dusts and gases from the artificial turf fields) were considered in the conceptual model.
Results	The pyrene concentration was approximately 20 mg/kg. Similarly, B(a)A was contained in all the SBR samples (n=6), with a concentration of about 10 mg/kg. Zinc showed the highest levels of the metals. Also iron, cobalt and manganese were detected at significant levels in spite of the efforts to separate steel from the crumb rubber. High concentrations of barium are possibly a result of its use to catalyze the synthesis of polybutadiene rubber. Lead was also identified, possibly due to the use of lead oxide as an activator of the vulcanization process. For all the pitches and for all the routes, the cumulative carcinogenic risk proved to be lower than 10−6 and the cumulative non-carcinogenic risk lower than 1. The cumulative CR due to the inhalation of contaminants from traffic was equal to 2.0 × 10−6 for the child receptor and 2.8 × 10−6 for the adult receptor. The non-carcinogenic risk was equal to 0.23 for the child receptor and 0.062 for the adult receptor.
Conclusion	The outdoor inhalation of dusts and gases was the main route of exposure for both carcinogenic and non-carcinogenic substances. The results given by the inhalation pathway were compared with those of a risk assessment carried out on citizens breathing gases and dusts from

	traffic emissions every day in Turin. For both classes of substances and for both receptors, the inhalation of atmospheric dusts and gases from vehicular traffic gave risk values of one order of magnitude higher than those due to playing soccer on an artificial field.
Remarks	In the model, the assumed exposure time for children was 6 years and for adults 30 years, which explains why the calculated carc risk for children was lower

Reference	**Castellano et al 2008: Assessment of exposure to chemical agents in infill material for artificial turf soccer pitches: development and implementation of a survey protocol. [56]**
Research question	To develop and implement a survey protocol to assess exposure of artificial turf pitches users (e.g., coaches and maintenance personnel) through environmental and biological monitoring of toxic and carcinogenic substances contained in some types of infill materials for artificial turf pitches.
Methodology	The exposure was assessed by personal and environmental sampling of hazardous substances during 3 days - particularly of benzene, toluene, xylene (BTX), polycyclic aromatic hydrocarbons (PAHs) and heavy metals (lead, cadmium, chromium, tin and zinc) - for comparison with the occupational exposure limit values as per the Italian regulations and the lists of the American Conference of Industrial Governmental Hygienists (ACGIH). In addition, biological monitoring was performed for the quantitative and qualitative determination of the exposure biomarkers of the substances of interest in potentially exposed individuals and in control group.
Results	Most samples contained BTEX compounds, probably due to urban background levels, while metal levels were all <LOD. Most PAHs were below LOD except pyrene, naphthalene, fluoranthene, and phenanthrene.
Conclusion	The analytical results from the first monitoring campaign revealed the critical points to be addressed for completing the research, in consideration that the majority of artificial turf soccer pitches in Italy are outdoors. Thus, in order to refine the entire exposure assessment process, it would be necessary to perform a series of environmental and personal monitoring operations to be repeated on various days and seasons, under different meteorological conditions and on pitches characterized by different recent and older infill materials. Moreover, a series of reference data would be needed to compare hourly, daily and seasonal fluctuations of the pollutant concentrations of interest in the surrounding urban environment.
Remarks	Only air sampling

Reference	**Marsili et al 2014: Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes [37]**
Research question	The aim of this study was to determine the levels of metals and PAHs in rubber granulates and to estimate the "hazard" for athletes inhaling PAHs released at the high temperatures this synthetic turf may reach.
Methodology	In nine samples of rubber crumb the total content of some heavy metals (Zn, Cd, Pb, Cu, Cr, Ni, Fe) normally found in tyres was determined by microwave mineralization and the levels of the 14 US EPA priority PAHs by Soxhlet extraction and HPLC analysis.

	A risk assessment at 25°C was done, using the Average Daily Dose (ADD) assumed by athletes, expressed in terms of mass of contaminant per unit of body weight per day (mg/kg day), and the Lifetime Average Daily Dose (LADD) and then evaluating the Hazard Index (HI) and the Cumulative Excess Cancer Risk (ΣECR).
Results	The results showed high levels of PAHs (highest sum 58211.37 ng/g) and zinc (3474-13202 mg/kg) in all rubber crumb samples compared to rubber granulate limits set by Italian National Amateur League (LND). The levels of contaminants decreased with the aging of the pitches. In the different rubber granulates samples the HI ranges from a minimum of 8.94×10^{-7} to a maximum of 1.16×10^{-6}, while the ΣECR ranges from a minimum of 4.91×10^{-9} to a maximum of 1.10×10^{-8}.
Conclusion	The toxicity equivalent (TEQ) of evaporates from rubber crumb is not negligible and represents a major contribution to the total daily intake of PAHs by different routes.
Remarks	

Reference	**Ecopneus (2016): CHARACTERIZATION OF RUBBER RECYCLED FROM ELTs AND ASSESSMENT OF THE RISKS ASSOCIATED WITH DERMAL AND INHALATION EXPOSURE. Fornai D., Ecopneus; version 03- 2016 [36]**
Research question	To determine the PAH content in granulates recycled from different classes of ELTs To determine the PAH migration rate in sweat and pulmonary surfactant To assess the carcinogenic risk to dermal and inhalatory exposure to recycled rubber
Methodology	The rubber recycled from the different classes of tyres (from 5 facilities) has been subjected to extensive chemical and physical analyses at four different laboratories, allowing the quantification of the PAH content with different test methods. Subsequent leaching tests in biological liquids (sweat and pulmonary surfactant) have allowed the migration coefficients of the PAHs to be determined and the quantification of their potential bioavailability in different exposure scenarios. Monitoring of dermal and inhalation exposure of workers during the installation of three new synthetic turf pitches infilled with rubber recycled from ELTs and one field infilled with material of plant origin has been completed. To verify the effective absorption of PAHs by subjects exposed to the rubber, the urine 1-hydroxypyrene content of 15 volunteers was monitored before and after exposure to tyre recycled rubber.
Results	• The PAH content1 in rubber recycled from ELTs varies on average between 5 and 10 mg/kg; • The ban on using aromatic oils for the production of tyres has led to a reduction of the PAH content in recycled rubber; a progressive, albeit limited reduction of this value is likely for another 3-4 years, due to the reduced presence of tyres produced before 2010 (the year that the ban entered into force) among the ELTs sent for recycling; • Despite the elimination of aromatic oils from the mixtures, the content of benzo(e)pyrene is on average between 2 and 4 mg/kg while the content of benzo(a)pyrene varies on average

<table>
<tr><td></td><td>between 1 and 2.5 mg/kg;

Migration tests of PAHs in artificial sweat (24 h @ 37°C) confirm the low bioavailability of these molecules contained in vulcanized rubber, with maximum release values measured for benzo(b)+(j) fluoranthene (<0.2 ng/g of rubber) and benzo(a)anthracene (<0.1 ng/g of rubber) equivalent to migration factors much less than 0.1% for each substance (PAH migration rates were <0.007%);
These migration values allow the release of rubber PAHs by simple dermal contact to be defined as highly improbable;
The monitoring performed during the installation of rubber infill and during the use of the playing field confirm the observations of international studies, i.e. a value of total incremental carcinogenic risk that is significantly lower (by an order of magnitude) than that recommended for the general population of 1x10-6;

<table>
<tr><th></th><th>Incremental carcinogenic risk –Inhalation-</th><th>Incremental carcinogenic risk -Dermal-</th></tr>
<tr><td>Athletes</td><td>1.43 x 10^{-8}</td><td>3.11 x 10^{-7}</td></tr>
<tr><td>Workers</td><td>7.73 x 10^{-9}</td><td>1.96 x 10^{-7}</td></tr>
</table>

During all of the monitoring performed, the concentration of PAHs measured in the air is consistent with the level of local atmospheric pollution, with a greater concentration of fine particulates and pollutants in the winter with respect to the values measured in the summer.
</td></tr>
<tr><td>Conclusion</td><td>The information acquired allows the confirmation of an absence of risks associated with the use of rubber recycled from tyres.
It is also necessary to stress the homogeneity of the PAH content in the 25 samples analysed, with values much lower than those occasionally reported in the literature. It is therefore likely that the samples of “rubber” taken directly from playing fields, which in some cases returned anomalous concentrations of PAHs, did not originate from the recovery of ELTs but most probably from other elastomeric materials (gaskets, brake tubes, etc.) erroneously identified by researchers as “tyre recycled rubber”.</td></tr>
<tr><td>Remarks</td><td>There are several preliminary reports, this abstract is from the file ECOPNEUS, Characterization of rubber, report, 2016</td></tr>
</table>

Reference	**Källqvist (Kopangen) 2005: Environmental Risk Assessment of Artificial Turf Systems [126]**
Research question	What is the environmental risk linked to run-off from artificial turf pitches
Methodology	The content and leaking potential of hazardous substances in the materials used was investigated.
Results	
Conclusion	The risk was mainly attributed to zinc, but also for octylphenol the predicted environmental concentration exceeded the no environmental

	effect concentration. The total annual amounts of hazardous substances leaching from a normal sports ground are fairly low which means that any environmental effects are expected to be local only.
Remarks	Very short summary (also of the report) and only environmental risk investigated

Reference	**Potential health and environmental effects linked to artificial turf systems-final report. Plesser, T; Lund, O. Byggforsk - Norwegian Building Research Institute, Trondheim, Norway, Project #O- 10820; 2004 [52]**
Research question	To study the potential health and environmental effects linked to artificial turf systems on behalf of the Norwegian Football Association (NFF)
Methodology	Three rubber granulates, one EPDM rubber and two artificial turf fibres were analysed with regard to the total content of arsenic, cadmium, copper, chromium, mercury, nickel, zinc, PCB, PAH, phthalates and phenols. Leachate tests and degassing tests were also carried out. The results are compared with Norwegian and foreign limits for soil and water.
Results	The PAH (16) levels varied from 51-76 mg/kg rubber granulates. In the leachate, a total of < 0.01 µg/L each of benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3,cd)pyrene, benzo(g,h,i)perylene and benzo(a)pyrene was found. Only one sample contained measurable quantities of PCBs (total (7) 0.202 mg/kg. The max values for the metals that were detected were 20 mg/kg lead, 2 mg/kg cadmium, 70 mg/kg copper, 0.04 mg/kg mercury, and 17000 mg/kg zinc. Of the phthalates, DINP and DEHP had the highest levels (resp 57-78 mg/kg and 21-29 mg/kg). With the exceptions of chromium and zinc, EPDM rubber contains smaller quantities of hazardous substances than the recycled rubber types overall. It also gives off much smaller quantities of volatile organic compounds.
Conclusion	The total analysis shows that the rubber granulates based on recycled rubber contain lead, cadmium, copper, mercury, zinc, polycyclic aromatic hydrocarbons (PAH), certain phthalates, 4-t-octylphenol and iso-nonylphenol. The chemical composition of products from a single manufacturer can vary considerably for individual parameters. However, products from two different manufacturers can also show great similarity. Stricter controls on rubber granulates by manufacturers, possibly in the form of a product control scheme, could give greater homogeneity and predictability with regard to chemical composition.
Remarks	

Reference	**NILU, 2006. Measurement of air pollution in indoor artificial turf halls, Norwegian Institute for Air Research (NILU). Report: NILU OR 03/2006. C. Dye, A. Bjerke, N. Schmidbauer, S. Manø. [28]**
Research question	Measurements of air quality in three indoor artificial turf pitches, to be used as a basis for exposure calculations and health risk assessment. Measurements focused on airborne dust (PM10 / PM2.5) concentrations

	and the presence of rubber, vulcanization compounds, preservative compounds, phthalates and PAH in the airborne dust, as well as the presence of VOC and PAH in the gas phase.
Methodology	Airborne dust samples were taken with active sampling using quartz fiber filters or glass fiber filters. Active sampling was also used for VOC analysis. Filters were extracted and analyzed for different compounds. Concentrations were compared to available national limits for outdoor or indoor air.
Results	Quantitative concentrations are presented per compound. In addition, by measuring the weight of the rubber granulates and comparing with the measured rubber content of the granulates, a quantitative estimation of oral exposure (swallowing of granulate) was made: people who swallow granulates will be exposed in the range of 0,1 – 1000 ng for each chemical, depending on the chemical and granulate type.
Conclusion	The quantity and composition of the airborne dust differed between the three sampled sports halls. In all three halls, a considerable proportion of organic material and presence of PAHs, phthalates, semi-volatile organic compounds, benzothiazoles and aromatic amines were found in the airborne dust. In two of the three halls, high concentrations of total VOC were found.
Remarks	The measured concentrations reported in this study have been used as input for health risk assessment in another Norwegian report (http://www.isss-sportsurfacescience.org/downloads/documents/74wa3x7e22_fhiengelsk.pdf)

Reference	**Norwegian Institute of Public Health and the Radium Hospital, 2006. Artificial turf pitches – an assessment of the health risks for football players.** http://www.isss-sportsurfacescience.org/downloads/documents/74wa3x7e22_fhiengelsk.pdf **[31]**
Research question	To estimate the potential risk of cancer and genotoxicity as a result of exposure to artificial turf pitches
Methodology	Information on the occurrence and concentrations of chemical substances in rubber granulate and release of these substances in the air was obtained from the report "Measurement of air pollution in indoor artificial turf sports halls" by the Norwegian Institute for Air Research (2006). Measured concentrations from that study were summed per substance category (PCBs, PAHs, phthalates, alkyl phenols and VOCs) and compared with available NOAEL values for e.g., cancer, reproductive damage and organ damage. In total, nine exposure scenarios were used: inhalation and skin exposure for children (7-11 years), older children (12-15 years), junior (16-19 years) and adults (> 20 years), and oral exposure for children only. Managers of two Norwegian sports halls provided information on duration and frequency of exposure, on which worst case scenarios were constructed per age group. In these worst case exposures scenario's, 100% absorption was assumed for dermal and oral uptake.
Results	A Margin of Safety (MOS) was calculated for each estimated exposure for each available NOAEL. For inhalation exposure to VOCs, a possible risk of irritation was found for limonene, and formaldehyde. For benzoic acid, estimated MOS

	ranged from 193 – 617 based on a NOAEL of 5 mg/kg/day for increased number of resorptions in rats. For xylene, MOS were 5600 – 5700 based on a NOAEL for neurological effects in humans. MOS for toluene, styrene, benzene and benzothiazole indicated negligible risks. For benzene, a maximum 'worst case lifetime cancer risk' if 0,2 *10-5 was calculated, which is considered negligible or tolerable. For inhalation exposure to PAHs it was estimated that no additional cancer risk was caused by PAH exposure. For inhalation exposure to phthalates, MOS estimates ranged from 23.000 – 80.000. For inhalation exposure to alkyl phenols, MOS estimates ranged from 83.000 – 300.000. No risk characterization was carried out for skin contact with PCBs, PAHs, phthalates and alkyl phenols, because exposure to these substances via the skin is extremely low. For oral intake, MOS estimates were 1700 and 1150 for 6 months oral exposure to phthalates and alkyl phenols, respectively. For repeated exposure, exposure estimates were 11,0 microgram/kg body weight/day for both substances.
Conclusion	Based on the estimated exposure values and the doses/concentrations that can cause harmful effects in humans or animal experiments, it was concluded that the use of artificial turf in sports halls does not cause any elevated health risk. This applied to children, older children, juniors and adults. The possibility that the use of car tyres could lead to exposure to latex allergens cannot be ruled out, however, at the moment the available knowledge in this area is insufficient to perform a risk assessment for the development of asthma and airway allergies.
Remarks	From the PowerPoint presentation (http://www.isss-sportsurfacescience.org/downloads/documents/KH9NGAKRFF_Health_risk_artificial_turf_pitches_oct_06.pdf) it states that MOS > 100 is regarded as safe.

Reference	**Danish EPA, 2005. Emissions and evaluation of health effects of PAH's and aromatic mines from tyres. N.H. Nilsson, A. Feilberg and K. Pommer. Danish EPA, Danish Technological Institute, Survey of Chemical Substances in Consumer Products, No. 54. [48]**
Research question	To investigate the presence of hazardous substances in tyres that are used in playgrounds, as well as migration of these substances from the tyres, and assessment of related health risks.
Methodology	Twenty tyres (commonly used in playgrounds as e.g. swings, tight-rope walking and sandpits) and 2 falling protection tiles made of granulated tyre rubber were sampled and analysed using TLC-screening and GC/MS. Migration tests were performed using artificial sweat. A health risk assessment was performed based on the measured concentrations of PAHs and other substances. NOAEL/LOAEL levels and reference doses were obtained from literature for the selected substances. A worst case scenario for the dermal route was described as a child that is exposed on a skin area of 200 cm^2 for one hour, five times a week, during one year. A worst case scenario for the oral route

	was described as a child weighing 10 kg, that ingests 10 g of sand contaminated with migrated substances from the tyre, five times a week for 6 months, assuming 100% oral absorption.
Results	All investigated tyres contained a number of PAHs in varying concentrations, and also high concentrations of aromatic amines (para-phenylene-diamines) (individual concentrations are presented on page 26). Migration studies with artificial sweat indicated that only the most water soluble PHAs and aromatic amines migrate to the sweat. Measurable amounts of the following substances were detected: fluoranthene, pyrene, 6PPD and IPPD. The health risk assessment indicated that for the investigated substances (fluoranthene, pyrene, 6PPD, IPPD, and benzo[a]pyrene) the estimated Margin of Safety (MOS) varied from 10.000 to more than a million. For the other identified PAHs, a MOS of 750.000 was estimated.
Conclusion	The potential health risk related to use of discarded tyres on playgrounds is insignificant.
Remarks	Analyses and risk assessment were mainly performed for whole tyres, not for granulated tyres. One rubber tile was sampled and analyzed in the migration test. A migration test from a tractor tyre to sand was also performed. There, it was concluded that the most important source for PAHs in the sand was atmospheric dry deposition, and not migration from the tyre.

Reference	**Danish EPA (2008). Mapping Emissions and Environmental and Health Assessment of Chemical Substances in Artificial Turf. Danish Environmental Protection Agency. Nilsson, NH; Malmgren-Hansen, B; Sognstrup Thomsen, U. Survey of Chemical Substances in Consumer Products, No. 100 [49].** http://sportengemeenten.nl/wp-content/uploads/2016/10/Danish_investigations_of_artificial_turf-2008.pdf
Research question	The aims of the project were mapping of artificial turf products on the Danish market, analysis of materials included in the artificial turf pitches, chemical analysis, description of exposure scenario's, and health and environmental assessment.
Methodology	An investigation was carried out of the materials and chemical substances that are used in artificial turf pitches in Denmark. A literature survey was conducted for health and environmental risks from artificial turf pitches, in which studies from Norway, Sweden, The Netherlands, Switzerland and France were included. Samples from elastic infills, artificial turf mats and pads were analyzed semi-quantitatively for emission of volatile substances in a headspace screening and for organic component content in sample extracts, using GC/MS. Zinc content was quantified using ICP-AES. Also, leaching tests were performed. In addition, microscopy was performed on filtered-off fine dust particles from two of the leaching tests. Based on results of leaching tests, four substances were selected that were considered to be representative of harmful substances emitted from the products: benzothiazole, dicyclohexylamine, cyclohexanamine and dibutyl phthalate. Investigated exposure routes were the dermal and oral route.
Results	Results of the headspace analysis and the organic content analysis are

	tabulated on page 53 – 54 of the report. For the frequency and duration of exposure, an exposure scenario obtained from the Norwegian studies was selected as a worst case starting point. Possible health risks based on the exposure scenario were assessed for each of the four selected substances (benzothiazole, dicyclohexylamine, cyclohexanamine and dibutyl phthalate). For benzothiazole, a Margin of Safety (MOS) for dermal and oral uptake was estimated at 200.000 and it was assessed that there may be an allergy risk for sensitive individuals. For cyclohexanamine, the estimated MOS for skin uptake was 10.200 and the estimated MOS for oral uptake was at the same level; a risk of allergic reactions is mentioned for particularly sensitive individuals. For dicyclohexylamine, the estimated MOS was 157.00 for skin uptake, and the estimated MOS for oral uptake was at the same level; also here a risk of allergic reactions is mentioned for particularly sensitive individuals. For dibutyl phthalate, a MOS for oral uptake was estimated at 314.000 and the MOS for skin uptake was estimated to be 10 times higher.
Conclusion	The health risk assessment indicated no health risks for exposure to the selected substances, with the exception of possible allergenic risk for individuals sensitive to benzothiazole and amines.
Remarks	In reaction on previous Swedish and Norwegian reports, use of granules based on car tyres has in several cases been replaced with granules from grey industrial rubber in Denmark. Environmental risk assessment, including the effect of salting the pitches in winter, is extensively described in the report. Those results are not included in this summary.

Reference	**KEMI, 2006. Synthetic turf from a chemical perspective – a status report. Swedish Chemicals Inspectorate, PM 3/06 [127].** https://www.kemi.se/global/pm/2006/pm-3-06-en.pdf
Research question	The report is intended to discuss the properties and use of synthetic turf that contains granulate from recycled tyres for football pitches, from a chemical perspective. It should serve as a basis for product development in synthetic turf companies and for facilitating local decisions and assessments.
Methodology	Literature review, including earlier assessment reports by Sweden and Norway and European guidelines and standards.
Results	The main findings and conclusions of several literature reports are described.
Conclusion	Synthetic turf contains substances of very high concern, such as PAHs, phthalates and metals. Nevertheless, this does not necessarily mean that there is a direct risk for human health, as the risk for human health depends on the extent of exposure. However, the exposure levels and any allergic reactions have been poorly studied. KEMI recommends that synthetic turf that contains substances of very high concern should not be used when laying new surfaces. However, existing synthetic turf surfaces may remain in place, since the current health and environmental risks are assessed as being small.
Remarks	Assessed literature focused mainly on inhalation route of exposure. Environmental risks were also described, but they are not included in this summary.

Reference	**Sadiktsis 2012: Automobile Tires - A Potential Source of Highly Carcinogenic Dibenzopyrenes to the Environment [128]**
Research question	To determine dibenzopyrenes in tires in order to evaluate the importance of automobile tires as a source of dibenzopyrenes to the environment using a previously developed method for the 15 HMW (>252 Da) PAHs;
Methodology	Eight tires were analyzed for 15 high molecular weight (HMW) polycyclic aromatic hydrocarbons (PAH), using pressurized fluid extraction.
Results	The variability of the PAH concentrations determined between different tires was large; a factor of 22.6 between the lowest and the highest. The relative abundance of the analytes was quite similar regardless of tire. Almost all (92.3%) of the total extractable PAH content was attributed to five PAHs: benzo[ghi]perylene, coronene, indeno[1,2,3-cd]pyrene, benzo[e]pyrene, and benzo[a]pyrene. The difference in the measured PAH content between summer and winter tires varied substantially across manufacturers, making estimates of total vehicle fleet emissions very uncertain. However, when comparing different types of tires from the same manufacturer they had significantly (p = 0.05) different PAH content. The four dibenzopyrene isomers dibenzo[a,l]pyrene, dibenzo[a,e]pyrene, dibenzo[a,i]pyrene, and dibenzo[a,h]pyrene constituted <2% of the sum of the 15 analyzed HMW PAHs.
Conclusion	These findings show that automobile tires may be a potential previously unknown source of carcinogenic dibenzopyrenes to the environment.
Remarks	

Reference	**Llompart et al, 2013. Hazardous chemicals in rubber recycled tyre playgrounds and pavers. Chemosphere, vol. 90, issue 2 [129].** http://www.sciencedirect.com/science/article/pii/S0045653512009848
Research question	Investigation of hazardous organic chemical content of playground surface from recycled tyres, and release of compounds into the air from this material.
Methodology	Seventeen samples of floor tiles compositions and carpet covers were taken from nine different urban playgrounds in the Northwest of Spain. In addition, seven commercial samples (two puzzle pavers and five recycled rubber tyre tiles of different colours) were obtained in a local store of a multinational company. Sixteen different PAHs and fifteen other compounds (vulcanization additives, antioxidants and plasticizers) were analyzed in the sample extracts using GC-MS. In addition, headspace analysis of the samples was performed using SPME.
Results	For the 16 PAHs and 15 other compounds analyzed, the average, median, minimum and maximum concentrations are given. All samples contained PAHs, and the total amount of PAHs per sample varied between 1,25 µg/g – 178 µg/g with a median of 8,42 µg/g. The commercial paver samples showed a considerably higher PAH content compared to the playground samples (median 2812 µg/g; range 396 – 18.699 µg/g). Also for phthalates the concentrations in the commercial samples were much higher than in the playground samples, with the exception of DINP. Many of the target compounds were also qualitatively detected in the headspace analysis. All the PAHs identified in the playground samples

	were identified in the vapour phase at 60°C and at 25°C.
Conclusion	The use of this kind of materials on fields or playgrounds for children should be reconsidered. These materials should be carefully controlled and their final use should be restricted or even prohibited in some cases.
Remarks	

Reference	**Celeiro et al, 2014. Investigation of PAH and other hazardous contaminant occurrence in recycled tyre rubber surfaces. Case-study: restaurant playground in an indoor shopping centre. *International Journal of Environmental Analytical Chemistry,* vol. 94, issue 12. [130]**
Research question	Investigate presence of PAHs and other hazardous organic chemicals in a recycled tyre playground surface
Methodology	Playground samples were extracted and analysed by GC-MS and by HS-SPME. Compounds were measured in extracts, in vapour phase, and also in runoff water to determine leaching.
Results	Fourteen of the 16 studied PAHs were identified in the extracts and nine of the 16 PAHs also in the vapour phase. Nine PAHs were identified in the runoff/cleaning water, with a total PAH concentration at the ppm level.
Conclusion	The identification of these hazardous compounds in the playground samples are a reason for concern.
Remarks	Summary based on abstract only.

Reference	**R. Moretto, 2007. Environmental and Health Evaluation of the Use of Elastomer Granulates (Virgin and From Used Tyres) as Filling in Third-generation Artificial Turf. Moretto R. ALIAPUR in partnership with Fieldturf Tarkett and the ADEME (Environmental French Agency), France [40].** http://c.ymcdn.com/sites/syntheticturfcouncil.site-ym.com/resource/resmgr/Docs/environmental_and_health_ass.pdf
Research question	Study initiated by the joint organization of tyre manufacturers in France (ALIAPUR) in partnership with Fieldtuf Tarkett (producer of artificial turf, part of which stems from recycled tyres and other types of rubber) and the Environmental French Agency (ADEME), to evaluate the environmental and health impacts of the different materials used as filling in artificial turf. Environmental impact was studied by analysis of substances present in rain percolate collected after transfer through different constituent materials of the sporting surface, and ecotoxicity tests performed with the percolate. Regarding human health impact, a health risk evaluation was performed by INERIS (French National Institute of Health Risk Evaluation) for inhalatory exposure to VOCs and formaldehyde in an indoor sports surface usage scenario (worst case).
Methodology	Three types of artificial turf were tested, originating from 1) recycled car tyres, 2) ethylene propylene diene monomer (EPDM), and 3) thermoplastic elastomer (TPE). Both field experiments and experiments in a laboratory setting were performed. Results of the ecotoxicity tests are not included in this summary. VOCs and formaldehyde emissions were measured in controlled emission test chambers according to ISO 16000-9. In total, 112 individual substances were measured. INERIS evaluated acute and chronic exposure based on the emission

	tests and modelled exposure scenario's for workers, professional athletes and coaches, amateur athletes and spectators in an indoor gymnasium.
Results	Concentration profiles in the percolate over time are given for sulphate, chloride, metals (arsenic, zinc, copper, lead), and the sum of 6 PAHs (benzo[k]fluoranthene, fluoranthene, benzo[b]fluoranthene, benzo[a]pyrene, indeno[1,2,3-cd]pyrene and benzo[g,h,i]perylene). Emission of total VOCs decreased significantly between sampling day 1 and 3. At 28 days, the TVOC emission of artificial turf containing used tyre granulates was 134 µg/m^3. The modeled maximum VOC concentrations in the gymnasium were of the same magnitude as ubiquitous ambient air concentrations in France.
Conclusion	Concentrations of organic composites, metals and anions of the percolates were compatible with water resource quality requirements. For the athletes and the general public, no health concerns from VOC and aldehyde emissions from the artificial floors were expected. INERIS concluded that for the health risks associated with inhalation of VOC and aldehydes emitted by artificial turf in outdoor situations, there is no actual cause for concern.
Remarks	For workers who are exposed for over 5 years while installing artificial surfaces in small and poorly ventilated gymnasiums a health risk could not be excluded; it was recommended that during installation an air renewal rate of at least 2 vol./h is assured.

Reference	**Savary and Vincent, 2011. Used Tire Recycling to Produce Granulates: Evaluation of Occupational Exposure to Chemical Agents. Ann Occup Hyg 55(8), 931-936 [131]**
Research question	Occupational exposure assessment of workers in granulation facilities
Methodology	Air sampling for workers' personal exposure measurement (4 – 8 hr; n = 30) and stationary sampling (n = 21) was carried out in four different granulation facilities, that differed slightly in process conditions. In addition, dust samples were obtained from deposited dust on the installations and analyzed using Scanning Electron Microscopy, and volatile organic compounds (VOC) in the workshop atmosphere were sampled using multibed sorbent tubes (n = 6).
Results	Inhalable dust exposure levels (8-h TWA) varied from 0,31 mg/m^3 – 41,0 mg/m^3, with median levels ranging from 0,58 – 3,95 mg/m^3 and 75% percentiles ranging from 4,05 – 12,0 mg/m^3. The ambient inhalable dust concentrations ranged from 0,17 – 6,23 mg/m^3. The electron microscopy picture of the sampled settled dust indicated presence of carbon and sulphur particles with silica and iron oxide at their surface, with particle sizes ranging from nanometer size to 150 micrometer. Furthermore, textile fibres were detected with an average length of 830 micrometer and a median diameter of 15 micrometer. No VOCs were detected (detection limit: 1 ppm).
Conclusion	No conclusion was provided based on the data presented in this study. It was recommended that prevention measures, such as adapted exhaust ventilation and medical surveillance of workers, should be present in granulation facilities.
Remarks	It was noted that the measured inhalable dust concentrations cannot be compared with the 8-hr OEL for general 'nuisance dust', as the microscopic analysis indicated presence of carbon black, sulphur,

	silicon, and iron oxide.

Reference	**Kolitzus 2006: Investigation and Assessment of Synthetic Sports Surfaces in Switzerland Including Athletic and Soccer Facilities [132]**
Research question	To get data of what is really released from sports surfaces to water running off the surfaces and probably contaminating rivers or the underground. The incentive for the study is that the wrong method was used for years.
Methodology	The total amount of rain water seeping through or running off ten sports surfaces has been collected and analyzed.
Results	Zinc concentrations: 0.009 to 0.003 mg/l Sum of all 16 PAHs is about 0.1 to 0.3 µg/l. None of the surface systems including the surfaces with recycled granules showed any noticeable PAH concentration. In surface systems with EPDM and recycled rubber infill several aromatic Amino complexes and Benzothiazoles were determined in the range of 10 – 300 µg/l.
Conclusion	Although a final assessment of the health risks is not possible acc. to the data available today, the estimatable PAH stress is low even in worst case scenarios compared with stress from other sources. The health risk for players and spectators is classified low. Thus, from the health point of view no urgent need of action is seen.
Remarks	Limited study, only run-off measurements

Reference	**National Institute for Health and Welfare (THL), 2015: Air quality problems related to artificial turf fields in indoor football arenas. Report 10/2015; [133]** **Pennanen et al, 2014. VOCs and ordinary dust responsible for impaired air quality in indoor football arenas with artificial turf fields. Poster [134]** **Pennanen et al, 2013. Artificial turf field as a source of harmful air pollutants in indoor football arenas. Poster [135]**
Research question	What is the effect of chemical composition of rubber granulates, type of indoor football arena, and performance of mechanical ventilation on the levels of air pollutants.
Methodology	Four permanent arenas and two pressurized canvas domes were studied during usual daily activity in the end of winter season. VOC samples and particulate samples for PAH and metal analyses were collected along with continuous monitoring of fine (PM2.5), thoracic (PM10), and coarse particles. VOC emissions and PAH contents were analyzed from rubber granulates vacuum-sampled from the field surface. Health symptoms and nuisance experienced by football players were investigated using a structured questionnaire.
Results	The total PAH contents of vacuum-cleaned SBR granulate samples were clearly higher (38–81 mg/kg) than those of other types of rubber granulates (TPO 0.1 mg/kg, EPDM 1.5 mg/kg). However, all indoor air PAH concentrations were very low. The VOC emission from rubber granulates, especially SBR (styrene butadiene rubber), consisted mostly of aldehydes and ketones, which together with benzothiazole were frequently found also in the indoor air of arenas. These

	compounds may irritate the respiratory tract, the eyes and the skin. The indoor PM10 concentrations (10–20 µg/m^3) were comparable to urban outdoor levels and mainly due to infiltration of outdoor air. Coarse dust measured inside arenas likely had an indoor source (e.g. bottom field layer of sand, dirt transported from outdoors). The measured ventilation air supply, especially in permanent arenas, failed to meet the guideline level for sports arenas. Increased ventilation in two arenas reduced the VOC and CO2 concentrations but did not affect the PM10 levels. More than half (49/90) of adolescent football players reported at least one symptom or nuisance (sore throat, running nose, eye or skin irritation, odd smell, dusty air). The indoor air of all studied arenas was reported to cause some harm.
Conclusion	The report makes a recommendation that SBR granulates cannot be recommended as fillings in artificial turf pitches in indoor football arenas, although they are highly unlikely to cause significant exposure to dust or persistent organic compounds. It is recommended that new installations of all types of fresh rubber granulates in permanent indoor arenas are done in May, and the arena is, thereafter, efficiently ventilated in the summer. The mechanical air exchange and control systems, including CO2-sensors, should be checked in all arenas. The fresh ventilation air supply should be adjusted to meet the Finnish guideline level 2 dm³/s/m^2 when necessary.
Remarks	Finnish study, abstract and posters in English

Reference	**Beausoleil et al 2009: Chemicals in Outdoor Artificial Turf: A health risk for users? [136]**
Research question	What are the toxicological risks of the chemicals contained in or emitted by artificial turf used for outdoor sports
Methodology	Literature review following the following points: Identification of the measured concentrations of chemicals associated with artificial turf material to compare them with various threshold limit values established to protect the health of the general population (threshold limits for concentrations in materials, concentrations discharged into water by the materials in the laboratory and in the field, concentrations emitted into the air in the laboratory and those measured in outdoor air or indoor air in gymnasiums). Review and evaluation of the results of toxicological risk analyses for users of artificial turf conducted by various recognized agencies. Reporting the findings of the ministries of public health and the environment in several countries (in EU: No, SW, and Swiss) regarding the potential health risks of the chemicals associated with artificial turf for users and their recommendations regarding the use of the various materials in the manufacture and installation of artificial turf.
Results	
Conclusion	The health risks for players who use artificial turf are not significant and that it is completely safe to engage in sports activities on this type of outdoor field. Although metal analyses have identified the presence of chromium, cobalt and lead in certain materials, these metals are not mobilized by rainwater or emitted into the air. Moreover, although zinc concentrations measured in all the materials were higher, zinc has low toxicity in humans and the concentrations

	measured in water are generally below the limit value for drinking water in Canada. The concentrations of organic compounds (volatile and semi-volatile compounds and polycyclic 8 aromatic hydrocarbons) do not exceed the limit values established to protect human health. The various toxicological risk assessments carried out by recognized agencies indicate that health risks for players are not a concern. It should be noted that the small number of countries that have chosen to avoid SBRr aggregates in the construction of new artificial turf pitches still believe that the health risks associated with these materials are very low and state that their choice is based solely on environment objectives.
Remarks	Literature review, no actual concentrations but indications of type of compounds and quantities

Reference	**Birkholz et al 2003: Toxicological evaluation for the hazard assessment of tire crumb for use in public playgrounds. [137]**
Research question	To evaluate and address potential human health and environmental concerns associated with the use of tire crumb in playgrounds.
Methodology	Human health concerns were addressed using conventional hazard analyses, mutagenicity assays (3 samples in 3 bacterial assays), and aquatic toxicity tests of extracted tire crumb.
Results	No positive response either with or without metabolic activation in any test. 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.
Conclusion	The use of tire crumb in playgrounds results in minimal hazard to children and the receiving environment.
Remarks	The conclusion stretches too far by stating that there is no risk to children from such limited testing.

Reference	**US EPA 2009: A Scoping-Level Field Monitoring Study of Synthetic Turf Fields and Playgrounds [41]**
Research question	To gain experience conducting multiroute field monitoring of recreational surfaces that contain tire crumb by evaluating readily available methods for measuring environmental concentrations of tire crumb constituents; and to generate limited field monitoring data that will be used by EPA to help the Agency determine possible next steps to address questions from the public regarding the safety of tire crumb infill in recreational pitches.
Methodology	Samples were taken at two synthetic turf pitches and one playground. At each field and the playground, air sampling was conducted to collect integrated particulate matter (PM10) and grab volatile organic chemical (VOC) samples at two to three locations on each turf field and playground and also at an upwind background location. The air samples were collected at a height of 1 m in close proximity to, but without interfering with, planned recreational activities. The VOC samples were collected around 2:00 p.m. Wipe samples were collected at the three turf field sampling locations, along with readily available tire crumb infill and turf blade samples. Tire crumb material was collected from the playground. The full protocol was implemented at one of the synthetic turf pitches on a second consecutive day providing repeat sampling data. Selected samples were collected at a few additional synthetic turf pitches and one playground.

	Standard laboratory analysis methods were employed to analyze the environmental samples for the targeted analytes. The PM10 samples were analyzed for PM mass, metals, and particle morphology. The VOC samples were analyzed for 56 volatile organic analytes. The wipe and material samples were analyzed for total extractable concentrations of several metals and bioaccessible lead.
Results	PM10: Concentrations of PM10 and metals (including lead) measured in air above the turf pitches were similar to background concentrations. Concentrations of PM10 and metals at the playground site with high play activity were higher than background levels. All PM10 air concentrations were well below the National Ambient Air Quality Standards (NAAQS) for PM10 (150 µg/m^3). All air concentrations for lead were well below the NAAQS for lead (150 ng/m^3) VOCs: All VOCs were measured at extremely low concentrations that are typical of ambient air concentrations. One VOC associated with tire crumb materials (methyl isobutyl ketone) was detected in the samples collected on one synthetic turf field but was not detected in the corresponding background sample. Metals: Total extractable metal concentrations from the infill, turf blade samples and tire crumb material were variable in the samples collected at a given site and between sites. The average extractable lead concentrations for turf blade, tire crumb infill, and tire crumb rubber were low (infill: 11 to 61 µg/g). Although there are no standards for lead in recycled tire material or synthetic turf, average concentrations were well below the EPA standard for lead in soil (400 ppm). Likewise the average extractable lead concentrations for turf field wipe samples were low (<2.0 µg/ft^2). Although there are no directly comparable standards, average concentrations were well below the EPA standard for lead in residential floor dust (40 µg/ft^2).
Conclusion	On average, concentrations of components monitored in this study were below levels of concern; however, given the very limited nature of this study (i.e., limited number of components monitored, samples sites, and samples taken at each site) and the wide diversity of tire crumb material, it is not possible to reach any more comprehensive conclusions without the consideration of additional data.
Remarks	Preliminary study

Reference	**OEHHA Vidair 2009: Chemicals and particulates in the air above the new generation of artificial turf playing fields, and artificial turf as a risk factor for infection by methicillin-resistant Staphylococcus aureus (MRSA)** **Literature review and data gap identification [138]**
Research question	Determine whether these pitches emit levels of chemicals or particulates into the air that cause illness when inhaled. Determine whether these pitches infect athletes with the dangerous bacterium called methicillin-resistant Staphylococcus aureus (MRSA).
Methodology	Literature review
Results	Studies included: Dye et al., 2006 IBV 2006 Broderick 2007

	van Bruggen et al., 2007 Milone & MacBroom 2008
Conclusion	Estimated inhalation exposures of soccer players to five carcinogens (benzene, formaldehyde, naphthalene, nitromethane and styrene) gave theoretical increased lifetime cancer risks that exceeded the insignificant risk level of 10^{-6}. However, data from indoor pitches were used to estimate outdoor exposures and calculate these cancer risks. In addition, it was assumed that all organized soccer play over a lifetime occurred on artificial turf pitches. Together, these assumptions tend to overestimate the cancer risks for soccer players using artificial turf fields.
Remarks	This literature study was performed by the same group as the next reference (OEHHA 2010)

Reference	**OEHHA Vidair 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. Prepared for the California Department of Resources Recycling and Recovery. October 2010 [42]**
Research question	Determine whether the new generation of artificial turf athletic field containing recycled crumb rubber infill is a public health hazard with regard to: 1. Inhalation: Do these fields release significant amounts of volatile organic compounds (VOCs) or fine particulates of aerodynamic diameter less than 2.5 microns (PM2.5 and associated metals) into the air? If so, are the levels harmful to the health of persons using these fields? 2. Skin infection: Do these fields increase the risk of serious skin infections in athletes, either by harboring more bacteria or by causing more skin abrasions (also known as turf burns) than natural turf?
Methodology	Inhalation hazard: Measure PM2.5 and bound metals in air sampled from above artificial turf fields during periods of active field use. Compare to concentrations in the air sampled upwind of each field. Measure VOCs in the air sampled from above artificial turf fields during hot summer days. Compare to concentrations in the air sampled from above nearby natural turf fields.
Results	PM2.5 and associated elements (including lead and other heavy metals) were either below the level of detection or at similar concentrations above artificial turf athletic fields and upwind of the fields. No public health concern was identified. The large majority of air samples collected from above artificial turf had VOC concentrations that were below the limit of detection. Those VOCs that were detected were usually present in only one or two samples out of the eight samples collected per field. There was also little consistency among the four artificial turf fields with regards to the VOCs detected. Nevertheless, seven VOCs detected above artificial turf were evaluated in a screening-level estimate of health risks for both chronic and acute inhalation exposure scenario's. All exposures were below health-based screening levels, suggesting that adverse health effects were unlikely to occur in persons using artificial turf. There was no correlation between the concentrations or types of VOCs detected above artificial turf and the surface temperature.
Conclusion	There was no relationship between surface temperature and the

	concentrations of VOCs detected above artificial turf fields. Therefore, there is no reason for recommending that field usage in the summer be restricted to cooler mornings as a strategy for avoiding exposure to VOCs.
Remarks	The report is divided into chapters, each consists of a separate article. Only the inhalation measurements were included as the skin infection risk is not of interest in the current investigation

Reference	**Cal EPA/OEHHA 2007: Evaluation of Health Effects of Recycled Waste Tires in Playground and Track Products [51]**
Research question	To better understand the potential health risks to children using outdoor playground and track surfaces constructed from recycled waste tires, three studies were performed
Methodology	• The playground surfaces were evaluated for the release of chemicals that could cause toxicity in children following ingestion or dermal contact. Three routes of child exposure to chemicals in the rubber were considered: 1) ingestion of loose rubber tire shreds (3 tire shreds samples), 2) ingestion via hand-to-surface contact followed by hand-to-mouth contact (chronic exposure), and 3) skin sensitization via dermal contact (acute exposure). • Playground surfaces constructed from recycled tires were tested for their ability to attenuate fall-related impacts. • The potential of these rubberized surfaces to impact the local environment, including the local ecology, was also addressed through a discussion of the published literature.
Results	Gastric digestion simulation: All 13 metals were higher in the three rubber samples than in the control (lead: 48-140 µg/l). Three sVOCs were also present in all three rubber samples but not in the control: benzothiazole, 2(3H)-benzothiazolone and aniline. The increased cancer risk from exposure to four carcinogenic chemicals (arsenic, cadmium, lead, aniline) is 3.7 x 10^{-8}, assuming one time ingestion of 10 gr rubber by a 15 kg child.
Conclusion	This risk is considerably below the minimal risk level of 1 x 10^{-6}, generally considered an acceptable cancer risk due to its small magnitude compared to the overall cancer rate (OEHHA, 2006). The assumption that the risk from a onetime exposure is equivalent to the risk from the same dose spread over a lifetime is uncertain, and may overestimate or underestimate the true risk.
Remarks	Only the results of the gastric digestion study have been included in this summary, as these are relevant to the current investigation. This study was performed with rubber shreds, thus the particles were probably larger than rubber granules.

Reference	**UMDNJ- EOHSI (New Jersey) 2011: Crumb Infill and Turf Characterization for Trace Elements and Organic Materials [50]**
Research question	To conduct a thorough evaluation for hazardous chemicals within major product lines of crumb infill and associated turf that are available for use on athletic fields and public parks.
Methodology	Synthetic lung, sweat and digestive biofluids were analyzed for trace metals, polyaromatic hydrocarbons (PAHs) and scanned for semi-volatile organic compounds. In addition acid extraction for metals and high temperature volatilization for semi-volatile and volatile organic

	compounds were done to assess total extractable levels of these compounds.
Results	Overall the metals, PAHs and semi-volatile compounds found all classes of materials to be at very low concentrations (eg only 2 art sweat samples showed lead: 2 and 3 ng/ml). The PAHs levels were all below detection across all of the biofluids or the SPME analysis of the raw material. Thus, for the metals and compounds identified there would be de minimus exposures and risk among anyone using fields with the exception of lead in a single new turf material (probably caused by painting).
Conclusion	For the compounds that have known hazard the levels in the biofluids were below standards for soil cleanup so no formal risk assessment is currently recommended. In addition, the many organic compounds identified in the biofluids for which there are no hazard data currently available were also at very low concentrations so no further risk assessment is currently recommended unless new hazard information becomes available. In the future, the types of bioaccessibily studies conducted as part of these experiments should be completed for all new turf/infill products.
Remarks	

Reference	**Pavilonis et al, 2014. Bioaccessibility and Risk of Exposure to Metals and SVOCs in Artificial Turf Field Fill Materials and Fibres [30]**
Research question	To evaluate potential exposures from playing on artificial turf fields and associated risks to trace metals, semi-volatile organic compounds (SVOCs), and polycyclic aromatic hydrocarbons (PAHs)
Methodology	An examination was performed of typical artificial turf fibres (n = 8), different types of infill (n = 8), and samples from actual fields (n = 7). Three artificial biofluids were prepared, which included: lung, sweat, and digestive fluids.
Results	PAHs were routinely below the limit of detection across all three biofluids, precluding completion of a meaningful risk assessment. No SVOCs were identified at quantifiable levels in any extracts based on a match of their mass spectrum to compounds that are regulated in soil. The metals were measurable but at concentrations for which human health risk was estimated to be low. Lead concentrations in field samples ranged after nitric acid digestion 4.1–140 mg/kg, in sweat extracts <0.20–1.5 mg/kg, digestive biofluid 2.5–260 mg/kg and lung fluid <0.020–0.023 mg/kg.
Conclusion	The study demonstrated that for the products and fields we tested, exposure to infill and artificial turf was generally considered de minimus, with the possible exception of lead for some fields and materials.
Remarks	

Reference	**Shalat et al, 2011. An Evaluation of Potential Exposures to Lead and Other Metals as the Result of Aerosolized Particulate Matter from Artificial Turf Playing Fields [139]**
Research question	Is there a risk of metal exposure to the players on artificial turf fields
Methodology	Air sampling with static samplers, samplers on players and with a moving robot sampler. Also a number of wipe samples were taken (5

	fields)
Results	Lead in wipe samples ranged from 20-10330 ng/ft^2, however the highest measurement was an outlier, without that field the range would be 20-100 ng/ft^2. The highest air sample was from the same field as the wipe sample with the highest concentration, namely 71.9 ng/m^3. The other samples were all below 10 ng/m^3.
Conclusion	While it is not possible to draw broad conclusions from this limited sample of fields the results suggest that there is a potential for inhalable lead to be present on turf fields that have significant amounts of lead present as detectable by surface wipes. It also would appear likely from this sample that if the lead is present to any appreciable extent in the wipes it will likely be present in the breathing zone of players who are active on these fields, and that furthermore, these levels potentially exceed ambient EPA standards. Given that these are only occasional exposures this tends to reduce the risk of adverse health effects. However given that children are particulate at risk for adverse developmental effects of lead, only a comprehensive mandated testing of fields can provide assurance that no health hazard on these fields exists from lead or other metals used in their construction and maintenance.
Remarks	The study was limited in methodology and number of samples and only lead was really discussed

Reference	**Zhang et al. 2008, Hazardous chemicals in synthetic turf materials and their bioaccessibility in digestive fluids [54]**
Research question	To obtain data that will help assess potential health risks associated with chemical exposure from rubber granulate infills
Methodology	Seven samples were collected of rubber granules and one sample of artificial grass fiber from synthetic turf fields at different ages of the fields. These samples were analysed to determine the contents (maximum concentrations) of polycyclic aromatic hydrocarbons (PAHs) and several metals (Zn, Cr, As, Cd, and Pb). Also analyzed were the bioaccessible fractions of PAHs and metals in synthetic digestive fluids including saliva, gastric fluid, and intestinal fluid through a laboratory simulation technique.
Results	(1) rubber granules often, especially when the synthetic turf fields were newer, contained PAHs at levels above health-based soil standards (total 15 PAHs in 7 samples: 4.4-38.15 mg/kg). The levels of PAHs generally appear to decline as the field ages. However, the decay trend may be complicated by adding new rubber granules to compensate for the loss of the material. (2) PAHs contained in rubber granules had zero or near-zero bioaccessibility in the synthetic digestive fluids. (3) The zinc contents were found to far exceed the soil limit. (4) Except one sample with a moderate lead content of 53 p.p.m., the other samples had relatively low concentrations of lead (3.12–5.76 p.p.m.), according to soil standards. However, 24.7–44.2% of the lead in the rubber granules was bioaccessible in the synthetic gastric fluid. (5) The artificial grass fiber sample showed a chromium content of 3.93 p.p.m., and 34.6% and 54.0% bioaccessibility of lead in the synthetic gastric and intestinal fluids, respectively.
Conclusion	See results

Remarks	

Reference	**Ginsberg and Toal, 2010. Human health risk assessment of artificial turf fields based upon results from five fields in Connecticut. Connecticut Department of Public Health, 2010. [44,45]**
Research question	Health risk assessment of inhalation exposure at outdoor and indoor artificial turf fields
Methodology	Stationary and personal air sampling was performed at 1 indoor and 4 outdoor artificial turf fields in Connecticut. In addition, samples were collected upwind from the fields and background air samples were collected on an outdoor suburban grass area (see accompanying report Simcox et al., 2010). The health risk assessment focused on VOCs and SVOCs that had been detected at > 25% above background levels in the air samples. Other substances analyzed in the air samples were not included in the health risk assessment, because their concentrations were below background levels (PM10 and nitrosamines) or below the safe target for products intended for use by children (lead). In total, 13 VOCs, 17 PAHs, 2 targeted SVOCs (benzothiazole and butylated hydroxytoluene) and some miscellaneous SVOCs (aliphatics, hopanes, terpenes and pristanes) were included in the health risk assessment. Exposure by inhalation of volatile or semi-volatile chemicals emitted from the rubber in gas phase, and inhalation of particles and particle-borne chemicals were considered in the exposure assessment. Dermal and oral exposure was not considered, based on earlier risk assessment by Norway (Norwegian Inst of Public Health and the Radium Hospital, 2007) and California (CalEPA, 2007). Separate exposure scenarios were considered for children and adults, including correction factors for ventilation rate. Time-weight average exposures were calculated per compound based on the highest measured concentration of the compound and compared with toxicological reference values and cancer risks, Hazard Quotients (for chronic effects) and cumulative Hazard Index (for acute effects) were calculated.
Results	Concentrations of VOCs and SVOCs (including PAHs) above background levels were compared between personal and stationary samples, and between indoor and outdoor fields. Cancer risks were slightly above the negligible risk (1:1.000.000), being nearly 2-fold higher at the indoor field compared to the outdoor fields, and being higher for children than for adults, due to greater vulnerability and relatively higher ventilation rate of children compared to adults. Benzene and methylene chloride contributed most to the cancer risk, while PAHs, benzothiazole and chloromethane had much smaller contributions. The Hazard Quotient for all investigated substances was below reference level. In addition, the cumulative HQ of all investigated substances added together was below reference level. The same applied to the Hazard Index results. The calculated risks, including the worst case scenario of children playing at the indoor facility, were well within the range of typical risk levels in the community from ambient pollution sources.
Conclusion	The use of outdoor and indoor artificial turf fields is not associated with elevated health risks. However, adequate ventilation is recommended

	in indoor facilities to prevent accumulation of rubber-related VOCs and SVOCs. Also, uncertainties remain regarding new fields under hot weather conditions, which were not evaluated in this study.
Remarks	The following substances were detected in personal air samples but not in the stationary samples or headspace analysis, and were considered to originate from other sources than the turf field (e.g., exhaled breath, which may contain acrolein due to cigarette smoking). As such, they were not included in the health risk assessment: 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzenes &1,3,5-trimethylbenzenes, 1,2-dichloropropane, acrolein, bromoform, ethyl acetate, propene, tetrachloroethylene, tetrahydrofuran, trichloroethylene, and vinyl acetate. Benzene, methylene chloride and chloromethane were detected in personal air samples but not in stationary air samples (even at ground level), suggesting that at least part of the measured concentration in the personal samples may have been originated from non-field related sources. This supports the conclusion that the cancer risks were not elevated into a range of public concern. This study was peer reviewed by the Connecticut Academy of Science and Engineering (June 15, 2010).

Reference	**Li et al., 2010. Characterization of substances released from crumb rubber material used on artificial turf fields. Chemosphere 80 (2010), 279-285. [140]**
Research question	To develop methods for analyzing volatilized and leached substances from crumb rubber material (CRM)
Methodology	A qualitative method based on SPME coupled with GC-MS was developed for headspace analysis of volatile and semi-volatile organic compounds from CRM samples and direct vapour phase injection into the GC-MS was applied for quantitative analysis. Leaching experiments were performed using a modified method based on EPA 1312 (Synthetic Precipitation Leaching Procedure). Commercial samples of 'fresh' CRM and samples from a 2-year old turf field were analyzed.
Results	Ten compounds were identified in the headspace analysis: BT, six PAHs (NA, Phe, 1-MeNA, 2-MeNA, Flu, Pyr) and three anti-oxidants (BHA, BHT and 4-t-OP). In the aged sample from the 2-year old field, the amounts of BT, 1-MeNA, 2-MeNA and NA were significantly reduced. Other relatively less volatile compounds (BHA, BHT, 4-t-OP, Phe, Flu and Pyr) were detected at 20 – 90% of the signals from the commercial CRM. An ageing experiment with commercial CRM showed that reduction of volatile organic compounds in the CRM occurred within 14 days, and reached consistent levels after 14 days. BT and zinc were found in the leachate.
Conclusion	The data from these experiments can be used for field studies.
Remarks	

Reference	**Milone and MacBroom, 2008. Report: Evaluation of the environmental effects of synthetic turf athletic fields [141]**
Research question	A study was conducted by the 'Millone and MacBroom' company, a company that advises clients and designs athletic fields using both

	natural grass and synthetic surfaces, in cooperation with the Connecticut Department of Public Health. The aim of the study was to answer the following questions: • Does the temperature of the synthetic field become excessively hot in summer months? • Does the crumb rubber infill material have an effect on air quality? • Do metals leach from the crumb rubber infill material at a level that would adversely affect the quality of water? Only the second research question, described in the sub-report "Evaluation of Benzothiazole, 4-(tert-octyl) Phenol and Volatile Nitrosamines in Air at Synthetic Turf Athletic Fields", will be addressed in this summary.
Methodology	Air samples were collected on two different sports fields in Connecticut, using pumps for active air sampling and dedicated adsorbent media, with the intakes set at approximately four feet above ground surface. Both fields are multipurpose fields used for sports such as football, soccer, field hockey, and/or lacrosse among others and are encircled by synthetic running track surfaces. On each location, one sample was collected in the centre of the synthetic turf field and four samples were collected at the ends or sides of the fields ("background samples"). Samples were analyzed for benzothiazole, 4-(tert-octyl)-phenol, and nitrosamines. In addition, meteorological conditions were measured and recorded.
Results	At field 1, no detectable concentrations of benzothiazole, 4-(tert-octyl) phenol, or nitrosamines were found in any of the samples. At field 2, no detectable concentrations of benzothiazole, 4-(tert-octyl) phenol, or nitrosamines were found in the background samples. In the sample taken from the centre of the synthetic turf field, benzothiazole was detected at a concentration of 0.39 ug/m3. However, quality control samples of trip spikes showed possible degradation of the samples prior to laboratory analysis. Based on the trip spike sample results, the concentration of benzothiazole in the air sample was estimated at 1.0 ug/m3. Nitrosamines and 4-(tert-octyl)-phenol could not be detected in this sample.
Conclusion	See Results.
Remarks	

Reference	**Mattina et al., 2007. Examination of crumb rubber produced from recycled tires. The Connecticut Agricultural Experiment Station, Department of Analytical Chemistry, Report no. AC005 (8/07). [142]**
Research question	This study aimed to answer the following questions: 1. Are compounds volatilizing or out-gassing from the tire crumbs? 2. What is the identity of the volatilized compounds derived from the tire crumbs? 3. Can organic or elemental components be leached from the tire crumbs by water?
Methodology	Crumb rubber sample were provided to the laboratory by the non-profit organization "Environment and Human Health Inc.". Volatilization or out-gassing of compounds from the crumb rubber (headspace analysis at 60 °C) was analyzed by SMPE combined with

	GC-MS. The analysis of the identified compounds was confirmed by spike sample analysis.
Results	The following compounds were identified in the headspace analysis with measured concentrations, normalized per gram of tire: benzothiazole (867 ng/mL air), butylated hydroxyanisole (6.04 ng/mL air), n-hexadecane (21.6 ng/mL air), 4-(t-octyl) phenol (53.3 ng/mL air).
Conclusion	The laboratory data presented here support the conclusion that under relatively mild conditions of temperature (60 °C), components of crumb rubber produced from tires volatilize into the vapor phase.
Remarks	Results of the leaching experiments are not included in this summary.

Reference	**Ginsberg and Toal, 2010. Human health risk assessment of artificial turf fields based upon results from five fields in Connecticut. Connecticut Department of Public Health, 2010. [44,45]**
Research question	Health risk assessment of inhalation exposure at outdoor and indoor artificial turf fields
Methodology	Stationary and personal air sampling was performed at 1 indoor and 4 outdoor artificial turf fields in Connecticut. In addition, samples were collected upwind from the fields and background air samples were collected on an outdoor suburban grass area (see accompanying report Simcox et al., 2010). The health risk assessment focused on VOCs and SVOCs that had been detected at > 25% above background levels in the air samples. Other substances analyzed in the air samples were not included in the health risk assessment, because their concentrations were below background levels (PM10 and nitrosamines) or below the safe target for products intended for use by children (lead). In total, 13 VOCs, 17 PAHs, 2 targeted SVOCs (benzothiazole and butylated hydroxytoluene) and some miscellaneous SVOCs (aliphatics, hopanes, terpenes and pristanes) were included in the health risk assessment. Exposure by inhalation of volatile or semi-volatile chemicals emitted from the rubber in gas phase, and inhalation of particles and particle-borne chemicals were considered in the exposure assessment. Dermal and oral exposure was not considered, based on earlier risk assessment by Norway (Norwegian Inst of Public Health and the Radium Hospital, 2007) and California (CalEPA, 2007). Separate exposure scenarios were considered for children and adults, including correction factors for ventilation rate. Time-weight average exposures were calculated per compound based on the highest measured concentration of the compound and compared with toxicological reference values and cancer risks, Hazard Quotients (for chronic effects) and cumulative Hazard Index (for acute effects) were calculated.
Results	Concentrations of VOCs and SVOCs (including PAHs) above background levels were compared between personal and stationary samples, and between indoor and outdoor fields. Cancer risks were slightly above the negligible risk (1:1.000.000), being nearly 2-fold higher at the indoor field compared to the outdoor fields, and being higher for children than for adults, due to greater vulnerability and relatively higher ventilation rate of children compared to adults. Benzene and methylene chloride contributed most to the

	cancer risk, while PAHs, benzothiazole and chloromethane had much smaller contributions. The Hazard Quotient for all investigated substances was below reference level. In addition, the cumulative HQ of all investigated substances added together was below reference level. The same applied to the Hazard Index results. The calculated risks, including the worst case scenario of children playing at the indoor facility, were well within the range of typical risk levels in the community from ambient pollution sources.
Conclusion	The use of outdoor and indoor artificial turf fields is not associated with elevated health risks. However, adequate ventilation is recommended in indoor facilities to prevent accumulation of rubber-related VOCs and SVOCs. Also, uncertainties remain regarding new fields under hot weather conditions, which were not evaluated in this study.
Remarks	The following substances were detected in personal air samples but not in the stationary samples or headspace analysis, and were considered to originate from other sources than the turf field (e.g., exhaled breath, which may contain acrolein due to cigarette smoking). As such, they were not included in the health risk assessment: 1-ethyl-4-methylbenzene, 1,2,4-trimethylbenzenes &1,3,5-trimethylbenzenes, 1,2-dichloropropane, acrolein, bromoform, ethyl acetate, propene, tetrachloroethylene, tetrahydrofuran, trichloroethylene, and vinyl acetate. Benzene, methylene chloride and chloromethane were detected in personal air samples but not in stationary air samples (even at ground level), suggesting that at least part of the measured concentration in the personal samples may have been originated from non-field related sources. This supports the conclusion that the cancer risks were not elevated into a range of public concern. This study was peer reviewed by the Connecticut Academy of Science and Engineering (June 15, 2010). The main comment of the CAS considered the presentation of the conclusions in the report: according to CAS, it should be emphasized that the risk assessment was very worst case. They stated that "*The conclusion fails to indicate that such risks are highly improbable, reflecting a series of systematic overestimates of exposure and risk, and including a contaminant that is almost certainly not actually off-gassing from the crumb rubber*". This study was also published in a peer-reviewed journal (Journal of Toxicology and Environmental Health). In that publication, the emphasis on the worst case approach as described by the CAS review is addressed in the discussion section.

Reference	**Simcox, Bracker and Meyer, 2010. Artificial turf field investigation in Connecticut – Final report. University of Connecticut Health Center, 2010. [43,46]**
Research question	The aim of this study was to characterize the concentrations of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), rubber-related chemicals, and particulate matter (PM10) and its constituents in ambient air at selected crumb rubber fields in Connecticut under conditions of active field use.
Methodology	Air samples were collected at 4 outdoor fields with artificial turf, 1

	indoor field with artificial turf, and 1 outdoor suburban grass area (background samples). In addition, bulk samples of the crumb rubber were collected for headspace analyses. Personal air samples were collected at waist height (to simulate small children's breathing zone) during a simulated soccer game. Stationary air samples were collected at different heights above the fields, to obtain a vertical emission profile.
Results	Eighteen different VOCs and 3 different SVOCs (benzothiazole, 4-tert-(octyl)-phenol and butylated hydroxytoluene) were identified in the headspace samples of the bulk crumb rubber. Nitrosamine, butylated hydroxyanisole and 2-mercaptobenzothiazole could not be detected in the headspace samples. Lead concentrations in composite samples of the fiber and the crumb rubber ranged between 59.0 – 78.7 µg/g, with one outlier sample yielding a concentration of 271 µg/g. These concentrations are all below the "soil-lead hazard" level as determined by EPA (400 µg/g). Twenty-seven VOCs were identified in the personal and stationary air samples. Sixteen VOCs were only found in personal samples, not in stationary samples. In contrast, butane was only found in stationary samples (indoor field). Nineteen PAHs were measured on the 4 outdoor fields and 11 of them were also measured at the indoor field. Other SVOCs that were detected in the air samples were benzothiazole, 2-mercapto benzothiazole, 4-tert-octyl, BHA and BT. Nitrosamines were below the detection level.
Conclusion	The airborne concentrations of VOCs, targeted SVOCs and miscellaneous SVOCs were higher in the indoor facility than at the outdoor fields.
Remarks	This study was peer reviewed by the Connecticut Academy of Science and Engineering (June 15, 2010). According to the CASE review, a limitation of the study is that analysis of latex antigen has not been included in the study, and should be included in future studies. This limitation has been endorsed by the authors. This study was also published in a peer-reviewed journal (Journal of Toxicology and Environmental Health).

Reference	**Li et al., 2010. 2009 Study of crumb rubber derived from recycled tyres – final report. Connecticut agricultural experiment station; Department of analytical chemistry [140, 143]**
Research question	This project was part of a broad study on artificial turf fields. The objectives of this project were to develop laboratory protocols and accordingly conduct the laboratory analysis for identifying substances which volatilize and leach from crumb rubber and alternative infill materials under laboratory conditions, including ageing and leaching protocols.
Methodology	Volatile compounds emission from crumb rubber were identified using SMPE analysis.
Results	The following compounds were identified in the crumb rubber: 1-methyl naphthalene (concentration range 0,03 – 0,13 ng/mL); 2-methyl naphthalene (concentration range 0,06 – 0,20 ng/mL), 4-(t-octyl)-phenol (concentration range 0,06 – 0,52 ng/mL), benzothiazole (concentration range 1,03 – 8,67 ng/mL), butylated hydroxytoluene

	(concentration range 0,09 – 0,67 ng/mL), naphthalene (concentration range 0,05 – 0,42 ng/mL), and butylated hydroxyanisole (concentration range 0,34 – 0,75 ng/mL). Fluoranthene, hexadecane, phenanthrene, and pyrene were also identified, but could not be quantified. Results of the leaching and ageing/weathering experiments are not included in this summary.
Conclusion	See results.
Remarks	

Reference	**Brown et al, 2007. Artificial turf – Exposures to Ground-Up Rubber Tires – Athletic Fields – Playgrounds – Gardening Mulch. Environment and Human Health, Inc. [144]**
Research question	Health risk assessment of crumb rubber on artificial turf fields
Methodology	Literature review and exploratory analysis of rubber crumb samples (see also [142])
Results	Of the four chemicals identified with confirmatory analyses in the laboratory tests (benzothiazole, butylated hydroxyanisole, n-hexadecane, and 4-(t-octyl)phenol, seel #34), the hazard classification and other reported health effects are described, as well as other literature data on health effects of rubber crumb in artificial turf fields. In addition, conclusions on risk assessments by institutes from the USA (US EPA), Canada, Norway, California, and France are shortly summarized and data gaps are identified.
Conclusion	Human exposure to chemicals released during the use of synthetic turf fields seems probable, but there are still many data gaps.
Remarks	

Reference	**Denly, Rutkowski and Vetrano, 2008. A review of the potential health and safety risks from synthetic turf fields containing crumb rubber infill. TRC, Windsor, Connecticut., Project No. 153896. *Prepared for* New York City Department of Health and Mental Hygiene [145]**
Research question	Review existing literature, and identify knowledge gaps, on the potential exposures and health effects related to synthetic turf fields.
Methodology	Literature review. The literature review covered the following topics: - Chemical composition of crumb rubber infill, and chemicals of potential concern (COPCs) - Potential for exposure to these COPCs and potential health effects - Physical health effects associated with synthetic turf systems, including the risk of physical injury, heat-related illness, burns and infections with MRSA - Benefits associated with using synthetic turf fields - Recommendations for the crumb rubber industry and synthetic turf field operators
Results	Substances identified by direct analysis (vigorous extraction methods) or indirect analysis (e.g., leachate) include PAHs, VOCs, SVOCs, benzothiazole, metals, phthalates, alkylphenols and benzene. The presence and concentration of COPCs is expected to vary between

	products and even among batches from the same manufacturer. Three possible exposure routes to COPCs from rubber infill are inhalation, ingestion, and dermal absorption. Eleven human health risk assessments were identified in this literature review that evaluated exposure to substances in crumb rubber, which were based on quantitative measurement of the various tyre materials, ambient air measurements, or leachate analysis. The overall conclusion was comparable across these 11 assessments: exposure to COPCs from the crumb rubber may occur, however, the degree of exposure is likely to be too small to increase the risk for health effects. The risk estimations are generally conservative, and do account for higher susceptibility of children. However, uncertainties exist in the magnitude of factors to account for children's increased susceptibility, and inclusion of new data may be warranted in future risk assessments. The following data gaps were identified: - Lack of consistent test methods for determining chemicals in crumb rubber made of different source material; it was recommended that the crumb rubber industry provide more information - Lack of outdoor air concentrations of COPCs; most air concentration measurements were performed at indoor fields - There is no information on background air concentrations of COPCs in New York City, while many of the COPCs found in crumb rubber are also present in urban environments. It is recommended that future air sampling studies include background air samples.
Conclusion	According to the eleven reviewed health risk assessments, there is no increased risk for human health as a result of ingestion, dermal or inhalation exposure at synthetic turf fields with crumb rubber infill.
Remarks	Based on executive summary

Reference	**Vetrano and Ritter, 2009. AIR QUALITY SURVEY OF SYNTHETIC TURF FIELDS CONTAINING CRUMB RUBBER INFILL. Prepared by TRC (Windsor Connecticut) for the New York City Department of Mental Health and Hygiene, New York, NY. TRC Project No. 153896. March 2009 [75]**
Research question	To investigate the potential release of contaminants from crumb rubber synthetic turf fields and the subsequent potential exposures in the breathing zones of young children to those airborne contaminants.
Methodology	The measurements consisted of air sampling for a suite of SVOCs (PAHs and benzothiazole), VOCs, metals and particulate matter (PM2.5) at two outdoor crumb rubber athletic fields in NYC; Thomas Jefferson Park (East Harlem, Manhattan) and Mullaly Park (Bronx). Stationary samplers placed on turf fields were used to take measurements in the breathing zone of young children (three feet above ground surface). Air samples were collected under simulated playing conditions such as a practice soccer game and walking/running around the samplers. Stationary background samples were collected upwind of the field at the same time as the corresponding active field samples. A grass field also located at Mullaly Park was sampled in a manner similar to the synthetic turf fields for comparison purposes. Air sampling was conducted under summer conditions (August 2009) in the late morning to afternoon hours to represent potentially the highest concentrations

	of VOCs released due to the heating of the fields by the sun.
Results	Of 69 VOCs tested, eight VOCs were detected in the air measurements. Although VOCs were detected in the air, there was little evidence of harmful levels at the two sampled synthetic turf fields. Also, there was no consistent pattern to indicate that detected VOCs were associated with the synthetic turf. Similar concentrations were found in the background samples from the comparison grass field and upwind locations. None of the 17 PAHs tested were detected in any of the ambient air samples. Benzothiazole, which is considered a chemical "marker" for synthetic rubber (DOHMH 2008) was not detected in any of the air samples, including background samples. Of 10 metals tested, two were detected in the ambient air samples (chromium, zinc). Only chromium, however, was detected in the ambient air samples collected from the synthetic turf fields. Similar concentrations were found in both the grass field and upwind samples. Ranges of particulate matter (PM2.5) air concentrations from both turf fields were within the background levels found at the comparison grass field and upwind locations.
Conclusion	An analysis of the air in the breathing zones of children above synthetic turf fields did not show appreciable levels from COPCs contained in the crumb rubber. Therefore, a risk assessment related to actual exposure to children was not warranted from the inhalation route of exposure. Results from one of the bulk crumb rubber samples collected as part of this project identified an elevated lead level in the synthetic turf field at Thomas Jefferson Park
Remarks	

Reference	**Lim & Walker 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** **New York State Department of Health; May 2009 [57]**
Research question	The study focused on three areas of concern: the release and potential environmental impacts of chemicals into surface water and groundwater; the release and potential public health impacts of chemicals from the surface of the fields to the air; and elevated surface temperatures and indicators of the potential for heat-related illness ("heat stress") at synthetic turf fields
Methodology	Four types of tyre crumb were analysed. Measured were the release of chemicals using the simulated precipitation leaching procedure (SPLP), acid digestion, and off-gassing. A field evaluation of chemical releases from synthetic turf surfaces was conducted at two locations using an air sampling method that allowed for identification of low concentration analytes and involved the evaluation of the potential releases of analytes not previously reported. The temperature was monitored above synthetic fields, grass and sand.
Results	The results of the SPLP evaluation indicate a potential for release of zinc, aniline, phenol, and benzothiazole. Lead concentration in the crumb rubber samples were well below the federal hazard standard for lead in soil (lead leaching: 12.8 µg/L). The evaluation of volatile and semi-volatile organic compounds by offgassing proved difficult to

	conduct quantitatively due to the strong absorptive nature of the crumb rubber samples. The ambient air particulate matter sampling did not reveal meaningful differences in concentrations measured on the field and those measured upwind of the field.
Conclusion	A public health evaluation was conducted on the results from the ambient air sampling and concluded that the measured levels of chemicals in air at the Thomas Jefferson and John Mullaly Fields do not raise a concern for non-cancer or cancer health effects for people who use or visit the fields.
Remarks	The summary focusses only on the human health risk of the chemical composition

Reference	**Kim et al, 2012. Health Risk Assessment for Artificial Turf Playgrounds in School Athletic Facilities: Multi-route Exposure Estimation for Use Patterns [146]**
Research question	To identify major exposure pathways and to calculate total risk through a health risk assessment (HRA) of hazardous chemicals released from artificial turf playgrounds and urethane flooring tracks via multiple routes of exposure.
Methodology	50 schools from urban areas that had constructed artificial turf and urethane flooring were surveyed. 18 chemicals were investigated. Air sampling was conducted on top of the central playground
Results	The quantity of lead in infill chips was shown to exceed the domestic product content standard (90 mg/kg) at eight (16%) out of 50 schools. PAHs were shown to exceed standards (10 mg/kg) at two (4%) out of the 50 schools. The excess cancer risk (ECR) of carcinogens was shown to be 1×10^{-6} in most users for the worst exposure scenario. In children with pica, who represented the most extreme exposure group, the ECR was expected to be as high as 1×10^{-4}, showing the low risk level of carcinogens. The hazard index (HI) for individual chemicals was shown to be low, at around 0.1 or less, except for children with pica, according to the mean exposure scenario of artificial turf playground exposure. However, the HI was shown to exceed 1.0 in children with pica.
Conclusion	No direct health risk was found in using artificial turf playgrounds and urethane flooring tracks for the mean exposure scenario, except in children with pica.
Remarks	The reporting in this study is somewhat difficult to follow, especially which values are specifically for the rubber infills

11. Part D: Leukaemia and lymphoma

11.1 Introduction

In recent years, the media in the United States has reported on several cases of leukaemia and lymphoma among young football players (particularly goalkeepers) who played on synthetic turf pitches with rubber granulate infill. The role of environmental factors in the development of leukaemia and lymphoma in children and adolescents will be discussed as a response to recent stories in the Dutch media referring to these reports and a similar report from Scotland. Subsequently, the incidence of leukaemia and lymphoma in the Netherlands will be described, including any changes over time.

11.2 Risk factors for leukaemia and lymphoma

Leukaemia and lymphoma are collective names for a variety of malignant conditions of the blood forming tissues and lymphatic system, respectively. Both groups of conditions are strongly related. The development of malignant conditions such as leukaemia and lymphoma involved a complex interplay between genetic and environmental factors. Genetic abnormalities in blood and lymph cells make some people more susceptible to external risk factors than others.

Risk factors for leukaemia in children
In 2012, the Health Council of the Netherlands summarised the scientific literature on the role of environmental and other factors in the development of childhood leukaemia[1]. Exposure to ionizing radiation is currently the only environmental factor with a scientifically proven causal relationship with leukaemia. Other factors that likely play a role are exposure to high concentrations of carcinogenic substances, such as benzene, various pesticides and cigarette smoke. The Council established that leukaemia in children is caused by a complex interplay between genetic and environmental factors, some of which are also protective. The Council concluded that it is not easy to obtain a clear picture of the role played by individual environmental factors in the development childhood leukaemia. The most important conclusion is that the majority of cases of childhood leukaemia cannot be explained, and that only a small percentage may be prevented.

Using a similar search strategy, RIVM screened the scientific literature through the end of 2016 for major findings (see Annex I for the search strategy). A search of the epidemiological literature did not reveal any review articles that provided new insights. Recent international research confirms that high parental exposure to carcinogenic substances in particular, for example due to smoking or occupational exposure to pesticides, can increase the risk of leukaemia in their children. Conversely, breastfeeding and day care attendance from a young age reduce the risk of childhood leukaemia.
Risk factors of lymphoma in children and adolescents

[1] Childhood leukaemia and environmental factors. Health Council of the Netherlands, 2012/33

An initial literature research revealed that some auto-immune conditions may increase the risk of developing certain types of lymphoma. Environmental factors that may increase the risk of developing some types of lymphoma include high exposure to carcinogenic substances, such as cigarette smoke or intensive domestic use of insecticides. In contrast, an allergic constitution may reduce the risk of certain types of lymphoma.

Conclusion
Genetic factors are important to the development of leukaemia and lymphoma in children and adolescents. They make some people more susceptible to risk factors than others. A complex interplay between various genetic and environmental factors in involved. Most cases cannot be prevented, and it will likely never be possible to determine the causes of specific disease cases.

11.3 Trends in the incidence of leukaemia and lymphoma in children and adolescents in the Netherlands

The incidence of leukaemia and lymphoma can be studied based on data from cancer registries. There are two cancer registries in the Netherlands: one for cancer at all ages (NKR) and one specifically for children up to the age of 18 years (Netherlands Paediatric Oncology Foundation, SKION). For this report, RIVM used data from the NKR, as this contains data on both children and young adults aged 18 and older. See Annex II for further comments on this data and the classification of relevant conditions.

Data from the NKR shows that in the period 2006-2015, almost 2300 children under the age of 18 were diagnosed with leukaemia or lymphoma. This represents about 40% of all cancers in children under the age of 18 years (NKR, 2016).
The most common cancer in children up to the age of 15 is (acute lymphocytic) leukaemia. Lymphoma becomes more common after the age of 15, particularly (Non-)Hodgkin lymphomas.

An age and sex standardised incidence for leukaemia and lymphoma was calculated for young people between the ages of 10 and 29 years using the NKR data. The incidence is expressed as the number of new disease cases per 100,000 persons per year. The age group 10-29 (including both children and young adults) was selected because it is the most similar to the age group for which concerns about the possible relationship with playing sports of artificial turf (rubber granulate) were raised in the USA. The analyses below all pertain to this age group (10-29 years). The incidence of leukaemia and lymphoma in children and young people ages 10-29 years in the period 1989-2015 is displayed in Figure 1.

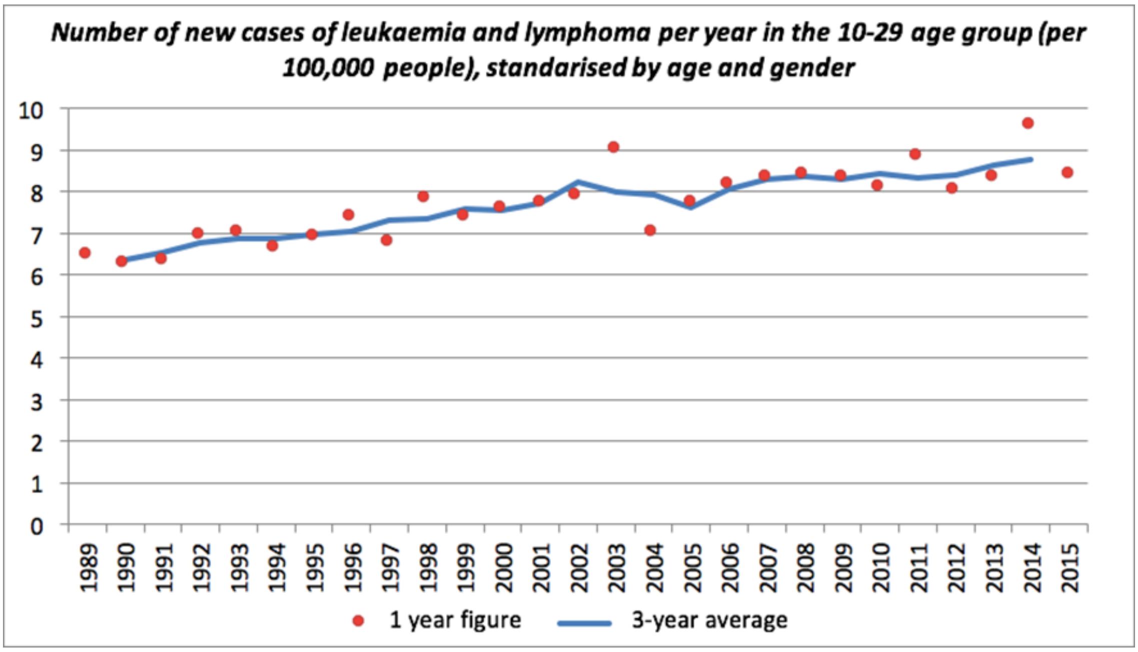


Figure 1: Standardised incidence of leukaemia and lymphoma in young people aged 10-29 years (per 100,000); presented as annual incidence and three-year moving average.

Due to the relatively low numbers, there is always some degree of year-to-year variation. In addition to annual data (red dots), a three-year moving average was calculated and included in the graph (solid blue line). This line connects the dots calculated as the average value for the current, previous and subsequent year. The incidence of leukaemia and lymph node cancer has increased gradually since the 1990s, from 6.4 to 8.8 per 100,000 young people ages 10-29 per year. Since the incidence was higher in men than in women, this represents about 200 boys and men, and 160 girls and women in 2015. The trend in incidence data was subsequently examined for the entire period with available data (1989-2015). A slight but statistically significant increase in incidence of about four cases per year in the Netherlands was found for the age group 10-29 over this 27-year period. Additionally, indications for changes in this trend were examined, such as acceleration or slowing. This was not found to be the case, either for the entire population or individual sexes. This analysis was likely to detect c a change in the trend for leukaemia and lymphoma in the group of people ages 10-29 in the Netherlands of about –two to three cases per year, although it provides no insight into the causes of the change.

Conclusion on trends
The analysis did not indicate any changes in the trend for the incidence of leukaemia or lymphoma at any time in the period 1989-2015.

11.4 Reflection on trends in leukaemia and lymphoma

In 2012, the Health Council determined that the incidence of leukaemia in children (0-14) had increased in the last decade of the 20th century, based on registry data from the Netherlands Paediatric Oncology Foundation. This increase stopped or reversed in the first decade of the 21st century. RIVM research using data from the Netherlands Cancer

Registry examining variation in leukaemia incidence in children and adolescents (0-19 years) in the period 1995-2010 did not show statistically significant clustering in time or place (Mulder et al., 2014).

International publications also describe the course of the incidence of leukaemia and lymphoma over time. Worldwide, no major changes were observed for leukaemia and lymphoma in children and adolescents up to the age of 19 years between 1978 and 2007 (Linet, 2016). On average, a gradual increase in the incidence of lymphoma was described for all age groups in Australia for the period 1980-2009 (van Leeuwen, 2014). In the USA, a decrease in the incidence of lymphoma was described near the end of the 2001-2012 period, but trends varied per subtype (Teras, 2016). European data is currently being prepared as part of the ACCIS[1] project.

Significance for potential relationship with playing sports on synthetic turf

The previous paragraph provided insights into the trends for leukaemia and lymphoma over the past 27 years. Although comparing trends in potential risk factors and effects does not imply causation, the decision was made to provide insight into the course of the incidence of leukaemia and lymphoma in the Netherlands.

Synthetic turf pitches with rubber granulate infill were gradually introduced in the Netherlands starting in 2001. By 2015, about 30% of football pitches were synthetic turf, most with rubber granulate infill. Analysis of data from the NKR shows that the trend in the incidence of leukaemia and lymphoma for the age group 10-29 years has not changed significantly over the past 27 years.

No changes were observed since the (gradual) introduction of rubber granulate in synthetic turf pitches in 2001, and no additional increase in leukaemia and lymphoma was observed in the Netherlands until the year 2015 in this age group beyond the pre-existing gradual increase that had started prior to the introduction of rubber granulate.

This trend analysis is fairly sensitive, and a change of a few extra cases of leukaemia and lymphoma per year in the Netherlands should have been detected in this manner. On the other hand, the relevance of this analysis is limited, because it only describes the absence of a change in incidence trends. Changes to known risk factors for leukaemia and lymphoma could not be taken into account, for example. Individual data about disease and potential risk factors was not available for this analysis. Global trend analyses also could not correct for:

- other explanations for changes in trends (for example improved diagnostic testing);
- latency period (period between exposure to risk factors and development of a disease).

Considering these uncertainties, the results from a number of ongoing US studies are important, because synthetic turf with rubber granulate

[1] ACCIS: Automated Childhood Cancer Information System

infill was implemented in the US earlier than in the Netherlands. If a relationship exists, it is likely to be observable in the US before it is in the Netherlands. Commentary on a number of ongoing studies and their implications for the situation in the Netherlands is provided in the following section.

11.5 Research into playing sports on synthetic turf and leukaemia or lymphoma[1]?

What do we know about the relationship between leukaemia or lymphoma and playing football on synthetic turf?

Reports from the USA; database

The concerns about a relationship between leukaemia and playing football (goalkeeping) on synthetic turf pitches are based on a collection of data from a US goalkeeper trainer from Washington State (USA). A description of the dataset is presented in Annex III. Since 2014 she has been keeping a list of cancer patients who play or played sports on synthetic turf (with rubber granulate infill), because the trainer had noticed a number of young football goalkeepers with cancer. People can register themselves or their child for this database. The list was created to stimulate scientific research on the relationship between rubber granulate and cancer. The information itself was not collected for scientific purposes. Due to the collection method (self-reporting), the database has a number of shortcomings that make it difficult to draw conclusions about a relationship between playing football/goalkeeping on synthetic turf and the occurrence of leukaemia or lymphoma; how complete the data is remains unclear, and selection bias is likely.

The Department of Health in Washington state (USA) is currently determining how the data collected may be interpreted. To this end, the database is compared with the data from the cancer registry in the state of Washington.

The goal is to examine whether there is an increased risk for specific types of cancer among football players, particularly among goalkeepers. A report is expected in early 2017[2]. Until then, RIVM cannot draw any conclusions about the relationship between playing sports on synthetic turf and the risk of leukaemia and lymphoma based on this database.

Second USA study (California)

Scientific research was conducted in California (USA) in response to the above-mentioned report (Bleyer and Keegan; see Annex IV for a description of this research). The research has not yet been published in a scientific journal, but information about the results is available[3]. The research tests the hypothesis that there is a relationship between playing football on synthetic turf (with rubber granulate infill) and the incidence of lymphoma.

[1] Malignant lymphomas

[2] Update: the results have been published in January 2017 (http://www.doh.wa.gov/Portals/1/Documents/Pubs/210-091.pdf). There was no increased number of cancer diagnoses among football players compared to what would be expected if football players experienced the same cancer rates as Washington residents of the same ages.

[3] http://comedsoc.org/images/Incid%20Lymph%201974-2013%201992-2013%202000-2013%20Highest%20Field%20Density%20Counties%20Sex.pdf

The authors use two cancer registries in the US and California to test this. The incidence of lymphoma is compared with the geographic spread of synthetic turf pitches (USA) or the density of synthetic turf pitches with rubber granulate (California). Geographic aggregate data was used, but individual characteristics (sex, age, lifestyle etc.) were not adjusted for. This type of research is also called ecological research. The results of this type of research are less robust than for research that uses individual data (such as age, sex, lifestyle factors, address details, etc.). The preliminary results of this study did not reveal any indication of a link between playing sports on synthetic turf pitches and an increased risk of lymphoma. There is no trend visible in the incidence of lymphoma in areas with the highest number of synthetic turf pitches. There is also no increased incidence of lymphoma in the parts of California with the highest number of synthetic turf pitches.

The authors indicate that the research results do not rule out that synthetic turf pitches may contribute to the incidence of lymphoma, but that findings are consistent with the lack of such a relationship. The article about the research is currently under peer review; the author expects it will take a few more months before it can be published.

Little else is known
Requests filed with the European network of environmental epidemiologists (See Annex V) did not reveal any additional data collections or research based on which the indication of an increased risk of leukaemia or lymphoma due to playing sports of synthetic turf (with rubber granulate infill) can be verified. No research on the relationship between playing football on synthetic turf (with rubber granulate infill) and leukaemia or lymphoma in children and adolescents was found in scientific literature. No Dutch research was found examining the relationship between playing football on synthetic turf pitches and the incidence of leukaemia and lymphoma.

Does RIVM see any reason to conduct epidemiological research in the Netherlands?
This exploration does not provide any indication that playing football on synthetic turf pitches increases the risk of leukaemia or lymphoma, namely:

1. Of the carcinogenic substances associated specifically with leukaemia or lymphoma, benzene was not found in any rubber granulate sample. The risk estimate for 2-mercaptobenzothiazole indicates that exposure is so low that no risk may be expected [see Part C of the scientific background information]. The rubber granulate also did not contain any styrenes or 1,3-butadiene, substances that past studies among people working in the rubber industry or animal experiments have indicated may be associated with causing leukaemia.
2. The ecological research in the USA does not show an increased incidence of lymphoma in areas with relatively more synthetic turf pitches. There is also no trend in the incidence of lymphoma in the parts of California with the highest number of synthetic turf pitches.
3. Data from the Netherlands Cancer Registry shows that the trend in the incidence of leukaemia and lymphoma for the age group

10-29 years has not changed significantly over the past 27 years. This trend analysis should be able to detect a few extra cases per year.

RIVM currently recommends against conducting epidemiological research on the relationship between leukaemia and lymphoma and playing football on synthetic turf. During the course of 2017, various results from research on the health risks of playing football on synthetic turf pitches will become available (ECHA, US EPA research). Insights into the relevance of the Washington State database are also expected shortly. RIVM will assess whether these results require re-evaluation of the above recommendation.

11.6 References

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11.7 Consulted experts

We are grateful to the following individuals for their advice during the writing of this report.

- Dr O. Visser, head of Registration for the Netherlands Comprehensive Cancer Organisation (IKNL)
- Professor F. van Leeuwen, NKI, professor of cancer epidemiology, VU University Amsterdam
- Professor R. Pieters, Princess Maxima Centre, professor of paediatric oncology, Utrecht University

We would also like to thank three of our international contacts, namely:

- Amy Griffin, for making the database available;
- Professor W.A. Bleyer, for the comments on his online publication; and
- Dr Nigel Maguire, for making his literature references available.

11.8 Annex I. Literature search strategy

Scientific literature was explored using a search strategy for the purposes of this literature review.

The search used by the Health Council for their report on Childhood Leukaemia and Environmental Factors (Health Council, 2012) was used as the starting point for this strategy. The PubMed/Medline database was searched for all potentially relevant articles from 1990 onwards. A search (subject and text) was performed for leukaemia (including specific forms ALL and AML), children, aetiology, and supplemented with specific agents, risk factors and genetic factors.

The full search strategy is described in Annex 1 of the Health Council background report. See:
https://www.gezondheidsraad.nl/sites/default/files/Evidence_Summary__ALL__AML.pdf

The current literature review was expanded in four ways:

- the search period was extended from 2010 to November 2016
- the age group for the epidemiological studies was expanded to include young adults
- the diseases were expanded to include lymphoma, including (Non-)Hodgkin lymphoma.
- Embase and Scopus (all scientific fields) databases were searched in addition to Medline.

Leukaemia and lymphoma in relation to risk factors
The literature identified in these three databases was deduplicated using bibliography software EndNote. The combined search in these three databases (Medline, Embase and Scopus) ensured good coverage of scientific publications in journals.
The literature search on environmental factors related to leukaemia and lymphoma yielded a total of 223 articles: 179 from Medline, 19 (only) from Embase, and 25 (only) from Scopus.

Scope
Considering the short time frame for the current research, the emphasis was on (systematic) reviews and meta-analyses by two international research consortia for leukaemia and lymphoma respectively. Specific studies on occupational epidemiology were not considered.

11.9 Annex II. IKNL data on leukaemia and lymphoma

Data provided by the Netherlands Comprehensive Cancer Organisation (IKNL) was used to calculate standardised incidence rates and for trend analyses. This data is available via the website: http://cijfersoverkanker.nl/

Incidence data from the Haematology Group was used for the calculations. Four subgroups relevant to the analyses can be identified, namely:

- Hodgkin lymphoma (HL)
  - Classic Hodgkin lymphoma
  - Nodular lymphocyte-predominant Hodgkin lymphoma
- Lymphoblastic leukaemia/lymphoma (LLL)
  - B-ALL, not otherwise specified
  - B-ALL with specific cytogenetic abnormalities
  - B-LBL
  - T-ALL
  - T-LBL
- Non Hodgkin Lymphoma (NHL)
  - B-CLL/small cell B-cell lymphoma
  - Indolent non-Hodgkin lymphoma
  - Aggressive non-Hodgkin lymphoma
  - Mature T and NK cell tumours (excluding skin lymphomas)
  - Cutaneous lymphomas
- Myeloid Leukaemia (ML)
  - Acute Myeloid Leukaemia (AML)
  - Unspecified and biphenotypical leukaemia
  - Myeloproliferative diseases
  - Myelodysplastic syndrome and myelodysplastic/myeloproliferative conditions

Data for these four groups was combined for the calculations.

Incidence data used for the period 1989-2015

Considering no data was available for “Myelodysplastic syndrome and myelodysplastic / myeloproliferative diseases” for the period 1989-2000 (due to changes in diagnostic criteria), this subgroup was not considered in the joinpoint analysis for the period 1989-2015. This is not expected to have a significant effect, as these diseases are extremely rare among young people.

Confirmed incidence data for 2015 was not yet available at the time calculations of standardised incidence and trend analyses for the 10-29 age group were performed. In order to address this, current data for 2015 was obtained from IKNL in November 2016. This data was used for calculation of 2015 figures.

The joinpoint analysis (Kim et al., 2000) was performed using Joinpoint Regression Program (Version 4.3.1.0), National Cancer Institute (USA). The statistical power of the analysis was derived from Zanetti et al. (2015).

11.10 Annex III. Description of Griffin database

The reason for the worries about an elevated risk of leukaemia and lymphoma among football players, as expressed by the ZEMBLA broadcast of 5 October 2016, is a dataset from the USA. In 2009, Amy Griffin, former goalkeeper for the USA national football team and football coach for Washington University in Seattle (WA), noticed a number of goalkeepers were receiving treatment for cancer. One of them suggested a potential link with rubber granulate infill in the synthetic turf pitches. Griffin decided to keep a list of football players (and people who play other sports) diagnosed with cancer who had come into contact with rubber granulate. The list gradually grew to over 200 people. The list can still be updated by filling out an online questionnaire. The most important objective was to help shape health and safety regulations for rubber granulate and guide research into the safety of synthetic turf pitches. Upon request, the list is provided to environmental and health organizations such as the US EPA and CDC, in order to allow further research and definition of guidelines.

Database contents

Following a request by RIVM in November 2016, the most recent version of the database was provided, containing information about 232 people. The database is anonymised and does not contain any information about the athlete’s city or state.

185 of the 232 persons (80%) report football as the primary sport played on synthetic turf. American football (14%) and baseball/softball (6%) were mentioned less frequently. We limit the further description to data on these 185 registered football players who play on synthetic turf, as this group is the most relevant to the situation in the Netherlands.

Of the 185 football players who play on synthetic turf, 60% indicated they primarily played as goalkeeper, and 40% played other positions in the pitch. 54% of the football players were girls or women. Leukaemia or lymphoma was diagnosed in 109 of the 185 football players (59%). The following diagnoses - in decreasing order - were also listed in the database: sarcoma (bone and soft tissue tumours) (9%), testicular cancer (6%), thyroid cancer (5%), brain tumour (5%) and lung cancer (2%). The other 27 football players (15%) were diagnosed with other conditions.

The percentage of goalkeepers or girls/women is no different among 109 football players diagnosed with leukaemia or lymphoma, compared with the entire group of 185 football players diagnosed with cancer. Most cases were diagnosed after 2005 (See figure II-1). 92 of the 109 cases (84%) were aged between 10 and 30 years at the time of diagnosis (see figure II-2). This age group was also used for trend analyses for leukaemia and lymphoma in the Netherlands, in part based on this description.

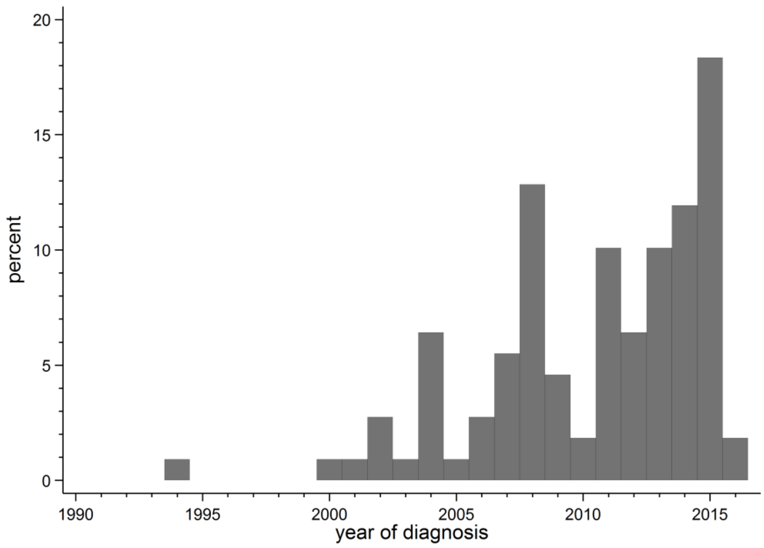

Figure II-1. Year of diagnosis

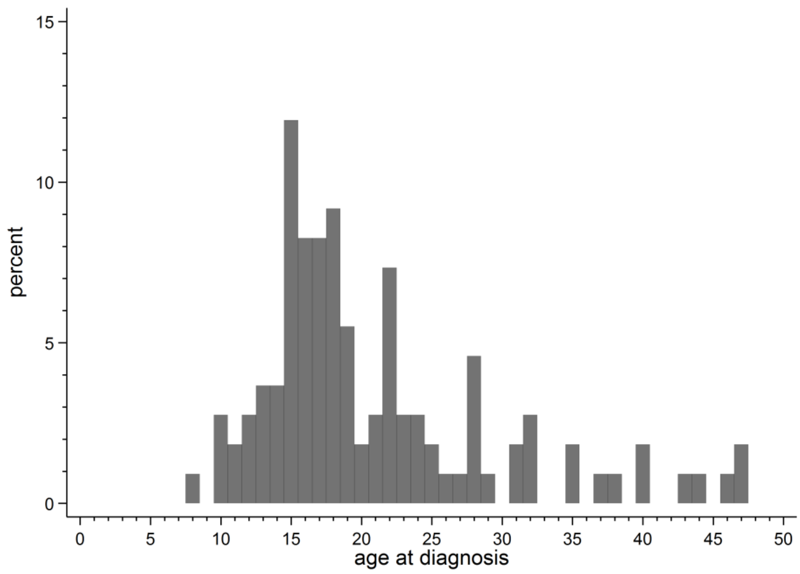

Figure II-2. Age at diagnosis

Database is not necessarily an indicator of risk
As described above, the list was created to stimulate research on the relationship between rubber granulate and cancer. The information was not collected for scientific purposes. This means that from a scientific perspective, the collected information has a number of shortcomings, such as:

- It is unknown whether the list is complete for a specific group (in this case, football players who play on synthetic turf). With completeness, we mean that all cases occurring within a specified period and region are documented in the list. The way the list was created means it is unlikely to be complete. This cannot be verified by RIVM, in part because data on the city and/or state of residence is missing for privacy reasons. Should research assume the list is complete if this is not the case, this will lead to underestimation of cancer incidence within the group.

- If the list is incomplete, it is unknown whether the data is representative for all football players who play on synthetic turf. By representative, we mean that the list is a random selection from a larger group of cancer patients (among football players who play on synthetic turf in a certain period and region). The description of how the list was drawn up indicates that the first registered patients were collected from the football coach's immediate surroundings. This list was then expanded with information about patients tracked down or provided by her contacts within the football community. National attention was drawn to the subject by the US media, for example via a news item on NBC in October 2014, and a documentary on ESPN (Entertainment and Sports Programming Network) that aired in November 2015. Since collection of data began with a few cancer cases among goalkeepers, and the broadcasts specifically mentioned goalkeepers, it is likely goalkeepers are overrepresented in the database. The relevance of this topic is greater to them than for outfield players, so the threshold for registration will be lower. Over-representation of goalkeepers means the risks of cancer among goalkeepers would be estimated to be higher than for outfield players. However, the degree of goalkeeper over-representation is unknown. This also means the degree to which the risks for goalkeepers are distorted remains unclear.
- The list only contains information about people playing sport who have come into contact with synthetic turf. There is no recorded data on football players who played only on natural pitches, for example, so comparison of cancer risks based on playing surface is impossible.
- The information in the database is self-reported. Patients may describe their disease incorrectly, resulting in misclassification. For example, we identified a number of descriptions of leukaemia and lymphoma that were not categorised under leukaemia or lymphoma, but under other cancers or non-malignant conditions.

These examples of shortcomings do not undercut the purpose for which the list was created, nor the efforts involved in its creation. These examples only serve to illustrate that the existence of the list and/or data it contains cannot be interpreted as an indication for an increased risk of cancer among football players and/or goalkeepers who play on synthetic turf pitches. Without additional information, for example about the completeness or representativeness of the data, the city and/or state of residence of the athletes, it is impossible for RIVM to interpret or consider the data in the database. Therefore, it is impossible for RIVM to determine the value of conclusions drawn from the database.

Database verification

The Washington State Department of Health is currently investigating the list based on the concerns raised about the incidence of cancer among football players and the relationship with playing on synthetic turf.

(http://www.doh.wa.gov/CommunityandEnvironment/Schools/EnvironmentalHealth/syntheticTurf) The first step is an assessment of the list and verification of information in the database by comparing it with information from Washington State cancer registries. The goal is to examine whether there is an increased risk for specific types of cancer among football players, particularly among goalkeepers. This is done by comparing the number of cases occurring within a specific timeframe with the number of cases that may be expected based on the incidence of these cancers in the whole of Washington State, correcting for age and sex. In their description of the research, the researchers state that any increased risk of cancer observed among football player and/or goalkeepers does not provide an explanation for the cause of this increase. Identifying a common cause has proven challenging in situations where an increased incidence of a specific cancer has been observed in certain groups. The research started in 2015. A report is expected in early 2017.

11.11 Annex IV. Research description (Bleyer et al.)

Based on the database by A. Griffin (see Annex III), the Oregon Health and Science University performed research into the relationship between the presence of synthetic turf pitches with rubber granulate infill and the incidence of lymphoma in the general population, under the leadership of Professor W.A. Bleyer. Geographic aggregate data was used, but individual data characteristics (sex, age, lifestyle etc.) was not adjusted for. This type of research is also called ecological research. The results of this type of research are considered less robust that for research that uses individual data (such as age, sex, lifestyle factors, address details, etc.).

The article about the research is currently (December 2016) under peer review at the American Journal of Sports Medicine, and the authors expect it will take a few more months before it will be published. An overview of the research, including results, is already available online. This annex summarises the research based on the information provided on the website (Bleyer, 2016).

Purpose of the research
The study tests the hypothesis that parts of the USA with relatively high numbers of synthetic turf pitches have a higher incidence of lymphoma among adolescents and young adults (AYA, age group 14-30 years) than regions with relatively fewer synthetic turf pitches.

Cancer registration in the USA
In the USA, 18 National Cancer institutes register so-called SEER (Surveillance, Epidemiology and End Results Program) data, including the annual incidence of lymphoma. This data is from regions across the entire USA, and based on data for 28% of the US population (with a slight under-representation of the two largest population groups, white and black Americans, and over-representation of other races/ethnicities). The study examined the relationship per race/ethnicity wherever possible, as it is known that the incidence of the disease is strongly associated with race/ethnicity (see below). It is also known that synthetic turf pitches are relatively more common in areas with a high socio-economic status, while there is also a relationship between family income and the incidence of lymphoma (with the highest incidence in the higher income groups, independently of race/ethnicity). Therefore, the analyses also took into account the role of socio-economic status in the relationship between the incidence of lymphoma and the density of synthetic turf pitches.

In addition to the National SEER database, county-level incidence of cancer has been documented in the state of California since 2000. Information on both race/ethnicity and the number of synthetic turf pitches is available for all 58 counties in California, allowing analysis of the relationship between the incidence of lymphoma and the density of synthetic turf pitches (number of pitches per population unit) to be analysed.

Incidence of lymphoma
The highest incidence of lymphoma in the 18 SEER regions was found among "Non-Hispanic White" in all age groups, with larger differences in incidence between races/ethnicities in higher age categories. "Black" had the second highest incidence. There was a trend towards increasing incidence with increasing age in these two groups. The lowest incidence was observed among "North American Natives". "Hispanic" and "Asian" had similar incidences for all age categories. The highest incidence was found in the highest income category for all groups.

Relationship with the number of synthetic turf pitches
No relationship was found between the incidence of lymphoma and synthetic turf pitch density for any of the groups; the incidence in SEER regions with high numbers of synthetic turf pitches was comparable to that in SEER regions with few synthetic turf pitches within each race/ethnicity.
Similar findings were seen within race/ethnicity per income group when examining the relationship between the incidence of lymphoma and the density of synthetic turf pitches: there was no difference in incidence between regions with a high or low number of synthetic turf pitches. Based on these analyses, the authors conclude no relationship can be proven between the incidence of lymphoma and the density of synthetic turf pitches in the 18 regions in the SEER database.

Incidence trends
The research performed in California focused primarily on incidence trends before and after the introduction of synthetic turf with granulate infill since 1997. In contrast with the analyses of the 18 SEER regions, which refers to 'synthetic turf fields', the description of the Californian data speaks of 'synthetic turf fields with rubber granulate infill'. It remains unclear whether the two studies are comparable in this respect. The Californian research also examined the age group 14-30 years (AYA). Analysis of the 40-year incidence of lymphoma (1974 to 2013) in the two California counties with the highest density of synthetic turf pitches (San Mateo and Marin; 29 pitches per 100,000) found no increase or decrease in the incidence over time. Similarly, no such trend was found for the period from 1992 onwards for the eight counties with the highest density (San Mateo and Marin plus counties for which synthetic turf pitch data became available in 1992; 23 pitches per 100,000). Splitting data for girls and boys did not change the results. According to the researchers, any changes in demographics (race/ethnicity) over the years did not affect the conclusions. Although the proportion of whites decreased slightly halfway through the research period, which could indicate a rising incidence among other population groups assuming an unchanged incidence, incidence was found to be unchanged at the end of the observation period despite an increasing proportion of whites.

Bleyer et al. conclusions
The authors' overall conclusion is that the absence of a spatial correlation between the incidence of lymphoma and synthetic turf pitch density, and the absence of a trend in incidence in counties with the highest number of synthetic turf pitches, is evidence against a causal relationship between synthetic turf pitches and lymphoma. The authors

indicate that the study results do not rule out that synthetic turf pitches contribute to the incidence of lymphoma, but that findings are consistent with the lack of such a relationship. In their final conclusions, the authors explicitly mention rubber granulate, suggesting that the synthetic turf pitches in SEER regions also had rubber granulate infill.

References

Bleyer and Keegan, 2016. Incident of Malignant Lymphoma in Adolescents and Young Adults (AYAs) in 18 States and Regios of the United States with Varying Synthetic Turf Field Density and Selected Counties in California with Highest Densities.
http://comedsoc.org/images/Incid%20Lymph%201974-2013%201992-2013%202000-2013%20Highest%20Field%20Density%20Counties%20Sex.pdf

11.12 Annex V. Description of European network request

In November 2016, RIVM filed a request with fellow researchers and institutes within Europe and globally, asking whether other data similar to that collected in the US database were available, and/or whether epidemiological research on the risks of playing football on synthetic turf pitches is being or has been conducted. The following institutes/networks were contacted.

International Network on Public Health and Environment Tracking (INPHET; http://www.epiprev.it/INPHET/home)

ERA-ENVHEALTH (http://www.era-envhealth.eu)

The question was also raised during a meeting of the WHO Environment and Health Task Force on November 30th, 2016. Almost all 53 member states of the WHO European Region were in attendance, with representatives from the Ministry of Health or the Ministry of the Environment (sometimes both) and a number of NGOs present. (http://www.euro.who.int/en/health-topics/environment-and-health/pages/european-environment-and-health-process-ehp/governance/european-environment-and-health-task-force-ehtf)

The Health Council also filed a request with the Belgian members of the Child Leukaemia and Environmental Factors Committee.

No other relevant research or data collections were identified.

Consulted INPHET members:
PHE - Public Health England, United Kingdom
ECDC - European Centre for Disease Prevention and Control, Sweden
ARPA Emilia-Romagna, Italy
University of Copenhagen, Denmark
University of Basel, Swiss Tropical and Public Health Institute, Switzerland
CDC, American Centre for Disease Prevention and Control, USA
Santé Publique France, France

Consulted ERA-ENVHEALTH network members:
ADEME - French Environment and Energy Management Agency, France
ANSES - French agency for food, environmental and occupational health safety, France
BelSPO - Belgian federal Science Policy Office, Belgium
CNR – Italian National Research Council, Italy
EPA- Environmental Protection Agency, Ireland
FPS - Federal Public Service Health, Food Chain Safety and environment, Belgium
MEDDE – French Ministry of Ecology, Sustainable Development and Energy, France
NERC - Natural Environment Research Council, United Kingdom
Folkhalsomyndigheten, Public Health Agency of Sweden, Sweden
SPW - Service Public de Wallonie, Belgium

Swedish EPA - Swedish Environmental Protection, Sweden
UA - University of Aveiro, Portugal
UBA - Federal Environment Agency, Germany
UoWM - University of Western Macedonia, Greece
UVZ - Public Health Authority, Slovak Republic

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