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*

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

RIVM Report 2017-0016

Colophon

DOI: 10.21945/RIVM-2017-0016

A.G. Oomen (editor), RIVM
G.M. de Groot (editor), RIVM

Contact:
info@rivm.nl

This investigation has been performed by order and for the account of the Ministry of Health, Welfare and Sport, within the framework of project V/050313 – Rubber granulate in synthetic turf pitches.

This is a publication of:
National Institute for Public Health and the Environment
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl

Synopsis

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

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

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 report describes 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. A comprehensive scientific report of this RIVM research will become available in early 2017.

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 foreign 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.

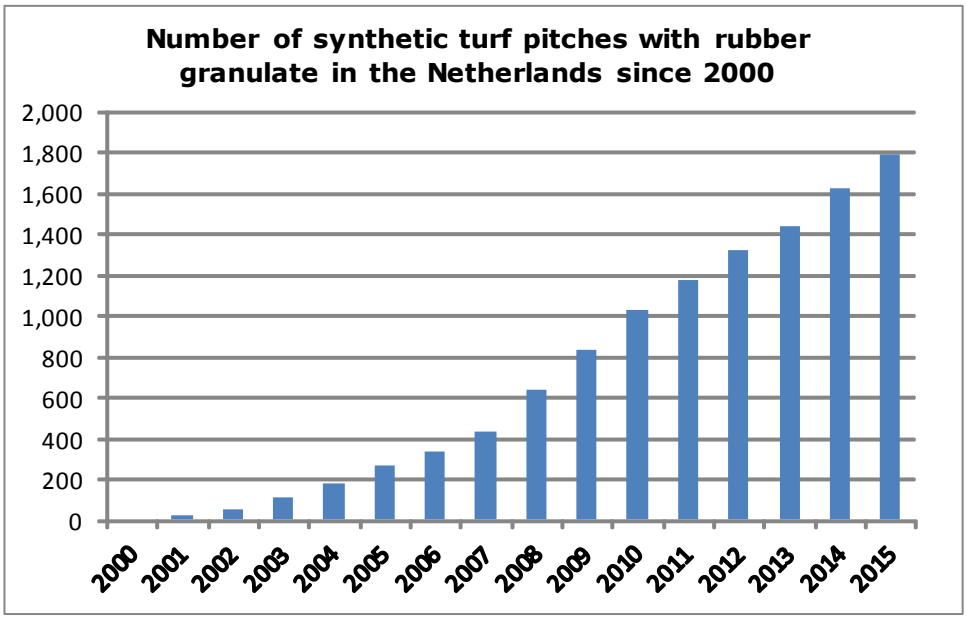

Figure 2 Estimate of the number of synthetic turf pitches with rubber granulate in the Netherlands since 2000 (Source: KNVB)

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)
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)
3. What is known about the relationship between playing sports on synthetic turf with rubber granulate and leukaemia and lymphoma? (Chapter 4)
4. How do the concentrations of substances found relate to regulatory and other limits? (Chapter 5)

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.

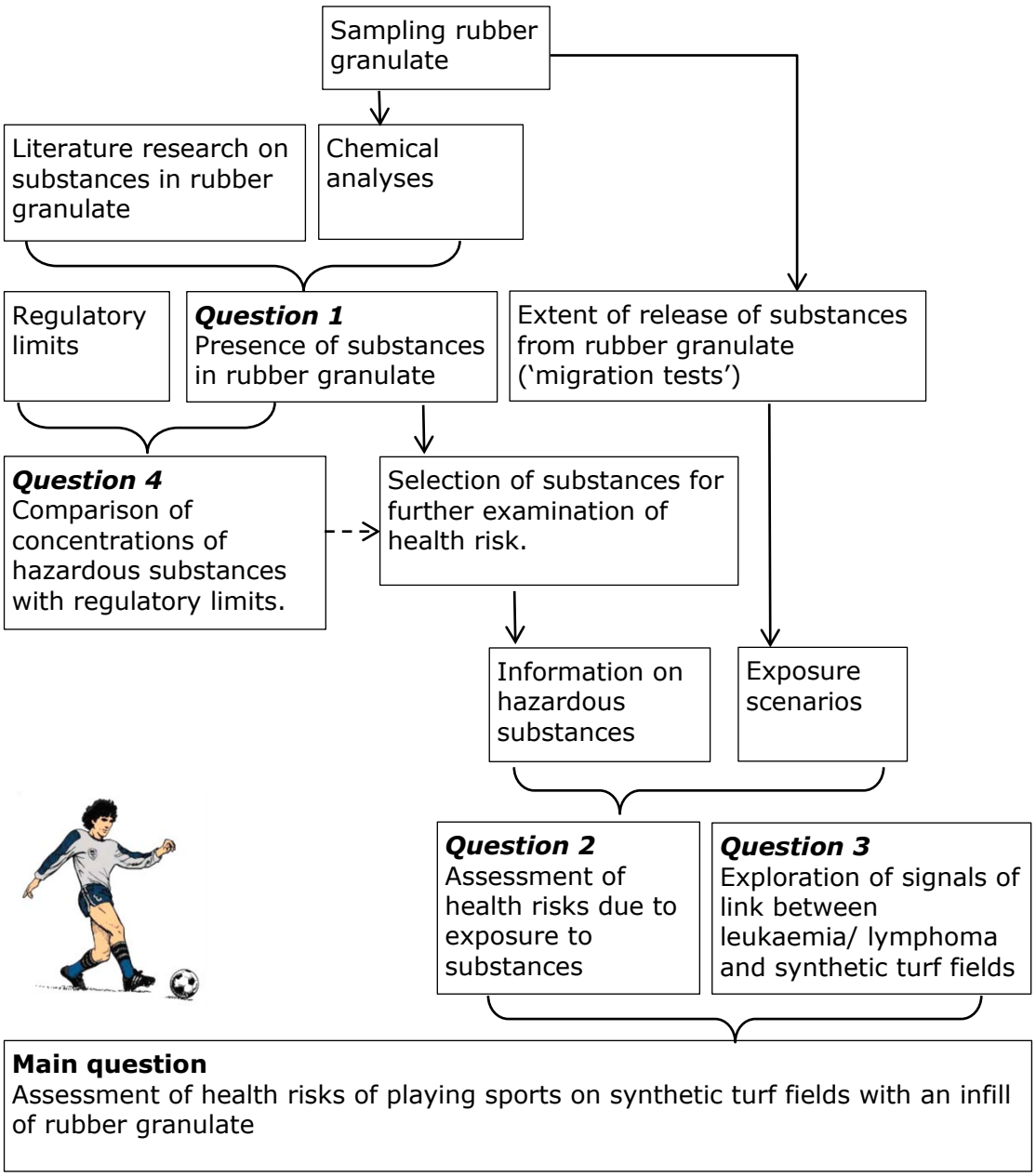

Figure 3 Schematic overview of the research

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. Annex 1 has more information on the sampling.

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.

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 can be found in Annex 2.

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 Annex 2).

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.

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 a field 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.
Annex 3 presents more details on the exposure scenarios. The inhalation exposure to vapours arising from rubber granulate is described in section 3.3.

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.

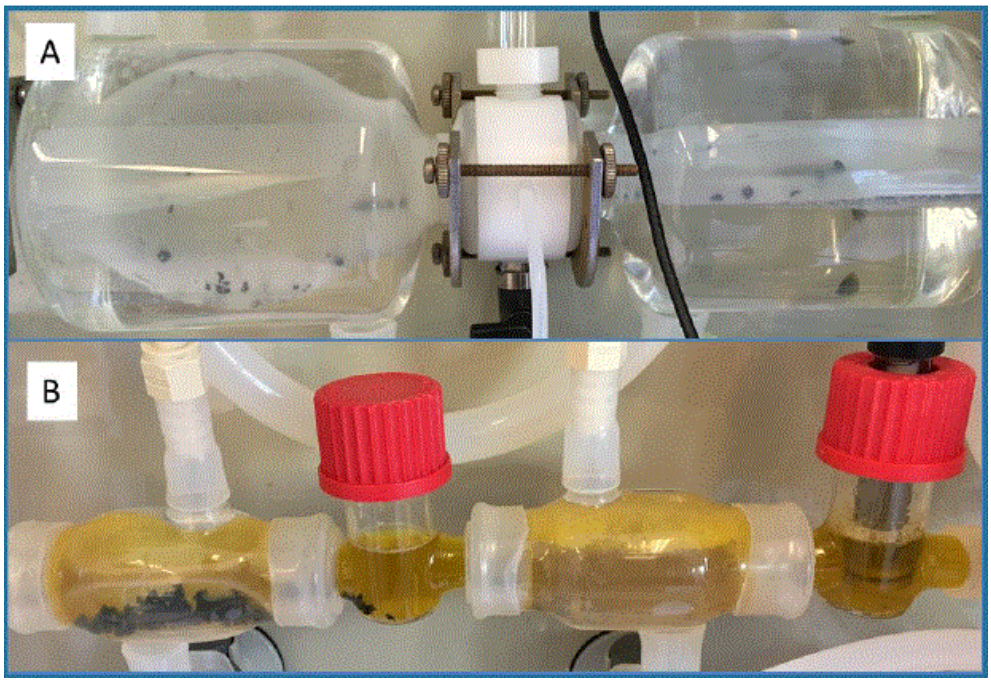

Figure 6 Photos of rubber granulate in the tiny TIM system during the experiment
A. Rubber granulate in the artificial stomach compartment.
B. Rubber granulate in the artificial intestines compartment

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 field 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.

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).

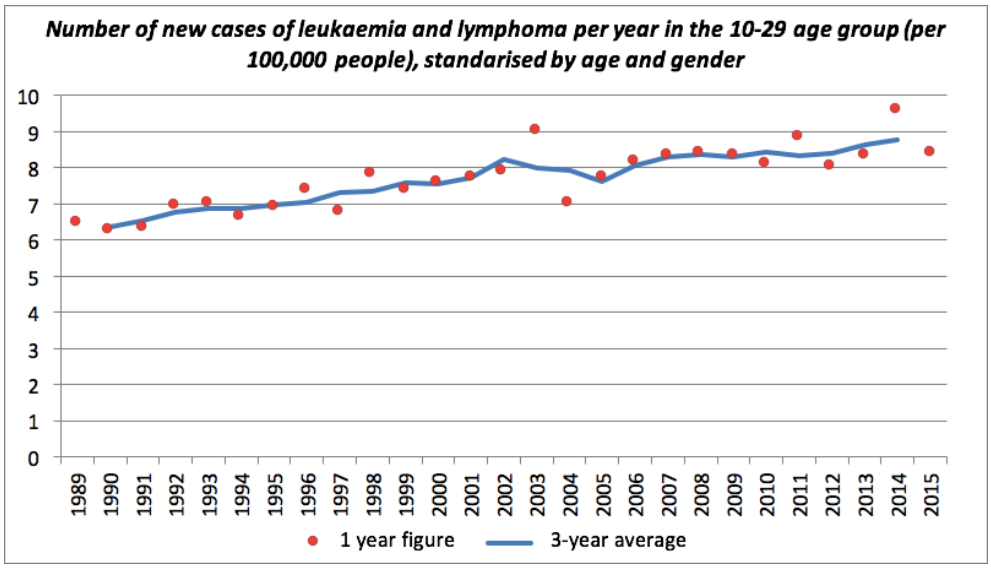

Figure 7 Number of new cases of leukaemia or lymphoma per year in the 10-29 age group (per 100,000 people), standardised by age and gender.

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

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] 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

[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.

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.

Acknowledgments

This research was realised thanks to the collaboration of many organisations and individuals. RIVM would like to thank:

- Owners (football clubs, korfball clubs, Johan Cruyff Foundation and municipalities) and managers of the 100 synthetic turf pitches where the samples were taken.
- Royal Dutch Football Association (KNVB)
- Mulier Institute
- Association of GGDs (Community Health Services)
- 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)

Our special thanks go to the staff of the external laboratories that performed the analyses on composition and some of the migration tests. We are most grateful for their flexibility in conducting analyses and experiments under demanding time constraints, the speed with which the results became available, the high quality of the data delivered and the pleasant and constructive cooperation. They are:

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

We would especially like to thank the members of the scientific advisory board for advising and assessing the quality of the research, the results, their interpretation and conclusions:

- Prof. Dr. Martin van den Berg
- Dr. Joris IJzermans
- 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

Annex 1: Sample collection

Selection of synthetic turf pitches
To investigate hazardous substances in rubber granulate on synthetic turf pitches, samples were taken from the rubber granulate of 100 synthetic turf pitches. For the selection of the synthetic turf pitches, a database from the KNVB with information on more than 1,900 synthetic turf pitches was used and a (largely overlapping) database from the Mulier Institute. This dataset was supplemented with data on other synthetic turf pitches with rubber granulate: 27 so-called Cruyff Courts, 28 korfball pitches and seven rugby pitches.
A random sample was taken from synthetic turf pitches throughout the Netherlands. The 100 sampled synthetic turf pitches involved 96 football pitches, two Cruyff Courts and two korfball pitches (see Figure 8). This random sample represents more than 5% of the total number of synthetic turf pitches with SBR granulate in the Netherlands.

Figure 8 Locations (red) where rubber granulate was sampled for RIVM research. The black dots indicate the locations of sports accommodations with one or more synthetic turf pitches (Source: Mulier Institute).

Six locations were sampled on each pitch. We used the same locations as required to assess the quality of the pitch according to FIFA regulations. These are intensively and less intensively used sites: the corner, the goal area, the centre of one half of the pitch, the centre spot, the edge of the pitch and the penalty mark (see Figure 9).

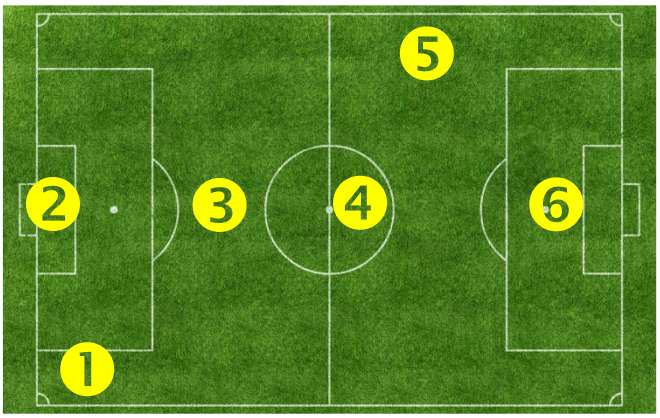

Figure 9 Location of sampling points on the pitch.

Sampling method
Rubber granulate was collected within a circle with a surface area of approx. 380 cm^2 (size of a bucket) during two minutes with a vacuum cleaner (with dust bag and filters). A test sample showed that this provides approximately one litre of rubber granulate (approx. 500 grams). The 'gaps' created by the sampling were subsequently filled with rubber granulate that lay alongside the pitch. On some, usually older pitches, or certain places on the pitch (centre circle, penalty box) the infill often appeared to be fairly sandy. In that case, the vacuum cleaner was used for one minute at two adjacent sites. After each pitch, the filters were replaced and the vacuum cleaner cleaned.

For each sample location, the collected material was stored in a glass pot, labelled with a barcode. Only RIVM knows the combination of barcode, pitch and FIFA sampling point. Thus, the laboratories that performed the analyses were not aware of the exact origin of the samples.

For additional measurements, three times as much material was sampled on 10 pitches. The two additional samples for each 'FIFA spot' ('batch 2' and 'batch 3') were used for control measurements (counterchecks) and additional analyses.

In total, 720 samples of rubber granulate were taken.

Annex 2: Substances in rubber granulate

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

Substance/Substance group	Percentage of samples above the detection limit	Concentration (mg/kg dry matter) (average values of each pitch)			Maximum value international studies
		Median (P50)	P90	Maximum	
PAHs					
phenanthrene	38[2]	<0.6	2.0	7.1	12.3
anthracene	5[2]	<0.5	<0.5	1.1	11.9
fluoranthene	93[2]	3.4	8.3	20.3	11.3
pyrene	98[2]	7.5	23.6	28.7	37
benzo(ghi)perylene	62[2]	4.1	6.5	7.7	29.2
benzo(c)fluorene	43[3]	0.2	0.6	0.7	no data
cyclopenta(cd)pyrene	100[3]	1.5	2.3	2.5	no data
benzo(a)anthracene[1]	27[2]	<0.9	1.2	2.2	15.3
benzo(b) + benzo(j)fluoranthene[1]	48[2]	<1.2	1.8	3.0	15.7
benzo(k)fluoranthene[1]	1[2]	<0.5	<0.5	0.5	7.3
benzo(a)pyrene[1]	25[2]	<1.1	1.3	2.2	10.7
benzo(e)pyrene[1]	57[4]	2.8	4.2	7.8	1.6
chrysene[1]	57[2]	1.3	1.9	3.5	7.6
dibenzo(a,h)anthracene[1]	0[2]	<0.5	<0.5	<0.5	8.1
Sum PAH (ECHA 8)[1]		5.8	10.9	19.8	
Phthalates					
di-2-ethylhexylphthalate	100[2]	7.6	14.2	27.2	62
di-isobutylphthalate	17[2]	<0.5	0.8	2.3	175
di-isononylphthalate	77[5]	35	53	61	78
dicyclohexylphthalate	47[5]	0.1	0.2	0.2	unknown
di-n-nonylphthalate	37[5]	0.5	0.8	0.8	unknown
diphenylphthalate	7[5]	<0.1	<0.1	0.1	unknown
bis(2-ethylhexyl)adipate	63[5]	0.3	0.7	1.1	unknown
Benzothiazoles					
benzothiazole	100[3]	2.7	5.7	6.3	171
2-hydroxybenzothiazole	100[3]	1.6	8.1	13.8	unknown
2-mercaptobenzothiazole	100[3]	2.6	6.3	7.6	no data

[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] Analyses of 546 samples from 91 fields.
[3] Analyses of seven mixed samples derived from seven fields.
[4] Analyses of seven mixed samples derived from seven fields. Due to the strong correlation with chrysene (r2=0.98), the assessments for all fields were made using the formula [BeP]=2.2407 x [Chr].
[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 (mg/kg dry matter) (average values of each pitch)			Maximum value international studies
		Median (P50)	P90	Maximum	
2-methoxybenzothiazole	100[3]	2.6	9.7	10.2	unknown
2-aminobenzothiazole	100[3]	0.1	0.3	0.4	unknown
N-cyclohexyl-1,3-benzothiazole-2-amine	100[3]	1.5	3.6	3.9	no data
2,2-dithiobis-(benzothiazole)	71[3]	0.2	0.3	0.3	no data
N-cyclohexyl-2-benzothiazole sulphenamide	43[3]	<0.02	0.04	0.04	no data
Phenols					
4-tert-octylphenol	100[3]	4.8	19.6	22.4	33.7
Bisphenol A	100[3]	0.5	2.0	2.5	unknown
Polychlorobiphenyls					
PCBs[6]	29[3]	<0.035	0.06	0.074	0.2

The footnotes for above table can be found on previous page.

Table 6 Leaching (to water) of metals in rubber granulate. Reported are the metals that are detected in at least 5% of the samples.

	Leaching concentration in mg/kg dry matter (average values of each pitch)		Limits for building materials[1]
Metals[2]	Median	Max	
Zinc	12.0	75	4.5
Copper	0.08	0.86	0.9
Cobalt	<0.039	0.25	0.54
Barium	<0.05	0.17	22

[1] The limit for building materials concerns the maximum emission value and is not legally applicable to the use of rubber granulate from old car tyres on synthetic turf fields and should only serve as an indication.
[2] The measured value concerns the leaching concentrations to water. The limit concerns the maximum emission value.

Annex 3: Values for exposure scenarios

Table 7 Values for exposure estimation for the four scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
	Children aged 4 to 11 years	**Goalkeepers starting at 7 years of age**	**Children aged 11 to 18 years, performance oriented sports**	**Adults (18 to 35 years of age), performance oriented sports**
General				
Bodyweight (kg)	15.7	24.3	44.8	68.8
Frequency (times a week)	2	3	5	5
Duration (hours per event)	1 x 1 hour, 1 x 1.5 hours	1 x 1 hour, 2 x 1.5 hours	1.5 hours	2 hours
Duration (months per year)	7 (all routes)	7 (skin) 10 (inhalation and ingestion)	7 (skin) 10 (inhalation and ingestion)	7 (skin) 10 (inhalation and ingestion)
Via the skin				
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)
Amount of granulate (g)*	1 (according to the literature)	10 (estimate, literature x factor 10)	3.3 (according to the literature)	6 (according to the literature)
Via inhalation				
Respiratory rate (m^3/hour; with intensive activity)	1.58	1.92	2.53	3.07
PM10 (µg/m^3) rubber granulate	12	12	12	12
Via ingestion				
Direct ingestion (g/time)	0.2	0.2	0.05	0.05

The exposure calculations were then based on the following equations:

- Daily dermal exposure = *mass of granulate in dermal contact (per sport occasion) x migration fraction / bodyweight*
- Air concentration chemical substance in PM10 = *air concentration PM10 x weight fraction in granulate*
- Daily exposure through ingestion = *mass of ingested granulate (per sport occasion) x migration fraction / bodyweight*

References

EC, 2015. Follow-up to document CACS/40/2015 - Interpretation of entry 50 of Annex XVII to REACH: Applicability of the restriction in paragraph 5 of entry 50 to REACH as regards PAH to rubber infill used in synthetic turf and to rubber tiles placed on the market for use in public places. 21/12/2015. European Commission, Brussels.

ECHA, 2016. ECHA evaluating whether recycled rubber filling on artificial sports grounds poses a health risk. https://echa.europa.eu/nl/view-article/-/journal_content/title/echa-evaluating-whether-recycled-rubber-filling-on-artificial-sports-grounds-poses-a-health-risk

EFSA, 2008. Polycyclic Aromatic Hydrocarbons in Food. Scientific Opinion of the Panel on Contaminants in the Food Chain. http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2008.724/epdf

EPA, 2005. Supplemental Guidance for Assessing Susceptibility from Early-Lifetime Exposure to Carcinogens. EPA/630/R-03/003F. Risk Assessment Forum. U.S. Environmental Protection Agency.

EPA, 2016. Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields. https://www.epa.gov/chemical-research/federal-research-action-plan-recycled-tire-crumb-used-playing-fields

NKR, 2016. Cijfers over kanker. Kinderen en kanker, incidentie.[Figures about cancer. Children and cancer, incidence] http://cijfersoverkanker.nl/kinderen-en-kanker-55.html

OEHHA, 2009. Technical Support Document for Cancer Potency Factors: Methodologies for derivation, listing of available values, and adjustments to allow for early life stage exposures. California Environmental Protection Agency. Office of Environmental Health Hazard Assessment. Air Toxicology and Epidemiology Branch. 2009

OEHHA, 2016. Human Health Studies on Synthetic Turf. http://oehha.ca.gov/risk-assessment/background/human-health-studies-synthetic-turf.

RIVM, 2016. REACH Helpdesk – Restrictions. http://reachhelpdesk.nl/Veelgestelde_vragen/Beperkingen_restricties

Verwei, M., M. Minekus, E. Zeijdner, R. Schilderink, R. Havenaar. (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.

A.G. Oomen | G.M. de Groot

RIVM Report 2017-0016

Published by

National Institute for Public Health and the Environment
P.O. Box 1 | 3720 BA Bilthoven
The Netherlands
www.rivm.nl/en

february 2017

Committed to *health and sustainability*