BYGGFORSK
Norwegian Building Research Institute

Head office
Forskningsveien 3b
Postboks 123 Blindern
N-0314 OSLO
Telephone +47 22 96 55 55
Fax +47 22 69 94 38

Regional office
Høgskoleringen 7b
N-7491 TRONDHEIM
Telephone +47 73 59 33 90
Fax +47 73 59 33 80

E-mail firmapost@byggforsk.no
Website www.byggforsk.no
Company Reg. No. NO 943 813 361 MVA

Client
Norwegian Football Association

Client's address
Serviceboks 1 Ullevål Stadion
0840 Oslo

Client's reference
Ole Myhrvold

Project no./archive no.	Date	Rev. date	No. of pages	No. of enclosures	Classification	Author(s)
O-10820	10.09.04		15	0	Confidential	Thale S.W. Plesser, Ole J. Lund

Project manager	Sign.	Responsible line manager	Sign.	Quality assured by	Sign.
Ole J. Lund		Gro Markeset		Jørund Furre	

Assignment report

Potential health and environmental effects linked to artificial turf systems - final report

Brief summary

The Norwegian Building Research Institute (NBI) has carried out a study of potential health and environmental effects linked to artificial turf systems on behalf of the Norwegian Football Association (NFF). The study covers a total of four types of rubber granulate and two types of artificial turf fibre, which are in use in the Nordic region. This report presents the results from three types of rubber granulate made from recycled rubber, one EPDM rubber granulate and two artificial turf fibres.

The rubber granulates and 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.

Address of the building			Year of construction
	Method Laboratory study	Keywords Artificial turf, rubber granulate, environmental toxins, risk assessment	File name Report NFF

Extracts or abbreviated reproduction of the report is not permitted without the special approval of the NBI.
If the report is to be translated, NBI reserves the right to approve the translation. Costs will be charged to the client.

1 Introduction

In the winter of 2003, the Norwegian Building Research Institute (NBI) was commissioned to study the potential environmental and health effects linked to the use of artificial turf systems. The client was the Norwegian Football Association, c/o Ole Myhrvold.

There are currently no accepted requirements or test methods for the use of rubber granulate in artificial turf systems. The mechanisms for changes in the rubber granulate's properties and constancy over time when subjected to various environmental stresses have not been studied in detail. Similarly, the potential health-related and environmental influences of rubber granulates on the surroundings have not be studied in any detail.

The aim of this project was to give a satisfactory fingerprint of potentially hazardous substances for soil, air, water and humans, linked to the use of rubber granulate in artificial turf systems. The generation of high quality data was an aim, enabling the data to be included in a more comprehensive risk assessment and used as a basis in any development of a Norwegian, Nordic or European product approval scheme for rubber granulate for use in artificial turf systems.

The study covers laboratory testing and a simplified risk assessment for four types of rubber granulate and two types of artificial turf fibre. Three of the rubber granulates are based on recycled rubber, while the fourth is an EPDM rubber.

2 Test object

Rubber granulate and artificial turf fibre from a number of manufacturers were obtained from suppliers of artificial turf systems; see Table 1.

Table 1. Description of rubber granulates and artificial turf fibre.

Sample no.	Manufacturer	Sample type	Material	Description
1	Genan Business & Development	Rubber granulate	Recycled rubber	Coarse-grained, 2-4 mm
2	Jacobs Rubber	Rubber granulate	Recycled rubber	Fine-grained
5	Jacobs Rubber	Rubber granulate	Recycled rubber	Coarse-grained
6	Saltex Oy	Rubber granulate	EPDM	1-4 mm
3	CABRITA	Artificial turf	Polyethene	Split fibre
4	Desso	Artificial turf	Polyethene /polypropene copolymer	Monofibre

3 Test methods

3.1 Total analysis

To determine the total content of selected elements and organic compounds, see Table 2, rubber granulates and artificial turf fibre were sent to NBI's subcontractor AnalyCen AS for chemical analysis.

Table 2. Total analysis. Test method.

Parameter	Detection limit	Measurement uncertainty	Method based on
Arsenic, As	0.03 mg/kg	± 35 %	NS 4781-1 m
Lead, Pb	0.4 mg/kg	± 20 %	NS-EN ISO 11885
Cadmium, Cd	0.017 mg/kg	± 20 %	NS-EN ISO 11885
Copper, Cu	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Chromium, Cr	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Mercury, Hg	0.5 µg/kg	± 30 %	NS 4781-1 m
Nickel, Ni	0.2 mg/kg	± 20 %	NS-EN ISO 11885
Zinc, Zn	0.2 mg/kg	± 20 %	NS-EN ISO 11885
PCB(7) in artificial turf fibre	0.002 mg/kg	± 25 %	NTR 329 Sintef 1997
PCB(7) in rubber granulate	0.2 mg/kg	± 25 %	SNV report 4697
PAH(16)	0.01 mg/kg	± 25 %	NTR 329 Sintef 1997
Phthalates(8)	0.1-1 mg/kg	± 20 %	
4-t-Octylphenol	5-50 µg/kg	± 10 %	Derivatisation
4-n-Nonylphenol	5-50 µg/kg	± 10 %	Derivatisation
iso-Nonylphenol	5-50 µg/kg	± 10 %	Derivatisation

3.2 Leaching

The leaching procedures were based on pr EN 12457-4 and NT ENVIR 005.

3.2.1 Leaching of elements from artificial turf fibre and rubber granulate

Deionised water and artificial turf fibre or rubber granulate were transferred to a 2-litre rectangular polyethene container. The water to solid material ratio L/S was 10 L/kg. The conductivity, pH and temperature of the deionised water were measured before mixing; see Table 3. The container with water and solid material was rotated at a speed of 10 RPM for 24 hours. Immediately after this process, the temperature, pH and conductivity of the leachate were measured. The leachate was then vacuum-filtered. A Sartorius glass vacuum filter holder with a 0.45 µ Millipore MF membrane filter with nitrocellulose was used for the filtration. The filtrate was acidified using 1% v/v concentrated HNO_3 and stored in a polypropene bottle.

Table 3. Leaching of metals from artificial turf fibre and rubber granulates. Test conditions.

Sample type	Sample no.	Sample weight [g]	Deionised water			
			Volume [ml]	Temp. [°C]	pH	Conduct. [µS/cm]
Granulate	1	100.02	1000	18.5	6.25	1.21
Granulate	2	100.03	1000	18.5	6.25	1.21
Granulate	5	100.03	1000	22.4	5.63	0.75
Granulate	6	100.05	1000	22.4	5.63	0.75
Fibre	3	50.00	500	21.0	5.60	0.82
Fibre	4	50.00	500	21.0	5.60	0.82

The analysis of zinc in the leachate was carried out by NBI using a flame atomic absorption spectrometer. The detection limit was 0.02 mg/L.

The analysis of chromium in the leachate was undertaken by NBI using a graphite furnace atomic absorption spectrometer. The detection limit was 0.6 µg/l.

3.2.2 Leaching of organic compounds from rubber granulate

Deionised water and rubber granulate were transferred to a rectangular 1-litre Duran glass container with a Teflon-coated cork. The water to solid material ratio L/S was 10 L/kg. The conductivity, pH and temperature of the deionised water were measured before mixing; see Table 4. The container with water and solid material was rotated at a speed of 10 RPM for 48 hours. Immediately after this process, the temperature, pH and conductivity of the leachate were measured. The leachate was then filtered at normal pressure. An ash-free paper filter (598[3]) from Schleicher and Schull was used for the filtration. The filtrates were sent to AnalyCen for analysis of organic compounds; see Table 5.

Table 4. Leaching of organic compounds from rubber granulates. Test conditions.

Sample type	Parallel	Sample weight [g]	Deionised water			
			Volume [ml]	Temp. [°C]	pH	Conduct. [μS/cm]
1	1	90.90	910	20.2	5.63	0.81
1	2	90.89	910	20.2	5.63	0.81
1	3	90.86	910	20.2	5.63	0.81
1	4	90.93	910	20.2	5.63	0.81
2	1	90.96	910	21.3	6.35	0.72
2	2	90.93	910	21.3	6.35	0.72
2	3	90.92	910	21.3	6.35	0.72
2	4	90.90	910	21.3	6.35	0.72
5	1	90.92	910	20.7	5.90	0.79
5	2	90.93	910	15.5	6.20	0.64
6	1	90.92	910	15.5	6.20	0.64

Table 5. Analysis of organic compounds in leachate. Test methods.

Parameter	Detection limit	Measurement uncertainty	Method based on
PAH(16)	0.02 μg/L	± 30 %	NS 9815
Phthalates(8)	0.1-1 μg/L	± 20 %	-
4-t-Octylphenol, 4-n-Nonylphenol, iso-Nonylphenol	5-50 ng/L	± 10 %	Derivatisation
Total organic carbon (TOC)	0.1 mg/L	± 10 %	NS-EN 1484
Dissolved organic carbon (DOC)	0.1 mg/L	± 10 %	NS-EN 1484-1
Turbidity	0.05 FTU	± 10 %	NS-ISO 7027-1
Suspended matter	0.6 mg/L	± 20 %	NS 4733-2

3.3 Degassing from rubber granulate

For the degassing test, 2g of rubber granulate was weighed out. This granulate was then heated to 70°C for 30 minutes before the gas mixture was analysed. The degassing test was carried out by NBI's subcontractor AnalyCen AS.

4 Results

4.1 Total analysis

Tables 6 and 7 show the analysis results for total content of selected elements and organic compounds in rubber granulates and artificial turf fibres.

Table 6. Total content of selected elements and organic compounds in rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6	SFT's normative value[1)]	Agriculture Canada [2)]	PNEC[3)]
Arsenic, As	mg/kg	< 3	< 3	< 2	< 2	2	12	
Lead, Pb	mg/kg	20	15	17	8	60	70	
Cadmium, Cd	mg/kg	1	1	2	< 0.5	3	1.4	
Copper, Cu	mg/kg	35	20	70	< 3	100	63	
Chromium, Cr	mg/kg	< 2	< 2	< 2	5200	25	64	
Mercury, Hg	mg/kg	0.04	0.04	< 0.03	< 0.03	1	6.6	
Nickel, Ni	mg/kg	< 2	< 1	< 5	< 5	50	50	
Zinc, Zn	mg/kg	7500	7300	17000	9500	100	200	
Polychlorinated biphenyls (PCB)								
PCB(7)	mg/kg	< 0.175	< 0.175	0.202	< 0.004	0.01	0.5	
PCB 28	mg/kg	< 0.05	< 0.05	0.114	< 0.001			
PCB 52	mg/kg	< 0.05	< 0.05	0.072	< 0.001			
PCB 101	mg/kg	< 0.05	< 0.05	0.002	< 0.001			
PCB 118	mg/kg	< 0.05	< 0.05	0.001	< 0.001			
PCB 153	mg/kg	< 0.05	< 0.05	0.003	< 0.001			
PCB 138	mg/kg	< 0.05	< 0.05	0.008	< 0.001			
PCB 180	mg/kg	< 0.05	< 0.05	0.002	< 0.001			
Polycyclic aromatic hydrocarbons (PAH)								
PAH(16)	mg/kg	51	74	76	1	2		
Naphthalene	mg/kg	0.4	0.32	0.72	0.19	0.8	0.1	
Acenaphthylene	mg/kg	0.6	0.79	1	< 0.08			
Acenaphthene	mg/kg	< 0.2	< 0.2	0.32	< 0.08			
Fluorene	mg/kg	0.4	0.55	0.68	< 0.08	0.6		
Phenanthrene	mg/kg	4.8	5.9	5.8	0.43		0.1	
Anthracene	mg/kg	0.6	0.55	0.76	< 0.08			
Fluoranthene	mg/kg	7.8	11	11	0.12	0.1		
Pyrene	mg/kg	23	37	34	0.16	0.1	0.1	
Benzo(a)anthracene	mg/kg	1.4	1.9	1.8	< 0.08		0.1	
Crysene	mg/kg	2.2	2.2	4.2	< 0.08			
Benzo(b)fluoranthene	mg/kg	2.2	3.5	3.9	< 0.08		0.1	
Benzo(k)fluoranthene	mg/kg	0.4	0.55	1.5	< 0.08		0.1	
Benzo(a)pyrene	mg/kg	2.4	3.1	3	0.12	0.1	0.1	
Indeno(1,2,3,cd)pyrene	mg/kg	0.8	0.95	1.4	< 0.08		0.1	
Dibenzo(a,h)anthracene	mg/kg	< 0.4	< 0.2	0.44	< 0.08		0.1	
Benzo(g,h,i)perylene	mg/kg	3.4	5.8	5.1	< 0.08			
Phthalates								
Dimetylphthalate (DMP)	mg/kg	< 1.0	< 1.0	< 1.0	3.4			
Dietylphthalate (DEP)	mg/kg	< 1.0	< 1.0	< 1.0	1.5			
Dibutylphthalate (DBP)	mg/kg	3.4	2.6	3.9	1.6			2[4)]

Benzylbutylphthalate (BBP)	mg/kg	1.3	2.8	1.9	< 1.0			
Diethylhexylphthalate (DEHP)	mg/kg	21	21	29	3.9			
Di n-octylphthalate (DOP)	mg/kg	< 1.0	< 1.0	< 1.0	3.2			
Diisononylphthalate (DINP)	mg/kg	57	78					30[4]
Diisodecylphthalate (DIDP)	mg/kg	< 1.0	< 1.0					100[4]
Phenols								
4-t-Octylphenol	µg/kg	33700	27800	19600	49.8			
4-n-Nonylphenol	µg/kg	< 5	< 5	< 5	< 5		5700[5]	
iso-Nonylphenol	µg/kg	21200	21600	9120	1120		5700[5]	300[4]

1) Guidance concerning risk assessment of polluted ground. Norwegian Pollution Control Authority guidance 99:01a. 1999.
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration.
4) European Commission, Summary Risk Assessment Reports, 2002 and 2003.
5) The values apply to total nonylphenols.

Table 7. Total content of selected elements and organic compounds in artificial turf fibre.

Parameter	**Unit**	**Sample 3**	**Sample 4**	**SFT's normative value[1]**	**Agriculture Canada[2]**	**PNEC[3]**
Arsenic, As	mg/kg	< 3	< 2	2	12	
Lead, Pb	mg/kg	< 2	< 2	60	70	
Cadmium, Cd	mg/kg	< 0.1	< 0.1	3	1.4	
Copper, Cu	mg/kg	59	68	100	63	
Chromium, Cr	mg/kg	< 2	< 2	25	64	
Mercury, Hg	mg/kg	< 0.03	< 0.03	1	6.6	
Nickel, Ni	mg/kg	< 1	< 1	50	50	
Zinc, Zn	mg/kg	3100	3300	100	200	
Polychlorinated biphenyls (PCB)						
PCB(7)	mg/kg	< 0.007	< 0.007	0.01	0.5	
PCB 28	mg/kg	< 0.02	< 0.02			
PCB 52	mg/kg	< 0.02	< 0.02			
PCB 101	mg/kg	< 0.02	< 0.02			
PCB 118	mg/kg	< 0.02	< 0.02			
PCB 153	mg/kg	< 0.02	< 0.02			
PCB 138	mg/kg	< 0.02	< 0.02			
PCB 180	mg/kg	< 0.02	< 0.02			
Polycyclic aromatic hydrocarbons (PAH)						
PAH(16)	mg/kg	< 1.0	< 2.0	2		
Naphthalene	mg/kg	< 0.05	< 0.1	0.8	0.1	
Acenaphthylene	mg/kg	< 0.05	< 0.1			
Acenaphthene	mg/kg	< 0.05	< 0.1			
Fluorene	mg/kg	< 0.05	< 0.1	0.6		
Phenanthrene	mg/kg	< 0.05	< 0.1		0.1	
Anthracene	mg/kg	< 0.05	< 0.1			
Fluoranthene	mg/kg	< 0.05	< 0.1	0.1		

Pyrene	mg/kg	< 0.05	< 0.1	0.1	0.1	
Benzo(a)anthracene	mg/kg	< 0.05	< 0.1		0.1	
Crysene	mg/kg	< 0.05	< 0.1			
Benzo(b)fluoranthene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(k)fluoranthene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(a)pyrene	mg/kg	< 0.05	< 0.1	0.1	0.1	
Indeno(1,2,3,cd)pyrene	mg/kg	< 0.05	< 0.1		0.1	
Dibenzo(a,h)anthracene	mg/kg	< 0.05	< 0.1		0.1	
Benzo(g,h,i)perylene	mg/kg	< 0.05	< 0.1			
Phthalates						
Dimetylphthalate (DMP)	mg/kg	< 1.0	1.2			
Dietylphthalate (DEP)	mg/kg	< 1.0	< 1.0			
Dibutylphthalate (DBP)	mg/kg	< 1.0	1			2[4]
Benzylbutylphthalate (BBP)	mg/kg	< 1.0	< 1.0			
Diethylhexylphthalate (DEHP)	mg/kg	1.7	8			
Di n-octylphthalate (DOP)	mg/kg	< 1.0	< 1.0			
Diisononylphthalate (DINP)	mg/kg	< 1.0	5.5			30[4]
Diisodecylphthalate (DIDP)	mg/kg	< 1.0	< 1.0			100[4]
Phenols						
4-t-Octylphenol	µg/kg	< 5	36.4			
4-n-Nonylphenol	µg/kg	< 5	< 5		5700[5]	
iso-Nonylphenol	µg/kg	< 50	213		5700[5]	300[4]

1) Guidance concerning risk assessment of polluted ground. SFT guidance 99:01a. 1999.
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration.
4) European Commission, Summary Risk Assessment Reports, 2002 and 2003.
5) The values apply to total nonylphenols.

4.2 Leaching

4.2.1 Leaching of elements from artificial turf fibre and rubber granulate

Table 8 shows the results of the leaching of Zn and Cr from artificial turf fibre and rubber granulates.

Table 8. Leaching of Zn and Cr from artificial turf fibre and rubber granulates.

Sample type	Sample no.	Leachate				
		Temperature [ºC]	pH	Conductivity [µS/cm]	Zn [µg/l]	Cr [µg/l]
Granulate	1	27.0	7.69	77.4	2290	-
Granulate	2	26.0	7.80	34.4	1220	-
Granulate	5	27.8	7.54	35.1	590	-
Granulate	6	27.7	11.36	1276	80	< 2
Fibre	3	27.2	7.12	28.4	1000	-
Fibre	4	27.3	6.95	69.5	860	-

4.2.2 Leaching of organic compounds from rubber granulate

Tables 9 and 10 show the results of the leaching of organic compounds from rubber granulate.

Table 9. Leaching of organic compounds from rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6	Drinking water Norway[1)]	SFT Environmental Quality Class I[2)]	SFT Environmental Quality Class V[2)]
pH		7.7	7.7	7.9	11.6	6.5-9.5	> 6.5	< 5
Conductivity	µS/cm	85.6	38.3	37.6	1390	2500		
Temperature	°C	28.0	28.4	24.6	24.6			
Total organic carbon (TOC)	mg/L	57	35	35	170	5	< 2.5	> 15
Dissolved organic carbon (DOC)	mg/L	56	34	34	170			
Turbidity	FTU	2.1	3.2	2.3	1.0	4	< 0.5	> 5
Suspended matter	mg/L	2.9	2.7	2.7	1.3		< 1.5	> 10

1) Regulation on water supply and drinking water (the Drinking Water Regulation), 2004
2) SFT, Classification of environmental quality in freshwater, guidance 97:04, 1997. Environmental quality class for nutrient salts, organic matter, pH, particles and bacteria. Status class I: Very good. Status class V: Very poor.

Table 10. Leaching of organic compounds from rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Drinking Water Norway[1)]	Freshwater Canada[2)]	PNEC[3)]
Polychlorinated biphenyls (PCB)							
PCB(7)	µg/L			< 0.01		0.0001	
PCB 28	µg/L			< 0.01			
PCB 52	µg/L			< 0.01			
PCB 101	µg/L			< 0.01			
PCB 118	µg/L			< 0.01			
PCB 153	µg/L			< 0.01			
PCB 138	µg/L			< 0.01			
PCB 180	µg/L			< 0.01			
Polycyclic aromatic hydrocarbons (PAH)							
Sum PAH(16)	µg/L	0.87	0.44				
Sum PAH(4)[4)]	µg/L	< 0.01	< 0.01		0.1		
Naphthalene	µg/L	0.15	< 0.01			1.1	
Acenaphthylene	µg/L	0.27	< 0.01				
Acenaphthene	µg/L	0.03	0.02			5.8	
Fluorene	µg/L	0.04	0.04			3.0	
Phenanthrene	µg/L	0.16	0.17			0.4	
Anthracene	µg/L	0.03	0.03			0.012	
Fluoranthene	µg/L	0.06	0.06			0.04	
Pyrene	µg/L	0.13	0.12			0.025	
Benzo(a)anthracene	µg/L	< 0.01	< 0.01			0.018	

Crysene	µg/L	< 0.01	< 0.01		
Benzo(b)fluoranthene	µg/L	< 0.01	< 0.01		
Benzo(k)fluoranthene	µg/L	< 0.01	< 0.01		
Benzo(a)pyrene	µg/L	< 0.01	< 0.01	0.015	
Indeno(1,2,3,cd)pyrene	µg/L	< 0.01	< 0.01		
Dibenzo(a,h)anthracene	µg/L	< 0.01	< 0.01		
Benzo(g,h,i)perylene	µg/L	< 0.01	< 0.01		
Phthalates					
Dimetylphthalate (DMP)	µg/L	0.6	1.6		
Dietylphthalate (DEP)	µg/L	6.6	8.3		
Dibutylphthalate (DBP)	µg/L	3.3	2.1	19	10
Benzylbutylphthalate (BBP)	µg/L	< 0.1	0.3		
Diethylhexylphthalate (DEHP)	µg/L	5.1	5.6	16	
Di n-octylphthalate (DOP)	µg/L	2.9	4.4		
Diisononylphthalate (DINP)	µg/L	2.7	2.2		No effect
Diisodecylphthalate (DIDP)	µg/L	< 1.0	1.0		No effect
Phenols					
4-t-Octylphenol	µg/L	3600	2950		
4-n-Nonylphenol	µg/L	43	< 20	1000[5)]	330[5)]
iso-Nonylphenol	µg/L	1120	568	1000[5)]	330[5)]

1) Regulation on water supply and drinking water (the Drinking Water Regulation), 2004
2) Canadian Environmental Quality Guidelines. Summary of Existing Canadian Environmental Quality Guidelines. 2002.
3) PNEC = Predicted No Effect Concentration. The values were taken from the European Commission, Summary Risk Assessment Report, 2003 and 2004.
4) Total of the concentrations of benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene and indeno(1,2,3-cd)pyrene.
5) The limit applies to total nonylphenols.
6) Water Quality Criteria for Polychlorinated Biphenyls (PCBs). Technical appendix. Ministry of Environment, Land and Parks Province of British Columbia. Canada. 1992.

4.3 Degassing of volatile organic compounds

The results from the degassing test are shown in Table 11.

Table 11. Degassing test - rubber granulates.

Parameter	Unit	Sample 1	Sample 2	Sample 5	Sample 6
Alkylated benzenes					
Toluene	µg/kg	80	56	28	9
Ethylbenzene	µg/kg	18	12	7.8	< 5
Propylbenzene	µg/kg	15	< 0.8	8.8	5
iso-Propylbenzene	µg/kg	0.7	12	< 5	< 5
n-Butylbenzene	µg/kg	31	21	28	< 5
m/p-Xylene	µg/kg	37	28	25	< 5
o-Xylene	µg/kg	35	24	20	< 5
p-Isopropyltoluene	µg/kg	23	8.6	17	< 5
1.2-4-Trimethylbenzene	µg/kg	102	83	100	9.4
1.3.5-Trimethylbenzene	µg/kg	23	18	19	< 5
Chlorinated compounds					

Trichloromethane	µg/kg	8	- < 5 < 5		
cis-1,2-Dichlorethene	µg/kg	< 5	< 5	32	10

5 Assessment

5.1 Total analysis and leaching

A simplified risk assessment was carried out for the rubber granulates and artificial turf fibres. In a simplified risk assessment, the total content of hazardous compounds in the source material is compared with the Norwegian Pollution Control Authority's normative values for 'most sensitive land use'. 'Most sensitive land use' covers areas intended for housing, gardens, nurseries, schools, etc.

The Norwegian Pollution Control Authority's list of normative values for most sensitive land use does not contain any values for phthalates or phenols. Values for phenols taken from the "Canadian Environmental Quality Guidelines - Agricultural Soil" were used instead. PNEC values (Predicted No Effect Concentration) for individual phthalates were taken from the EU's programme for risk assessment.

If the normative value is not exceeded, the source material is considered to have an acceptable concentration of the hazardous compound. If the total content of a compound exceeds normative values for most sensitive land use, an extended assessment is carried out. The extended assessment is based on leaching tests. The assessment of water quality depends on how the water is to be used. The limits for drinking water intended for human consumption can in some cases differ considerably from the limits which are considered acceptable for aquatic organisms. In connection with the assessment of the leaching test, it was decided to compare the concentration of the relevant compound with limits for the concentration of the same compound in both drinking water and freshwater. The limits were taken from the Norwegian Drinking Water Regulation, the Norwegian Pollution Control Authority's Environmental Quality Classes I-V and Canada's limits for hazardous compounds in drinking water and freshwater.

For the leaching tests, the mobility of the compounds was calculated, both as a % mobilised compound and as a K_d value. The mobility of a compound expresses the degree to which the compound is transferred from the granulate or fibre to the leachate. The percentage mobilised compound gives an indication of how much of the total content in the granulate or fibre was dissolved into the water. The K_d factor can be considered as the number of litres of extraction water which contains the same quantity of a compound as is found of the compound in 1 kg of granulate or fibre. A high K_d value indicates a low mobility and vice versa.

5.1.1 Assessment of the artificial turf fibres

The total analysis shows that there is little difference between the two artificial turf fibre types with regard to the content of arsenic, lead, cadmium, copper, chromium, mercury, nickel, zinc, PCB and PAH; see Table 7. Sample 4 contains slightly more phthalates and phenols than sample 3.

Copper and zinc were demonstrated in both the artificial turf fibres. Any concentrations of arsenic, lead, cadmium, chromium, mercury, nickel, PCB or PAH are below the detection limit

for the analysis method. Both the artificial turf fibre types come under the Norwegian Pollution Control Authority's normative values for lead, cadmium, copper, mercury, nickel, PCB and PAH.

Both the artificial turf fibres exceed the Norwegian Pollution Control Authority's normative value for zinc. A leachate test was therefore performed with the aim of determining the degree to which zinc is dissolved out of the artificial turf fibre. The Drinking Water Regulation does not specify a limit for the concentration of zinc in drinking water. The concentration of zinc in the leachate from both fibres is above the Norwegian Pollution Control Authority's limit for zinc in water with Environmental Quality Class V (very strongly polluted), but lower than the permitted zinc concentration in Canadian drinking water (=5 mg/l).

The concentration of arsenic in the artificial turf fibres is less than 3 mg/kg, whilst the Norwegian Pollution Control Authority's normative value for most sensitive land use is 2 mg/kg. The data does not therefore provide a basis for concluding whether the Norwegian Pollution Control Authority's normative value for arsenic has been exceeded, but if it has been exceeded it can only be by a small amount.

4-t-octylphenol and iso-nonylphenol were demonstrated in sample 4. Any concentrations of octylphenol or nonylphenol in sample 3 are below the detection limit of the analysis method. The concentration of nonylphenols in the artificial turf fibres is below the limits specified in the Canadian Environmental Quality Guidelines and the PNEC value. No limits were found for octylphenol.

DEHP was demonstrated in samples 3 and 4. Sample 4 contains four times as much DEHP as sample 3. Sample 4 also contained DMP and DINP. The quantities of DBP, DINP and DIDP in both artificial turf fibres are below the PNEC values for terrestrial life. No limits were found for the remaining phthalates in soil, but it is worth noting that DMP is included in the environmental protection authorities' list of particularly hazardous chemicals because it has properties which are harmful to reproductive health. DEHP also has considerable potential for bioaccumulation and high acute toxicity.

The pH measured in the leachate from the artificial turf fibres is within the range specified in the Drinking Water Regulation (6.5-9.5). The conductivity of the leachate also complies with the corresponding limit in the Drinking Water Regulation (2500 µS/cm).

5.1.2 Assessment of the rubber granulates

5.1.2.1 Rubber granulates based on recycled rubber

Samples 1, 2 and 5 are rubber granulates based on recycled rubber. Samples 2 and 5 are fine-grained and coarse-grained rubber types respectively from the same manufacturer.

Sample 1 and sample 2 are very similar with regard to the total concentration of environmental toxins. Sample 5 contains more than twice as much copper and zinc as samples 1 and 2. In addition, sample 5 contains PCB. PCB was not demonstrated in samples 1 or 2. The differences between sample 2 and sample 5, which are both from the same manufacturer, show that products from a single manufacturer can vary considerably. At the same time, products from two different manufacturers can show great similarity with regard to concentrations of environmental toxins, as is the case for sample 1 compared with sample 2.

Lead, cadmium, copper, zinc, PAH, phthalates and phenols were demonstrated in all the rubber granulates based on recycled rubber. Samples 1 and 2 also contained some mercury, whilst PCB was demonstrated in sample 5.

The recycled rubber granulate types are below the Norwegian Pollution Control Authority's normative values for lead, cadmium, copper, chromium, mercury and nickel. The concentration of arsenic in sample 5 is also below the Norwegian Pollution Control Authority's normative values. The concentrations of arsenic in samples 1 and 2 are below 3 mg/kg, while the Norwegian Pollution Control Authority's normative value for most sensitive land use is 2 mg/kg. The data does not therefore provide an adequate basis on which to decide whether the Norwegian Pollution Control Authority's normative value for arsenic has been exceeded, but if it has been exceeded it can only be by a small amount. Similarly, the total analysis shows that the concentrations of PCB in samples 1 and 2 are below 0.175 mg/kg. The Norwegian Pollution Control Authority's normative value for most sensitive land use is 0.01 mg/kg. It is therefore difficult to decide whether the normative values for PCB are exceeded in samples 1 and 2.

The total concentration of zinc exceeds the Norwegian Pollution Control Authority's normative value for recycled rubber granulates. The leaching test shows that zinc is transferred from the granulate to water. The zinc values are above the Norwegian Pollution Control Authority's limit for zinc in water in Environmental Quality Class V (very strongly polluted), but lower than the zinc concentration permitted in Canadian drinking water (5 mg/l).

The concentration of PCB in sample 5 exceeds the Norwegian Pollution Control Authority's normative values. The leaching test shows that little PCB is transferred to the water phase. PCB is virtually insoluble in water.

The total concentration of PAH exceeds the Norwegian Pollution Control Authority's normative value for all three recycled rubber granulates. The leachate from samples 1 and 2 also contained PAH. No leaching test was carried out on sample 5. 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. The leachate can therefore be said to comply with the requirements in the Drinking Water Regulation, as the Regulation only specifies values for benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3,cd)pyrene, benzo(g,h,i)perylene and benzo(a)pyrene. Neither the Drinking Water Regulation nor the Norwegian Pollution Control Authority's environmental quality classes specify limits for the remaining PAH compounds which were found in the leachate. It was therefore decided to compare the values with the limits for freshwater in Canada. The values for anthracene, fluoranthene and pyrene in the leachate from samples 1 and 2 exceed the limits for freshwater in Canada, while the concentrations of naphthalene, acenaphthene, fluorene and phenanthrene are lower. No limit data was found for acenaphthylene.

DBP, BBP and DEHP were demonstrated in all recycled rubber granulates. DINP was also demonstrated in samples 1 and 2. No analysis for DINP or DIDP was carried out for sample 5. Any concentrations of DMP, DEP, DOP and DIDP are below the detection limit for the analysis method. The Norwegian Pollution Control Authority does not specify any normative values for phthalates in soil. It was therefore decided to compares values with PNEC values where such values are available. The total quantities of DBP and DINP in both the rubber granulates exceed the PNEC values for terrestrial life. The rubber granulates also contain some BBP and DEHP. No limits were found for BBP and DEHP, but both are on the environmental protection authorities' list of particularly hazardous chemicals, because they have properties that are harmful to reproductive health, considerable potential for bioaccumulation and high acute toxicity.

Significant quantities of phthalates were found in the leachate, particularly DEP and DEHP, but DMP, DBP, DOP, DINP and DIDP were also found. The concentrations of DBP and DEHP in the leachate were below the limits for freshwater in Canada. No limits were found for the remaining phthalates in water, but it is worth noting that DMP is included in the environmental protection authorities' list of particularly hazardous chemicals as it has properties that are harmful to reproductive health and that BBP also has considerable potential for bioaccumulation and high acute toxicity. The EU's programme for risk assessment concludes that DINP and DIDP do not have any effect on aqueous life.

The presence of 4-t-octylphenol and iso-nonylphenol was demonstrated in both rubber granulates. The concentration of nonylphenol is above the limits specified in the Canadian Environmental Quality Guidelines. The concentration of nonylphenol in the leachate from sample 1 exceeds both the limits for freshwater in Canada and the PNEC value for water. The concentration of nonylphenol in the leachate from sample 2 exceeds the PNEC value for water. No limits were found for octylphenol in soil or water.

The concentration of total organic carbon (TOC) in the leachate from the rubber granulates exceeds the limit in the Drinking Water Regulation (5 mg/l). With regard to TOC, the leachate comes under the Norwegian Pollution Control Authority's Environmental Quality Class V (very poor). The high concentration of organic carbon is probably due to small particulate waste from the rubber granulates which were not captured by the filter during the filtration.

The turbidity of the leachate from the rubber granulates is below the value specified in the Drinking Water Regulation for water for subscribers (4 FTU), but it corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class IV (poor). The quantity of suspended matter in the leachate corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class II (good). No limit is specified for suspended matter in the Drinking Water Regulation. The pH of the leachate is within the range specified in the Drinking Water Regulation (6.5-9.5). The conductivity of the leachate also complies with the Drinking Water Regulation's limit (2500 µS/cm).

The recycled rubber granulates release a large number of alkylated benzenes in gaseous form. Trichloromethane (sample 1) and cis-1,2-dichlorethene (sample 5) were also found. Some of these compounds are regulated through the "Administrative norms for pollution of the working atmosphere"; see Table 12. These norms specify the highest acceptable average concentration over eight hours.

Relating the results of the degassing test to actual air concentrations above an artificial turf pitch falls outside the scope of the project. It is therefore recommended that measurements of air quality be made above pitches to determine whether the quality is satisfactory.

Table 12. Extract from "Administrative norms for pollution of the working atmosphere". These norms specify the highest acceptable average concentration in the air over an eight-hour period.

Compound	**Air concentration [mg/m^3]**	**Remarks**
	Alkylated benzenes	
Ethylbenzene	20	Absorbed through the skin. Carcinogenic.
Trimethylbenzene (all isomers)	100	
m-Xylene	108	Absorbed through the skin.
p-Xylene	108	Absorbed through the skin.

o-Xylene	108	Absorbed through the skin.
	Chlorinated compounds	
1,2-Dichloroethene (mixture of the cis- and trans-forms)	395	
Trichloromethane	10	Absorbed through the skin. Carcinogenic. Reprotoxic.

5.1.2.2 Mobility of metals and organic compounds in rubber granulates

Table 13 shows the calculated mobility for the compounds in the leaching test. Zinc shows a high mobility, yet only a small proportion of the total zinc content has been leached out. The organic compounds show low mobility. The proportion of the total content of organic compounds which have been leached out is low.

Table 13. Mobilistion of compounds.

Parameter	**Sample 1**		**Sample 2**		**Sample 5**		**Sample 6**	
	% mobilised	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**	**% mobilised**	**K_d [l/kg]**
Chromium, Cr	-	-	-	-	-	-	< 0.0004	> 2600
Zinc, Zn	0.31	3	0.17	6	0.03	29	0.01	119
Polychlorinated biphenyls (PCB)								
PCB (7)	-	-	-	-	< 0.005	-	-	-
PCB 28	-	-	-	-	< 0.009	-	-	-
PCB 52	-	-	-	-	< 0.014	-	-	-
PCB 101	-	-	-	-	< 0.5	-	-	-
PCB 118	-	-	-	-	< 1	-	-	-
PCB 153	-	-	-	-	< 0.3	-	-	-
PCB 153	-	-	-	-	< 0.1	-	-	-
PCB 138	-	-	-	-	< 0.5	-	-	-
PCB 180	-	-	-	-		-	-	-
Polycyclic aromatic hydrocarbons (PAH)								
PAH (16)	0.002	58621	0.001	168182	-	-	-	-
Naphthalene	0.038	2667	< 0.0031	> 32000	-	-	-	-
Acenaphthylene	0.045	2222	< 0.0013	> 79000	-	-	-	-
Acenaphthene	-	< 6667	-	< 10000	-	-	-	-
Flourene	0.010	10000	0.007	13750	-	-	-	-
Phenanthrene	0.003	30000	0.003	34706	-	-	-	-
Anthracene	0.005	20000	0.005	18333	-	-	-	-
Fluoranthene	0.001	130000	0.001	183333	-	-	-	-
Pyrene	0.001	176923	0.000	308333	-	-	-	-
Benzo(a)anthracene	< 0.0007	> 140000	< 0.0005	> 190000	-	-	-	-
Crysene	< 0.0005	> 220000	< 0.0005	> 220000	-	-	-	-
Benzo(b)fluoranthene	< 0.0005	> 220000	< 0.0003	> 350000	-	-	-	-
Benzo(k)fluoranthene	< 0.0025	> 40000	< 0.0018	> 55000	-	-	-	-
Benzo(a)pyrene	< 0.0004	> 240000	< 0.0003	> 310000	-	-	-	-
Indeno(1,2,3,cd)pyrene	< 0.0013	> 80000	< 0.0011	> 95000	-	-	-	-
Dibenzo(a,h)anthracene	-	-	-	-	-	-	-	-
Benzo(g,h,i)perylene	< 0.0003	> 340000	< 0.0002	> 580000	-	-	-	-
Phthalates								
Dimetylphthalate (DMP)	-	< 1667	-	< 625	-	-	-	-
Dietylphthalate (DEP)	-	< 152	-	< 120	-	-	-	-
Dibutylphthalate (DBP)	0.097	1030	0.081	1238	-	-	-	-
Benzylbutylphthalate					-	-	-	-

(BBP)	< 0.008	> 13000	0.011	9333				
Diethylhexylphthalate (DEHP)	0.024	4118	0.027	3750	-	-	-	-
Di n-octylphthalate (DOP)	-	< 345	-	< 227	-	-	-	-
Diisononylphthalate (DINP)	0.005	21111	0.003	35455	-	-	-	-
Diisodecylphthalate (DIDP)	-	-	-	-	-	-	-	-
			Phenols					
4-t-Octylphenol	0.011	9361	0.011	9424	-	-	-	-
4-n-Nonylphenol		< 116			-	-	-	-
iso-Nonylphenol	0.005	18929	0.003	38028	-	-	-	-

5.1.2.3 Comparison of recycled rubber granulate and EPDM rubber granulate

The EPDM rubber (sample 6) contains more chromium than the recycled rubber types. The zinc concentration in the EPDM rubber is at the same level as in the recycled rubber types, while concentrations of PAH, phthalates and phenols are lower. No PCB was demonstrated in the EPDM rubber.

Concentrations of chromium and zinc in the EPDM rubber exceed the Norwegian Pollution Control Authority's normative values for most sensitive land use. The concentration of zinc in the leachate corresponds to the Norwegian Pollution Control Authority's Leaching Class IV (strongly polluted). The concentration of chromium in the leachate was below the requirements in the Drinking Water Regulation and corresponds to the Norwegian Pollution Control Authority's Environmental Quality Class II (moderately polluted).

The leachate from the EPDM rubber has a considerably higher pH and conductivity than that from the recycled rubber. The pH is higher than the recommended range for drinking water in Norway. The conductivity complies with the limit in the Drinking Water Regulation.

The mobility of zinc is slightly lower than for the recycled rubbers.

The EPDM rubber gives off a smaller quantity of volatile organic compounds than the recycled rubber types.

With the exception of chromium and zinc, the EPDM rubber contains lower concentrations of hazardous substances than the recycled rubber types overall.

5.1.3 Comparison of rubber granulates and artificial turf fibre

Per square metre of artificial turf, there is approximately 0.8 kg of artificial turf fibre and 17-18 kg of rubber granulate. The artificial turf fibre-rubber ratio is therefore approximately 0.05 kg fibre/kg of granulate. As the measured concentration of environmental toxins (with the exception of copper) in the artificial turf fibres is lower than in the rubber granulates, and the artificial turf fibres in any case represent a much smaller proportion of the artificial turf system in terms of mass than the rubber granulate, it is suggested that further investigations concentrate on the rubber granulates.

6 Conclusions

6.1 Artificial turf fibre

The total analysis shows that the artificial turf fibres contain copper, zinc, individual phthalates, 4-t-octylphenol and iso-nonyl-phenol. The concentration of zinc complies with the Norwegian Pollution Control Authority's normative values for most sensitive land use for both fibre types. The two fibre types are very similar.

The total content of copper in the artificial turf fibres is below the Norwegian Pollution Control Authority's normative values for most sensitive land use and probably does not constitute an unacceptable environmental risk in either the short or the long term.

The leachate from the fibres contained zinc. The concentration is higher than the Norwegian Pollution Control Authority's limit for zinc in water with Environmental Quality Class V (very strongly polluted water), but lower than the permitted zinc concentration in Canadian drinking water.

As the measured concentration of environmental toxins (with the exception of copper) in the artificial turf fibres is lower than in the rubber granulates, and the artificial turf fibres in any case constitute a much smaller proportion of the artificial turf system in terms of mass, it is suggested that further investigations concentrate on the rubber granulates.

6.2 Rubber granulate

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.

The total concentration of lead, cadmium, copper and mercury in the recycled rubber granulates is below the Norwegian Pollution Control Authority's normative values for most sensitive land use and probably does not constitute an unacceptable environmental risk in the short or the long term.

The total concentrations of zinc and PAH in the recycled rubber granulates exceed the Norwegian Pollution Control Authority's normative values for most sensitive land use. The concentrations of dibutylphthalate (DBP) and diisononylphthalate (DINP) exceed the PNEC values for terrestrial life taken from the EU's programme for risk assessment. The concentration of isononylphenol is above the limits specified for cultivated land in the Canadian Environmental Quality Guidelines.

The leachate from the recycled granulates contain zinc, polycyclic aromatic hydrocarbons (PAH), phthalates and phenols. The concentration of zinc indicates that the leachate water is placed in the Norwegian Pollution Control Authority's Environmental Quality Class V (very strongly polluted water), but is lower than the permissible zinc concentration in Canadian drinking water. The concentration of anthracene, fluoranthene, pyrene and nonylphenols exceed the limits for freshwater specified in the Canadian Environmental Quality Guidelines. An expanded risk assessment with an analysis of possible spreading paths and changes in leaching properties over time is necessary to determine the degree to which the concentrations of zinc, anthracene, fluoranthene, pyrene, phthalates and nonylphenols in the leachate are actually harmful to people and the environment.

The recycled rubber granulates give off a significant number of alkylated benzenes in gaseous form. Trichloromethane (sample 1) and cis-1,2-dichlorethene (sample 5) were also found. It is

recommended that measurements be taken of air quality above pitches to determine whether the air quality is satisfactory. 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.

Oslo, 10.09.04
for the Norwegian Building Research Institute

Thale Plesser