Artificial turf pitches –
an assessment of the health risks for football players

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Introduction

Sports halls with artificial turf pitches are used for indoor football. Artificial turf pitches consist of artificial turf fibre and rubber granulates. Rubber granulates can be one of several main types: recycled rubber (ground car tyres), thermoplastic elastomer or EPDM rubber. Recycled rubber granulates can be produced in a variety of qualities (coarse-ground/fine-ground, different chemical compositions/different additives). Two types of artificial turf fibre are also used (split fibre and monofibre). Information on the occurrence and concentrations of chemical substances in rubber granulate and in sports hall air is based on the report by the Norwegian Institute for Air Research (NILU) entitled "Measurement of air pollution in indoor artificial turf sports halls" of January 2006 (TA number: TA-2148/2006). The assessment of the potential risk of cancer and gentoxicity was undertaken by Tore Sanner of the Radium Hospital.

Given the large number of substances which were identified in the rubber granulates and during the degassing of volatile organic compounds (VOC), it was decided to use worst case scenarios where quantities within each substance category (PCBs, PAHs, phthalates, alkyl phenols and VOCs) were summed and the lowest no observed adverse effect (NOAEL) value was used (when available) for the most relevant biological end points (e.g. cancer, reproductive damage, organ damage). Such an approach will clearly overestimate the health risk. We have chosen the highest analysis values as regards recycled rubber granulate because this type of rubber granulate contains the largest quantities of potentially hazardous substances and leads to the highest measured values in sports hall air. An analytical detection limit was chosen in cases where no measured value was available.

Nine exposure scenarios were used: adults, juniors, older children and children.

- inhalation exposure: adults, junior, older children and children (Scenarios 1-4)
- skin exposure: adults, junior, older children and children (Scenarios 5-8)
- oral exposure: children (Scenario 9).

Exposure levels were based on inhalation values (inhalation volumes during training sessions/matches) and skin exposure (mg/cm^2 deposited on the skin). As regards oral exposure (swallowing), we have assumed that up to 1.0 gram of rubber granulate can be swallowed per training session/match.

Exposure duration and frequency are based on information from the managers of the Valhall and Manglerudhallen sports halls in Oslo and Nordlandshallen and Skarpehallen in Tromsø. On the basis of this information, we selected worst case scenarios for the various age groups. These worst case scenarios are based on the highest measured values and the longest/most frequent training/match periods that are used.

Exposure scenarios

As regards the choice of exposure scenarios, four main types of scenario were used for training sessions and matches on artificial turf pitches: adults (≥20 years, 20-40 years was used for the assessment of cancer risk), juniors (16-19 years), older children (12-15) and children (7 -11 years). Exposure times and the type of activity (training and matches) were based on information obtained from the following sports halls: Valhall and Manglerudhallen in Oslo and Nordlandshallen and Skarpehallen in Tromsø. The pattern of use will vary from pitch to pitch and geographic location will be an important factor as regards the times of the year during which indoor pitches are used. Exposure will take place through the inhalation of volatile compounds and particles, through particles coming into contact with the skin (skin exposure is of little importance as regards volatile compounds) and to some extent through swallowing (assumed to apply largely to children).

Inhalation

The exposure characterisation covers four main scenarios: adults who play/train, juniors who play/train, older children who play and train and children who play/train and play cup tournaments. The respiration volumes are based on information from the Norwegian University of Sport and Physical Education and assume maximum exertion during training sessions. The inhalation volumes used are: adults 6 m^3/hour, junior 4.8 m^3/hour, older children 3.6 m^3/hour and children 1.8 m^3/hour. For comparative purposes, the US EPA uses a figure of 3.63 m^3/hour for physically demanding work for adults and 2.23 m^3/hour for children (6-13 years). The EU uses a figure of 2.6 m^3/hour for physically demanding work. The scenarios are described below and are based on information concerning patterns of use of sports halls with artificial turf.

- Scenario 1: Adults who train and play matches indoors (Skarphallen, Tromsø):
  - Body weight = 70 kg
  - Inhalation volume during training/match = 6 m^3/hour
  - Duration per week = 20 hours
  - Duration in months = 6 months

  In addition to the above, there are also six hours of matches per week for six months.

  This indicates a weekly exposure volume (m^3/week) of: 156 m^3/week for a total of 6 months, 2.23 m^3/kg body weight/week, **0.32 m^3/kg body weight/day.**

- Scenario 2: Juniors who train and play matches indoors (2 x Valhall):
  - Body weight = 65 kg
  - Inhalation volume during training/match = 4.8 m^3/hour
  - Duration per session = 2 hours
  - Number of sessions per week = seven sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1 x Valhall, three sessions per week)

In addition to the above, there are also two matches of two hours per month for three months.

This indicates a weekly exposure volume (m^3/week) of: 75 m^3/week for a total of 16 weeks, 1.11 m^3/kg body weight/week, **0.16 m^3/kg body weight/day**.

- Scenario 3: Older children who train and play matches indoors (Nordlandshallen and Skarpehallen in Tromsø):
    - Body weight = 50 kg
    - Inhalation volume during training/match = 3.6 m^3/hour
    - Duration per week = 10 hours
    - Duration in months = 6

  In addition to the above, there are also two hours of matches per week for six months.

  This indicates a weekly exposure volume (m^3/day) of: 43.2 m^3/week for a total of six months. 0.86 m^3/kg body weight/week**, 0.12 m^3/kg body weight/day**.

- Scenario 4a: Children who train and play matches indoors (Nordlandshallen and Skarpehallen in Tromsø):
    - Body weight = 30 kg
    - Inhalation volume during training/match = 1.8 m^3/hour
    - Duration per week = 10 hours
    - Duration in months = 6

  In addition to the above, there are two hours of matches per week for six months.

  This indicates a weekly exposure (m^3/day) of: 21.6 m^3/week for a total of six months. 0.72 m^3/kg body weight/week**, 0.10 m^3/kg body weight/day**.

- Scenario 4b: Children who play cup tournaments indoors (Valhall):
    - Body weight = 30 kg
    - Inhalation volume during matches 1.8 m^3/hour
    - Inhalation volume with light exertion = 0.8 m^3/hour
    - Time spent in hall, light exertion per cup tournament = 17 hours
    - Time spent in hall, playing matches per cup tournament = 7 hours
    - Number of cup tournaments per year = 2 cups
    - Duration of cup tournament: 2.5 days

  This indicates an average exposure volume of: 10.48 m^3/day for a total of 5.0 days per year. **0.35 m^3/kg body weight/day**, five days per year.

Skin contact

During training sessions and matches on artificial turf pitches, there may also be some uptake via the skin. Dust/particles which are released from the rubber granulate (primarily during use) will come into contact with bare skin. Some exposure from covered skin can also be expected, but this will be significantly lower than for bare skin. The skin area which is assumed to be exposed on an adult is: parts of the legs (25% of 2070 cm^2), thigh (1980 cm^2), arms (2570 cm^2), hands (840 cm^2) and head (face, 1180 cm^2). In total, this represents approximately 7100 cm^2. If it is assumed that the body area approximately correlates with body weight, juniors and older children have a skin surface which could potentially be exposed of 6600 and 5100 cm^2 respectively, while the corresponding figure for children (30 kg) is 3000 cm^2. Where there is no clear evidence that lower skin uptake levels are likely (e.g. for phthalates, 5%), an uptake of 100% is used as a worst case.

One problem when calculating uptake through the skin of chemicals in particles/dust is determining the quantity of particles/dust that is deposited on the skin (specified as mg/cm^2). The worst case scenario for children playing on soil has been specified as being 10 mg/cm^2. As regards exposure of the hands from soil in connection with rugby matches for example, the default value is specified as being 0.2 – 1.0 mg/cm^2. It is not entirely clear what value should be used for people who use artificial turf pitches. In this study, 1.0 mg/cm^2 has been chosen as regards the calculation of skin exposure. In addition, 100% skin absorption has been used for chemicals for which there is no specific information concerning skin uptake. A realistic uptake is probably of the order of < 1% to 10% depending on the substance. This means that the uptake that is calculated here is clearly higher than the actual value.

- Scenario 5: Adults who train and play matches indoors:
  - Body weight = 70 kg
  - Skin surface which is exposed = 7100 cm^2
  - Duration per session = 4 hours
  - Number of sessions per week = 5 sessions
  - Duration in months = 6 months

  In addition to the above, there will be six hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place. Total skin exposure per week: 42 600 mg rubber granulate/week and 608 mg rubber granulate/kg body weight/week, **87 mg rubber granulate/kg body weight/day.**

- Scenario 6: Juniors who train and play matches indoors:
  - Body weight = 65 kg
  - Skin surface which is exposed = 6600 cm^2
  - Duration per session = 2 hours
  - Number of sessions per week = 7 sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1x Valhall, three sessions per week)

In addition to the above there will be two matches of two hours per month for three months. It is assumed that these matches are played during the same period in which the training sessions take place.

Total skin exposure per week: 49 500 mg rubber granulate/week and 762 mg rubber granulate/kg body weight/week, **109 mg rubber granulate/kg body weight/day.**

- Scenario 7: Older children who train and play matches indoors:
  - Body weight = 50 kg
  - Skin surface which is exposed = 5100 cm^2
  - Duration per session= 2.5 hours
  - Number of sessions per week = 4 sessions per week
  - Duration in months = 4 months (2 x Valhall) + 1.5 mths (1x Valhall, three sessions per week)

In addition to the above there are two hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place.

Total skin exposure per week: 25 500 mg rubber granulate/week and 510 mg rubber granulate/kg body weight/week, **73 mg rubber granulate/kg body weight/day.**

- Scenario 8a: Children who train and play matches indoors:
  - Body weight = 30 kg
  - Skin surface which is exposed = 3000 cm^2
  - Duration per session: 2.5 hours
  - Number of sessions per week: 4
  - Duration in months: 6

In addition to the above there are two hours of matches per week for six months. It is assumed that these matches are played during the same period in which the training sessions take place.

Total skin exposure per week: 15 000 mg rubber granulate/week and 500 mg rubber granulate/kg body weight/week, **71 mg rubber granulate/kg body weight/day.**

- Scenario 8b: Children who play cup tournaments indoors:
  - Body weight = 30 kg
  - Skin surface which is exposed = 3000 cm^2
  - Time spent in hall, light exertion per cup tournament = 17 hours
  - Time spent in hall, playing matches per cup tournament = 7 hours
  - Number of cup tournaments per year = 2 cup tournaments

- Number of matches per cup tournament: 7
- Duration per cup tournament: 2.5 days

It is assumed that the children will shower between each match, so that their skin is exposed on seven occasions during a cup tournament. Normal time spent in the hall is not considered to lead to significant skin exposure. This indicates an average exposure (mg/day) of: **280 mg rubber granulate/kg body weight/day** for a total of five days.

Oral intake

It is assumed that children who play and train on artificial turf pitches can also be exposed to the rubber material that is used by placing it in their mouth and then chewing and possibly also swallowing it. We do not have any indication of how much rubber material may be involved, but it will probably be of the order of 0.5-1 grams per match/training session. In a worst case assessment, it is reasonable to assume a value of 1 gram per match/training session and that 100% of what is swallowed is taken up via the gastrointestinal trackt.

- Scenario 9a: Children who train and play matches indoors:
  - Body weight = 30 kg
  - Quantity swallowed per training session/match = 1.0 gram
  - Assumed uptake = 100%
  - Number of sessions per week = 4
  - Duration in months = 6
  - Total number of times per year = 64

  In addition to the above, there will be one match per week for six months.

  This indicates a repeated exposure per week of: 5 grams of rubber granulate and 0.71 grams/day, and **23.7 mg/kg body weight/day** with a duration of six months.

- Scenario 9b: Children who play cup tournaments indoors:
  - Body weight = 30 kg
  - Quantity swallowed per match = 1.0 gram
  - Assumed uptake = 100%
  - Number of exposures per year = 14 times (7 matches per cup tournament, two cup tournaments per year)

This indicates an acute exposure per cup tournament of: 7.0 gram, 2.8 gram/day (one cup tournament lasts 2.5 days) and **93.4 mg rubber granulate/kg body weight/day** for five days a year.

Measurements and calculations

Many different chemical substances have been demonstrated in samples of rubber granulate and during the degassing of these samples which are classified as hazardous.

The results of analyses of two different types of elastomer, one type of recycled rubber granulate, one type of EPDM rubber granulate, one type of thermoplastic elastomer and two types of artificial turf fibre are available. Leaching studies have also been carried out on various types of rubber granulate and artificial turf fibre, in addition to the degassing from rubber granulate. As the content of hazardous chemicals in the EPDM rubber was clearly lower than that for the recycled rubber granulates, it was decided not to include EPDM rubber granulate in the following risk assessment.

Based on the content of hazardous substances to health and the degree of exposure, it is concluded that oral exposure resulting from training/playing on pitches based on artificial turf fibre will not cause any increased health risk. The assessment of health risk is therefore related to exposure which is due to particles/dust and degassing from the rubber granulate itself. To assess the health risk, data from the sample of recycled rubber granulate which showed the highest concentrations of hazardous substances was used.

Analyses of rubber granulates and artificial turf fibres were undertaken by AnalyCen AS whilst at NILU analyses were carried out for selected elements and organic compounds. Leaching from artificial turf fibre and rubber granulates was carried out using standardised methods. The leaching of heavy metals into water was measured by adding 200 grams of rubber granulate or artificial turf fibre to 2 litres of water and leaving the solid material in contact with the water for 24 hours. To measure the leaching of organic compounds, 1 litre of water and 100 grams of rubber granulate were used with a contact time between the water and granulate of 48 hours. As regards degassing from rubber granulate, 2 grams of rubber granulate heated to 70^{o}C for 30 minutes were used. The quantity of airborne dust was determined gravimetrically after it had been collected on a quartz filter. A distinction was made between particle sizes (PM10 and PM2.5). For more information on the analyses, see the NILU report of January 2006. Uncertainty in the measurements is of the order of 10 – 30%.

Inhalation

Degassing of volatile organic compounds (VOC)

The degassing of organic compounds was measured for recycled rubber granulate and one type of EPDM rubber granulate. Selected alkylated benzenes and two chlorinated compounds were measured. Degassing from the EPDM rubber was clearly lower than that from the other rubber granulates. In total, this was in the order of 250-400 µg/kg of granulate. The degassing was investigated at a temperature of 70^{o}C, which is well above the likely temperature of the hall. The values quoted are therefore higher than would be expected during normal use of artificial turf pitches. These values will not be used in the risk assessment because measurements of indoor air are available for artificial turf pitches.

Measurements are available for VOC from a number of indoor artificial turf pitches during training sessions. In Manglerudhallen, 234 chemical compounds were found (concentration > 0.1 µg/m^3, of which 29 were identified), which gave a total VOC of approx. 716 µg/m^3. Four-fifths of the sampling period was carried out with full ventilation in the hall, which means that the concentration of VOC must have been higher before ventilation was commenced, possibly as high as 1000 µg/m^3. This is the result from just one measurement. Concentrations varied from approx. 85 to 0.8 µg/m^3. For 14 of these compounds, the concentration was in the range 10-85 µg/m^3. 4-Methyl-2-pentanone, benzothiazole, isomers of xylene, toluene, octenal, acetone, styrene and dodecane were among these compounds. During the second sampling period, a total VOC of approx. 230 µg/m^3 was measured. People often begin to complain about the air quality when the total VOC is higher than 100-200 µg/m^3. It can be concluded that the rubber granulate is the main source of the VOCs which were measured in the hall. Subsequent samples in the hall (roof hatches and windows closed, temperature of 15^{o}C) showed a total VOC of 255 µg/m^3. Under conditions where the temperature inside the hall was again 20^{o}C, a total VOC of 732 µg/m^3 was measured.

In Østfoldhallen, where new factory-made granulate was used, the concentration of VOC was relatively low (approx. 150 µg/m^3), even during exertion. This level is not uncommon in general indoor environments. A number of sources are assumed to contribute to the VOC measured inside the hall (artificial turf, rubber granulate, timber in the hall and road traffic outside the hall).

For the Valhall artificial turf pitch, a mean total VOC of 234 µg/m^3 was measured, whilst in the second half of the measurement period, 290 µg/m^3 was measured. It is concluded that the main source of VOC in the hall is the rubber granulate.

In the subsequent risk assessment, a total VOC concentration in the hall air of 716 µg/m^3 was chosen as a worst case scenario. This value was chosen because it is based on measurements taken under conditions which can occur in the hall. Measurements in both Østfoldhallen and Valhall indicate values 2.5 to 3 times lower however.

Based on these scenarios, the total uptake of VOC through inhalation (assuming 100% uptake) has been calculated. The resulting figures are shown in the table below.

Table 1: Uptake of total VOC via the lungs

Scenarios	**Exposure** weeks	**Inhalation volume** m^3/kg body weight/day	**Concentration of VOC in hall air** µg/m^3	**Uptake** %	**Uptake VOC** µg/kg body weight/day
Adults	26*	0.32	716	100	**229**
Junior	16*	0.16	716	100	**115**
Older children	26*	0.12	716	100	**86**
Children training + matches	26*	0.10	716	100	**72**
Children Cup tournament	0.7**	0.35	716	100	**251**

* Repeated exposure

** Single exposure

The table below shows the measured concentrations and classification of volatile organic compounds (VOC) in artificial turf halls with recycled rubber granulate. Many of these substances are not classified. This does not however mean that the substances cannot constitute a health risk; simply that no toxicological information is available or the substance has not been assessed with regard to classification. The substances which have been identified vary from hall to hall, and there is no clear link between the concentrations of total VOC which have been measured in a hall and the concentrations of many of the individual volatile compounds.

Table 2: Concentrations ≥ 2.0 μg/m^3 of volatile compounds (VOC) in artificial turf halls with recycled rubber granulate

Substance	**CAS no.**	**Classification (health)**	**Concentration** μg/m3
Toluene	108-88-3	R38-48/20-63-65-67	85.0*, 15.3**
Butenylbenzene (isomers)	-	-	82.5*
Benzoic acid	65-85-0	-	81.0*, 19.3**
Diethenylbenzene (isomers)	-	-	65.7*
p- and *m*-Xylene	106-42-3	R20/21-38	25.5*, 9.6**
Ethylbenzene aldehyde (isomers)	53951-50-1	-	34.7*
Benzothiazole	95-16-9	-	15.7*, 31.7**
1,1'-Biphenyl	92-52-4	R36/37/38	15.6*
Acetone	67-64-1	R36-66-67	15.3*, 9.5**
o-Xylene	95-47-6	R20/21-38	13.1*
4-Methyl-2-pentanone	108-10-1	R20-36/37	12.7*, 12.7**
3-Phenyl-2-propenal	104-55-2	-	10.2*
Pentenylbenzene (isomers)	-	-	7.3*
Pentanedioic acid dimethyl ester	1119-40-0	-	6.8*
Ethylbenzene	100-41-4	R20	6.7*, 3.3**
Styrene	100-42-5	R20-36/38	6.1*, 3.2**
Hexenylbenzene (isomers)	-	-	15.5*
Ethylcyclohexane	1678-91-7	-	5.6*
Formaldehyde	50-00-0	R23/24/25-34-40-43	5.5*, 6.5**
2-Butoxyethanol	111-76-2	R20/21/22	5.3*
Unidentified naphthalene derivative	-	-	9.3*
Octane	111-65-9	R38-65-67	4.6*
Undecane	1120-21-4	-	4.6*, 3.1**
Acetaldehyde	75-07-0	R36/37-40	4.3*, 2.9**
Nitromethane	75-52-5	R22	4.1*
1-Propylbenzene	673-32-5	-	4.0*
Alpha-pinene	80-56-8	-	10.5**
Cyclohexanone	108-94-1	R20	9.8**
Junipene	475-20-7	-	7.2**
Acetic acid	64-19-7	R35 < 0% no class.	4.3**
Decane	124-18-5	-	5.0**

Dodecane	112-40-3	-	3.7**
1,2,3-Trimethylbenzene	95-63-6	R20-36/37/38	3.2**
Limonene	138-86-3	R38-43	2.6**
2-Methylnaphthalene	91-57-6	-	2.5**
Benzene	71-43-2	R45-46-36/38-48/23/24/25-65	2.4**
3-Carene	13466-78-9	-	2.2**
Pentadecane	629-62-9	-	2.2**
2,3-Dihydreo-1,1,3,-trimethyl-3-phenyl-1H-indene	3910-35-8	-	2.1**
Hexanal	66-25-1	-	2.0**
1,2-Propanediol	57-55-6	-	2.0**
1-Methoxy-2-propanol	107-98-2	-	2.0**

* Total identified VOC 590 µg/m^3, Manglerudhallen
** Total identified VOC 190 µg/m^3, Valhall

As is apparent from the table above, most of the substances which have been classified have been classified on the basis of acute toxicity and irritation. Only a few substances have been classified with regard to possible long-term effects and allergies.

Table 3: Estimated uptake through inhalation of selected volatile compounds based on concentrations measured in the hall air for artificial turf pitches in which recycled rubber granulate is used.

Compounds	**Concentration** µg/m^3	**Estimated uptake through inhalation** µg/kg body weight/day				
		Adults (0.32 m^3/kg/day)	**Juniors** (0.16 m^3/kg/day)	**Older children** (0.12 m^3/kg/day)	**Children training** (0.10 m^3/kg/day)	**Children cup tournaments** (0.35 m^3/kg/day)
Toluene	85.0	27.2	13.6	10.2	8.5	29.8
Butenylbenzene	82.5	26.4	13.2	9.9	8.3	28.9
Benzoic acid	81.0	25.9	13.0	9.7	8.1	28.4
Diethenylbenzene	66.7	21.3	10.7	8.0	6.7	23.3
p- and *m*-Xylene	25.5	8.2	4.1	3.1	2.6	8.9
Ethylbenzene aldehyde	34.7	11.1	5.6	4.2	3.5	12.0
Benzothiazole	31.7	10.1	5.1	3.8	3.2	11.1
1,1'-Biphenyl	15.6	5.0	2.5	1.9	1.6	5.5
Acetone	15.3	4.9	2.5	1.8	1.5	5.4
o-Xylene	13.1	4.2	2.1	1.6	1.3	4.6
4-Methyl-2-pentanone	12.7	4.1	2.1	1.5	1.3	4.5
3-Phenyl-2-propenal	10.2	3.3	1.7	1.2	1.0	3.6
Styrene	6.1	2.0	1.0	0.7	0.6	2.1
Formaldehyde	6.5	2.1	1.1	0.8	0.7	2.3
Acetaldehyde	4.3	1.4	0.7	0.5	0.4	1.5
Alpha-pinene	10.5	3.4	1.7	1.3	1.1	3.7
Limonene	2.6	8.3	4.2	0.3	0.3	0.9
Benzene	2.4	0.8	0.4	0.3	0.2	0.8

Amongst the substances in the table above, there are compounds which have either been classified as allergy-triggering through skin contact or where on the basis of structural similarity with known allergens it is reasonable to assume that they could lead to contact allergy. Many of the substances can act as an irritant to the skin, eyes and mucous membranes. The concentration of volatile irritating compounds is however so low that it is unlikely that they would cause irritation during training, matches or other time spent in the halls. As regards acute effects, the estimated uptake via the lungs is of the order of 1 – 40 µg/kg body weight/day. For comparative purposes, the doses which have been shown to lead to acute poisoning are more than 1000 times higher than those estimated for exposure as a result of inhalation in indoor halls.

Our assessment is that exposure (through inhalation) to volatile organic compounds (VOC) as a result of using halls in which recycled rubber granulate is used will not cause an increased health risk as regards the harmful effects of short-term exposure (acute poisoning and irritation). The degree to which repeated exposure (inhalation) could constitute a health risk has been assessed on the basis of information concerning NOAEL values and the type of harmful effect for each individual substance and the degree of exposure.

Airborne dust

The quantity of airborne dust in indoor environments is influenced by many factors such as level of exertion and the room's shape, ventilation and building materials. In Manglerudhallen, a PM10 of 40 $\mu g/m^3$ and a PM2.5 of 17 $\mu g/m^3$ were measured during ventilation. The corresponding mean values for outdoor air in the Oslo study are 21 $\mu g/m^3$ and 7 $\mu g/m^3$ respectively. In Østfoldhallen, the PM10 level was 31 $\mu g/m^3$ whilst the PM2.5 level was 10 $\mu g/m^3$. In Valhall, the PM10 level was 32 $\mu g/m^3$ whilst the PM2.5 level was 19 $\mu g/m^3$. By comparison, it is noted that the average concentration of PM10 in homes, nurseries and schools is of the order of 20 $\mu g/m^3$. In both Manglerudhallen and Valhall, it is assumed that the main source of airborne dust is recycled rubber granulate. In Manglerudhallen, 30% of the PM10 fraction and 50% of the PM2.5 fraction was rubber dust.

In the subsequent risk assessment, the highest measured level for PM10 of 40 $\mu g/m^3$ was selected as regards respirable dust (particles).

The table below shows estimated intake scaled up in relation to the PM10 fraction through the inhalation of dust/particles.

Table 4: Estimated intake of PM10 via the lungs

Scenarios	**Exposure** weeks	**Inhalation volume** m^3/kg body weight/day	**Concentration of PM10 in hall air** µg/m^3	**Intake** %	**Intake PM10** µg/kg body weight/day
Adults	26*	0.32	40	100	**12.8**
Junior	16*	0.16	40	100	**6.4**
Older children	26*	0.12	40	100	**4.8**
Children training/matches	26*	0.10	40	100	**4.0**
Children cup tournaments	0.7**	0.35	40	100	**14.0**

* Repeated exposure
** Single exposure

Table 5: Estimated intake via the lungs of PCBs, PAHs, phthalates and alkyl phenols in the PM10 based on the concentration of these substance groups in recycled rubber granulate

Scenarios	**Exposure** weeks	**Intake PM10** µg/kg body weight/day	**Total content in recycled rubber granulate** pg/µg rubber granulate				**Estimated uptake** pg/kg body weight/day			
			PCBs	**PAHs**	**Phthalates**	**Alkyl phenols**	**PCBs**	**PAHs**	**Phthalates**	**Alkyl phenols**
Adults	26*	12.8	0.202	76	118	55	**2.6**	**973**	**1510**	**704**
Junior	16*	6.4	0.202	76	118	55	**1.3**	**486**	**755**	**352**
Older children	26*	4.8	0.202	76	118	55	**1.0**	**365**	**566**	**264**
Children training/matches	26*	4.0	0.202	76	118	55	**0.8**	**304**	**472**	**220**
Children cup tournaments	0.7**	14.0	0.202	76	118	55	**2.8**	**1064**	**1652**	**770**

* Repeated exposure
** Single exposure

Table 6: Estimated intake of PAHs based on measured values of PAHs in the PM10 fraction in artificial turf halls where recycled rubber granulate is used (uptake set at 100%)

Scenarios	**Exp.** weeks	**Inhalation volume** m^3/kg body weight/ day	**Concentration of PAH in PM10 in hall air** ng/m^3	**Concentration of phthalates in PM10 in hall air** ng/m^3	**Intake PAH** pg/kg body weight/day	**Intake phthalates** pg/kg body weight/day

Adults	26*	0.32	10.8	134.4	**3456**	**43 000**
Junior	16*	0.16	10.8	134.4	**1728**	**21 500**
Older children	26*	0.12	10.8	134.4	**1296**	**16 130**
Children training/matches	26*	0.10	10.9	134.4	**1080**	**13 400**
Children cup tournaments	0.7**	0.35	10.8	134.4	**3780**	**47 000**

** Repeated exposure*
*** Single exposure*

It appears that the quantity of PAH based on measurements of PAH in the PM10 fraction is approximately three times higher than the figure estimated on the basis of total PM10 and the concentration which was measured in the recycled rubber granulate. The extent to which this is due to actual differences, or differences in the analysis results as regards concentrations of PAH in the granulate and in the PM10 fraction of the granulate or the result of other sources contributing PAH to the PM10 fraction has not been clarified. If the measurements of PAH in the PM10 fraction are used as a basis, the uptake of PAH is of the order of 2-5 µg/kg body weight/day. There are no specific PM10 values as regards PCBs or alkyl phenols. For these, values estimated on the basis of concentration in the rubber granulate and the total quantity of PM10 which is assumed to be taken up via the lungs must be used.

A daily uptake of 3800 pg PAH/kg body weight is used as a worst case scenario in the subsequent risk characterisation. For PCB, a value of 3 pg/kg body weight was used, whilst values of 47000 pg/kg and 800 pg/kg body weight were used for phthalates and alkyl phenols respectively. Given the very small quantities of this type of compounds which are taken up per day, it can be concluded that they do not constitute an increased health risk.

Phthalates
Measurements in hall air of phthalates in µg/m^3 taken from the NILU report is hown in table 7.

Table 7: Measurements of phthalates in hall air

Phthalate	**µg/m^3**
di-butylphthalate (DBP)	0.38
di-ethylphthalate (DEP)	0.09
di-isobutylphthalate (DIBP)	0.13

Total	**0.6**

Total content of phthalates in rubber granulates from Byggforsk (worst case measurement from 2-4 samples) is shown in table 8.

Table 8: Content of phthalates in rubber granulates

Phthalate	Rubber granulate (mg/kg)
Di-methylphthalate (DMP)	< 1.0
Di-ethylphthalate (DEP)	< 1.0
Di-butylphthalate (DBP)	3.9
Benzylbutylphthalate (BBP)	2.8
Di-ethylhexylphthalate (DEHP)	29.0
Di-n-octylphthalate (DOP)	< 1.0
Di-isononylphthalate (DINP)	78.0
Di-isodecylphthalate (DIDP)	< 1.0
Total	**117.7**

• Scenario 1: adults who train and play matches indoors:

They inhale 0.32 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.19 µg/kg body weight/day.

• Scenario 2: Juniors who train and play matches indoors:

They inhale 0.16 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.10 µg/kg body weight/day.

• Scenario 3: Older children who train and play matches indoors:

They inhale 0.12 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.07 µg/kg body weight/day

• Scenario 4a: Children who train and play matches indoors:

They inhale 0.10 m^3/kg body weight/day.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.06 µg/kg body weight/day

• Scenario 4b: Children who play cup tournaments indoors:

They inhale 0.35 m^3/kg body weight/day for five days a year.
Based on NILU, the quantity of phthalates in the air was 0.6 µg/m^3:
The quantity of phthalate inhaled per day is therefore 0.21 µg/kg body weight/day for five days a year.

Alkyl phenols
Alkyl phenols were below the detection limit in the air measurements from Manglerudhallen, Valhall and Østfoldhallen undertaken by NILU. In the calculations, the detection limit of 0.01 to 0.05 µg/m^3 was used as a starting point (the detection limit for phthalates has been used).

Total content of alkyl phenols in rubber granulates, Byggforsk (worst case measurement from two-four samples) is shown in table 9.

T*able 9: the content of alkyl phenols in rubber granulates*

Alkyl phenol	**Rubber granulates (µg/kg)**
4-t-octylphenol	33700
4-n-nonylphenol	< 5
Iso-nonylphenol	21600
Total	**55305**

• Scenario 1: adults who train and play matches indoors:

They inhale 0.32 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.016 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 2: Juniors who train and play matches indoors:

They inhale 0.16 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.008 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 3: Older children who train and play matches indoors:

They inhale 0.12 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.006 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 4a: Children who train and play matches indoors

They inhale 0.10 m^3/kg body weight/day.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day is therefore 0.005 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

• Scenario 4b: Children who play cup tournaments indoors:

They inhale 0.35 m^3/kg body weight/day for five days a year.
Measurements of alkyl phenols were below the detection limit in all three halls. The detection limit for alkyl phenols is assumed by NILU to vary from 0.01 – 0.05 µg/m^3:
The quantity of alkyl phenols inhaled per day, over a total of five days per year, is therefore 0.018 µg/kg body weight/day based on the detection limit of 0.05 µg/m^3.

Skin contact
Of the total quantity of chemicals which exist in the form of particles/dust, only a limited proportion will be available for uptake into the body through the skin. Studies of leaching from rubber particles have been carried out on behalf of Byggforsk in which leaching from 100 grams of rubber granulate/fibre was measured after contact for 48 hours with 1 litre of deionised water. If it is assumed that the quantity of chemical substances which is available for uptake via the skin corresponds to what has been found for leaching into water, it is possible to estimate approximately how much will be available for skin uptake. The degree of leaching into water will depend on how the substance is bound to the rubber granulate (strongly bound or not) and the substance's physical-chemical properties (e.g. water solubility). In our calculation of skin exposure, we chose to use the leaching factor which gives the most leaching. Based on analyses carried out on behalf of Byggforsk and results for total organic carbon, it was decided to use a leaching figure of 60 mg/litre/100g of rubber granulate. This corresponds to 0.06% of the weight of the rubber granulate. Based on the analysis data, leaching has been calculated at 0.8 x 10^{-6}% for total PCBS, 1 x 10^{-6}% for total PAHs, 30 x 10^{-6} % for total phthalates and 5 x 10^{-6}% for total alkyl phenols.

Table 10 shows the estimated quantities of PCBs, PAHs, phthalate and alkyl phenol which are assumed to be available for skin uptake following exposure to rubber granulate particles and dust

Scenario	**Particle/dust exposure (mg/kg body weight/day**	**PCBs ng/kg body weight/day**	**PAHs ng/kg body weight/day**	**Phthalates ng/kg body weight/day**	**Alkyl phenols ng/kg body weight/day**
		Bioavailability 0.8 x 10^{-6}%	Bioavailability 1 x 10^{-6}%	Bioavailability 30 x 10^{-6}%	Bioavailability 5 x 10^{-6}%
Adults	87	0.7	0.87	26.10	4.35
Junior	109	0.87	1.09	32.70	5.45

Older children	73	0.58	0.73	21.90	3.65
Children training/matches	71	0.57	0.71	21.30	3.55
Children cup tournaments	280*	2.24*	2.8*	84.00*	14.00*

* Short-term exposure (total of approximately five days per year)

As is apparent from the table above, exposure via the skin is extremely low. In reality, it will be much lower still for many of the substances. This particularly applies to phthalates, where uptake through the skin is of the order of 5% of the component which is available for uptake.

Oral intake

It must be assumed that children in particular could swallow some rubber granulate during matches or training sessions. It has been assumed that this will amount to no more than approximately 1 gram per training session/match. 100% uptake from the gastro-intestinal trackt is also assumed. The oral intake for children has been estimated on the basis of these assumptions.

Phthalates

Scenario 9a, children who train and play matches indoors swallow 23.7 mg of rubber granulate/kg body weight/day. The quantity of phthalate in rubber granulate is 118 ng/mg rubber granulate. Children are therefore exposed to **2.8 µg phthalate/kg body weight/day** over 6 months.

Scenario 9b, children who play cup tournaments indoors swallow 93.4 mg of rubber granulate/kg body weight/day over five days a year. The quantity of phthalate in rubber granulate is 118 ng/mg of rubber granulate. Children are therefore exposed to **11.0 µg phthalate/kg body weight/day** over five days a year.

Alkyl phenols

Scenario 9a, children who train and play matches indoors swallow 23.7 mg of rubber granulate/kg body weight/day. The quantity of alkyl phenols in rubber granulate is 55.3 ng/mg of rubber granulate. Children are therefore exposed to **1.3 µg alkyl phenols/kg body weight/day** over 6 months.

Scenario 9b, children who play cup tournaments indoors swallow 93.4 mg of rubber granulate/kg body weight/day over five days a year. The quantity of alkyl phenols in rubber granulate is 55.3 ng/mg of rubber granulate. Children are therefore exposed to **5.2 µg of alkyl phenols/kg body weight/day** over five days a year.

Assessment of harmful effects

VOC

Volatile organic compounds can cause a variety of adverse effects on health. The effect will depend on whether one is exposed sufficiently and the duration/frequency of the exposure. Unfortunately, there is little or no information available on the potential health hazards posed by many of these substances. Examples of harmful effects include damage to the nervous system, liver, kidney, blood-forming organs, genetic material and reproductive organs as well as allergy and cancer. The table below shows the classification and relevant NOAEL values for a number of VOCs which have been identified in the gas phase (the hall air) in artificial turf pitches in which recycled rubber granulate is used.

Table 11: Classification and NOAEL (C) values for selected VOCs

Substance	**Classification**	**NOAEL(C)**	**Effect**
Toluene	R38-48/20-63-65-67	340 mg/kg/day* 390 mg/kg/day* 150 mg/m^3 **	Reduced sperm quality in rats Neurological effects in rats (hearing) Headaches, irritation and tiredness in humans
Butenylbenzene	No information found.	No information found.	No information found.
Benzoic acid	No information found.	 550 mg/kg/day* (one dose) 5 mg/kg/day*	Inhalation causes irritation in the nose and throat, and particles in the eyes and on the skin of humans. Reduced weight in rats, otherwise no effects concerning neurotoxicity. Increased number of resorptions in rats
Xylenes	R20/21-38	20 ppm* (87 mg/m^3) 50 – 100 ppm* (220 – 440 mg/m^3) 50 ppm* (220 mg/m^3)	Irritation of eyes and airways in humans Neurological effects in humans Reduced number of red and white blood cells in rats
Styrene	R20-36/38	150 ppm* (640 mg/m^3)	Reduced body weight and delayed development in offspring
Formaldehyde	R23/24/25-34-40-43		*Effects on humans*

		0.5 mg/m^3* 0.06 mg/m^3** 0.12 mg/m^3** 0.45 mg/m^3* 1.0 – 1.8 mg/m^3*	Effect in the nasal cavity Eye irritation Airway irritation Airway contractions Nasal cancer
Benzene	R45-46-36/38-48/23/24/25-65	Acceptable air concentration for life-long exposure (RfC) = 30 µg/m^3; RfD = 4 µg/kg/day	Effects on bone marrow, reduced number of red and white blood cells. Neurological and reproducitve effects at slightly higher doses
Limonene	R38-43	5.6-6.6 g/kg body weight** 10 mg/kg/day*	Liver toxicity Irritation
Benzothiazole	The substance is assumed to cause allergic reactions	Intravenously in mice = 95 mg/kg body weight**	Moderate acute toxicity, no chronic toxicity data found.

* Repeated exposure
** Single exposure

Total VOC
Total VOC (the sum of the concentrations of selected organic compounds defined on the basis of their volatility and analysis and estimation method) were used in assessments of indoor air quality. The levels of this collective parameter vary considerably between indoor environments and is also strongly affected by static and variable indoor sources. As total VOC represents the sum of many different chemical compounds with different properties, total VOC levels do not provide a basis for a health risk assessment. In normal indoor air assessments, abnormally high levels will however result in an assessment of whether there are specific sources and if so how these sources can be reduced on the basis of a general desire to minimise exposure to chemicals. In the analyses that are available, total VOC levels are significantly higher than those which NILU found in general indoor environments without any special sources which liberate volatile organic compounds to the atmosphere. It is also concluded in the NILU report that the composition of individual chemicals in the total VOC samples indicates that the rubber granulate used in the pitches is an important contributor to total VOC. This is because small particles on the pitch surface give the rubber granulate a large surface area, enabling volatile chemicals in the material to evaporate into the air over time. Other common examples which contribute to elevated total VOC levels as in this case are rooms with wooden panels on the walls and rooms with recently carpeted floors. Total VOC levels also remain high for a long time after rooms have been refurbished.

As the air samples taken from these halls also indicate a mixture of many organic compounds, none of the individual substances will occur in concentrations which give cause for concern over health effects. It is however possible that individual substances or mixtures of substances could contribute to odours or mucous membrane irritation which particularly sensitive individuals may notice even at these relatively low levels. This could contribute to the perception of poor, heavy or “dry” air. As smell is part of mankind’s warning system for possible dangers, the possibility of some people reacting with symptoms such as tiredness or headaches must be kept open. In this type of indoor area, where people voluntarily spend time on enjoyable activities, such links must be assumed to be unlikely.

There is no adequate scientific basis for concluding that short or extended periods of time spent in an atmosphere with total VOC levels equivalent to those which were measured in indoor halls with artificial turf could lead to adverse effects on health.

The most important reason for “poor air” in sports halls is body odour linked to physical activity. This is the reason why sports halls have more demanding requirements for ventilation than other premises.

PCBs

PCB (polychlorinated biphenyls) is a complex group of chemicals, some of which have dioxin-like effects. Exposure to PCBs is associated with a broad spectrum of health effects in animals. Amongst the harmful effects of PCB exposure in animals are cancer and effects on the immune, reproductive, nervous and hormonal systems. PCBs are classified as harmful (Xn) and can be accumulated in the body as a result of repeated exposure (R33). The IARC (International Agency for Research on Cancer) classifies PCBs as possibly being carcinogenic in humans. We have chosen to compare the exposure levels for PCBs with a no observed adverse effect level based on reproductive effects (NOAEL = 5 µg/kg body weight/day).

Benzene

Benzene is a carcinogenic substance which has been found to cause leukaemia in humans. The WHO Air Quality Guidelines for Europe (WHO Regional Publications, European Series, No. 91, Copenhagen 2000) has recommended that when estimating lifetime cancer risk, a level of 1.7 $\mu g/m^3$ benzene should be assumed to cause a lifetime cancer risk of 10^{-5}. As regards cancer risk, it has been assumed that it is impossible to identify a threshold risk value, i.e. any exposure will cause a certain degree of risk.

PAHs

Polycyclic aromatic hydrocarbons (PAHs) or tar compounds is a collective term for a large number of chemical substances which are formed during combustion. The substance group PAH contains a number of mutagenic substances, some of which are demonstrably or probably carcinogenic. Benzo(a)pyrene (BaP) is the most studied PAH compound. It has been shown to be carcinogenic in animal experiments both after inhalation and as a result of intake through food. When assessing the cancer risk due to exposure to PAH, it is therefore common to use BaP as an indicator and calculate the cancer risk on the basis of the concentration of BaP in air or food.

Many PAHs are classified as carcinogenic substances in cancer category 2, whilst B(a)P is classified as carcinogenic R45 category 2, R46 Mut. category 2. and Repro category 2 R60 and R61. We have chosen B(a)P as a worst case and used the measured values and a $NOAEL_{BaP}$ = 40 mg/kg/body weight/day for fertility as a basis.

Phthalates

Some of the most harmful phthalates are DEHP, DBP and BBP. In animal experiments, these have been shown to cause adverse effects on reproduction, particular in young male animals, covering both reproductive ability and embryo development. In the EU, DEHP, DBP and BBP are classified in category 2 for reproductive effects, which means that the use of these phthalates in consumer products is regulated. As phthalates are present in many consumer products which are used indoors, a possible link has been found between exposure to phthalates in house dust and asthma/allergy illnesses in children, but this link has yet to be clarified. In table 12 below the No Observed Adverse Effect Levels (NOAEL) for testicular toxicity/fertility and effects on the development of embryos for DEHP, DBP and BBP are shown.

Table 12: NOAEL for testicular toxicity/fertility and embryo development

Phthalate	**NOAEL** **Fertility/testicular toxicity** **mg/kg body weight/day**	**NOAEL** **Embryo development** **mg/kg body weight/day**
DEHP	4.8	4.8
DBP	52	50.0
BBP	100	50.0

A NOAEL of 4.8 mg/kg body weight is used in the subsequent risk characterisation of phthalates.

Alkyl phenols

In animal experiments, alkyl phenols such as 4-nonylphenol and 4-t-octylphenol have been shown to have properties equivalent to the female sex hormone oestrogen. This means that it can disrupt the hormonal balance in animals, which in turn can affect development of the experimental animals' ability to reproduce. In the EU, 4-nonylphenol is classified in category 3 for effects on reproduction, whilst 4-t-octylphenol is not classified in the EU with regard to possible effects on reproduction. Classification in category 3 means that the use of alkyl phenols in consumer products is not regulated. As 4-nonylphenol is the alkyl phenol which is associated with the most concerns, the no observed adverse effect level (NOAEL) for this alkyl phenol will be used in the risk assessment. In accordance with the EU's risk report for 4-nonylphenol, the NOAEL value for effects on the development of reproductive organs is 15 mg/kg body weight/day. In animal experiments, it has been assumed that only 10% of 4-nonylphenol is absorbed, and is thus bioavailable. The NOAEL value used in the risk assessment for exposure to alkyl phenols will therefore be 1.5 mg/kg body weight/day.

Allergy

With regard to contact allergy (allergic contact dermatitis), for the substances which are assumed to be contact allergens, the decisive exposure factor is not body dose, but the dose per unit area of the skin (i.e. a dose which sensitises if it is applied in a concentrated form over a small area of the skin will not sensitise if it is spread over a larger skin area). In general, at the exposure levels that apply to artificial turf pitches the dose will be low and distributed over most of the body. The only exception could be in shoes, where dust can collect over time, so the changing/cleaning of footwear could be one aspect to remember in connection with training on artificial turf.

As regards airway allergies, latex (natural rubber) is a potent allergen and latex allergy is not uncommon. Car tyres can contain large quantities of latex, and emissions of latex from road traffic due to tyre wear are very high compared to other allergens. However, no increased occurrence of latex allergy has been demonstrated in individuals who live near busy roads compared with people who leave further away from such roads. The explanation given is that the bioavailability of latex is low in car tyre dust and/or that the latex allergens are deactivated during the vulcanisation process, etc. Sensitisation to IgE-mediated allergy can take place via the skin, but probably mostly occurs via the mucous membranes in the airways. Much of the dust that is deposited in the nose/throat will probably be swallowed. The effect of swallowing allergen-carrying dust in an allergy context is uncertain; it will probably induce tolerance/reduce the development of an allergy rather than promote allergy development. The quantity of dust which is deposited in the airways will depend on the size distribution. The estimated uptake of PM10 via the lungs is of such an order of magnitude that even if only a small proportion consists of an immune-active latex allergen, the dose in an allergen context would be large and the risk of sensitisation would be real (1 µg of allergen deposited on the mucous membranes represents a significant individual dose). No data is available on the immune-active latex allergen content of the dust, and the data that is available concerning latex from car tyre wear must be said to be reassuring. In the absence of data on the latex allergen content of dust, the possibility of a risk of latex allergy development as a result of regular training on artificial turf pitches cannot however be eliminated on the basis of the information that is available on car tyres. Similarly, the possibility that people who already have a latex allergy could suffer an acute asthma attack and other allergy symptoms as a result of inhaling dust from such artificial turf pitches cannot be eliminated. This can be of particular concern when it occurs in connection with vigorous physical activity.

Latex in dust can be measured to some extent, although it is open to discussion as to whether and if so how much biologically active latex allergen (the natural rubber allergen) is present even if latex is demonstrated. Experience of asthma and allergies caused by the use of such artificial turf pitches will therefore be of considerable importance for the assessment, if such experience exists.

However, a recently published study found slightly higher concentrations of individual phthalates in dust at home in children with asthma or allergy symptoms. This has resulted in considerable attention being directed at phthalate exposure. The results are important and provide interesting information, but at the present time there is no certain evidence on which to claim that phthalates can contribute to the development of asthma and allergies in the population.

Risk assessment

Inhalation

VOC

Table 13: MOS values for exposure scenarios 1-4

Substance	**NOAEL(C)**	**Effect**	**Exposure/scenario/VOC Scenarios 1-4 (µg/kg body weight/day)**	**Margin of Safety /MOS Scenarios 1-4**
Toluene	340 mg/kg/day*	Reduced sperm quality in rats	Scenario 1: 27.2 Scenario 2: 13.6 Scenario 3: 10.2 Scenario 4a: 8.5 Scenario 4b:29.8	Scenario 1: 12 500 Scenario 2: 25 000 Scenario 3: 33 300 Scenario 4a:40 000 Scenario 4b:11 400
Butenyl-benzene	No values found	No data found		
Benzoic acid	5 mg/kg/day*	Increased number of resorptions in rats	Scenario 1: 25.9 Scenario 2: 13.0 Scenario 3: 9.7 Scenario 4a: 8.1 Scenario 4b:28.4	Scenario 1: 193 Scenario 2: 385 Scenario 3: 515 Scenario 4a: 617 Scenario 4b: 176
Xylenes	50 ppm* (220 mg/m^3) Scenario 1: 70.4 mg/kg/day Scenario 2: 35.2 mg/kg/day Scenario 3: 26.4 mg/kg/day Scenario 4a: 22.0 mg/kg/day Scenario 4b: 77.0 mg/kg/day	Neurological effects in humans	Scenario 1: 12.3 Scenario 2: 6.2 Scenario 3: 4.7 Scenario 4a: 3.9 Scenario 4b:13.5	Scenario 1: 5700 Scenario 2: 5700 Scenario 3: 5600 Scenario 4a: 5600 Scenario 4b: 5700
Styrene	150 ppm* (640 mg/m^3) (42.9 mg/kg body weight/day***)	Reduced body weight and delayed development in offspring.	Scenario 1: 2.0 Scenario 2: 1.0 Scenario 3: 0.7 Scenario 4a: 0.6 Scenario 4b 2.1	Scenario 1: 21 500 Scenario 2: 43 000 Scenario 3: 61 300 Scenario 4a: 71 500 Scenario 4b 20 400
Formaldehyde	0.5 mg/m^3* Scenario 1: 0.16 Scenario 2: 0.08	Effects on humans	Scenario 1: 2.1 Scenario 2: 1.1 Scenario 3: 0.8	Scenario 1: 76* Scenario 2: 73* Scenario 3: 75*

	Scenario 3: 0.06 Scenario 4a: 0.05 Scenario 4b: 0.18 0.06 mg/m^3**	Effect on nasal cavity and bronchial contractions Eye irritation	Scenario 4a: 0.7 Scenario 4b: 2.3	Scenario 4a: 72* Scenario 4b: 78*
Benzene	Acceptable air concentration for life-time exposure (RfC) = 30 $\mu g/m^3$; RfD = 8.57 µg/kg/day	Effects on bone marrow, reduced white blood cell counts Neurological and reprotoxic effect at slightly higher doses	Scenario 1: 0.8 Scenario 2: 0.4 Scenario 3: 0.3 Scenario 4a: 0.2 Scenario 4b: 0.8	For all scenarios (1 to 4b), exposure is well below the reference value of 8.57 µg/kg/day.
Limonene	10 mg/kg/day*	Irritation	Scenario 1: 8.3 Scenario 2: 4.2 Scenario 3: 0.3 Scenario 4a: 0.3 Scenario 4b: 0.9	Scenario 1: 1200 Scenario 2: 2400 Scenario 3: 33 000 Scenario 4a: 33 000 Scenario 4b 11 000
Benzo-thiazole	Intravenously in mice = 95 mg/kg body weight**	Moderate acute toxicity, no chronic toxicity data found.	Scenario 1: 10.1 Scenario 2: 5.1 Scenario 3: 3.8 Scenario 4a: 3.2 Scenario 4b:11.1	Scenario 1: 9400 Scenario 2: 19 000 Scenario 3: 25 000 Scenario 4a: 30 000 Scenario 4b: 8600

* repeated exposure
** single exposure
*** Conversion values for rats: respiration frequency 85.5/min, tidal volume 0.86 ml, weight 400 grams, exposure 6 hours/day

Total VOC

It is impossible to carry out a health risk assessment on the basis of measurements of total VOC. It is possible that individual substances or mixtures of substances could contribute to odours or mucous membrane irritation which sensitive individuals are able to detect even at these relatively low levels. This could lead to the perception of “poor”, heavy or “dry” air. As smell is part of mankind’s warning system for possible dangers, the possibility of some people reacting with symptoms such as tiredness or headaches must be kept open.

Allergy

On the basis of the analysis data, substances were found in the VOC fraction which are classified as contact allergens. However, the concentrations of these substances are so low that they could not cause a contact allergy in individuals using the halls. One possible exception is the deposition of rubber dust on shoes where dust can collect over time.

As regards airway allergies, latex (natural rubber) is a potent allergen and latex allergy is not unusual. Car tyres can contain large quantities of latex, and emissions of latex caused by road traffic due to tyre wear are very high in an allergen context. However, no increased occurrence of latex allergy has been found in individuals who live near busy roads compared with people who live further away from such roads. The explanation given is that the bioavailability of latex in car tyre dust is low and/or that latex allergens are deactivated during the vulcanisation process, etc. No data on the concentration of immune-active latex allergen in the dust is available, and the data that is available concerning latex from the wear of car tyres must be considered to be reassuring. In the absence of data on concentrations of latex allergen in the dust, the possibility of a risk of developing a latex allergy as a result of regular training on artificial turf pitches cannot be eliminated on the basis of the available information on car tyres. Similarly, the possibility that people who already have a latex allergy could suffer an acute asthma attack and other allergy symptoms as a result of inhaling dust from such artificial turf pitches cannot be eliminated. This can be of particular concern when it occurs in connection with vigorous physical activity.

As regards exposure to phthalates in indoor air, some studies indicate that some phthalates could have an adverse effect on the health of those who are exposed, but there is currently insufficient evidence to claim that phthalates contribute to the development of asthma and allergies in the population.

Cancer

Benzene

The total inhalation volume during training in sports halls has been estimated as a "worst case" exposure for the age group 7 – 40. For all age groups, it has been assumed that individuals train for six months a year in indoor halls.

Children 7 – 11 years: 1.8 m^3/hr x 10 = 18 m^3/week for 26 weeks = 468 over 5 years. Total: 2340 m^3
Juniors 12 – 15 years: 3.6 m^3/hr x 12 = 43.2m^3/week for 26 weeks = 1123 over 4 years. Total: 4492 m^3
Juniors 16 – 19 years; 4.8 m^3/hr x15.6= 75 m^3/week for 26 weeks = 1950 over 4 years. Total: 7800 m^3
Adults 20 – 40 years: 6.0 m^3/hr x 26 =156 m^3/week for 26 weeks = 4056 over 20 years. Total: 81120 m^3

In October 2005, NILU took three measurements of benzene in Manglerudhallen (1.7, 2.2 and 2.3 μg/m^3), two measurements in Valhall (2.1 and 2.4 μg/m^3) and two measurements in Østfoldhallen (1.8 and 2.0 μg/m^3). When these measurements are corrected for benzene in the surrounding air, it is apparent that the "worst case" exposure based on benzene released from artificial turf in the hall is 1.4 μg/m^3 benzene. The US EPA's new guidelines for estimating cancer risk assume that children in the age group 2 - 15 are three times more sensitive than adults. In the calculations below we have taken this into account by multiplying the inhalation volume by three. The WHO's risk estimate is based on the inhalation of 1.7 µg/m^3 of benzene for 70 years. If it is assumed that the average air intake is 20 m^3 per day, inhalation of a benzene quantity of (20 x 365 x 70 x 1.7) 8.7 x 10^5 µg of benzene would correspond to a lifetime leukaemia risk of 10^{-5}. In connection with training in sports halls with artificial turf, the "worst case" inhaled benzene would be ([{2340 + 4492} x 3 + 7800 + 81120] x 1.4) 1.5 x 10^5. The maximum "worst case lifetime cancer risk" is therefore (1.5 x 10^5/8,7 x 10^5) **0.2 x 10^{-5}**. It is generally accepted that calculations performed in this way represent a maximum risk and that the actual risk will very probably be lower. A risk as low as that calculated above is considered by the authorities of most countries who carry out quantitative cancer risk assessments to be negligible or tolerable.

PAHs
The Norwegian Pollution Control Authority (SFT) commissioned NILU to analyse 38 individual PAH compounds, including BaP, in three sports halls. These analyses were carried out on both the gas phase and airborne dust, PM10. BaP was substantially demonstrated in PM10. No measurements were taken outside the halls. NILU has however stated that the tar compounds which were measured including BaP in the PM10 fraction were in all probability caused by PAH penetrating from the surroundings through open windows or by being sucked into the ventilation system. The results of the BaP measurements in the sports halls are shown in Table 14.

Table 14: Measurements of BaP in sports halls

Sports hall	**BaP in PM10 (ng/m^3)**	**BaP in gas phase (ng/m^3)**
Valhall	0.56	< 0.01^x
Østfoldhallen	0.38	0.01
Manglerudhallen	1.15	0.02

^{x} Detection limit 0.01 in the gas phase

The WHO Air Quality Guidelines for Europe (WHO Regional Publications, European Series, No. 91, Copenhagen 2000) state that the annual average level of BaP in major European cities is in the range 1 – 10 ng/m^3. The EU has set a limit for BaP of 1 ng/m^3 which will apply from 2010 (?). The WHO Air Quality Guidelines for Europe has recommended that, when estimating lifetime cancer risk, it should be assumed that a level of 1.2 ng/m^3 BaP will give a lifetime cancer risk of 10^{-4}.

NILU concludes that the PAH values measured are due to PAH in the surrounding air. This means that using halls with artificial turf does not cause any additional risk of cancer caused by PAH exposure.

Airborne dust
A daily uptake of 3800 pg PAH/kg body weight was used as a worst case scenario. A daily uptake of 3 pg/kg body weight was used for PCB, with the corresponding values for

phthalates and alkyl phenols being 47 000 pg/kg body weight and 800 pg/kg body weight respectively. On the basis of the very small quantities of this type of compound which are taken up per day, it can be concluded that this type of compound does not cause any increased health risk.

Phthalates
The exposure calculations were based on the total exposure measurements for phthalates taken by NILU. As a worst case scenario, the lowest NOAEL value was used, i.e. 4.8 mg /kg body weight/day based on effects on fertility and embryo development in experimental animals exposed to DEHP. In table 15 the Margin of Safety (MOS) for the various scenarios is shown.

Table 15: The MOS values for scenarios 1-4 following exposure to phthalates

Scenario	**Total-phthalate mg/kg body weight/day**	**NOAEL fertility/embryo development mg/kg body weight/day**	**MOS**
Adults (1)	0.00019*	4.8	25 000
Junior (2)	0.0001*	4.8	48 000
Older children (3)	0.00007*	4.8	69 000
Children (4a)	0.00006*	4.8	80 000
Children (4b)	0.00021**	4.8	23 000

*Repeated exposure
** Single exposure

Alkyl phenols
The detection limit for phthalates/alkyl phenols of 0.05 µg/m^3 was used as exposure. The NOAEL value for 4-nonylphenol of 1.5 mg/kg body weight/day was used. This is based on the disruption of genitalia development. The table shows the Margin of Safety (MOS) for the various scenarios.

Table 16: The MOS values for scenarios 1-4 following exposure to alkyl phenols

Scenario	**Detection limit alkyl phenols µg/kg body weight/day**	**NOAEL disruption of genitalia development mg/kg body weight/day**	**MOS**
Adults (1)	0.016*	1.5	94 000
Junior (2)	0.008*	1.5	190 000
Older children (3)	0.006*	1.5	250 000
Children (4a)	0.005*	1.5	300 000
Children (4b)	0.018**	1.5	83 000

*Repeated exposure
**Single exposure

Skin contact
As Table 10 shows, exposure to PCBs, PAHs, phthalates and alkyl phenols via the skin is extremely low and is measured in ng/kg body weight/day. No risk characterisation was therefore carried out for this exposure path for effects other than cancer.

Skin exposure to benzene will be far less than inhalation exposure and will not represent a cancer risk. During activity on artificial turf, players may be exposed to tar compounds through direct contact. It is well known that tar compounds (PAHs) can cause cancer through skin exposure. The small quantities of tar compounds that players could come into contact with are however so small that they would not represent a cancer risk.

Oral intake

Phthalates
Scenario 9a, children who train and play matches indoors are assumed to swallow a maximum of 2.8 µg phthalate/kg body weight/day over 6 months. This gives a Margin of Safety (MOS) value of 1700.

Scenario 9b, children who play cup tournaments indoors are assumed to swallow 11.0 µg phthalate/kg body weight/day over five days a year. This is assumed to be as a single exposure and not a repeated exposure as in scenario 9a. The estimated phthalate exposure of 11.0 µg /kg body weight/day is well below LD_{50} values for phthalates.

Alkyl phenols
Scenario 9a, children who train and play matches indoors are assumed to swallow 1.3 µg alkyl phenols/kg body weight/day over 6 months. This gives a Margin of Safety (MOS) value of 1150.

Scenario 9b, children who play cup tournaments indoors are assumed to swallow a maximum of 5.2 µg alkyl phenols/kg body weight/day over five days a year. This is assumed to be a single exposure and not a repeated exposure as in scenario 9a. The estimated alkyl phenol exposure of 11.0 µg /kg body weight/day is well below the exposure levels which have been shown to cause damage through a single exposure to alkyl phenols.

Summary

Inhalation
VOC
It is concluded that exposure to (inhalation of) volatile organic compounds (VOC) as a result of using halls in which recycled rubber granulate is used will not cause any increased health risk as regards acute harmful effects (acute poisoning and irritation). The extent to which repeated exposure (inhalation) could cause an elevated risk of other types

of harmful effects was assessed specifically on the basis of information concerning NOAEL values and the harmful effects of selected individual substances which have been identified in the VOC fraction. Unfortunately, no information is available on harmful effects for many of the substances which were identified in the VOC fraction. It is therefore not possible to carry out a complete risk assessment for VOCs, but on the basis of the total VOC measured in the halls, there would appear to be no cause for concern. As regards selected substances, MOS values range from 71 500 to 72. It is not possible to draw an unequivocal conclusion as to whether the concentrations of VOC in the hall could cause an increased risk of asthma/allergy. Substances have been identified which are classified as allergens, but these occur in extremely low concentrations (see the specific section on allergies below).

Total VOC
It is not possible on the basis of the information on total VOC to carry out a complete health risk assessment, but the levels of this parameter that were measured indicate that the health risk is insignificant. It is however possible that individual substances or mixtures of VOCs could contribute to odours or mucous membrane irritation which some hypersensitive people could perceive as unpleasant even at these relatively low levels. These are reversible effects and would not cause any permanent discomfort.

Airborne dust/PAH/PCB
As a worst case scenario, a daily uptake of 3800 pg PAH/kg body weight was used. A value of 3 pg/kg body weight was used for PCB, whilst the corresponding value for phthalates was 47000 pg/kg body weight and for alkyl phenols 800 pg/kg body weight. Given that such small quantities of this type of compound can be taken up each day, it can be concluded that these compounds do not constitute any elevated health risk.

Phthalates
For adults, juniors, older children and children with repeated exposure to phthalates, the MOS values were 25 000, 48 000, 69 000 and 80 000 respectively. The exposure to total phthalates in measurements by NILU and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. It can be concluded that this exposure will not cause any elevated health risk for adults, juniors, older children or children. For children who are exposed to phthalates in connection with cup tournaments five days a year (single exposure), it is concluded that this exposure will not cause any increased health risk.

Alkyl phenols
For adults, junior, older children and children with repeated exposure to alkyl phenols, the MOS values were 94 000, 190 000, 250 000 and 300 000 respectively. The detection limit for alkyl phenols of 0.05 $\mu g/m^3$ and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. It can be concluded that this exposure will not cause any increased health risk for adults, juniors, older children or children. For children who are exposed to alkyl phenols in connection with cup tournaments five days a year (single exposure) it is concluded that this exposure will not cause any increased health risk.

Skin contact
As is apparent from Table 10, exposure to PCBs , PAHs, phthalates and alkyl phenols via the skin is extremely low and is measured in ng/kg body weight/day. It is therefore concluded that skin exposure to recycled rubber granulate will not cause any increased health risk.

Oral intake

Phthalates
For children who put in their mouth and chew/swallow recycled rubber granulate during training sessions/matches (repeated exposure), the MOS value was 1700 for phthalates. The worst case exposure for total phthalates in recycled rubber granulate and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. On the basis of this it can be concluded that this exposure will not cause any elevated health risk. For children who put in their mouth and chew/swallow recycled rubber granulate during cup tournaments lasting five days a year (single exposure), it is concluded that exposure to phthalates will be low and that this will not cause any elevated health risk.

Alkyl phenols
For children who put in their mouth and chew/swallow recycled rubber granulate during training sessions/matches (repeated exposure) the MOS value was 1150 for alkyl phenols. The worst case exposure to total alkyl phenols in recycled rubber granulate and the lowest NOAEL value for reproductive toxicity in animal studies were used in this calculation. On the basis of this it can be concluded that this exposure will not cause any increased health risk. For children who put in their mouth and chew/swallow recycled rubber granulate during cup tournaments lasting five days a year (single exposure), it is concluded that exposure to alkyl phenols will be low and that this will not cause any increased health risk.

Allergy
It is unlikely that the low levels of contact allergens which have been measured in the halls could lead to the development of a contact allergy.

As regards possible airway allergies, it is known that latex (natural rubber) is a potent allergen and latex allergy is not uncommon. Car tyres can contain large amounts of latex. However, it would appear that the bioavailability of latex in car rubber dust is low and/or that latex is deactivated during the vulcanisation process. The analyses that were carried out do not contain any information on immune-active latex allergen. Due to the quantities of dust which were measured in the halls, the possibility that there is a risk of individuals developing latex allergy or that individuals who have already developed a latex allergy could suffer acute asthma attacks when using the halls cannot be eliminated.

Relatively low concentrations of phthalates have been demonstrated in the hall air. Our present knowledge of a possible link between exposure to phthalates and the development of asthma/allergy is very inadequate and it is not possible to carry out a risk assessment in this area.

Cancer

It has been concluded that exposure to benzene and PAHs in the quantities in which they have been measured in the halls will not cause any increased risk of cancer in people using the halls.

Conclusion

Recycled rubber granulate contains many chemical substances which are potentially harmful to health. The concentrations of these substances are however extremely low, they are only leached from the rubber granulate in very small quantities and they are only present in low concentrations in the hall air. The quantities of this type of substance are consistently lower than in the other types of rubber granulate which are used. The assessment of health risk was therefore based on measurements (concentrations in the rubber granulate and in airborne dust, PM10, and VOC in the hall air) in halls in which recycled rubber granulate is used.

A number of worst case scenarios were prepared which are used in the risk characterisation. These scenarios are based on information concerning the use of the halls (matches and training sessions; frequency and duration); physiological parameters (skin surface area, inhalation volumes during exertion and body weight) and analyses (content in rubber granulate, airborne dust/PM10 and VOC). Exposure calculations were performed for adults, juniors, older children and children based on measurements of VOC, airborne dust, concentrations of chemicals in recycled rubber granulate and leaching from the granulate.

On the basis of estimated exposure values and the doses/concentrations which can cause harmful effects in humans or in animal experiments, it is concluded that the use of artificial turf halls does not cause any elevated health risk. This applies to children, older children, juniors and adults. The estimated Margins of Safety (MOS) also give no cause for concern.

As regards total VOC, higher values were measured than are normally found in homes. Values of up to 200-400 $\mu g/m^3$ *fall within the normal range for housing. It is concluded that the values which were measured for total VOC do not constitute any elevated health risk but our knowledge of this area is rather inadequate. It is reasonable to assume that the relatively high VOC values could contribute to the hall air being perceived as" poor" without this in itself actually causing any elevated health risk.*

As regards allergies, it is concluded that exposure to the low concentrations which were measured does not constitute any elevated risk with respect to the development of contact allergies. It is known that car tyres can contain relatively high concentrations of latex and therefore possibly also latex allergens. Latex is a potent airway allergen, but it would appear that latex in car rubber dust is either less available for uptake and/or deactivated. As no information is available concerning levels of latex in the rubber granulate that is used, it is not possible to assess the risk of developing an airway allergy. The possibility that the use of car tyres could cause exposure to latex allergens and thus lead to the development of airway allergies cannot be entirely eliminated. Studies have been carried out which indicate a link between exposure to phthalates and the development of asthma/allergies. At the present time, it is not possible to carry out a risk assessment in this area because of a lack of available knowledge.

Worst case calculations based on air measurements carried out by NILU and exposure values from the Norwegian Institute of Public Health indicate that training in sports halls does not cause any increased risk of leukaemia as a result of benzene exposure or any elevated risk as a result of exposure to polycyclic aromatic hydrocarbons.

On the basis of the exposures which have been calculated in connection with the use of indoor halls with artificial turf in which recycled rubber granulate is used, there is no evidence to indicate that the use of such halls causes an elevated health risk. A reservation must however be issued as regards the development of asthma/airway allergies, where the knowledge that is currently available is limited. This particularly applies to exposure to latex allergens, as no information is available on the occurrence of latex allergens in hall air, yet such allergens have been demonstrated in car tyre rubber. It should also be noted that little or no toxicological information is available for many of the volatile organic compounds which have been demonstrated as being present in the air in the halls. The concentrations of most substances for which insufficient information is available concerning harmful effects are extremely low and for this reason they are not expected to cause any increased health risk. However, not all organic compounds in the hall air have been identified. It is concluded that the exposure quantities which have been calculated for benzene and PAHs do not represent a cancer risk.

On the basis of the knowledge that is currently available concerning health effects and exposure linked to the use of indoor artificial turf pitches, we do not see any necessity to replace the recycled granulate at the present time. Due to a lack of knowledge as regards the possible induction of latex rubber, we recommend that recycled rubber granulate should not be used when rubber granulate is supplemented/replaced.