Environmental and health assessment of the use of elastomer granulates (virgin and from used tyres) as filling in third-generation artificial turf

Author: Dr Robert Moretto (EEDEMS)

ENVIRONMENTAL AND HEALTH ASSESSMENT OF THE USE OF ELASTOMER GRANULATES (VIRGIN AND FROM USED TYRES) AS FILLING IN THIRD-GENERATION ARTIFICIAL TURF

Background

The production of artificial turf sports surfaces is a market in the throes of expansion. The company FIELDTURF TARKETT, a world leader in third-generation[1] artificial turf for the practice of football and rugby, installs more than 650 large sports pitches per year worldwide (approximately a hundred in France in 2006).

As part of the construction of such sporting surfaces (the earliest production on a global scale dates from 1995), elastic granulates and absorbents have been used as filling materials with the artificial turf fibres. Some of these granulates come from the granulation of used tyres (in France, recycled PUNR[2]: collected and sorted within the framework of the French Decree no.2002-1563 of 24 December 2002 concerning the elimination of used tyres), while other are manufactured specifically for this purpose (EPDM[3] or TPE[4]), and to a lesser extent some result from the recycling of EPDM (washing machine joints, car doors, etc.…).

Since the development of its first third-generation artificial turf applications, the company FIELDTURF TARKETT has chosen to favour the use of granulates from recycled materials for their filling needs, thereby permitting the reuse of roughly 11,000 tons of used tyre granulates in France on large sports pitches in 2006.

These third-generation artificial turf playing surfaces present numerous advantages for sports clubs and local authorities. The length of time for which they can be used is just about unlimited, with stable long-term performance levels, and the pitch requires limited maintenance in comparison with natural turf. The qualities of the systems developed by FieldTurf Tarkett are acknowledged by FIFA[5], UEFA[6] and national federations. FIFA and UEFA have permitted competition matches to be played on this type of surface since 1st February 2004.

In recent years and during 2006 in particular, press articles, sometimes relayed by certain sports federations, have, due to the presence of certain composites classed as dangerous in the initial manufacture of a tyre, called into question the harmlessness regarding human health of the use of recycled tyre granulates compared with virgin granulates. Several scientific studies have thus been conducted from an environmental and health perspective in several European countries with the aim of characterising the emissions of pollutants via gaseous and/or aqueous means.

Mindful of the importance of making sure of these aspects and in order to possess objective elements in the face of this type of publication, the main tyre manufacturers through the intermediary of the company jointly founded by them, ALIAPUR[7], in partnership with Fieldturf Tarkett and the ADEME (Environmental French Agency), have undertaken starting in 2005 a programme of scientific study evaluating the environmental and health impact of the different material used as filling in artificial turf. These studies have been entrusted to the French *Research Network*, EEDEMS, which brings together the skills of the leading public and private bodies in these fields, most notably in the case of construction materials and products.

[1] Third-generation artificial turf appeared on the world market in 1995. Equipped with longer fibres (on average 60 mm), they are particularly characterised by a filling of sand and elastomer granulates of different types. The sporting performance of these surfaces rivals that of regularly maintained natural turf.
[2] Non-reusable used tyres
[3] Ethylene Propylene Diene Monomer
[4] Thermoplastic Elastomer (TPE)
[5] Fédération Internationale de Football Association
[6] Union of European Football Associations
[7] Company in charge of the recycling of 85% of the tyres on the French market in 2005; that is 31,550,000 tyres corresponding to 283,000 tons

This technical report contains the key facts from the studies and the general conclusions of the different evaluations. The document plan is as follows:

I. Interest and objectives of studies

The interest of the studies lies in the research and evaluation of possible environmental and health effects linked, on the one hand, to the transfer of meteoric water into the natural environment as a result of its percolation through the components of the sports surface and, on the other, to the gaseous emissions likely to be generated by the substances used in the composition of the sports surface.

Through the procedure adopted, three analytical approaches were carried out:

1. the chemical analysis for the determination of the concentrations of potentially polluting elements and substances present in the percolates collected after their transfer through the different constituent materials of the sporting surface,
2. the measurement of the ecotoxicity of the percolates collected after their transfer through the different constituent materials of the sporting surface,
3. the analysis of the volatile organic compounds (VOC) and formaldehydes emitted and their respective concentrations in an *"indoor"* sports surface usage scenario.

The concentration values obtained from the physicochemical analysis of the percolates was then compared with reference guide values (decree, acceptability values, etc.…). Those obtained by analysis of the VOC and formaldehydes emitted were used to conduct a Health Risk Evaluation study (HRE).

The experiments conducted, in this case the orchestrated monitoring of a football pitch and small-scale pilot studies on an experimental platform, correspond to the usage conditions of the pitches and to the development image of standards concerning other applications[8].

Eventually, the objectives of this study consist of:

1. obtaining reliable and precise information on the environmental and health impact of these applications,
2. providing responses to the main questions raised by the professionals, the sports federations, the institutions and the local authorities concerning certain elements and substances classed as representing a risk,
3. offering, in terms of the environmental and health effects, elements of comparison relative to the different types of granulates used as filling in artificial turf,
4. obtaining elements permitting the definition of standardised experimental protocols tailored to real usage conditions.

II. Evaluation of environmental impact on water

II.1. - The materials tested

The materials tested correspond to 3rd-generation artificial fibre turf from the FIELDTURF TARKETT range, combined with filling granulates of 3 different types:

- granulates from used tyres from the French market (PUNR),
- virgin EPDM granulates,
- TPE granulates.

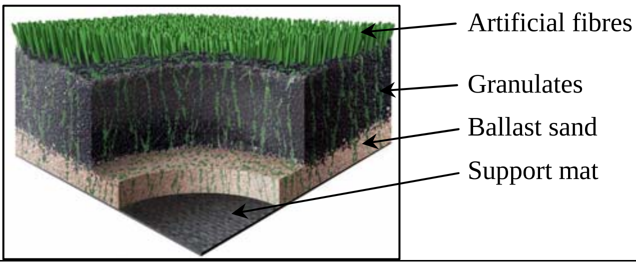

Figure 1: Vertical cross-section of a 3rd-generation sports surface (FIELDTURF TARKETT document).

[8] For example, the European standard on leaching tests EN 12-920 – Methodology for the determination of the leaching behaviour of a waste under specified conditions

The materials and products such as the ballast sand, the artificial assembly band and the polyurethane glue, used in the installation of a full-size sports pitch, have also been taken into account in the set-up of the experiments. Figure 1 shows the arrangement of the different constituent elements of the artificial turf sports surface.

The volumes of materials implemented per square metre in the different experiments presented below are 17.5 kg for the sand forming the ballast layer and 15 kg for each type of granulate considered.

II.2. - Two complementary approaches necessary for development of analytical protocols

In the aim of developing at the end of this study analytical protocols that correspond with the usage conditions permitting a characterisation of the environmental and health effects of artificial turf sports surfaces, two complementary analytical approaches were conducted in parallel.

The first approach, conducted on the EEDEMS experimental platform, consist of a controlled experiment in pilot scenario (on an intermediate scale between the laboratory and the true size) designed to compare the behaviour, from the point of view of the environmental and health impact, of 3 types of sports surfaces produced from 3 distinct types of granulate. A single type of artificial turf, with no granulates added, is used as control pilot.

The second approach consists of an experiment conducted *in situ* on a football pitch. The pitch, measured by means of a lysimetric box[9] placed beneath the artificial turf, contains used tyre granulates. This approach is carried out with the aim of providing complementary information as to the behaviour of the materials in the natural environment (subject to weather vagaries) and guaranteeing the representativity of the experiments conducted in pilot scenarios.

II.3. - Methodologies deployed

II.3.1. - Experiment *in situ*

An *in situ* device (Figure 2) was put in place during the construction of a training pitch in the Lyon region (69-France), to the rear of a goal area and on the periphery of the pitch (Figure 3).

This device consists of a lysimetric system made from a stainless steel sheet with a surface area of 2 m^2 and 10 cm in height covered by grating, buried in the support surface and laid out beneath the artificial turf in such a way as to collect the rain water that percolates through it (Figure 2).

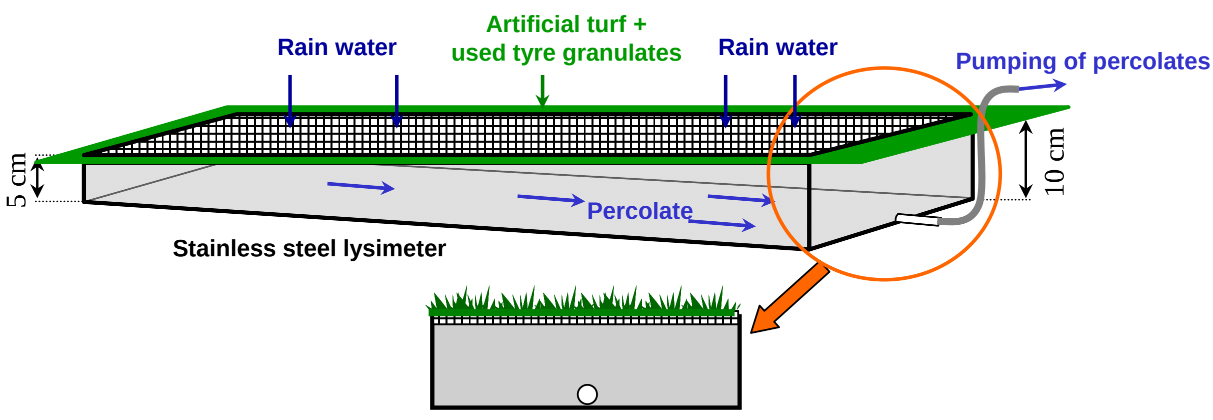

Figure 2: Diagram of the lysimetric system put in place on the football pitch.

[9] The simple lysimeter is generally presented as a cylinder or a tank, made of metal, concrete or plastic, with watertight sides and a base that allows the water to percolate so that it can be collected while measuring the flow rate and different parameters. It can be placed *in situ* (on the pitch to be studied) or *ex situ* (in the laboratory).

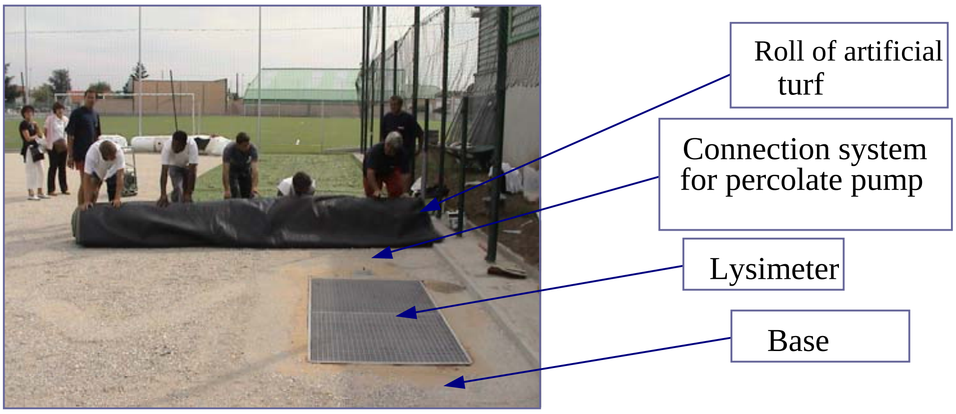

Figure 3: Installation of a roll of artificial fibre turf to cover the lysimetric system.

After full installation of the artificial turf and the filling material (sand and used tyre granulates), the lysimeter is scarcely detectable beneath the playing surface (Figure 4).

Figure 4: Manual filling of the artificial turf situated over the lysimeter with used tyre granulates.

The recovery of the water takes place via a pipe, fixed to a connection orifice located on the base of the lysimeter, which crosses the artificial turf and is then connected to a pump. To take a sample, the pipe is pulled outwards and then after recovery of the water, it is sealed by a cap and pushed back under the turf until the cap is concealed within the granulates (Figure 5).

Figure 5: System for the recovery of the percolates collected in the lysimeter situated under the artificial turf by means of a pipe crossing the artificial turf and connected to a sampling pump.

The monitoring period is **11 months**.

II.3.2. - <u>Experimentation in pilot scenarios</u>

The experimental pilots prepared are made up of rectangular aluminium tanks 2.5 m <u>in length and 1 m in width</u>. The base and sides are made watertight by means of a geomembrane. The tanks are raised to facilitate the collection of the percolates and their base displays a slight inclination towards a low point where the orifice for the emptying and collection of the percolates is located (Figure 6). The supporting floor of the artificial turf is formed by a bed of sand a few centimetres thick which serves as a drain for the percolates, in accordance with what occurs on outdoor pitches.

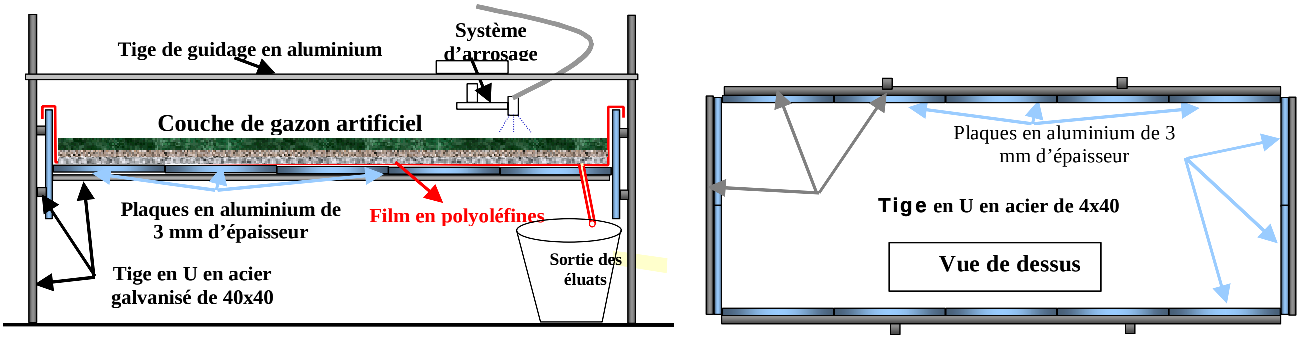

Figure 6 : Cross-section and overhead views of the pilot set-up plan on the EEDEMS experimental platform

The artificial turf mini-pitch is made with 2 rolls of green-coloured fibre separated by a roll of white-coloured fibre (pitch marking lines), all glued with polyurethane glue on the joining strip reserved for this effect. All of the materials correspond to those used on the football field (fibres, granulates of various types, glue) and were supplied to us by FIELDTURF TARKETT.

The implementation of the watering system designed to reproduce the rainfall level consists of a double rack containing 8 dispersion nozzles. The watering rack supplied with drinking water moves back and forth every hour, with 4 of the nozzles watering while going and the other 4 watering while returning, the aim of course being to spread the watering as well as possible. The cycle times and the injection durations are managed by a programmable logic controller. The quantity of water over the entire duration of the experiment has been set in relation to the annual average rainfall levels in the Lyon region, which is 800 mm per year (e.g. Paris: 641 mm; Vienna: 684 mm, Brussels: 833 mm, Budapest: 596 mm, Rome: 828 mm, London: 599 mm, Berlin: 583 mm[10]).

Four pilots (with TPE granulates, virgin EPDM granulates and granulates from PUNR and without filling materials) have been carried out (Figure 7) in a configuration comparable with that encountered on the experimental football pitch site.

As for the football stadium, the analytical monitoring period is **11 months**.

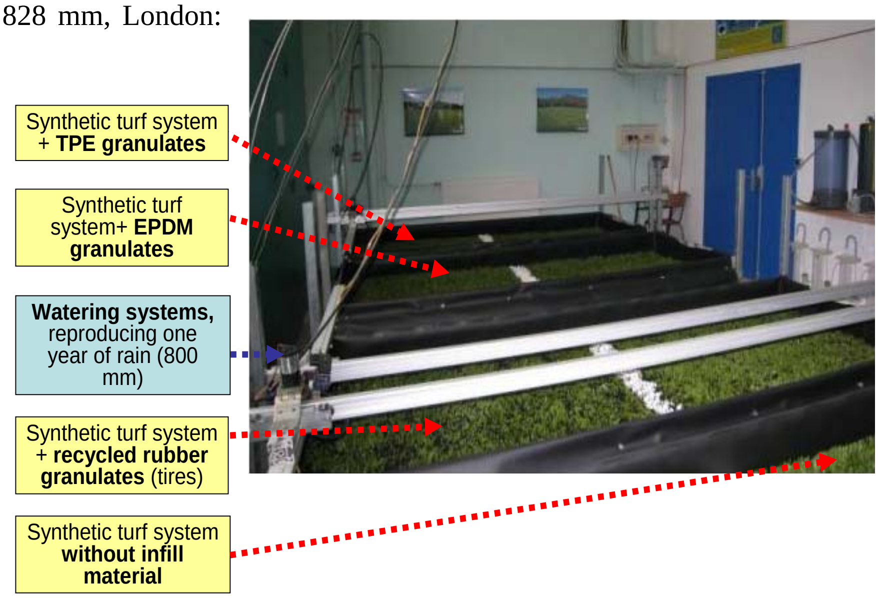

Figure 7: View of the 4 experimental pilots set up on the EEDEMS platform

II.4. - Analytical approaches for evaluation of environmental impact

II.4.1. - Sampling methods

On the four pilots, the percolates are collected each week, stabilised and stored in a cold room. The solutions analysed are reconstituted *pro rata* with the weekly volumes collected according to the volume necessary for the analyses and the period concerned. The analytical schedule is as follows: 7 solutions analysed after 15 days, 1, 2, 3, 6, 9 and 11 months of watering.

[10] http://www.meteo.fr/temps/monde/climats/3-2.htm

On the football pitch, the same number of samples was taken over the period of 11 months but, due to the weather conditions, the analytical schedule was established so as to benefit from a representative volume of periods including the rainy episodes of greater intensity between October 2005 and October 2006.

II.4.2. - Types of analyses carried out and reference systems

The evaluation of the environmental impact of the quality of percolation water is arrived at through physicochemical and ecotoxological analyses.

The elements and chemical substances researched are those entering into the composition of the filling materials, and more particularly those from used tyres. The study has been given this orientation with regard to the debate seen in recent years, and could equally have been aimed at substances of risk entering into the composition of other types of granulates. The exhaustive list comprises 42 physicochemical parameters: total cyanides, phenol index, total hydrocarbons (THC), 16 polynuclear aromatic hydrocarbons (PAHs), total organic carbon (TOC), Al, As, Ba, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, Zn, fluorides, nitrates, ammonium, chlorides and sulphates, pH and conductivity.

In order to evaluate possible enrichments of the percolates, the rainwater and supply network drinking water of the pilots was also characterised from a physicochemical perspective.

The evaluation of the impact was established by comparing the concentrations obtained in the percolates to the different French and European guide values currently in force (ICPE[11] discharge standards, acceptability criteria for Discharges of Inert Waste[12], standards concerning the quality of water destined for human consumption[13]). These 3 reference systems were chosen because the percolates' outlets are the natural environment via the infiltrations into the ground and the discharges into the environment via the urban networks. They were also chosen to obtain a minimum of at least one reference guide value for each of the physicochemical parameters. We should specify that the choice of Decree no. 2001-1220 of 20 December 2001 is nevertheless penalising for our study insofar as the percolates would be regarded as a reserve of drinkable water, without taking into account the phenomena of natural decrease in pollutants in the ground or dilution in the water (used and rain) collection networks.

The ecotoxological characterisation of the percolates is arrived at by means of a standardised test to determine the acute toxicity (*Daphnia magna*[14] mobility inhibition test) and a standardised chronic toxicity evaluation test (soft water algae growth inhibition test with *Pseudokirchneriella subcapitata*[15]).

The ecotoxological tests are vital complements to the physicochemical analyses and their interpretation. By putting living beings in contact, either with the materials tested or with water in contact with the materials (leachates, percolates, etc.) and observing the effects produced, it becomes possible to give a reasoned opinion on the potential impact of the substance on the environment. Indeed, the ecotoxological evaluation permits the highlighting of any effects caused by elements or substances not looked for in the chemical analyses, or in the state of traces at concentrations below the detection thresholds but able to display effects by synergy (greater than mere cumulative effects).

A contrario, these standardised tests are means of assessing the conditions under which no ecotoxic risk is run, in both the short and the longer term.

---

[11] Ruling on ICPE Discharges (Classified Installations for the Protection of the Environment) of 02/02/98 (art. 32)

12 Decision of the council of 19 December 2002 establishing the criteria and procedures for admission of waste in discharges, in accordance with article 16 and appendix II of Directive 1999/31/CE

[13] French Decree no. 2001-1220 of 20 December 2001 and Appendix 13-1 of the Public Health Code (guide values and imperative values for the classification of surface water destined for the production of alimentation water).

[14] Normative reference: NF EN ISO 6341, May 1996 (T90-301)

[15] Normatie reference : NF EN ISO 28692, May 1993

II.5. - Results and comments

II.5.1. - Results on the volumes collected

During the course of 11 months of experimentation, the average volume of percolates collected on each of the 4 experimental pilots was approximately 580 litres of water per m^2. Since the volume of water for each of the 4 pilots is of the order of 800 $l/m^2/15kg$ of granulates, it is proven that approximately 27 to 30% of this volume evaporates naturally in the atmosphere.

On the football pitch, the volumes of percolates collected during the experiment period were low in comparison with the local rainfall level data. For example, the total volume collected in the lysimeter was 86 litres of precipitation per m^2, while the total precipitation recorded in 2006 by the weather station located nearby was 750 mm or 750 litres of water per m^2. During the course of the 11 months of experimentation *in situ*, taking into account an evaporation rate equivalent to that of the 4 pilots, the volume of rain water which percolated through 15 kg of used tyre granulates is estimated at between 525 and 550 litres of water per m^2.

The total volume of percolates collected *in situ* therefore only represents approximately 12% of the volume of the precipitations. This finding can be explained by:

- The evaporation into the atmosphere of a part of the rainwater during rainy episodes of low intensity, the hydraulic charge being too low to permit infiltration;
- The preferential flow of water towards the peripheral outlets due to the calculated number of holes in the backing and the inclines of 1% of the supporting base, parameters ensuring good drainage of the pitch.

On the basis of these results, it is possible to estimate the volumes of percolates, on the one hand infiltrated in the ground beneath a large-size artificial turf pitch and, on the other, directed towards the peripheral drainage system. The estimation shows that for a surface area of 8,000 m^2, the volume of percolates which infiltrates into the supporting ground proves to be inferior to 2 m^3 per day and the volume of percolates directed towards the peripheral drainage system is inferior to 10 m^3 per day (cf. Table 1).

		Flow en m^3/m^2/year				
		Precipitations or watering (1)	Evaporation (2)	Percolates passing through artificial turf (3) = (1)-(2)	Percolates infiltrated in supporting ground (4)	Percolates directed to drainage system (5)=(3)-(4)
Results of experiments for **1 m²**	Experimental pilots	0,800	0,225	0,575		
	Lysimeter in-situ	0,750	0,225	0,525	0,085	0,440
Estimations for a stadium of **8 000 m²**	Stadium	6 000	1 800	4 200	680	3 520
					Equal 1,86 m^3/day	Equal 9,64 m^3/day

Table 1: Estimation of the flows of percolates infiltrating the ground or directed towards the peripheral drainage network and most often directed towards the waste water collection networks

II.5.2. - Physicochemistry results and report for percolates collected

The pH and conductivity values registered on the percolates from the 4 pilots (7.3 and 8.5; 323 and 637 µS/cm) were generally superior to those recorded on the football pitches (7.1 and 7.85; 72 and 384 µS/cm) but remain without environmental consequences. This finding is explained by the slight difference in chemical composition between the rain water on the one hand and that of the drinking water supply water for the pilots on the other.

Over time and irrespective of the type of filling material, the cyanide, phenol and total hydrocarbon concentrations were very low, most often inferior to the analytical detection limits (cyanide concentration inferior to 60 µg/l, phenol concentration inferior to 20 µg/l and total hydrocarbon concentration inferior to 50 µg/l).

Similarly, the sum of the concentrations of the 6 PHAs[16] (Figure 8) proves to be greatly inferior to the guide value from Decree no. 2001-1220 concerning water used for human consumption (1 µg/l).

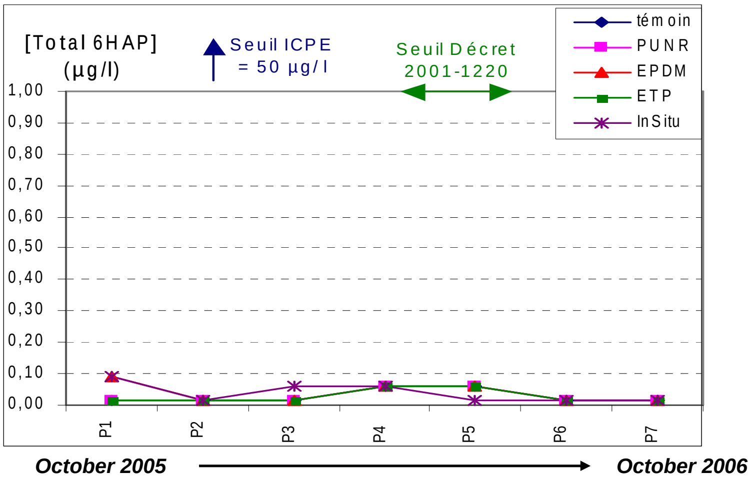

Figure 8: Development of the concentrations of the 6 PHA over time in the 5 experiments in relation to the reference guide values

Graphics Key:

P1 to P7 = No. of samples analysed over 11 months

- Synthetic turf system without infill material (reference)
- Synthetic turf system + recycled rubber granulates (tires)
- Synthetic turf system + EPDM granulates
- Synthetic turf system + TPE granulates
- Synthetic turf system + Rubber granulates (in situ)

Limit of legal values

- The Acceptance levels to use the water as drinking water (French Decree 2001-1220)
- Limit values concerning acceptability criteria for inert waste landfill as defined by Directive 1999/31/CE
- Limit values according to the Classified Installation for Environmental Protection French Decree

Overall, the organic composites displayed release kinetics which developed globally in a comparable fashion over time on all of the 5 experiments and in very close concentration ranges that were inferior to the guide values taken as a reference.

The metals Sn, As, Mo and Sb presented slight fluctuations in concentration over time but always at low concentrations and below the reference guide values (ex. Figure 9).

In all the experiments, the metals Al, Ba, Cd, Co, Cr, Cu, Hg, Ni, Pb, Sn and Zn showed a drop in concentrations over time, with a maximum at the level of the two first samples, i.e. on the first month (ex.: Figure 10, Figure 11, Figure 12). The concentrations, already very low at origin, continue to fall to reach values close to those of natural water (rain water and pilot water), below the reference guide values and sometimes even below the analytical detection limits, thereby showing that the essential part of the release of potentially polluting substances takes place in the 1st month after the deployment of the granulates in the artificial turf.

If the Selenium can, for its part, present over time concentrations superior to those of the guide values from Decree no.2001-1220 of 20/12/2001, for the reference control pilot and irrespective of the type of filling granulates, these concentrations are always inferior to the limit value from the Inert Waste Discharge Directive which permits the evaluation of the effects of a source term on the subterranean waters. Due to this fact, the Selenium release rates are regarded as being without impact on the water resources.

[16] The 6 PHAs concerned by the French Decree no. 2001-1220 of 20 December 2001: Benzo(k)fluoranthene, Fluoranthene, Benzo(b)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd) pyrene, Benzo(g,h,i)perylene.

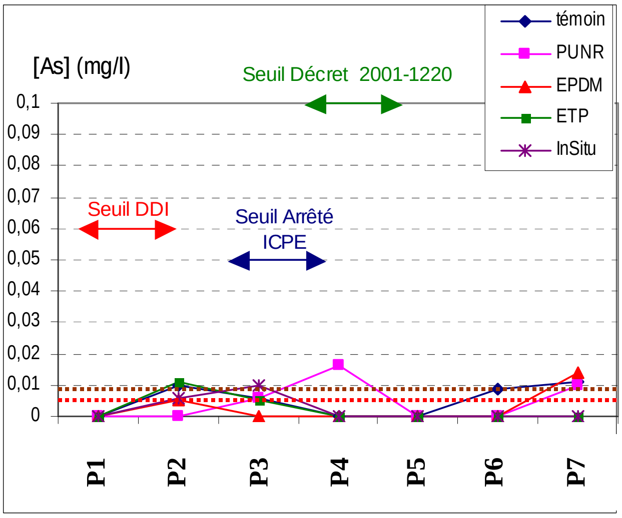

Figure 9: Development of As concentrations over time in the 5 experiments compared to the reference guide values (the red dotted straight line corresponds to the average contents of the pilot supply water and the rain water)

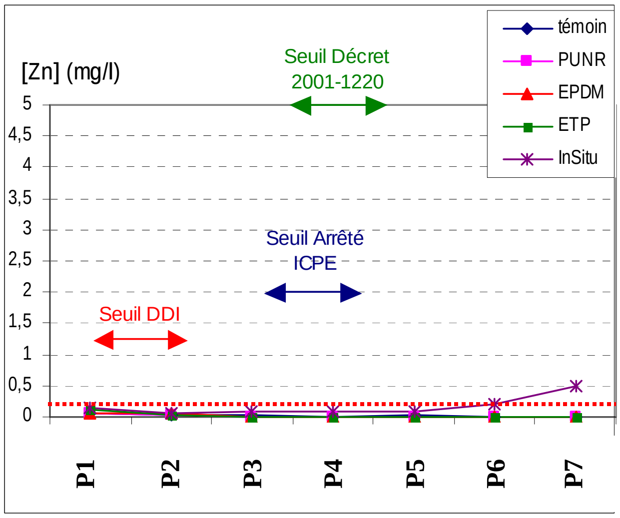

Figure 10: Development of Zn concentrations over time in the 5 experiments compared to the reference guide values (the red dotted straight line corresponds to the average contents of the pilot supply water and the rain water)

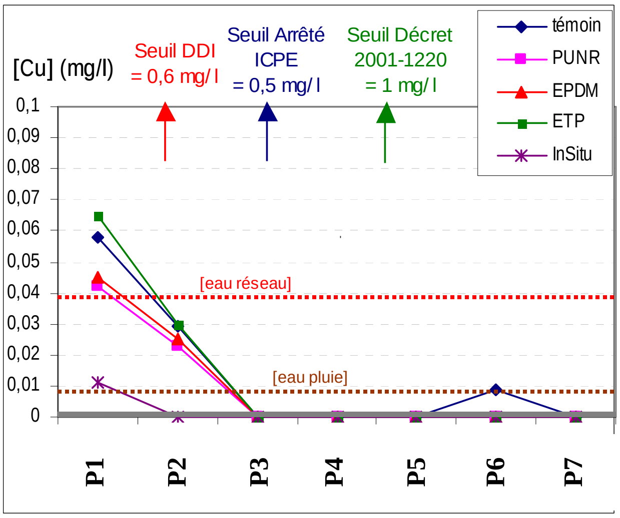

Figure 11: Development of Cu concentrations over time in the 5 experiments compared to the reference guide values (in grey: analytical detection limit)

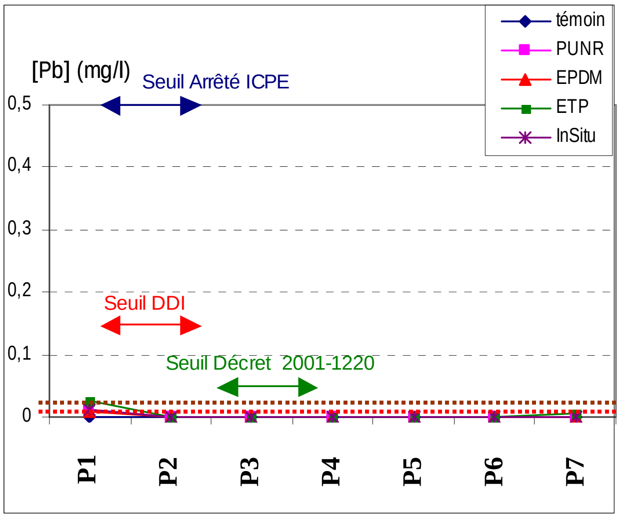

Figure 12: Development of Pb concentrations over time in the 5 experiments compared to the reference guide values (the red dotted straight line corresponds to the average content of the pilot supply water, while the brown dotted line corresponds to the average content of the rain water

Concerning the anions, despite a value for the sulphates very slightly greater than the reference guide value (French Decree no. 2001-1220 of 20/12/2001) at the start of experimentation on the pilot containing the used tyre granulates (1st sampling), the results obtained show low concentrations in the percolates on the 4 pilots but particularly *in situ* (ex. Figure 13 and Figure 14).

The same goes for NH_4^+ on the first month of pilot experimentation.

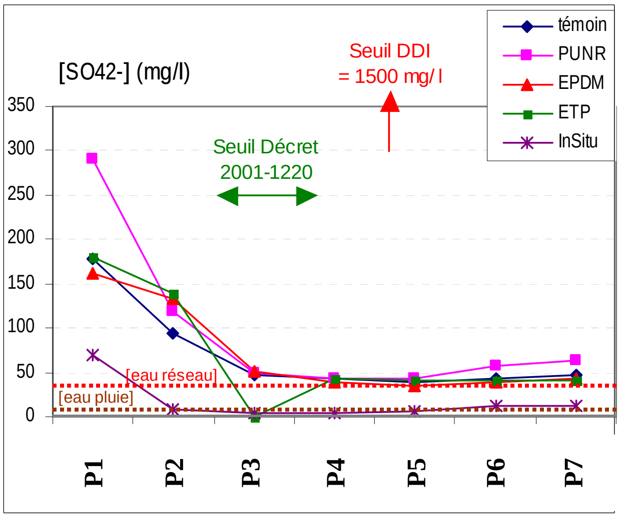

Figure 13: Development of Sulphate concentrations over time in the 5 experiments compared to the reference guide values

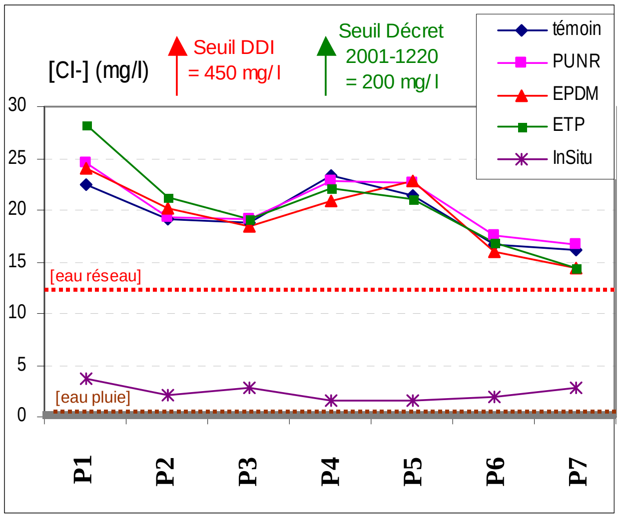

Figure 14: Development of Chloride concentrations over time in the 5 experiments compared to the reference guide values

II.5.3. - Conclusions

All of the results obtained on the percolates from the 3 pilots containing the granulates lead to the observation of a release kinetic comparable over time, with none of the 3 granulates distinguishing itself from the others and pilot n°1 in artificial turf only taken as control itself displaying release rates fairly close to those of the 3 pilots containing the different granulates. The concentrations recorded are low for the majority of the components and elements researched. Certain elements present slightly stronger concentrations at the start of experimentation, which then fall very rapidly, thereby indicating a very rapid decrease in release rates.

In situ on the football pitch, the concentrations and release kinetic observed are fairly comparable. It is interesting to note that the elements such as the chlorides, fluorides and sulphates are in lower concentrations than in the percolates collected on the pilots, this finding being connected with a difference in chemical composition of the water which percolates through the sports surface (rain water on the site and drinking water supply network water for the 4 pilots).

This analytical approach in the pilot scenarios as *in situ*, based on a comparison with the currently applicable French and European guide values, shows that the concentrations of organic composites, metals and anions of the percolates are compatible with the water resource quality requirements.

II.5.4. - Ecotoxological study results and report

For the football pitch (Table 2), the tests carried out on the samples (after 3; 3.5; 6 and 7.5 months) did not show toxicity for the daphnies or for the algae, except for the latter in the final sample at 7.5 months. The CE50[17] is in this case just reached (low impact), a fact which, with regard to the results of the chemical analyses and the results of these same tests on the percolates from the pilots, appears to be an artefact linked to the immediate environment of the pitch (external pollution).

Lysimeter on the football pitch		**To+3 months**	**T+3.5 months**	**T+6 months**	**T+7.5 months**
Sampling date		2-Jan.-06	19-Jan.-06	4-Apr.-06	30-May-06
Daphnia magna	CE50 24h (UT)	< 1	< 1	<1	<1
P. subcapitata	CE50 72h (UT)	Not performed vol. insufficient	<1.2	<1.2	1.4
	inhibition at 80%		7.5%	1.6%	57.5%

Table 2: Results of the ecotoxological tests on the percolates collected in the lysimeter positioned on the football pitch (Note: UT = 100 / CE50)

Essentially, the results of the physicochemical analyses of the percolates from the 4 pilots on the EEDEMS platform and collected 15 days after their launch show that these percolates are the most heavily charged. However, the ecotoxological tests performed on these same percolates show a very slight toxicity as regards both the daphnies and algae. For these two organisms, the CE50 was never reached. Subsequently, none of the samples (after 3 and 8 months) showed toxicity for these two organisms (Table 3).

		Pilots			
Sampling of 15-Nov-05		**Control T+15d**	**Used tyres T+15d**	**EPDM T+15d**	**ETP T+15d**
Daphnia magna	CE50 24h (UT)	<1	<1	<1	<1
	inhibition at 90%	25%	15%	30%	0%
P. subcapitata	CE50 72h (UT)	< 1,2	<1,2	<1,2	<1,2
	inhibition at 80%	10.3%	15.0%	33.3%	14.9%
Sampling of 30-Jan-06		**Control T+3 months**	**Used tyres T+3 months**	**EPDM T+3 months**	**TPE T+3 months**
Daphnia magna	CE50 24h (UT)	<1	<1	<1	<1
	inhibition at 90%	0%	0%	0%	0%
P. subcapitata	CE50 72h (UT)	< 1.2	<1.2	<1.2	<1.2
	inhibition at 80%	0.0%	0.0%	0.0%	0.0%
Sampling of 15-05-06		**Control T+ 8 months**	**Used tyres T+ 8 months**	**EPDM T+ 8 months**	**TPE T+ 8 months**
Daphnia magna	CE50 24h (UT)	<1	<1	<1	<1
	inhibition at 90%	0%	5%	0%	0%
P. subcapitata	CE50 72h (UT)	< 1.2	<1.2	<1.2	<1.2
	inhibition at 80%	0.4%	0.0%	1.0%	0.0%

Table 3: Results of the ecotoxological tests on the percolates collected on the 4 pilots set up on the EEDEMS platform (Note: UT = 100 / CE50)

[17] The CE50 is the effective concentration of percolates that leads to the immobilisation of 50% of a batch of daphnies subjected to the test for an exposure period of 24 hours.
The CE50 is the effective concentration of percolates which leads to 50% inhibition of the growth of a population of algae in relation to a control without percolates after an exposure period of 72 hours.

The placing in pilot scenarios in a room with a controlled atmosphere and supervised human intervention consequently permits the avoidance of the external vagaries inherent to an outdoor football pitch (pollution from various sources: weeding in the neighbourhood, urine, etc.) likely to have even very slight repercussions on the quality of the percolates vis-à-vis certain organisms.

II.5.5. - Conclusions

From an ecotoxological point of view, the nature of the percolates having passed through a 3rd-generation artificial pitch are proven to be without impact on the environment, irrespective of the type of filling granulates.

III. Evaluation of the health risks linked to gaseous emissions

III.1. - Characterisation of the VOC and formaldehyde emissions by artificial turf sports surfaces

The characterisation and measurement of the volatile organic compound (VOC) and aldehyde (including formaldehyde) emissions by the sports surfaces considered during the environmental impact evaluation study (previous §) was performed by the Centre Scientifique et Technique du Bâtiment (CSTB[18]), with the aid of the emission method test rooms used for the characterisation of chemical emissions in indoor air of construction products.

III.1.1. - Materials used

As for the experiments relating to the environmental evaluation, the different materials tested are: an artificial turf with green artificial fibres including a band of white artificial fibres; polyurethane glue; sand; elastomer granulates of 3 different types.

The proportions of the different constituents (stored in watertight bags until the experiment) are still 17.5 kg of sand and 15 kg of granulates per m^2, which for samples of 0.15 m^2, equals 2.625 kg of sand and 2.25 kg of granulates.

III.1.2. - Methodology

Each test sample is prepared by installing the artificial turf in a stainless steel box (Figure 15), adding a thickness of approximately 1 cm of sand (Figure 2) then approximately 4-5 cm of elastomer granulates. The test sample prepared in this way is then placed in the emission test chamber.

For the 4 tests performed at 23 ± 2°C, the samples were prepared in stainless steel tanks of a dimension of 0.78 m x 0.19 m. The effective emission surface of these test samples was 0.15 m^2.

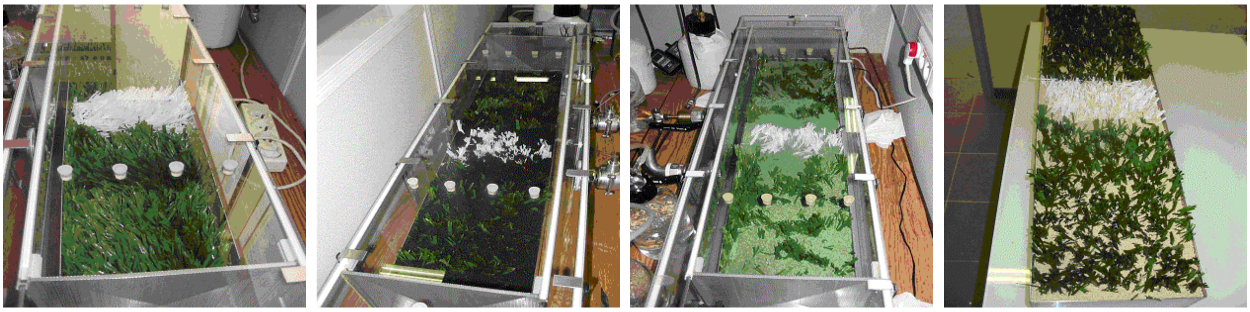

Figure 15: Test samples. From lest to right: artificial turf only; artificial turf with ballast sand and used tyre granulates; artificial turf with ballast sand and EPDM granulates; artificial turf with ballast sand and TPE granulates

[18] Centre scientifique et technique du bâtiment *(scientific and technical building centre)*: a public establishment of an industrial and commercial nature under the supervision of the minister for Housing, Directorate of Town Planning, the Environment and Construction

III.1.3. - Analytical conditions

Each of the test samples prepared was placed in an emission test chamber under controlled conditions of temperature (23 ± 2 °C) and relative humidity (50 ± 5 %), as per the recommendations of the standard project taken as a reference: prEN IS0 16000-9: *Indoor air – Part 9: Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method* (ISO, 2005).

The 5 tests were performed in accordance with a so-called "ground" emission scenario (specific ventilation rate: q = 1.25 $m^3.m^{-2}.h^{-1}$). The samples of VOC and aldehydes by pumping on special adsorbent support were performed in duplicate before the start of the test (**D0**) then after 24 ± 2 hours (**D1**), 72 ± 2 hours (**D3**) and 28 ± 2 days (**D28**) of conditioning of the sample in an emission chamber.

The samples and analyses of the VOC were performed as per the recommendations of the NF IS0 16000-6 standard: *Indoor air – Part 6: Dosage of volatile organic compounds in the indoor air of premises and test enclosures by active sampling on the sorbant Tenax TA, thermal desorption and chromatography in gaseous phase using MS/FID* (AFNOR, 2005).

The samples and analyses of the aldehydes were performed as per the recommendations of the NF ISO 16000-3 standard: *Indoor air – Part 3: Dosage of formaldehyde and other carbonylated compounds – Method by active sampling* (AFNOR, 2002).

III.1.4. - Results

The experiments conducted with the aid of emission chambers used for the characterisation of chemical emissions in indoor air of construction products permitted the identification of 112 substances (cf. table 4 in appendices).

The emission kinetic represented by Figure 16 shows that the concentration of Total VOCs (TVOCs) decreased very rapidly in the 4 samples. The fall is significant between D1 and D3. Between D3 and D28, the curve displays a lower incline and at end of testing on D28, the samples containing the used tyre and EDP granulates display comparable concentrations, slightly greater than that of the turf only, while those from the sample with the EPDM granulates are still relatively high.

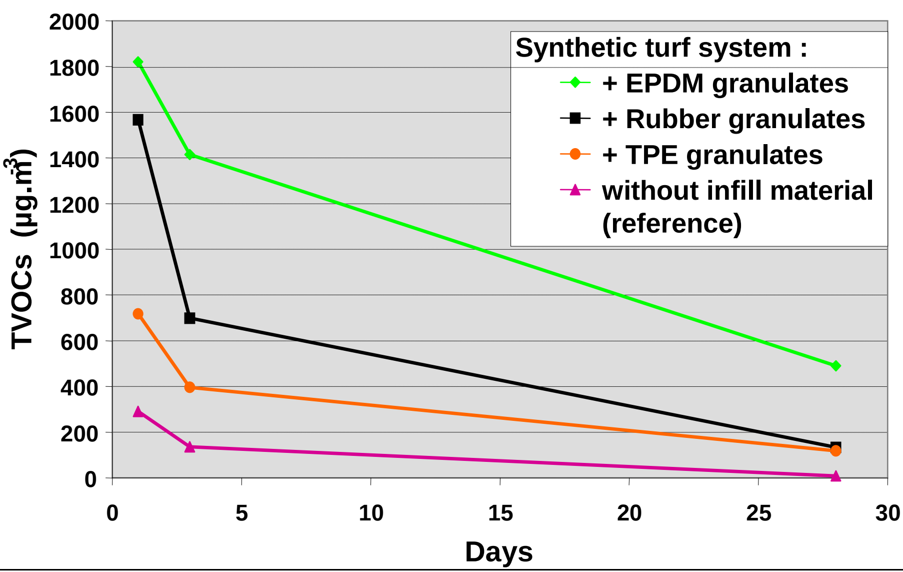

Figure 16: Comparison of the Total VOC concentrations issued between D1 and D28 by the 4 samples

The concentrations of VOC and aldehydes obtained correspond to the arithmetical average of the 2 samples taken and analysed, corrected from the chamber blank value measured at D0. These concentrations are the exposure concentrations for the product tested in its emission scenario.

The approach adopted permits a direct comparison of the VOC and formaldehyde emissions of the different elastomer granulate-based sports playing surface, under controlled conditions of temperature, relative humidity and air renewal.

The results of the tests were also expressed in specific emission factor form (SER_a in $\mu g.m^{-2}.h^{-1}$), calculated according to the following formula (as per prEN ISO 16000-9) : $\mathbf{SER_a = C . q}$

Where **C** represents the individual VOC (or TVOC) concentration in time t (in $\mu g.m^{-3}$) and **q** the specific ventilation rate of the test (q = 1.25 $m^3.m^{-2}.h^{-1}$ for the "ground" scenario).

III.1.5. - Conclusions

The emissions of VOC and formaldehydes by elastomer granulate-based sports playing surfaces was characterised with the aid of the standards applicable to the characterisation of emissions in indoor air of construction products (prEN ISO 16000-9, NF ISO 16000-6 and NF ISO 16000-3) and permitted the highlighting of the emission of 112 substances. It emerges from this that:

1 – The emissions from the artificial turf only are very low (TVOC = 8.3 $\mu g.m^{-3}$ at 28 days) compared with those from other construction products (ex: parquet flooring);

2 – The emissions from the artificial turf containing used tyre granulates are relatively low (TVOC = 134 $\mu g.m^{-3}$ at 28 days).

3 – The issues from the artificial turf containing TPE granulates are also relatively low (TVOC = 118 $\mu g.m^{-3}$ at 28 days). The compounds identified in the emission are overall comparable with those identified in the used tyre granulate emissions.

4 – The emissions from the artificial turf containing EPDM granulates are greater (TVOC = 490 $\mu g.m^{-3}$ at 28 days).

III.2. - Study of the Health Risk Evaluation (HRE)

A HRE was performed by INERIS[19], in order to evaluate more precisely in indoor situation the health risks linked to the inhalation of the substances identified (112 substances) as per the reference protocol implemented by the CSTB (cf. previous §).

This evaluation and its conclusions only concern the inhalation of the VOC and aldehydes of which the emissions have been quantified by the CSTB. The possible heath risks associated with the emissions of other substances in normal situations or due to ageing or accidental damage of the surfaces were not evaluated.

This type of study meets a strong current demand for the improvement of knowledge concerning emissions of chemical substances by construction materials and the characterisation of the associated health and environmental effects. On a European scale, within the framework of the European Directive "Construction products" (89/106/EEC), essential requirement no.3, "Hygiene, health and environment", addresses the characterisation of emissions of gaseous, particulate or radioactive substances from products placed on the community market. Due to the lack of harmonised methods at European level permitting the evaluation of these characteristics, this requirement is currently scarcely taken into account. Work aimed at harmonising these methods was launched in 2003 under the aegis of the European Commission. An inventory of the national systems for the determination of emissions from materials in indoor air was carried out and published in December 2005 [EU, 2005]. The protocol implemented for the characterisation of the gaseous emissions (previous §), on the results of which this evaluation of health risks is based, belongs to the list of reference protocols.

In France, the Plan National Santé Environnement (PNSE – *national plan for health & the environment)*) announced in June 2004 by the ministries of health, ecology, employment and research, set 45 actions, 12 of them priorities. Among the latter, action 15 aims to "put in place a labelling of the health and environmental characteristics of construction materials." The target set by the PNSE is a labelling rate of 50% to be reached by 2010. This evaluation of the health risks and the characterisation study of the emissions on which it is based therefore fit into a framework that fully meets current health requirements.

[19] Institut National de l'Environnement Industriel et des Risques: French National Institute of Health Risk Evaluation

The evaluation of the health risks corresponds to a rigorous scientific initiative put forward during the 1980s by the American National Research Council. In Europe, it constitutes the benchmark tool for evaluations of the health and environmental risks of chemical substances. Formalised in methodological guides (*Technical Guidance Document* of the European Commission, INERIS guide for classified installations [INERIS, 2003-a], for example.), it unfolds as per the following stages: 1) inventory of substances; 2) identification of the danger and research into dose-response relationships; 3) evaluation of exposures, then quantification of the health risks.

III.2.1. - Exposure scenarios

The artificial turf sports surfaces studied are almost exclusively used outdoors. Nevertheless, some usages can be encountered in closed gymnasia, generally of a large size. The exposure levels of persons (athletes and spectators) are then higher in the absence of atmospheric dispersion permitted by the wind and photochemical degradation of the compounds emitted, phenomena occurring *a contrario* outdoors.

The results of the French "Listing of Sporting Equipment" (LSE), constructed before 31 December 2005, have been available since July 2006. It confirms the highly heterogeneous character of the dimensions of these infrastructures. Consequently, in this study, it is impossible to take as a basis types of gymnasia representative of the French reality.

By virtue of the principle of prudence (these exposure situations being rare but still likely to have taken place), this evaluation of the health risks is limited to an unfavourable situation in terms of exposure, namely **indoor usage,** in closed gymnasia. It fits well into a context of first-level approach of the HRE where the most extreme situations are envisaged (worst-case scenario).

Moreover, the evaluation of exposure outdoors appears more complex. Study models for the atmospheric dispersion of gaseous or particulate compounds emitted by a surface exist, but they only permit the modelling of the concentrations in the air within a radius of 100 m to 10 km around the emitting surface. Their implementation in the present context would not permit the evaluation of the exposure of persons who train on the sporting surface. This constitutes an additional element that prompted the conducting of a study in an indoor scenario. The conclusions of the study, peculiar to this usage in an indoor scenario, shall be put into the perspective of general usage on outdoor sports surfaces.

For reasons of feasibility and by virtue of the principle of prudence in the first-level approach of the HRE, an unfavourable situation in a gymnasium has been chosen, rather than exposure on an open-air playing surface. The choice was therefore made of a worst-case situation by considering a gymnasium of the smallest size possible (in this way, the substances emitted will be less diluted in the volume of air). Among the different categories from the INSEE inventory of 1988, the smallest gymnasia (category A) have a surface area of 230 m^2. Moreover, the French Ministry of Youth and Sports has set minimum free heights above the floor: the lowest height is 7 m. Furthermore, two indoor structures constructed in 2006 (source: FIELDTURF TARKETT) with 3rd-generation artificial turf, have a surface area of 2,500 m^2, 1,800 m^2 of which is covered by artificial floor with an average under-ceiling height of 8 m. Insofar as a study conducted in 13 Parisian gymnasia produced one hall with a height of 6 m (the smallest gymnasium having a volume of 3,600 m^3), this value was chosen as the lowest height possible.

The standard gymnasium chosen in this study therefore has a surface area of 230 m^2 and a height of 6 m, giving a volume of 1,380 m^3. The air renewal rate chosen is 0.5 vol.h^1.

The choice was also made to consider all of the substances for which emission data is available and not to exclude any *a priori*. Only the chemical health risks were taken into consideration, as the biological, physical or radiological risks were not concerned in the present context.

The emission factors, determined by the characterisation study in § III.1.4, permitted the modelling of the interior concentrations in the gymnasium for each of the types of granulate associated with artificial turf and for artificial turf only. In parallel to this, the dangers by inhalation and the reference toxicological values (RTV) of all of the VOC and aldehydes measured, that is 112 substances (cf. Table 5 in appendix), were searched for in the reference international toxicological databases. For 16 compounds with an RTV (in bold in table 5 in the appendices), the quantitative evaluation of exposure levels and of the associate health risks was carried out.

Uncertainties exist concerning the dangers of the substances studied: uncertainties in the toxicological data and the RTV proposed (possible exacerbation or inhibition of toxicity in the case of mixing of pollutants emitted by the artificial surfaces, possible products of transformation of the pollutants emitted, reactions in heterogeneous phase by adsorption on the materials present in the building). These are inherent to any evaluation of the health risks according to current scientific knowledge and practice and cannot be quantified.

Acute and chronic exposure scenarios were developed for 4 population groups:

- the workers responsible for installing the surfaces. In a gymnasium, the installation of an artificial floor takes 10 days, devoted to the profiling of the ground, the laying of the mat and the installation of the sports surface with the granulates, which last 3 days (source: FIELDTURF TARKETT),
- the professional athletes and coaches present in the gymnasium throughout the day,
- the amateur athletes training regularly in the gymnasium. A fairly severe scenario was envisaged whereby the dedicated athlete trains twice during the week and once at the weekend (training of a duration of 2 hours). Moreover, it was considered that he would take part in an amateur competition at weekends (4 hours' presence in the gymnasium),
- the spectators at sporting events, attending the gymnasium regularly, namely every weekend (2 hours' presence in the gymnasium each time).

Each of these population groups may be exposed (Table 4):

- in an acute fashion when a new floor has just been laid. For the workers, the results of the measurements at D1 were used, while for the general public, who are presumably not authorised to enter the gymnasium on the very day of the new floor's laying, the measurements at D3 were used;
- in a chronic fashion, since it was considered that the exposure is repeated throughout the year. The workers are permanently exposed to the concentrations emitted during installation, so the concentrations measured at D1 are used. For the general public, the chronic exposure (the most frequent in addition) is calculated on the basis of the surface's emissions measured at D28. In the absence of measurement of the emissions some months after the laying of the floor, it was considered that the measurement at 28 days (D28) is representative of the residual emissions for the remainder of the surface's lifespan.

	Acute exposure	**Chronic exposure**
Workers laying artificial turf	At time of laying of artificial turf ➔ emissions at **D1**	8h per day, 71 days per year (1) $f_{workers} = 0.07$ ➔ emissions at **D1**
Professional athletes and coaches	At the opening of the gymnasium after the laying of new floor ➔ emissions at **D3**	8h per day, 365 days per year (2) $f_{athletes} = 0.33$ ➔ emissions à **J28**
Amateur athletes		10 h per week, 44 weeks per year (3) $f_{amateurs} = 0.05$ ➔ emissions at **D28**
Spectators		Dedicated spectator present at all the compétions (4) $f_{spectators} = 0.009$ ➔ emissions at **D28**

Table 4: Overview of exposure scenarios studied for chosen population groups

Key: f = fraction of annual time spent in gymnasium

Notes: (1) It was considered that 236 days are worked annually, corresponding to 365 days from which were subtracted the 2 days of the 52 weekends and the 5 x 5 days of paid leave. Given that, for the laying of a surface that takes 10 days, 3 days are devoted to the laying of the sporting surface containing the granulates, the annual exposure duration is 71 days ($71 = 236 \times 3/10$).

(2) It was considered that a top-level athlete would train every day.

(3) It was considered that training and competitions take place throughout the year except during the 8 weeks of the months of July and August.

(4) 40 competitions per year were envisaged.

As the calculation of the concentration inhaled does not involve physiological parameters, the results obtained apply equally to exposure by inhalation of an adult as of a child.

The concentrations inhaled were calculated so as to permit *in fine* the calculation of the risk indices (for the health effects with a threshold) and of the individual risk (for the effects without threshold, carcinogenic effects).

The non-carcinogenic effects are those for which an effect threshold exists (deterministic phenomenon). The US-EPA expresses this mechanism by a reference dose (RfD) or concentration (RfC) (for ingestion or inhalation respectively). These references doses are determined on the basis of the Doses Without Noxious Effect (DSENO or NOAEL) or Minimum Doses resulting in the Observation of a Noxious Effect (DMENO or LOAEL), divided by the safety factors (factor 10 taking account of the inter-species variability, factor taking account of the existence of sensitive persons, etc.).

The carcinogenic effects are those for which the relationship between the exposure and the appearance of the effect is without threshold (probabilistic phenomenon). The US-EPA expresses this mechanism by an excess of unitary risk (EUR) corresponding to the excess risk for an individual exposed throughout his life to a dose unit (inhalation of 1 $\mu g/m^3$ or ingestion of 1 mg/kg/j). For example, an EUR_i of 6.10^{-6} $(\mu g/m^3)^{-1}$ (case of benzene) signifies that an exposure of 1 million persons during 70 years to a concentration of 1 $\mu g/m^3$ of benzene is likely to result in 6 additional cases of leukaemia during the same period (compared with a non-exposed population of the same size).

The evaluation of the health risks was performed for a normal use of the artificial turf sports surfaces, namely in the absence of taking into account of the ageing of the surface or their accidental damage and any associated emissions.

The standard gymnasium chosen having a surface area of 230 m^2, denoted as S, and a height of 6 m, giving a volume of 1,380 m^3, denoted as V, the parameters chosen for the modelling of the concentration in the gymnasium were as follows:

- the entire surface area of the gymnasium was covered with artificial floor made either from granulates or not from granulates. The emitting surface was therefore equal to the surface of the gymnasium, which in this case was 230 m^2;
- the emissions from the artificial floor are spread uniformly throughout the volume of the gymnasium's air; in other words, the interior concentrations in the gymnasium are homogeneous;
- the air renewal rate in the gymnasium was average, or even mediocre. This rate was set at 0.5 volume/hour, as the literature did not provide data regarding the ventilation in the gymnasia. This rate (denoted as τ) was regarded as constant throughout the day, whether the gymnasium was empty or occupied.

The calculation of the concentrations in the gymnasium was made according to the equation (1):

$$\mathbf{C_{gymnasium} = (SER_{JX} \times S) / (\tau \times V)}$$

With:

- SER_{JX}, the specific emission factor established during the characterisation of the emissions (in $\mu g.m^{-2}.h^{-1}$). According to the scenarios chosen, this factor is that measured at D1, D3 or D28. The SER_{JX} at the detection threshold are taken as equal to this threshold.
- τ, the gymnasium's air renewal rate (h^{-1})
- S and V, respectively the surface area of the artificial floor, taken as equal to the surface area of the gymnasium (m^2) and the volume of the gymnasium (m^3)

The calculation of the concentrations inhaled was made:

- Within a context of acute exposure, with the concentration inhaled being taken as equal to the gymnasium's interior concentration, calculated as per the equation (1) with the emissions measured at D1 (workers installing the floor) or D3 (other population groups).

- For chronic exposure, the concentration inhaled (CI) is calculated according to the equation (2):

$$\mathbf{CI = C\ gymnasium \times f}$$

With:

- C gymnasium, the interior concentration in the gymnasium calculated as per the equation (1) with the emissions measured at D1 (workers installing the floor) or D28 (other population groups).
- f = fraction of annual time spent in the gymnasium

- The quantification of the health risks is evaluated for the effects with thresholds and for the effects without thresholds.

The characterisation of the risk for toxics with <u>threshold effects</u> by inhalation (acute or chronic exposure) is expressed by a risk index (IR) as per the equation (3): $IR = \frac{CI}{VTR}$

With:

- CI, the Concentration Inhaled (µg/m^3)
- RTV, the Reference Toxicological Value (µg/m^3)

The IR is calculated for each of the health risk tracers. The benchmark for the assessment of the health risk is set at 1. When the IR is inferior to the value of 1, the risk is regarded to be of no cause for concern within the current status of knowledge.

In the first HRE approach [INERIS, 2003-a], the sum of the IR is also calculated. However, strictly speaking, it can only provided an indication on the combined effects of the risks if the respective effects of each of the substances contributing to the risk concern the same target organ.

- The characterisation of the risk linked to an exposure to carcinogens (<u>effects without thresholds</u>) is expressed by an excess of individual risk (EIR).

This EIR represents the probability of the individual developing the effect associated with the substance during his life due to the exposure concerned.

$$\mathbf{ERIinh = CI \times ERUi \times T / Tm} \quad \text{equation (4)}$$

With:

- ERIinh, the Excess Individual Risk by inhalation
- CI, the Concentration Inhaled (µg/m^3)
- ERUi: Excess of Unitary Risk by inhalation ((µg/m^3)$^{-1}$)
- T: duration of exposure (years)
- Tm: period of time over which the exposure is averaged (70 years according to convention)

The benchmark for the assessment of the health risk is set at 10^{-5}. When the EIR is inferior to the value of 10^{-5}, the carcinogenic risk is generally regarded as acceptable according to current knowledge.

The excess of global risk of cancer (all cancer types) can be estimated by adding the EIR associated with each carcinogenic substance.

The results described in the next section correspond to a modelling which fits in well to a context of first-level HRE approach where the most extreme situations are envisaged (worst-case scenario), that is to say a small, poorly ventilated gymnasium and without taking into account the ventilation rate of individuals.

In order to be positioned as close as possible to the real usage conditions on the basis of the results acquired, the INERIS has also carried out sensitivity tests on:

- The dimension of the gymnasium: by considering a realistic situation (emitting surface of 1,800 m^2 and gymnasium volume of 20,000 m^3; the air renewal rate remaining unchanged),

- The average air renewal rate chosen for the HRE was set at 0.5 vol.h^{-1}. A study conducted in a French gymnasium [Air Normand, 2000] showed an average air renewal rate of between 0.54 vol.h^{-1} in summer and 1.2 vol.h^{-1} in the winter period. This confirms that the context for the calculation of the interior concentrations in the gymnasium and for the concentrations inhaled resulting from this is *a priori* fairly significant. The ventilation is a parameter that has a significant effect on the results.

- The ventilation rates of individuals (male and female) were not taken into account. A sensitivity test was conducted on the professional athletes group. This test shows that if an approach is chosen that takes account of respiratory rates, the risk indices turn out to be higher but the conclusions of the study are nevertheless not modified.

III.2.2. - Results and recommendations

The interior concentrations modelled in the standard gymnasium chosen (volume of 1,380 m^3) were compared to the average ubiquitous concentrations in the ambient exterior and interior air in France. This placing in perspective indicates that, for the 9 VOC and aldehydes concerned and on the basis of the results acquired during the characterisation of the emissions, the maximum concentrations in the gymnasium, modelled at D28, are of approximately the same magnitude as the ubiquitous concentrations in the ambient air (exterior and interior), or even inferior in certain cases.

The results of the INERIS HRE based on the concentration of the substances identified and on the previous hypotheses (worst-case scenarios) indicate that, according to current knowledge and on the basis of the information transmitted by the manufacturers (regarding exposure levels of workers responsible for installation in particular), the VOC and aldehyde emissions from the three types of artificial floors studied in indoor situation (small and poorly ventilated gymnasia) are of no cause for concern for human health, for the workers installing the surfaces as well as for the general public, professional or amateur athletes, adults and children, with the exception of the case of workers installing artificial surfaces in small and poorly ventilated gymnasia who are exposed for over 5 years. In this case, it is recommended that during installation, an air renewal rate of *at least* 2 vol.h^{-1} is assured.

This type of recommendation corresponds to that of the French Indoor Air Quality Observatory (OQAI), which recommends to private individuals several days' ventilation of rooms of a building which have just been constructed or renovated or after the installation of new furniture or decoration (page 5 of the "Les bons gestes pour un bon air" *(good moves for good air)* guide).

Concerning ventilation, moreover, it is appropriate to refer to the minimum fresh air intake rates imposed in France by the departmental health regulation (RSD) required irrespective of the ventilation system (these are the only regulatory provisions currently in force in terms of building ventilation). The INERIS recommends that this air renewal rate is maintained outside competitions, from the moment that professional or amateur athletes train on this type of indoor surface.

In conclusion to its study, the INERIS stipulates that the health risks associated with the inhalation of VOC and aldehydes emitted by artificial surfaces on pitches in outdoor situations give no actual cause for concern as regards human health.

IV. General conclusions

Evaluation of the environmental impact on water:

The analytical approaches as regards the environmental evaluation of water passing through artificial turf were conducted over a period of one year: on the one hand, by orchestrating representative pilots on the EEDEMS environmental platform (three types of filling granulates tested: TPE, EPDM, granulates recycled from used tyres) and on the other, *in situ* on a football pitch (recycled PUNR granulates). At the end of the experiments, the results showed that:

1 – All of the physicochemical results (42 parameters analysed) obtained on the percolates from the 3 2.5-m^2 pilots leads to the observation of a release kinetic for potentially polluting substances comparable to the course of time irrespective of the type of granulate used (7 percolate samples analysed at one year). The artificial turf pilot without filling granulates used as a control also displayed release rates fairly close to those of the 3 pilots. The concentrations recorded were low for the majority of the compounds and elements searched for. While certain elements displayed slightly higher concentrations at the start of experimentation, these fell very rapidly, thereby indicating a very rapid reduction effect in terms of release rates.

2 - *In situ* on the football pitch orchestrated in the Lyon region (France), the concentrations and release kinetics are fairly comparable to those observed on the pilots. The chlorides, fluorides and sulphates are even in lower concentrations than in the percolates collected on the pilots, a finding to be linked with the difference in chemical composition of the water that has percolated through the sports surfaces (rain water *in situ* and drinking water on the pilots).

3 – On the basis of a comparison with the French and European limit values currently in force, the concentrations of organic compounds, metals and anions from the percolates are without impact on water resources.

4 – From an ecotoxicological viewpoint, the results obtained show that the nature of the percolates likely to infiltrate into the ground underlying the artificial turf sports surface proves to be without impact on the aquatic environment in the short and medium term (standardised tests carried out on the first percolates and repeated several times during the year).

According to current research, after a year’s experimentation, the results on the 42 physicochemical parameters identified and on the ecotoxocological tests show that water passing through artificial turf using as filling either virgin TPE or EPDM or granulates resulting from the recycling of PUNR are not likely to affect water resources in the short and medium term.

Evaluation of the health risks linked to gaseous emissions

The characterisation of the emissions of Volatile Organic Compounds and aldehydes by elastomer granulate-based sports surfaces has been conducted by the CSTB (Centre Scientifique et Technique du Bâtiment - France) using the standards in force for the characterisation of the emissions in indoor air of construction products (emission chamber). The results show that:

1 – Emissions from the artificial turf only (control with no granulate filling) are very low in relation to those from other construction products;
2 - Emissions from the artificial turf containing used tyre granulates are relatively low;
3 - Emissions from the artificial turf containing TPE granulates are also relatively low. The compounds identified as being emitted is comparable overall to those identified in the used tyre granulate emissions;
4 - Emissions from the artificial turf containing the EPDM granulates are the most significant.

A Health Risk Evaluation (HRE) was conducted by the Institut National de l'Environnement Industriel et des Risques (France). This HRE was based on the values of the concentrations of 112 substances identified in the emission chambers and their comparison to the international toxicological reference values (RTV). According to the HRE methodology, a “worst-case scenario” was modelled (small, 1,380-m^3 gymnasium (6 m x 230 m^2) and poorly ventilated (0.5 vol.h^{-1})) taking into account four population groups (public, amateur athletes, professional athletes and coaches, artificial pitch installers).

According to current knowledge, the results of the HRE show that the VOC and aldehydes emissions identified for the three types of artificial floors and for the reference control present no cause for concern as regards human health in an indoor situation, for the workers responsible for laying the floors or for the general public, professional or amateur athletes, whether adults or children, with the exception of the case of workers installing artificial surfaces in small and poorly ventilated gymnasia who are exposed for over 5 years (worst-case scenario). In this case, it is recommended, when the floors are installed, that a minimum air renewal rate of 2 vol.h^{-1} is assured.

This type of recommendation corresponds to that of the French Indoor Air Quality Observatory (OQAI), which recommends to private individuals several days' ventilation of rooms of a building which have just been constructed or renovated or after the installation of new furniture or decoration (page 5 of the "Les bons gestes pour un bon air" *(good moves for good air)* guide).

In conclusion to its study, the INERIS stipulates that the health risks associated with the inhalation of VOC and aldehydes emitted by artificial surfaces on pitches in outdoor situations present no actual cause for concern as regards human health.

Initiated in 2005, this study was conducted with the scientific aim of getting as close as possible to the pitch usage conditions (representativity of the pilots conducted, quantities of materials tested, choice of limit thresholds, evaluation of effects over a year) and based on approaches and experimental protocols recognised on a European scale. The results of the evaluation of the environmental impact on the water and of the health risk evaluation (gaseous emissions) on the population groups show:

- comparable behaviour irrespective of the type of filling granulate (virgin TPE and EPDM, used tyre granulates),
- an absence of impact of this type of work on water resources,
- no effect worthy of concern on the health associated with the inhalation of VOC and aldehydes emitted by artificial surfaces.

This data consequently provides vital information on the environmental and health effects linked to the use of elastomer granulates (virgin and from used tyres) as filling in 3rd-generation artificial turf. These results offer elements of response to the principal questions raised by the professionals and sports federations.

On a French and European scale, the results of these studies will be able to be used in order to confirm or develop tailored sampling protocols and laboratory tests permitting the innocuousness in terms of the environment and health of 3rd-generation artificial turf under usage conditions.

APPENDICES

Compound	CASE No.
VOC	
acetophenone	98-86-2
alpha-methylstyrene	98-83-9
aniline	62-53-3
benzene	71-43-2
benzothiazole	95-16-9
butan-1-ol	71-36-3
butylcyclohexane	1678-93-9
1,5,9-cyclododecatriene	4904-61-4
cyclohexane	110-82-7
cyclohexanone	108-94-1
cymene	99-87-6
decahydro-2-methylnaphtalene	?
decane	124-18-5
1,4-diacethylbenzene	1009-61-6
1,2-dichlorobenzene	95-50-1
diethylbenzene	135-01-3
1,2-dihydro-2,2,4-trimethylquinoline	147-47-7
diisopropenylbenzene	3748-13-8
diisopropylbenzene	99-62-7
2,4-diisopropyl-1,1-dimethylcyclohexane	?
dimethylcyclohexane	2207-01-4
dimethylcyclopentane	?
dimethylethylbenzene	98-06-6
dimethylethylcyclohexane	3178-22-1
dimethylhexene	?
dimethylpentanol	?
dimethylphenylmethanol	617-94-7
2,4-dimethylquinoline	1463-17-8
dimethyltrisulfide	3658-80-8
2,6-ditertbutyl-p-benzoquinone	?
2,6-ditertbutyl-4-methylphenol	?
dodecane	112-40-3
dodecene	25378-22-7
1,2-ethanediol	107-21-1
ethanone, 1-[4-(1-hydroxy-1-methylethylphenyl)]	?
ethylbenzene	100-41-4
ethylcyclohexane	1678-91-7
5-ethyldihydro-5-methyl-2(3H)-furanone	?
2-ethylhexanol	104-76-7
5-ethyl-2,2,3-trimethylheptane	?
ethyltoluene	622-96-8
2,2,3,5,5,6,6-heptamethyl-3-heptene	?
heptane	142-82-5
heptene	592-76-7
2,5-hexanedione	110-13-4
1-hydroxycumene	617-94-7
hydroxydiisopropylbenzene	4779-94-6
isobutene tetramere	115-11-7
1-isopropoxy-2-methyl-2-propanol	?
isopropenylacetophenone	?
isopropylacetophenone	?
Isopropylbenzene (or cumene)	98-82-6
isothiocyanato-cyclohexane	1122-82-3
1-methoxy-2-propanol	107-92-8
(1-methoxy-1-methylethyl)-benzene	?
methyldecane	6975-98-0

Compound	CASE No.
3-methylheptane	589-81-1
methyl-2-hexanone	?
methylcycloheptane	4126-78-7
methylcyclohexane	108-87-2
3-methylcyclohexen-1-one	?
methylcyclopentanol	1462-03-9
methylethylcyclohexane	1678-82-6
methylethylcyclopentane	?
methylisobutylcetone (MIBK)	108-10-1
2-methyl-2-(1-methylethoxy)-propane	?
methylpropylbenzene	99-87-6
4-methyl-pyridine	1333-41-1
naphthalene	91-20-3
octahydro naphthalene methanol	?
octane	111-65-9
octenone	4312-99-6
pentadecane	629-62-9
2,2,4,6,6-pentamethylheptane	13475-82-6
2,2,4,6,6-pentamethyl-3-heptene	123-48-8
phenol	108-95-2
4-phenylcyclohexene	4994-16-5
1,2-propanediol	57-55-6
propylbenzene	103-65-1
propylcyclohexane	1678-92-8
styrene	100-42-5
4-tert-butylacetophenone	?
4-tert-butylcyclohexanone	98-53-3
tert-butylformamide	2425-74-3
tetradecane	629-59-4
tetraisobutylene	15220-85-6
tetramethylcyclopentane	*isomers*
3,3,6,6-tetramethyl-1,4-cyclohexadiene	?
2,2,6,6-tetramethyleneheptane	?
trichloroethylene	79-01-6
tridecane	629-50-5
1,2,3-trimethylbenzene	526-73-8
1,2,4-trimethylbenzene	95-63-6
1,3,5-trimethylbenzene	108-67-8
trimethylcyclohexane	*isomers*
3,5,5-trimethyl-2-cyclohexen-1-one	78-59-1
trimethylcyclopentane	*isomers*
1,3,3-trimethyl-2-methylene-indoline	118-12-7
toluene	108-88-3
undecane	1120-21-4
xylenes	1330-20-7
acetaldehyde	75-07-0
benzaldehyde	100-52-7
butyraldehyde	123-72-8
crotonaldehyde	123-73-9
decanal	112-31-2
formaldehyde	50-00-0
hexaldehyde	66-25-1
nonanal	124-19-6
propionaldehyde	123-38-6
m/p-tolualdehyde	620-23-5
valeraldehyde (pentanal)	110-62-3

Table 5: List of substances studied (in bold: the 16 substances with a RTV)

V. Bibliographic and normative references

FIFA : FIFA quality concept for artificial turf guide, http://www.fifa.com/documents/static/development/FIFA-guideM.pdf

BYGGFORSK Norwegian Building Research Institute (2004) : Potential health and environmental effects linked to artificial turf systems - final report.

Danish EPA (2005) : Emissions and evaluation of health effects of PAH's and aromatic amines from tyres, Nilsson N.H., Feilberg A. and Pommer K., Danish Technical Institute, Survey of Chemical Substances in Consumer Products no. 54. http://www.mst.dk

Detlef A. Birkholz, Kathy L. Belton, Tee L. Guidotti (2003) : Toxicological Evaluation for the Hazard Assessment of Tire Crumb for Use in Public Playgrounds, Journal of the Air & Waste Management Association.

Norwegian Institute of Public Health and the Radium Hospital, Oslo (Janvier 2006) : Artificial turf pitches – an assessment of the health risks for football players.

Norwegian Institute for Water Research (2005) : Environmental risk assessment of artificial turf systems.

NF ENV 12 920 : Caractérisation des déchets **-** Méthodologie pour la détermination du comportement à la lixiviation d'un déchet dans des conditions spécifiées

NF EN ISO 6341, mai 1996 (T90-301) : Détermination de la toxicité aiguë (inhibition de la mobilité de *Daphnia magna*)

NF EN ISO 28692, mai 1993 : Evaluation de la toxicité chronique des percolats [inhibition de la croissance algale avec *Pseudokirchneriella subcapitata* (anciennement *Selenastrum capricornutum*)

Directive 98/83/CE : adoptée par la Communauté le 03/11/1998 (JOCE n° L.330/32 du 05/12/1998) et relative à la qualité des eaux destinées à la consommation humaine à l'exception des eaux minérales.

Code la Santé Publique : Livre III, Titre II, section 1. Articles R1321**-**1 à R1321-66.

Décret n° 2001-1220 du 20 décembre 2001 : relatif aux eaux destinées à la consommation humaine, à l'exclusion des eaux minérales

Directive Décharge 1999/31/CE : Conditions d'acceptation des déchets inertes, prévues dans l'annexe 2 de la Directive 1999/31/CE, concernant la mise en décharge des déchets, dite la « Directive Décharge », Document réalisé pour la Commission Européenne par plusieurs pays : France (BRGM, INSA de Lyon, Ministère de l'Environnement) ; Pays Bas (ECN, Ministère de l'Environnement) ; Angleterre (WRC, Ministère de l'Environnement) ; Allemagne (Ministère de l'Environnement **-** BMU) ; Danemark (DHI, Ministère de l'Environnement) ; Autriche (Ministère de l'Environnement) ; Suède (SGI).

Arrêté Rejets ICPE du 02/02/98 (art. 32) : relatif aux prélèvements et à la consommation d'eau ainsi qu'aux émissions de toute nature des installations classées pour la protection de l'environnement soumises à autorisation

Protocole européen (ECA/IAQ, 1997) : European Collaborative Action Indoor Air Quality & its Impact on Man. Report 18: Evaluation of VOC emissions from building products – Solid flooring materials (1997)

NF IS0 16000-3 : Air intérieur – Partie 3 : Dosage du formaldéhyde et d'autres composés carbonylés – Méthode par échantillonnage actif (AFNOR, 2002).

NF IS0 16000-6 : Air intérieur – Partie 6 : Dosage des composés organiques volatils dans l'air intérieur des locaux et enceintes d'essai par échantillonnage actif sur le sorbant Tenax TA, désorption thermique et chromatographie en phase gazeuse utilisant MS/FID (AFNOR, 2005).

prEN IS0 16000-9 : Indoor air – Part 9 : Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method (ISO, 2005).

Directive européenne « Produits de construction » (89/106/EEC - 21/12/1988)

Air Normand (Mars 2000) : Qualité de l'air intérieur, Gymnase de Notre Dame de Gravenchon, Rapport d'étude n°E 00_9, Campagne du 04/02 au 17/03/1999 et du 27/05 au 30/05/1999..

Foster P., Laffond M., Baussand P. *et al.* (1991) : VOC measurements in the Grenoble area and study of benzaldehyde behaviour in a simulation chamber, Pollution atmosphérique, 175-191

ADEME (2003) : Base de données de paramètres descriptifs de la population française au voisinage d'un site pollué, ADEME/IRSN, Version 0.

INERIS (2003-a) : Substances chimiques, Évaluation des risques sanitaires dans les études d'impact des installations classées. http://www.ineris.fr/

INERIS (2003-b) : Hydrocarbures Aromatiques Polycycliques (HAPs), Évaluation de la relation dose-réponse pour des effets cancérigènes : Approche substance par substance (facteurs d'équivalence toxique – FET) et approche par mélanges, Évaluation de la relation dose-réponse pour des effets non cancérigènes : Valeurs Toxicologiques de Référence (RTV). http://www.ineris.fr/

INERIS (2006) : Pratique INERIS de choix des valeurs toxicologiques de référence dans les évaluations de risques sanitaires : http://www.ineris.fr/

INERIS (2006) : Rapport d'étude : Synthèse des valeurs réglementaires pour les substances chimiques, en vigueur dans l'eau, l'air et les denrées alimentaires en France au 1er mars 2006.

Kirchner S. *et al.* (1995) Habitat à moindre risque allergénique : mesures des conditions d'ambiance et de polluants chimiques. EAE/QAE- DAC n° 95067.012.

Le Moullec Y., Dusséaux M., Thibault G. (2004) : Connaissance de l'exposition des citadins à la pollution atmosphérique dans les établissements de loisir : gymnases. Laboratoire d'Hygiène de la Ville de Paris, Mairie de Paris.

Nisbet I.C.T. et Lagoy P.K. (1992) : Toxic equivalent factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs), Reg. Toxicology and Pharmacology, 16, 290-300

Norwegian Pollution Control Authority/Norwegian Institute for Air Research (2006) : Measurement of air pollution in indoor artificial turf halls.

OQAI (2006) : État des connaissances sur la qualité de l'air intérieur des lieux de vie fréquentés par les enfants, OQAI, rapport référencé DDD/DE/VAI-06-061R

Rohr A.C., Weschler C.J., Koutrakis P., Spengler J.D. (2003) Generation and quantification of ultrafine particles through terpene/ozone reaction in a chamber setting, Aerosol Science and Technology, 37(1), 65 – 78

UE (2005) : Harmonisation of indoor material emissions labelling systems in the EU, Inventory of existing schemes, Report N°24, European Collaborative Action, Urban Air, Indoor Environment and Human Exposure, European Commission, EUR 21891. http://www.inive.org/medias/ECA/ECA_Report24.pdf

Van den Hazel P., van Hooren V., van de Weerdt R. (2006) : Study of the health hazards SBR granulates in an artificial turf at the sports centre at Rijkerswoerd, Sportbedrijf Arnhem

Weschler C.J. (2004) : Chemical reactions among indoor pollutants: what we've learned in the new millennium, Indoor Air, 14 (S7), 184 – 194.

Wolkoff P., Wilkins C.K., Clausen P.A., Nielsen G.D. (2006) : Organic compounds in office environments - sensory irritation, odor, measurements and the role of reactive chemistry, Indoor Air, 16(1), 7 – 19.

http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB
http://chimie.ineris.fr
http://www.epa.gov/iris/
http://www-cie.iarc.fr/monoeval/grlistfr.htm
http://www.meteo.fr/temps/monde/climats/3-2.htm