Assessment of inhalation and dermal exposure of workers in artificial turf playing fields infilled with rubber granulate obtained from the recovery of end of life tires (ELTs)

Summary Report

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ACRONIMI E DEFINIZIONI

ACGIH	American Conference of Governmental Industrial Hygienists
ASTM	American Society for Testing and Materials
B[a]P	Benzo[a]pyrene
CEN	European Committee for Standardization (Comité Européen de Normalisation)
CDC	Centers for Disease Control and Prevention
CTN	National toxicology committee
ELTs	End of Life Tyres
EPA	Environmental Protection Agency
IARC	International Agency for Research on Cancer
ISO	International Standardization Organization
LOD	Limit of detection
LOQ	Limit of quantification
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety & Health Administration
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals
REL	Recommended Exposure Limit (NIOSH)
PAHs	Polycyclic Aromatic Hydrocarbons
PEL	Permissible Exposure Limit (OSHA)
SBR	Styrene Butadiene Rubber
TLV	Threshold Limit Value (ACGIH)
Environmental sampling	Sampling of environmental air through a high volume static sampler.
Personal sampling	Sampling of air in the breathing air of workers through personal samplers
Gravimetric determination	Measurement through precision scales
Aerodynamic diameter of a particle	Diameter of a particle with mass volume ratio of 1 g/cm^3 and with the same terminal velocity under gravitational force and in calm air and at the same temperature, pressure and humidity.
Limit of Detection (LOD)	The smallest amount which can be detected with reasonable certainty by the analytical method
Limit of quantification (LOQ)	The smallest amount which can be quantified with reasonable reliability by the analytical method
Selector	Device for the particle segregation based on the aerodynamic diameter
Breathing zone	The zone immediately surrounding the face of the operator, which may be considered representative of the air inhaled by the operator.

EXECUTIVE SUMMARY

This work describes the inhalation and dermal exposure measurements carried out on workers during the installation of artificial turf playing fields infilled with rubber granules derived from the recovery of end of life tires (defined as crumb rubber[1]).

The survey, carried out by WasteandChemicals Srl, is part of a more extensive test program geared at verifying the safety of workers and football players exposed to crumb rubber.

The monitoring campaigns, carried out from July 2015 to May 2016 in 5 playing fields in Italy, included two distinct steps. In the first step, the workers were monitored while installing crumb rubber infill and other granules of vegetal origin. This was done to measure their exposure to the pollutants released during these operations and to compare the risk for human health associated with the handling of the two types of infill materials. The second step was performed at a later time, and included the simulation of normal use conditions on fields selected among those monitored in step one: amateur football matches were organized and monitoring operations were carried out on the environment and on the individual players.

Under the first step of this study, six monitoring campaigns have been completed during the construction of four fields - three with coated rubber infill and one with infill of vegetal origin (Geofill [2]). The infill material used for the synthetic field was completely characterized, as it was part of a certified traceability program which encompasses all the recycling process, including the waste of origin (end of life tires), processing plants and installation in the field.

In each monitoring campaign, the exposure to pollutants (PAHs) was measured in the gaseous phase and as particulate, as well as respirable dust. To this end, personal samplers for the measurement of concentrations of PAHs and respirable dust were applied directly on the workers engaged in the installation of playing fields; adsorption pads were also applied to workers to measure the dermal exposure to the same pollutants. During these monitoring campaigns, the background concentration of PAHs was measured through high volume samplers positioned in the vicinity of the operational areas.

The construction of playing fields involves several consecutive phases which may be assigned to different workers on a case by case basis: therefore in each monitoring campaign the choice of the devices to be applied to the operators and the duration of sampling were tailored to the specific situation. Typically, the monitoring sessions lasted at least half the duration of a work shift.

Inhalation exposure was measured by means of individual samplers with constant flow; particulate material containing PAHs and PAHs in vapour phase were collected and measured by means of two-stage sampling probes. For both PAH and respirable dust samples, methods compliant with current legislation and official UNI reference standards (UNI EN 1232: 1999, UNI EN 689: 1997, EN 481: 1994; UNICHIM 2010: 2011, NIOSH 5515: 1994 US EPA TO 13A) were used. On the basis of relevant literature studies and reference documents, dermal exposure was monitored by means of an "interception" method, i.e. a sampling method using

1 In Italy almost all infills are made of rubber granules coated with a colorized polyurethane product.

2 Organic Infill made of vegetable fibers and cork

absorbent patches (pads) attached to the skin or clothing of workers, intercepting the contaminants before they reach the skin.

The simultaneous performance of dermal sampling and inhalation exposure allowed the assessment of the overall risks associated with the installation of artificial turf playing fields. All the samples were analyzed with high resolution GC/MS with a sensitivity of 10 pg- 10^{-12} g. This level of sensitivity was necessary to evaluate the risk associated with low-level exposure, and to compare the risk related to the different scenarios considered (workers operating with rubber and non-rubber infills). In addition to that, also the regulatory limits imposed by the Italian legislation (Legislative Decree n.81 / 08) or by international agencies (ACGIH, OSHA, NIOSH), were verified.

Based on the analytical results of the monitoring campaigns carried out to date, it may be said that, regardless of the type of material used as infill and the exposure scenario, all concentrations measured are well below the recommended limit values for both PAHs and for respirable dust, even considering the most restrictive reference limits (TRK for benzo (a)pyrene: 2 μg / m^3; ACGIH for respirable dust: 3 mg / m^3).

The risk analysis also showed that the incremental carcinogenic risk was found to be lower than the value of $1x10^{-6}$ recommended for the general population. For both type of monitored fields, the risk associated with dermal exposure was extremely low - at least one order of magnitude lower than the recommended value. The comparison of the exposure data for the two types of infill (with / without crumb rubber) shows no significant differences, although the risk associated to the vegetal origin infill (Geofill) was lower than the risk with the crumb rubber infill. It should be emphasized, however, that the values are of the same order of magnitude. Furthermore, the comparison included only one non-rubber field where data for only one operator were available, therefore being of limited significance.

It should be pointed out that to date it is not possible to determine to what extent the observed exposure levels are due to the monitored material (coated rubber granulate or Geofill) or whether they are related to external factors such as the variability of micro-meteorological conditions, the differences in the operating mode of the workers or to the environmental background concentrations of the pollutants of interest in the monitoring zone. In this regard, it is worth noting that the concentrations in ambient air measured in the playing field are consistent with the air quality data of urban areas close to the sites monitored, and documented in similar studies.

Anyway, even though the exposures observed also include exposures to background concentration, it should be stressed that in all the analyzed scenarios the values were found to be substantially lower than those recommended for the general population (1×10^{-6}).

FOREWORD

The crumb rubber[3] granules obtained from the recovery of end of life tires are widely used in artificial turf football fields. The rubber granules are used not only for the mats that form the field underlay, but also as a component of the infill of the artificial turf playing field.

This study is aimed at verifying the safety of this material when used as infill in artificial turf, with special reference to the occupational exposure during the installation of the fields.

Under this study, six monitoring campaigns have been carried out during the construction of four sports fields (Table 2) with coated rubber infills and with rubber-free vegetal origin infills (Geofill). In a second step of the study, seven campaigns were carried out during football matches in two of the above synthetic sports fields monitored during their installation and in one natural field (results not reported in this document).

This document discusses the results of the above campaigns in term of exposure level and the associated risks for the workers, for two types of exposure (inhalation and dermal) and for the two types of infill used for the installation of football fields.

1 METHODOLOGY

1.1 SAMPLING METHODS

In general, a football synthetic field[4] contains an average of 100-110 tonnes of infill material. The bottom layer is composed by silica sand; the top layer can be infilled with several types of materials. In this study, only two types were monitored during their installation: crumb rubber derived from the recovery of end of life tires (ELT) (size between 0.5 and 2,5 mm) and organic infill (organic components such as natural cork and/or ground fibers).

The pollutants from crumb rubber granulates can be released into the atmosphere in two main ways:

- Through the release of substances in the gaseous state. This is related to the temperature, the physical-chemical characteristics of the chemicals involved, and to the way these chemicals are bound or adsorbed to the polymer;
- Through the release of substances adsorbed or bound to the particulate matter generated during the handling or use of the granules. This depends both on the temperature of the granulate and on the condition of its use.

In each campaign, the exposure to PAHs and respirable dust was measured, as these are present in the granules and are a known hazard for human health.

Although the installation of an artificial turf playing field requires several sequential steps, it was decided to focus the study only on the steps closely connected to the handling or the use of the infilling material, as

3 In Italy almost all infills are made of rubber granules coated with a colorized polyurethane product

4 For full size 11 a-side pitches, FIFA defines minimum dimensions of 45m x 90m and max dimensions of 90m x 120m.

these are considered of greater interest for the analysis of the exposure to the possible release of pollutants from granules, namely:

- the laying of the infill at the time of the installation of the artificial grass field;
- the use of artificial grass field (during football matches / football training).

The infilling procedure proper involves the following steps:

- Loading the cargo bed of the truck spreading the infill over the football field (emptying the big bags);
- Spreading of the infill over the football field (by the above mentioned special purpose truck)
- Handling of the infill (using a special purpose machine) (raking).

In general, individual workers are not assigned fixed tasks; each worker can carry out various jobs during the installation of the artificial turf playing field and the number of workers employed depends on the size and on the time available for the installation of the football field (for example in the case of futsal fields the team is composed by two workers).

In each monitoring campaign, the choice as to what device to apply to the workers was evaluated on a case by case basis. The duration of the sampling spanned from two to four hours, approximately equal to half a work-shift, in compliance with standard methods (UNICHIM, 2013) .

To this purpose, the samples were taken individually, through monitoring devices applied directly on each worker engaged in the infilling operations, to measure dust and PAHs concentrations in the breathing zone or deposited on the skin surface.

Furthermore, environmental samples were taken by means of high-volume samplers located at the perimeter of the football field, to measure the background concentration of PAHs in the surrounding air.

Whenever possible, biological monitoring operations were carried out to assess the metabolic PAH absorption in the monitored subjects (the studies were carried out by “Mario Negri” Institute and their results are not described in this report).

1.1.1 Inhalation Exposure

The assessment of inhalation exposure was carried out through the sampling and measurement of the respirable fraction of dust and PAH in the breathing zone of the workers assigned to different tasks during the same shift. This was accomplished through personal samplers equipped with probes installed within the breathing zone of each worker.

The personal sampling methods adopted comply with Annex XLI of Legislative Decree n.81/08 (*Standardized Measuring Methods of the agents*), with special reference to standardized methods for the measurement of chemical agents. More specifically, in compliance to the UNI EN 689: 1997 (1997), personal sampling devices applied to the body of workers to determine their real exposure to the investigated substances were used. Sampling also covers the short breaks possibly taken by each worker during their shift.

In compliance with UNI EN 1232: 1999 (1999) - Workplace atmospheres. Pumps for personal sampling of chemical agents. Requirements and test methods- sampling air pumps with constant flow were used, with flow stability ensuring fluctuations of less than 10% (Tecora Ayron 5 Standard Flow 750-5000 cc / min) and a measurement system for the continuous storing of flow rates. With this approach, not only the monitored volume was exactly measured, but also the pump performance was checked at all times. The pumps were directly fastened on workers, with a shoulder strap system arranged to prevent interference with the normal performance of their work. In order to monitor both types of pollutants, the pumps were equipped with two different sampling probes.

To sample the respirable dust[5], a centrifugal Dorr-Oliver pre-selector was used, in compliance with the method NIOSH 0600 (1998) (sampling flow: 1.7 l/min). This device allows the selection and collection of the respirable fraction of particulate, reproducing the separation pattern indicated by UNI EN 481 (1994) when operating in the conditions stated by the manufacturer in accordance with UNI EN 13205 (2014). Following common practice and in compliance with standard UNI EN 481 (1994), pre-treated (oven dried) 25 mm glass filters were used for intercepting the respirable fraction of the particulate.

Figure 1-Left: Fractional deposition of inhalaed particles. Right: Sampling equipments for the Inhlation exposure assessment of the workers.

The samplers used to monitor the PAHs were equipped with a sampling train composed by a particulate filter (Munktell, MK360 diam.25mm) and an adsorbent vial (XAD2 200-400 mg Jumbo). As for respirable dust, Tecora Ayron air samplers applied to workers were used, but in this case the sampling flow was set at 2 l/min, in compliance with method NIOSH 5515 (1994).

[5] [5] Fraction of inhaled airborne particles whose dimensions are such as to determine the interaction with the human respiratory system, and in particular, the penetration beyond the terminal bronchioles into the gas-exchange region of the lungs, conventionally with an aerodynamic diameter equal to 4 µm.

1.1.2 Dermal Exposure

The development of a sampling method for dermal exposure required the examination of the main reference documents and standards in this area[6]. In this survey, a method based on the "interception principle" was used; this sampling method uses sorbent layers (exposure pads or patches) fixed on the skin or on clothing, which intercept pollutants before they reach the skin.

The main variables to be considered in the "pads technique" are: size, material, number and position of the pads. To date there are no standardized studies on such variables, so the dermal sampling method adopted in this study was a modification of the method described by Jongeneelen et al. (1988) , Van Rooij et al. (1993) e McClean et al. (2004).

The aim of the dermal sampling was to estimate the potential dose of pollutants that could be deposited on the skin, therefore the dermal patches were placed both on the skin and on protective clothing. Each worker was equipped with four pads on different spots on the body (chest, shoulder, wrist, calf). This configuration was specially designed to allow a good mapping of distribution of skin contamination on the entire body surface, reducing at the same time the discomfort for the workers.

Each patch was made by a polypropylene filter (Millipore, AN1H4700, 47 mm diameter, 10 µm size) placed between two layers of adhesive films: only a small area (diameter 20 mm) was left uncovered and used as monitoring area.

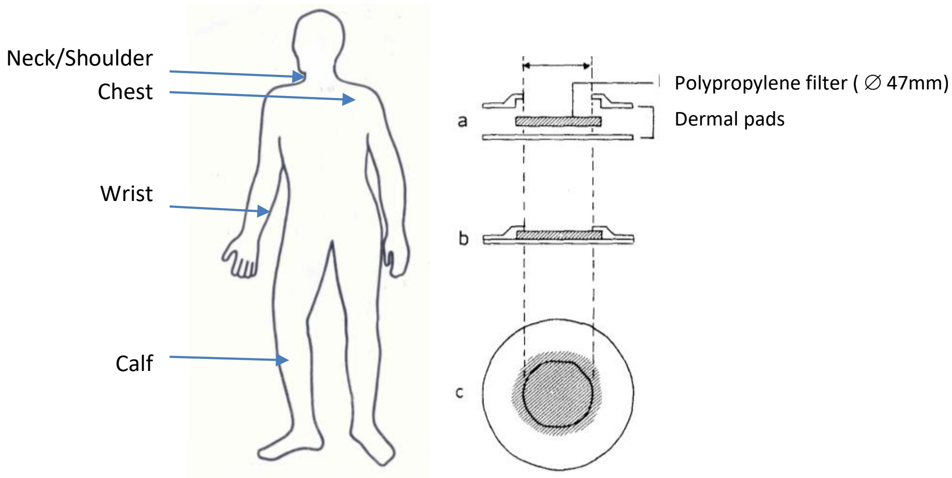

Figure 2- Body location of individual pad samplers (figure adapted from Van Rooij et al. (1993)) and design of pad (figure adapted from Jongeneelen et al (1988)

To reduce the uncertainty associated with this technique, the pads were applied on all workers. In additions, the laboratory was instructed to made a cumulative extraction of all the pads for each worker.

[6] CEN/TR 15278:2006 - *Workplace exposure. Strategy for the evaluation of dermal exposure* (2006), CEN/TS 15279:2006 -*Workplace exposure – Measurement of dermal exposure. Principles and methods* (2006); EPA/600/8-91/011B (Dermal Exposure assessment: Principles and Applications, 1992); EPA/600/R-09/052F (Exposure Factors Handbook, 2011 Edition, 2011); EPA/600/R-07/040F (Dermal Exposure Assessment: a summary of EPA approaches, 2007); NIOSH CDC 2002 (Exposure Assessment Methods: Research Needs and Priorities, 2002).

Immediately after sampling, pad samples were removed, packed in aluminum foil and stored at 4°C until analysis, and analyzed with the same methodology adopted for the samples collected for inhalation exposure.

1.1.3 Sampling in ambient air

The assessment of inhalation exposure (1.1.1) was integrated with the sampling of ambient air in locations close to the playing fields area. The determination of PAH concentration in environmental samplings was useful to understand the background contribution to the exposure of workers, although this piece of information was not used in the risk assessment calculation, because it was assumed that the personal sampling also included that contribution.

In accordance with the sampling method USEPA TO13A (United States Environmental Protection Agency, USEPA, 1999), the sampling of ambient air was carried out by means of a high volume sampler equipped with a sampling module formed by a 102 mm filter holder (quartz fiber filter Munktell MK360, 102 mm) and an absorbing cartridge holder (for Poly Urethane Foam PUF Tecora h50mm), allowing the simultaneous sampling of particulates and gas. PAHs were determined separately for the atmospheric particulate sampled on the quartz filter and for the volatile fraction absorbed on the PUF.

The monitoring was performed by setting a sampling flow of 200 l/min, for a time equal to or longer than the duration of personal samplings. The aforementioned sampling flow allows to collect a sufficient volume and to prevent overload problems and related losses due to clogging of the filtering device; it complies with methods ISO 12884 (flow indicated between 100 and 240 l/min) and US EPA TO9 (flow between 200 and 280 l/min).

In compliance with US EPA method TO 13A (United States Environmental Protection Agency, USEPA, 1999), both the filter and the PUF support underwent a conditioning procedure before the sampling (see par. 1.2). At the end of the monitoring procedure, the sampling module was disassembled to remove the filter and the PUF cartridge. The same procedures used for personal samples was adopted for the storage and transport of environmental samples.

Figure 3- High volume sampler ECHO HI VOL Tecora used for sampling of ambient air.

1.2 ANALYTICAL METHODS

The following analytical methods were used:

- For the measurement of PAHs: EPA TO 13A
- For the measurement of respirable dust: UNICHIM 2010.

22 PAHs were quantified on the samples, selected on the basis of bibliographic references from authoritative institutions (IARC, EPA, ACGIH, CTN, EC). The list includes the *priority pollutants* proposed by EPA, with the addition of benzo (a) pyrene and dibenzo-pyrenes: all the components of the list were quantified. During the processing of analytical data, the list was further reduced to 11 PAHs considered more relevant from the point of view of health risk, and matching the PAHs regulated by European and Italian laws (**Table 1**).

Table 1 – List of monitored PAHs

Parameter	CAS number	Vapour pressure (Pa, 25°C)	Carcinogenesis [A]			PAHs regulated by Legislative Decree n.152/2006 (soil- and sub-soil) [B]	PAHs regulated by Legislative Decree n.155/2010 (air quality) [C]	PAHs in REACH Restriction proposal [D]
			IARC	ACGIH	US-EPA			
benzo (a) anthracene	56-55-3	7.3×10^{-6}	2B	A2	B2	X		X
benzo (b) fluoranthene	205-99-2	-	2B	A2	B2	X		X
benzo (j) fluoranthene	205-82-3	-	2B	-				X
benzo (k) fluoranthene	207-08-9	-	2B	-	B2	X		X
benzo (g,h,i) perylene	191-24-2	6×10^{-8}	3	-	D	X		
benzo (a) pyrene	50-32-8	8.4×10^{-7}	1	A2	B2	X	X	X
benzo (e) pyrene	192-97-2	-	3	-				X
chrysene	218-01-9	5.7×10^{-7}	2B	A3	B2	X		X
dibenzo (a,h) anthracene	53-70-3	3.7×10^{-10}	2A	-	B2	X		X
indeno (1,2,3-cd) pyrene	193-39-5	-	2B	-	B2	X		
pyrene	129-00-0	8.86×10^{-4}	3	-	D	X		

[A] Assessment of carcinogenicity:

- *IARC: Group 1: Carcinogenic to humans; 2A: Probably carcinogenic to humans, 2B: possibly carcinogenic to humans 3: not classifiable as to its carcinogenicity to humans*
- *ACGIH: class A2: suspected human carcinogen, A3: confirmed animal carcinogen with unknown relevance to humans*
- *US-EPA: class B2: probable human carcinogen, D: not classifiable as to human carcinogenicity*

[B] Legislative decree. n. 152/06 Annex 5 Part IV, Title V, Table 1, Column A (threshold concentrations of contamination in soil and subsoil, referred to the specific land use of the sites-residential land use)

[C] Legislative decree n.155/2010 Annex XIII (art. 9, par. 2 and 5) (Target values for arsenic, cadmium, mercury, nickel and benzo (a) pyrene in ambient air)

[D] Proposal for a PAHs restriction in consumer articles. (Federal Institute for Occupational Safety and Health Division for Chemicals and Biocides Regulation, 2010)

With regard to the fraction of PAHs absorbed to the particulate, in compliance with the EPA method, quartz fibers filters were used. Both the quartz and PUF filters were pre-conditioned before their use in accordance with method requirements. The conditioning solvent was analyzed to measure PAHs concentrations.

After the extraction with Soxhlet apparatus, the samples were analyzed using high-resolution gas chromatography with mass-selective detection HRGC/HRMS. Quantification was based on the internal calibration with isotope dilution using deuterated internal standards.

The analytical result, including analyses on blanks (media blanks, field blanks, laboratory blanks), confirmed the good performance of the analytical methods because the limits of detection observed were of the order of pg (10^{-12}g). The method was therefore considered suitable to evaluate the risk associated with low-level exposure.

With regard to the respirable fraction, the amount of particulate intercepted by the filters was measured by a gravimetric method in compliance with UNICHIM Method 2010. In particular, the samples underwent double weighing through Sartorius analytical balance CO2 P-F with a sensitivity of 10^{-6} g.

2 CHARACTERISTICS OF THE MONITORED SITES

The monitoring campaigns were carried out from July 2015 to May 2016 in 5 playing fields in Italy during the installation of synthetic fields and during amateur football matches in natural and synthetic fields.

Six monitoring campaigns were completed during the installation of four playing fields, three with coated rubber infill and one with infill of vegetal origin (Geofill [7]). Table 2 shows the characteristics of the surveyed playing fields and associated monitoring campaigns.

Table 2 – Characteristics of playing fields and monitoring campaigns

N.	Sampling date	Type of monitored activity	Type of playing field					Sampling time (hh:min)	N. monitored subjects	T air (°C)	Sampling Type
			ID	dimensions	Synthetic		Natural				
					coated rubber infill	Organic infill	No infill				
1	14/07/15	infilling	field n.1 Trecella (MI)	8 a-side pitch	X			03:45	2	25	E, I, D
2	10/09/15	infilling	field n.2 Rome (RM)	11 a-side pitch	X			02:20	4	20	E, I, D, B
3	11/09/15	infilling	field n.2 Rome (RM)	11 a-side pitch	X			02:30	4	21	E, I, D, B
4	29/09/15	infilling	field n. 3 San Salvo (CH)	8 a-side pitch		X		02:00	2	16	E, I, D
5	20/10/15	infilling	field n. 4 Milan (MI)	8 a-side pitch	X			01:30	2	12	E, I, D, B
6	21/10/15	infilling	field n. 4 Milan (MI)	8 a-side pitch	X			02:00	2	11	E, I, D, B

E=Sampling of PAHs in ambient air, I=personal sampling to assess inhalation exposure, D=personal sampling to assess dermal exposure, B=biological sampling

[7] Organic Infill made of vegetable fibers and cork

2.1 FIELD N.1 TRECELLA (MI)- CAMPAIGN N.1

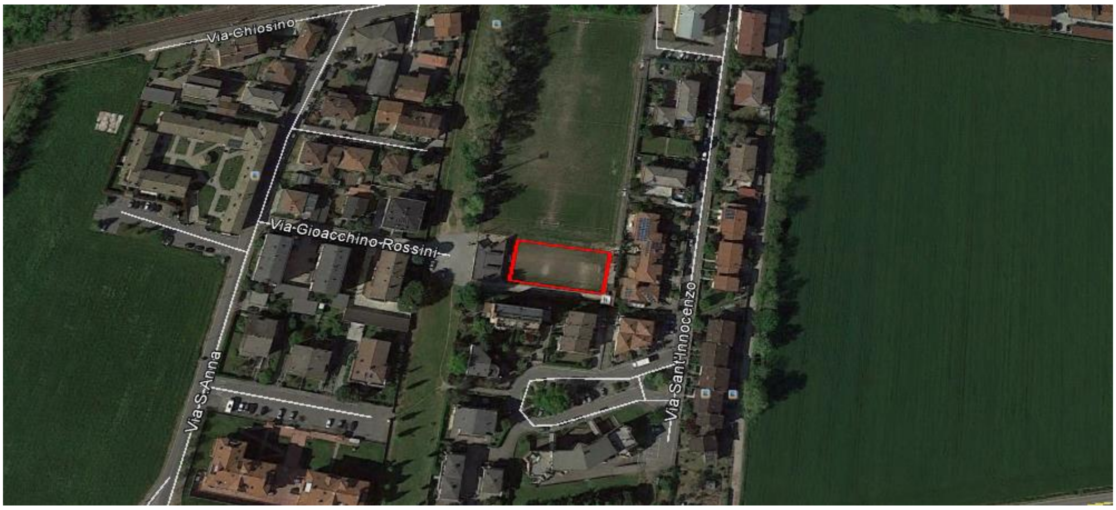

Figure 4 – Trecella: Location of the playing field

Figure 5 – Trecella: location of the high volume sampler

Figure 6 – **Trecella: Personal sampling devices applied to the body of workers**

The average temperature recorded by monitoring devices during the monitoring campaign was 25 ° C. The following weather conditions were recorded by the air quality monitoring stations of Arpa Lombardia during the sampling campaign.

Table 3 -Data recorded by the air quality monitoring station of Trezzo sull'Adda during the sampling campaign (Arpa Lombardia).

Date	Relative humidity [%]	Wind speed [m/s]	Wind direction (°)	Rain [mm]
14/07/2015 07.00	84.7	0.7	2.4	0
14/07/2015 08.00	75.5	1.2	83.6	0
14/07/2015 09.00	66.0	1.7	138.3	0
14/07/2015 10.00	63.3	1.9	146.8	0
14/07/2015 11.00	59.2	1.7	115.3	0
14/07/2015 12.00	54.3	1.3	93.4	0
14/07/2015 13.00	51.4	1.3	201.0	0

2.2 FIELD N.2 ROME (RM)- CAMPAIGNS N.2-3

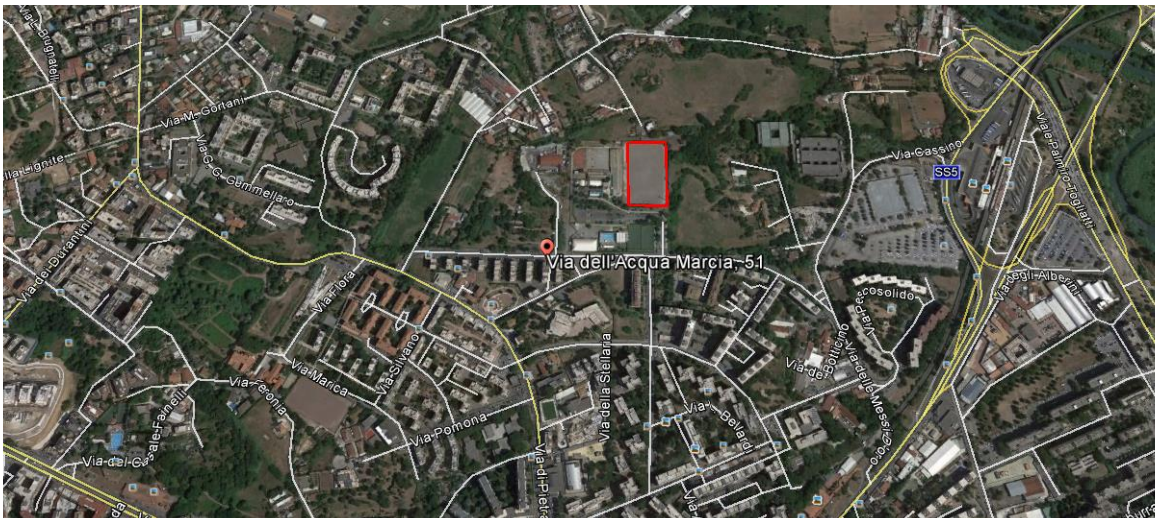

Figure 7 – Rome: Location of the playing field

Figure 8 – Rome: location of the high volume sampler

Figure 9 – Rome: Personal sampling devices applied to the body of workers

The average temperature recorded by monitoring devices during the first monitoring campaign was 22 °C, during the second 29°C. The following weather conditions were recorded by the nearest meteorological station of Rome Ciampino during the sampling campaigns.

Table 4 – Data recorded by the meteorological station of Rome Ciampino (meteo.it)

PARAMETERS	**10/09**	**11/09**
Average temperature [°C]	20	21
Average humidity [%]	57	63
Average wind speed [km/h]	10	8
Weather	Partly cloudy	Partly cloudy

2.3 FIELD N.3 SAN SALVO (CH)- CAMPAIGN N.4

Figure 10 – San Salvo: Location of the playing field

Figure 11– San Salvo: location of the high volume sampler

Figure 12– San Salvo: Personal sampling devices applied to the body of workers

The average temperature recorded by monitoring devices during the monitoring campaign was 19 ° C. The following weather conditions were recorded by the nearest meteorological station of Pescara during the sampling campaign.

Table 5- Data recorded by the meteorological station of Pescara (meteo.it)

PARAMETERS	29/09
Average temperature [°C]	16
Minimum temperature [°C]	13
Maximum temperature [°C]	19
Average humidity [%]	68
Maximum wind speed [km/h]	15
Average wind speed [km/h]	9
Weather	Partly cloudy

2.4 FILED N.4 MILAN (MI) – CAMPAIGNS N.5-6

Figure 13-– Milan : Location of the playing field

Figure 14–Milan: location of the high volume sampler

Figure 15–Milan: Personal sampling devices applied to the body of workers

The average temperature recorded by monitoring devices during the first monitoring campaign was 17 °C, during the second 16°C. The following weather conditions were recorded by the nearest meteorological station of Milan Linate during the sampling campaigns.

Table 6 - Data recorded by the meteorological station of Milan Linate (meteo.it)

PARAMETERS	20/10	21/10
Average temperature [°C]	12	11
Minimum temperature [°C]	10	6
Maximum temperature [°C]	17	17
Average humidity [%]	76	77
Maximum wind speed [km/h]	6	4
Average wind speed [km/h]	9	11
Weather	Partly cloudy	Fog

3 ANALYTICAL RESULTS

In each monitoring campaign, the following blanks were collected and analyzed: sampling media blanks (unused, unexposed), field blanks (unused, exposed in monitored site), laboratory blanks (extraction solvent). The analytical values measured in each monitoring samples were corrected by subtracting the corresponding pollutant value of either blank, whichever was the lowest.

The results of blanks analysis– not included in this report- confirmed the good performance of sampling and laboratory activities. The analysis of the blanks also allowed to detect an anomaly in a piece of analytic data presumably connected to a contamination problem of the laboratory extraction system.

The following paragraphs reports the analytical results of inhalation and dermal exposure measurements related to workers involved in installation of the four monitoring fields.

As for PAH concentration, in this summary only the concentration of B(a)P is reported. The concentration of all the PAHs will be made available in the final report.

The results for each type of monitored exposure by type of exposed subjects are reported as:

- Concentrations of B[a]P (ng/m^3) measured on samples collected through the high volume sampler positioned in the vicinity of fields;
- Concentrations of B[a]P (ng/m^3) and respirable dust (mg/m^3) measured on samples collected with personal samplers positioned in the breathing zone of workers;
- Concentrations of B[a] P (ng/cm^2) measured on pads placed on the skin or clothes of workers.

Table 7 shows the concentrations of benzo (a) pyrene in ambient air. These are measured during installation of fields infilled with coated rubber and Geofill in comparison with the target value[8] of 1 ng/m^3.

It is worth stressing that this comparison is not very significant because the target value refers to the total content of benzo(a)pyrene in the PM10 fraction averaged over a calendar year, while the concentrations measured include the amount of pollutant in the particulate and in the gaseous phase averaged over the monitoring time (always shorter than one day). Besides, it should be pointed out that the measured values are comparable with the annual average (Table 8) and monthly average of B[a] P concentrations recorded in

[8] Target value for the concentration of benzo(a)pyrene in the PM10 fraction; "target value" means "*a concentration in the ambient air established with the aim of avoiding, preventing or reducing harmful effects on human health and the environment as a whole, to be attained where possible over a given period*". (Directive 2004/107/EC implemented in Italian Legislative Decree n.155/2010)

the air quality monitoring stations of the Regional Environmental Protection Agency located in the vicinity of the monitored sites.

Table 7 – Comparison of concentrations of benzo (a) pyrene (ng/m³) in ambient air measured during the sampling campaign with Italian regulatory limit

PAHs	Target value	***Sampling in ambient air – Concentrations of B[a]P (ng/m³)***					
		14/07/15 Campaign n.1	10/09/15 Campaign n. 2	11/09/15 Campaign n. 3	29/09/15 Campaign n. 4	20/10/15 Campaign n. 5	21/10/15 Campaign n. 6
		field n. 1 Trecella (MI)	field n. 2 Rome (RM)	field n. 2 Rome (RM)	field n. 3 San Salvo (CH)	field n. 4 Milan (MI)	field n. 4 Milan (MI
		coated rubber infill	coated rubber infill	coated rubber infill	Geofill	coated rubber infill	coated rubber infill
B[a]P	1	<lod	0.15	0.86	0.25	0.21	0.45

LOD :50 pg

Table 8 – Annual average values of benzo(a)pyrene ng/m³) recorded in 2014 in air quality monitoring stations in the vicinity of monitored sites (Istituto Superiore per la Protezione e la Ricerca Ambientale , 2015)

Concentration of benzo(a)pyrene (ng/m³) –annual average values 2014		
Cities	**Station type**	**Concentration(ng/m³)**
Milan	Urban traffic	0.3
	Urban background	0.3
	Urban background	1.5
Bergamo	Urban background	0.4
Rome	Urban traffic	0.8
	Urban traffic	0.4
	Urban traffic	0.6
Pescara	Sub- urban background	0.8
	Urban traffic	0.7
Campobasso	Urban background	0.2

Concerning occupational exposure, since there are no regulatory limits imposed by the Italian legislation (Legislative decree n.81 / 08), limits set by other states or by international agencies (ACGIH, OSHA, NIOSH), are used. In particular, the German legislation sets a limit of 2 µg/m³for B[a]P, as TRK[9], OSHA sets an exposure limit of 0,2 mg/m³ for total PAHs (as benzene soluble fraction), as TLV-TWA[10], ACGIH and NIOSH do not set any numerical limit but recommend that exposure by all routes should be controlled to levels as low as possible.

Table 9 shows the comparison between the levels of inhalation exposure of workers, as concentrations of B[a]P (ng/m³), and the most restrictive reference limit for occupational exposure to PAHs (Germany, TRK). As

[9] *Technische Richtkonzentration:* Technical exposure limit (averaged value over a daily exposure period of 8 hours and a weekly exposure period of 40 hours).
[10] *Threshold Limit Value- Time-Weighted Average:* level to which it is believed a worker can be exposed without adverse health effects with an average exposure based on 8h/day, 40h/week work schedule.

can be noted, all concentrations measured during the monitoring campaigns resulted well within the regulatory limit.

Table 10 shows the levels of dermal exposure of workers. In this case, there are no regulatory limits to compare with the concentrations of PAHs measured on exposure pads.

Regarding the analytical results of respirable dust samplings, as observed in PAHs sampling, no values were found to be in excess of the value recommended by the international agency [11]; the concentrations of respirable dust are indeed well below that limit, as shown in Table 11.

With regard to the Trecella data, it should also be noted that the analyses of blanks revealed a problem of reliability of one analytical result, presumably due to contamination in the laboratory extraction system; this laboratory was not the same used for the analysis of other samples. The data is reported for the sake of completeness, and it is indeed used in the risk assessment, however it is believed that it should be considered as an outlier.

Table 9 –Comparison of concentrations of benzo (a) pyrene (ng/m³) in the breathing zone of workers during the sampling campaign with the most restrictive regulatory limit

TRK Limit value	***Inhalation exposure – Concentrations of B[a]P (ng/m³)***											
	ID campaign	14/07/15 Campaign n.1		10/09/15 Campaign n. 2			11/09/15 Campaign n. 3			29/09/15 Campaign n. 4	20/10/15 Campaign n. 5	21/10/15 Campaign n. 6
	Place	field n. 1 Trecella (MI)		field n. 2 Rome (RM)			field n. 2 Rome (RM)			field n. 3 San Salvo (CH)	field n. 4 Milan (MI)	field n. 4 Milan (MI
	Type of infill	coated rubber infill		coated rubber infill			coated rubber infill			Geofill	coated rubber infill	coated rubber infill
	Worker N°	1	2	1	2	3	1	2	3	1	1	1
2000.00	**B[a]P (ng/m³)**	26.72	22.37	0.09	0.82	0.00	1.18	2.23	4.31	0.05	16.88	0.94

Table 10 – Concentrations of benzo (a) pyrene (ng/m³) on dermal pads applied on workers during the sampling campaign

Dermal exposure – Concentrations of B[a]P (ng/cm²)														
ID campaign	14/07/15 Campaign n.1		10/09/15 Campaign n. 2			11/09/15 Campaign n. 3			29/09/15 Campaign n. 4		20/10/15 Campaign n. 5		21/10/15 Campaign n. 6	
Place	field n. 1 Trecella (MI)		field n. 2 Rome (RM)			field n. 2 Rome (RM)			field n. 3 San Salvo (CH)		field n. 4 Milan (MI)		field n. 4 Milan (MI	
Type of infill	coated rubber infill		coated rubber infill			coated rubber infill			Geofill		coated rubber infill		coated rubber infill	
Worker N°	1	2	1	2	3	1	2	3	1	2	1	2	1	2
B[a]P (ng/cm²)	0.00	0.00	0.00	0.01	0.00	0.19	0.08	0.02	0.02	0.02	0.00	0.00	0.12	0.03

[11] *ACGIH: recommended value for Particulates Not Otherwise Regulated (Respirable Fraction)*

Table 11 – Comparison of concentrations of respirable dust (mg/m³) in the breathing zone of workers during the sampling campaign with the most restrictive regulatory limit

ACGIH limit value	***Inhalation exposure – Concentrations of respirable dust (mg/m³)***							
	ID campaign	14/07/15 Campaign n.1		10/09/15 Campaign n. 2	11/09/15 Campaign n. 3	29/09/15 Campaign n. 4	20/10/15 Campaign n. 5	21/10/15 Campaign n. 6
	Place	field n. 1 Trecella (MI)		field n. 2 Rome (RM)	field n. 2 Rome (RM)	field n. 3 San Salvo (CH)	field n. 4 Milan (MI)	field n. 4 Milan (MI
	Type of infill	coated rubber infill		coated rubber infill	coated rubber infill	Geofill	coated rubber infill	coated rubber infill
	Worker N°	1	2	4	4	1	2	2
3.00	**Respirable dust (mg/m³)**	0.28	0.25	0.03	0.02	0.03	1.28	1.43

4 RISK ASSESSMENT ASSOCIATED TO EXPOSURE TO PAHS

4.1 EQUATIONS FOR THE CALCULATION OF CARCINOGENIC INCREMENTAL RISK

The incremental carcinogenic risk was calculated as the sum of the inhalation and dermal risk. In this study, the incremental carcinogenic risk associated to accidental ingestion of material contaminated by PAHs has been considered not relevant.

The following equation has been used for the calculation of carcinogenic risk:

1) Incremental risk associated to inhalation exposure R_I, for each substance:

$$R_I = SF_I \frac{(C_p+C_v)\times I_R \times HE \times EF \times ED}{BW \times AT \times 365\ days/year} \quad [1]$$

- Ri = incremental risk associated to inhalation of substance;
- SF_I = inhalation slope factor[1/(mg/kg-day)];
- C_p + C_v=concentration of substance in air, as the sum of substance adsorbed to particulate (C_p) and in gaseous state (C_v)[mg/m^3];
- I_R (Inhalation Rate) = inhalation rate [m^3/h];
- HE (Exposure duration in Hours): Duration of exposure events [h];
- EF (Exposure Frequency) = Frequency of Exposure Events per year [days/yr];
- ED (Exposure Duration] = exposure duration in years [yr];
- BW (Body weight) [Kg];
- AT (Average Time) = average life expectancy [yr];

2) Incremental risk associated to dermal exposure R_d, for each substance:

$$R_D = SF_d \frac{C_{pad} \times HE \times BF \times S \times EF \times ED}{ET \times BW \times AT \times 365\ days/year} \quad [2]$$

- Rd = incremental risk associated to dermal contact with the substance;
- SF_d = Dermal Slope Factor [1/(mg/kg-day]: calculated as Sfo (oral slope factor)/ABSgi (gastrointestinal absorption factor: an estimate of the rate at which the substance is absorbed from the gastrointestinal tract of a human= 1 for monitored PAHs);
- C_{pad} =concentration of substance on exposure pad (mg/cm^2);
- S = exposed body surface during the event [cm^2];
- BF [bioaccumulation factor] = dermal adsorpition coefficient [%];
- ET [Exposure Time] = duration of exposure of pad [h];
- HE (Exposure duration in Hours): Duration of exposure events [h];
- EF (Exposure Frequency) = Frequency of Exposure Events per year [days/yr];
- ED (Exposure Duration] = exposure duration in years [yr];

- BW (Body weight) [Kg];
- AT (Average Time) = average life expectancy [yr];

Incremental cancer risk for PAHs has been calculated as:

$$\sum_{IPA=1}^{N} R_i + R_D \qquad [3]$$

The physiological parameters for the calculation of human exposure were acquired through various literature sources, or through personal communication received from the monitored workers.

In particular the following data were acquired through interviews: body weight, height, age, number of cigarettes/day for smokers (data concerning age and cigarettes were not used in the risk assessment). For other physiological data, the following references have been adopted:

- **Inhalation Rate (I_R):** based on the assumed intensity of the activity performed, the following inhalation volumes (ECETOC Exposure factors (table 41) (2001)) were adopted: 1.5 m^3/h (moderate activity level-outdoor workers),
- **Life expectancy (AT):** a 75 year life expectancy was assumed, as proposed in table 22 for Italy in ECETOC (2001);
- **Duration of Exposure Events (HE):** for workers, a 6 hours duration of each exposure event based on personal communication received from the operators, has been adopted.
- **Frequency of Exposure Events (EF):** 120 worker days per year (conservatively assuming that workers are engaged in infill operations 10 days per month);
- **Average of exposure duration, years (ED):** 30 years (personal communication);
- **Dermal Adsorbtion Coefficient (BF):** The analysis of available scientific literature related to PAH adsorption provided adsorption coefficient values in the range of 0.3% to 1.4% (VanRooij JG, Absorption of polycyclic aromatic hydrocarbons through human skin: differences between anatomical sites and individuals., 1993) for pyrene and in the range 0.15% to 1.1% for benzo(a)pyrene (Stroo HF, Dermal bioavailability of benzo[a]pyrene on lampblack: implications for risk assessment., 2005). Based on these data, an average BF value of 1% was adopted for all the PAHs. It has to be noted that the result of the experimental determination of BF conducted until now by the Mario Negri institute in connection with this study provided BF values of 2 orders of magnitude lower.
- **Exposed body surface (S):** the exposed body surface for workers is m^2 0.38. The surface area has been designed calculating the total body surface by equation [4] and parameters provided by Table 12 (United States Environmental Protection Agency, USEPA, 1985). With this value, the skin surface area for each body part have been summed using equation [5]; calculated as rate of total surface area (Table 13) and parameters in (United States Environmental Protection Agency, USEPA, 2011)).

$$S_{TOT} = a_0 \times h^{a_1} \times BW^{a_2} \quad [4]$$

$$S_{exp} = S_{head} + S_{arms} + S_{hands} \qquad [5]$$

Table 12: Total body surface calculated using weight and height data of workers

	BW	h	a_0	a_1	a_2	S_{tot} (m^2)
workers	82	174	0.0239	0.417	0.517	2.005

Table 13: Exposed body surface calculated using total body surface

Body part	Total body surface [%]	surface (m^2)
head	6.60	0.1324
forearms	7.18	0.1441
hands	5.19	0.1042
Lower legs	13.01	0.2517
feet	6.65	0.1287
Total exposed surface area (m^2)	-	**0.3806**

4.2 RESULTS FOR THE INCREMENTAL CARCINOGENIC RISK ASSESSMENT

The following tables report the results of the carcinogenic risk assessment broken down as follows: the values concerning workers operating with coated crumb rubber infill and geofill are shown in Table 14 (risk calculated including Trecella data) and Table 15 (risk calculated excluding Trecella data).

Table 14 –Comparison of incremental risk for workers operating with coated crumb rubber and no rubber infills (Trecella data included)

PAHs	Inhalation exposure		Dermal exposure		Total incremental risk	
	Rubber infill	Geofill	Rubber infill	Geofill	Rubber infill	Geofill
Benzo[a]Pyrene	$4.2x10^{-7}$	$2.8x10^{-9}$	$3.4x10^{-8}$	$1.8x10^{-8}$	$4.6x10^{-7}$	$2.0x10^{-8}$
∑ PAHs	**$6.5x10^{-7}$**	**$1.4x10^{-7}$**	**$6.0x10^{-8}$**	**$2.7x10^{-8}$**	**$7.1x10^{-7}$**	**$1.7x10^{-7}$**

Table 15 – Comparison of incremental risk for workers operating with coated crumb rubber and no rubber infills (Trecella data not included)

PAHs	Inhalation exposure		Dermal exposure		Total incremental risk	
	Rubber infill	Geofill	Rubber infill	Geofill	Rubber infill	Rubber infill
Benzo[a]Pyrene	$1.9x10^{-7}$	$2.8x10^{-9}$	$4.0x10^{-8}$	$1.8x10^{-8}$	$2.3x10^{-7}$	$2.0x10^{-8}$
∑ PAHs	**$4.6x10^{-7}$**	**$1.4x10^{-7}$**	**$7.2x10^{-8}$**	**$2.7x10^{-8}$**	**$5.3x10^{-7}$**	**$1.7x10^{-7}$**

Based on these data, the following can be highlighted:

1) Overall, the analysis of the risk associated to the installation operations of artificial turf playing fields (with or without crumb rubber) allows to exclude any concern, as the incremental carcinogenic risk resulted always significantly lower than the risk recommended for the general population ($1x10^{--6}$()[12]).

2) Dermal exposure. For both type of infill, the risk associated with dermal exposure was extremely low - at least one order of magnitude lower than the recommended value. Furthermore, it was always lower than

12 *"Cancer risk levels of 10-5 and 10-6 could be seen as indicative tolerable risks levels when setting DMELs for workers and the general population, respectively."* ECHA (European Chemicals Agency (ECHA), 2012)

the risk associated to inhalation exposure. This kind of risk was lower for workers exposed to geofill than for those exposed to coated rubber infill.

3) Inhalation exposure. Also for inhalation exposure, the incremental risk for workers resulted lower than the recommended value by one order of magnitude, even though it was higher than the risk associated to dermal exposure. Also in this case, the risk associated to the infill of vegetal origin (Geofill) was lower than the risk associated to the coated crumb rubber infill.

4) Data and inter-laboratory comparison. To date, data for only one non-rubber field (San Salvo site) are available. Furthermore, regarding this monitored field, data for only one operator were available, therefore the comparison of the exposure data for the two types of infill (with/without rubber) is of limited significance.

5) It should be noted that the samples collected at Trecella field, characterized by higher values of PAHs, were analyzed by a different laboratory than the one used for other monitoring campaign. The results obtained by this laboratory could be abnormal, since the media blanks (unexposed) of XAD-2 vials (in closed glass vials which cannot be accidentally contaminated) were characterized by high values of B[a]P, showing a possible contamination problem in the laboratory extraction system. Even though these data do not significantly change the overall risk estimate, particularly in comparison with the recommended value, it would be advisable to consider these data as “outliers” for both statistical and substantial reasons.

6) For both type of infill, it should be pointed out that, to date, it is not possible to determine to what extent the observed exposure levels are related to the investigated material (coated crumb granulate or Geofill) or to external factors such as the variability of micro-meteorological conditions, the differences in the operating mode of the workers and the background concentrations in ambient air in the monitoring area. In this regard, it is interesting to note that the concentrations measured in ambient air at playing fields are consistent with the air quality data of urban centers close to the monitored sites, as it is well documented by similar studies in this field.

7) In any case, it is important to highlight that, although the exposures observed also include the background exposure, in all the considered scenarios the risk analysis indicates values substantially lower than those recommended for the general population (1×10^{-6}).

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