

**Submission  
No 114**

**INQUIRY INTO PLANNING SYSTEM AND THE IMPACTS  
OF CLIMATE CHANGE ON THE ENVIRONMENT AND  
COMMUNITIES**

**Name:** Dr Greta Werner  
**Date Received:** 3 November 2023

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**Clr Dr Greta Werner**  
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Ms Sue Higginson MLC  
Chair, Planning System Inquiry  
Via Parliamentary Inquiry Portal

Dear Ms Higginson,

**Re: Parliamentary Inquiry into the Planning system and the impacts of climate change on the environment and communities**

Thank you for the opportunity to provide a submission to this Inquiry

I have lived in the beautiful suburb of Banksia since 2008 and was elected to Bayside Council in 2021. I was elected partly due to my advocacy for better protection for our urban bush, parks, green and blue natural areas, and growing community understanding of the natural values of these areas.

While I am making this submission on behalf of myself, not Bayside Council, I have been approached by members of the community on planning issues as part of my role as Councillor and am thus often alerted to community concerns in relation to planning. My work as research associate in urban and regional planning at The University of Sydney also gives me a background in theoretical aspects of planning issues.

The following relates to sections a and b of the terms of reference:

(a) developments proposed or approved (iii) in areas that are threatened ecological communities or habitat for threatened species

(b) the adequacy of planning powers and planning bodies, particularly for local councils, to review, amend or revoke development approvals, and consider the costs, that are identified as placing people or the environment at risk as a consequence of:

- (i) the cumulative impacts of development,
- (ii) climate change and natural disasters,
- (iii) biodiversity loss, and
- (i) rapidly changing social, economic and environmental circumstances

The following are examples of developments that have been approved, despite having terrible impacts on endangered ecological communities, and despite there existing alternatives that would have provided similar benefits to the community:

## **1. Hawthorne Street Natural Area**

Bayside Council is redeveloping a sports facility upgrade in the Hawthorne Street Natural Area (plans are on council's website [here](#)). This area contains three Endangered Ecological Communities (EECs), one of which is protected under the NSW Biodiversity Conservation Act and is the most bio-diverse area in the whole of western Botany Bay according to Dr Arthur White, a local herpetologist.

Rather than building the new facility where the old tennis courts were, Bayside Council could have moved the facility further North and let the site of the old courts return to their previous state as Kurnell Dune Forest.

One of these EECs (Kurnell Dune Forest) was partly cleared when the old courts were constructed. Such an action would be illegal today because of the environmental protection given to EECs by the State's Biodiversity Conservation Act 2016.

The EEC classification remains despite the presence of the old courts in that they are capable of natural regeneration when the impact is removed.

I have visited the old courts, and I have seen small saplings and shrubs pushing up through the broken concrete of the base of the old courts. The site could clearly have regenerated itself.

Unfortunately, there is the additional issue of lighting. It will be more difficult for an operator to run the sports facility as a viable business without lighting to extend the time the courts are usable in winter. Council's current plans include infrastructure for lighting, but the effect of floodlighting would pose an unacceptable risk to birds and other local fauna.

Council commissioned a review of environmental factors and a construction environmental management plan, but rather than protecting the endangered ecological communities, the plans have facilitated the development and put these incredible remnants of Kurnell Dune Forest at further risk.

## **2. Barton Park**

Bayside Council has nearly finished redevelopment of a sports facility at Barton Park, a Ramsar listed natural area. This work was conducted under Part 5 of the planning act. After approval, local bird watchers noticed that the number of birds there has dramatically decreased since development started. Unfortunately, it seems that much of the clearing was conducted during nesting season and many nests, probably with eggs in them, may have been destroyed.

There were also several issues with the planning approval process. Please see the included 'Notes for Greta Werner' in Appendix 1 which were prepared for me in my capacity as Councillor by The Greens Planning and Environment Law Officer.

## **3. Synthetic Fields at Arncliffe, Gardiner, Bicentennial and Ador Parks**

These synthetic soccer fields were paid for by grants from the NSW state government under the Priority Precincts program, or by Transport for NSW as part of the M6 development. The fields at Arncliffe and Gardiner parks were not recommended by Council's consultant because they are in flood ways and there is a risk the crumbed rubber infill and microplastics from broken blades of plastic grass would migrate from the fields during heavy rain and flood events and make their way into Botany Bay.

Many residents objected to the development at Gardiner Park as it is a Heritage listed park, and installation would destroy the character of the park, give the impression it is only for use by a soccer

club rather than the whole community, and because of the environmental and health impacts associated with heat and chemicals in the synthetic field. Please see Appendix 2 for a study on synthetic fields.

The European Chemical Agency states:

*"The granules and mulches may contain potentially harmful chemicals including polycyclic aromatic hydrocarbons (PAHs), metals and phthalates. They may also release volatile and semi-volatile organic hydrocarbons (VOCs and SVOCs). The granules also contribute to microplastic pollution as they can be spread to the environment from the pitches, for example, through rainwater or players' footwear and clothing" (ECHA 2021, available at <https://echa.europa.eu/hot-topics/granules-mulches-on-pitches-playgrounds>).*

The rubber and plastic granules used on sports pitches are microplastics. Each year around 42 000 tonnes of microplastics end up in the environment when products containing them are used. Granular infill is a large source of pollution with estimated releases of up to 16 000 tonnes per year (ECHA 2021, available at <https://echa.europa.eu/hot-topics/granules-mulches-on-pitches-playgrounds>)

The focus in many articles is on PAH but the impact of most other toxic particles hasn't even been tested. EU has a ban in place for rubber crumb containing PAH over certain limits.

### **Conclusion**

Our significant natural areas are too precious to risk these kinds of development. Protecting our natural areas is worth the extra time and money it would take to consider other options. Risks to health from heat islands and microplastics created by synthetic fields are not worth it, given we have the alternative of natural grass. All developments in or near our wetlands and EECs, especially Ramsar listed ones, should be given much more oversight and protection than they currently are.

Sincerely,

Clr Dr Greta Werner

Councillor, Bayside Council  
Research Associate, Urban and Regional Planning



Figure 1 – Aerial view of Hawthorne Reserve, Ramsgate NSW

## Background

1. These observations regard the REF and determination (Independent Review) of the Barton Park Precinct.
2. The REF is dated 23 August 2021 and is authored by Eco Logical Australia on behalf of Bayside Council.
3. An independent peer review of the REF (IPR) by 'The Planning Studio' dated 28 February 2022, was conducted. It states (page 5):

*"...and a REF was prepared by Ecological Australia on behalf of Council. However, in order to avoid the perception of any conflict, Council have commissioned an independent review of the REF and supporting reports."*

4. Bayside Council has stated by email that the Director of City Futures, Peter Barber, signing of the IPR was the act of determining the Part 5 activity via approval (see email to great Werner from Peter Barber dated 29 November 2022). The IPR then is Councils statement of authorisation and can be taken as the basis on which Council has conducted itself.

## Regulatory framework

5. The subject land is described by the IPR as being Lot 100 in DP1228008 (Cron land managed by the Council) and Lot 1 in DP576148 (owned by Council).  
The access road is Lot 100 in DP1133869, owned by the Department of Planning, Industry and Environment (DPIE).

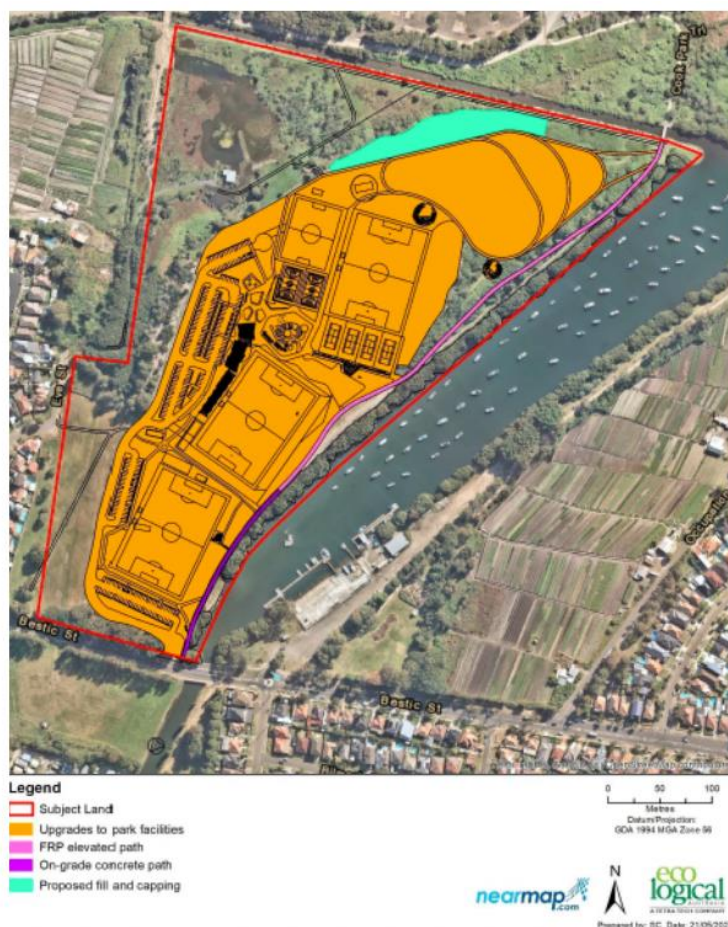


Figure 2: Locality Plan and scope of works (Ecological)

6. The IPR states the following with regard to the approval pathway:

### 1.3 ENVIRONMENTAL ASSESSMENT AND APPROVALS PROCESS

In determining the appropriate approvals process, the proposed works identified within the overall Masterplan were considered against the 'exempt' and 'development without consent' provisions of State Environmental Planning Policy (Infrastructure) 2007 (I-SEPP) and Sydney Regional Environmental Plan 22 (SREP 33).

It was determined that the works, as proposed, met the exempt and development without consent provisions, with the exception of:

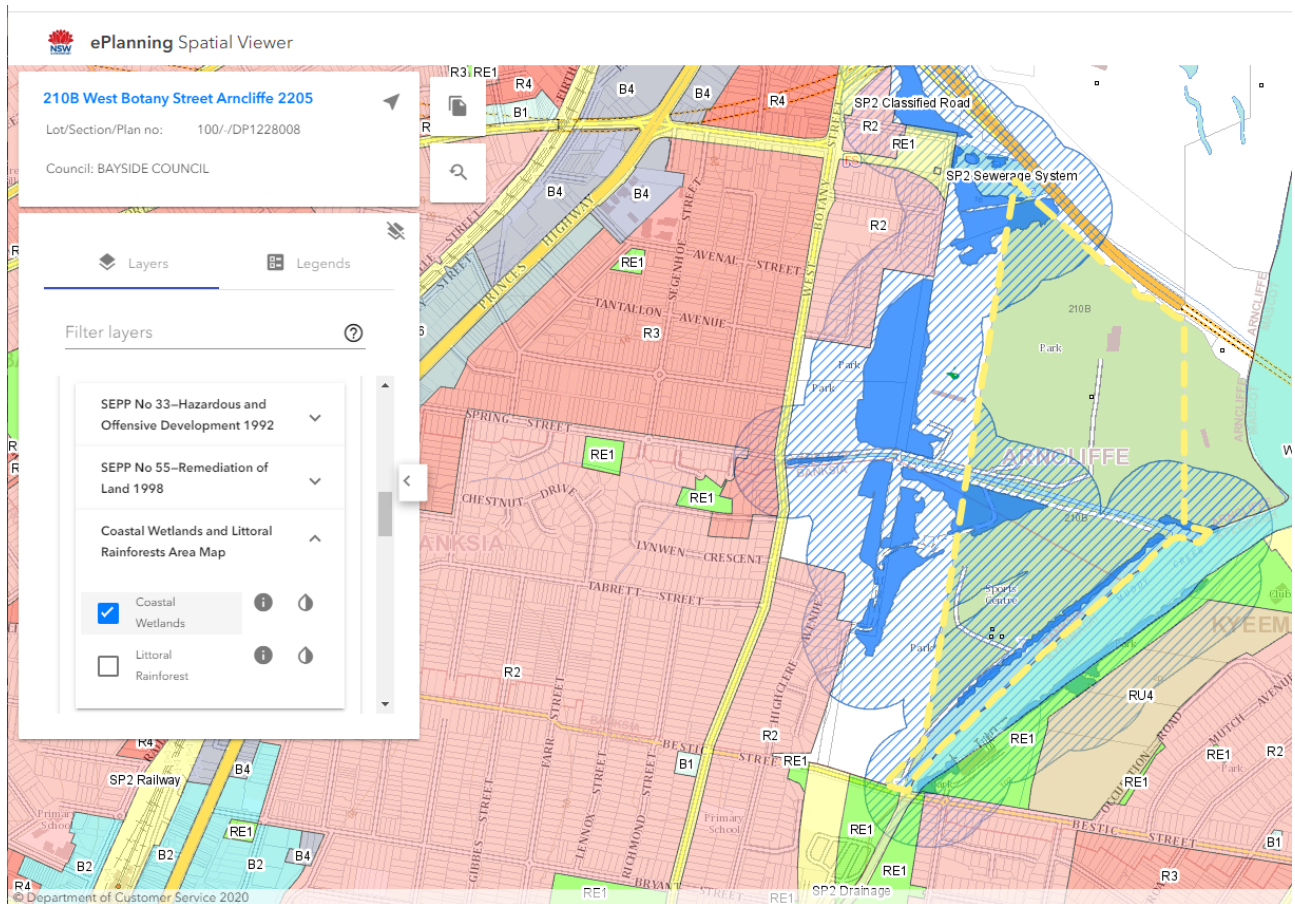
- Any proposed works located on land mapped as 'coastal wetland', under State Environmental Planning Policy (Coastal Management) 2019 (Coastal Management SEPP); and
- The construction of the grandstand, as it was deemed to have more than 'minimal visual impact'.

7. Accompanying the above statement is a map (below) depicting hatched areas as coastal wetlands. The proposed work is closely fitted around the hatch area presumably to avoid having to obtain a full development consent (as opposed to a Part 5 self approval).



**Figure 1:** Proposed works mapped against hatched 'coastal wetland' area (Mode Design)

8. The map below shows the much wider area of hatched Proximity Area for Coastal Wetlands, as well as the deeper blue of actual mapped wetlands.
9. The SEPP (Hazards and Resilience) 2021 requires development consent for work in the deeper blue areas, and for the hatched area for approving authority (without development consent) to be satisfied the activity will not significantly impact on the the *biophysical, hydrological or ecological integrity of the adjacent coastal wetland* (Clause 2.8) or that the activity has *considered whether the proposed development is likely to cause an adverse impact on ... the integrity and resilience of the biophysical, hydrological (surface and groundwater) and ecological environment* (Clause 2.10 (1)(a)).
10. I am concerned about the following statements which identify the significant contamination of the site as a former unregulated landfill site, which is currently and constantly leaching into the waterways.



## 11. From the Remediation Action Plan

Concentrations of heavy metals exceeded the Site Assessment Criteria (SAC) for recreational/open-space land use in some samples of cover soils. The potential for the presence of Asbestos Containing Materials (ACM) in cover soil and waste is also acknowledged. Additionally, exceedances of the nominated SAC occurred in samples of buried waste material. Under a scenario of ongoing recreational/open-space land use, management measures are required with respect to the potential risk to users of the site from contact with exposed cover soils (concentrations exceeding the SAC) and, potentially, exposed waste materials in the event that cover soils are eroded.

Groundwater at the site is unconfined, occurring within the waste mass and underlying alluvium. Groundwater is impacted with constituents derived from anoxic and anaerobic waste degradation (primarily ammonia) and is hydraulically connected to the surrounding surface-water bodies resources, namely: Spring Street Wetland; Spring Street Drain/Canal; Cooks River; Muddy Creek and the Landing Lights/Riverine Park Wetlands. The estimated quantity of impacted groundwater (and therefore contaminant loading) discharging to surface-water bodies is small relative to the volume of the diurnal tidal prism. Furthermore, the receiving waterways are substantially degraded as a result of urban runoff and organic-rich bed sediments, particularly in the wetlands, and are also likely to constitute a source of ammonia at low tide. On these bases, the risks arising from ammonia-impacted groundwater to baseflows in surface-water bodies are considered to be low. The likelihood of potential human contact with impacted groundwater is low due to the configuration of the discharge zone to receiving surface-water resources. Any management measures implemented to address ammonia impacts on surface-water systems must consider potential impacts on landfill-gas production and migration as well as loading of the waste mass. Measures should be implemented to minimise leachate generation by improving drainage and reducing infiltration.



12. The REF (p.24 cites Fisheries as providing feedback raising concerns with contaminants:

*Contaminants of Potential Concern are present within the works footprint. If the Long-Term Site Management Plan or Remediation Action Plan require harm (direct or indirect) to adjacent mangroves, then a Part 7 section 205 Permit form DPI Fisheries will be required.*

13. Page 36 of the REF states ... *Fill in the perimeter mounds variously contain elevated concentrations of lead, Polycyclic Aromatic Hydrocarbons (PAHs) and asbestos predominantly in the form of fragments of fibrous sheet or bituminous membrane. Petroleum-hydrocarbon impacted fill was identified at depth at one location (TP120, Figure 6-4), the extent of which has not been determined.*

14. Page – 43 ... *Leachate from the old landfill impacts the groundwater of the site and produces ammonia (Edison Environmental, 2021; Appendix E).*

15. In my opinion the REF 2021, The Independent Peer Review 2022, the Remediation Action Plan (Edison 2021), the Preliminary Geotechnical Investigation Report (Edison 2020) and the Long Term Site Management Plan (Edison 2020) have:

- i) NOT answered the requirements of SEPP (Hazards & Resilience) 2021 regarding groundwater for the construction period.
- ii) HAVE answered the requirements of SEPP (Hazards & Resilience) 2021 regarding groundwater for the finished project.

16. Given that the issue is complex and the project is well underway I don't think there is utility in challenging the project as a whole. I do think it is worth posing the following questions to Council:

- Given that Council has given the greenlight to a project that it says will have no significant impact on the *hydrological or ecological integrity of the adjacent coastal wetland*, the project has a list of mitigation measures that are required by a) the REF and b) the Peer review (which added a list of additional mitigation measures).
- Recognising there have been complaints from the public that works have occurred in the wetlands area in breach of the project approval - Has Council compiled a single summary of all of the mitigation measures required of the project by combining those listed in the REF and those additional measures added by the Peer Review, into a single document that is available to the public?
- Given the site is heavily contaminated and poses a significant risk for surrounding waterways has Council conducted monitoring of actual performance against compliance with the mitigation measures? Has is required the lead contractor to engage in monitoring actual performance against the mitigation measures?
- Given the site is heavily contaminated (as documented thoroughly by the technical studies commissioned by Council) and is currently leaching in to the surrounding waterways why was consideration not given to remediating the whole site instead of just the 'perimeter mounds' which surround the former St George football ground?
- Has the Council implemented the program of ongoing environmental monitoring required by the Long Term Site Management Plan (2020)? If Council has implemented this can a copy of the monitoring results be made available on Council webpage *Upgrading Barton Park*?

# Release of Polycyclic Aromatic Hydrocarbons and Heavy Metals from Rubber Crumb in Synthetic Turf Fields: Preliminary Hazard Assessment for Athletes

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## Abstract

Synthetic turf, made with an infill of rubber crumb from used tyres or virgin rubber, is now common in many sporting facilities. It is known that it contains compounds such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals. We evaluated in nine samples of rubber crumb the total content of some heavy metals (Zn, Cd, Pb, Cu, Cr, Ni, Fe) normally found in tyres by microwave mineralization and the levels of the 14 US EPA priority PAHs by Soxhlet extraction and HPLC analysis. The results showed high levels of PAHs and zinc in all rubber crumb samples compared to rubber granulate limits set by Italian National Amateur League (LND).

Following the precautionary principle, a risk assessment at 25°C was done, using the Average Daily Dose (ADD) assumed by athletes, expressed in terms of mass of contaminant per unit of body weight per day (mg/kg day), and the Lifetime Average Daily Dose (LADD) and then evaluating the Hazard Index (HI) and the Cumulative Excess Cancer Risk ( $\Sigma$ ECR). In the different rubber granulates samples the HI ranges from a minimum of  $8.94 \times 10^{-7}$  to a maximum of  $1.16 \times 10^{-6}$ , while the  $\Sigma$ ECR ranges from a minimum of  $4.91 \times 10^{-9}$  to a maximum of  $1.10 \times 10^{-8}$ .

Finally, the aim of this study was to estimate the "hazard" for athletes inhaling PAHs released at the high temperatures this synthetic turf may reach. Then a sequence of proofs was carried out at 60°C, a temperature that this rubber crumb can easily reach in sporting installations, to see whether PAH release occurs. The toxicity equivalent (TEQ) of evaporates from rubber crumb is not negligible and represents a major contribution to the total daily intake of PAHs by different routes.

**Keywords:** Synthetic turf; PAHs; Rubber crumb; Heavy metals; Hazard assessment

**Abbreviations:** ADD: Average Daily Dose; AT: Averaging Time; B[a]A: Benzo(a)anthracene; B[a]P: Benzo(a)pyrene; B[b]F: Benzo(b)fluoranthene; B[ghi]Per: Benzo(g,h,i)perylene; BaP<sub>eq</sub>: Benzo(a)pyrene equivalents; CDC: Centers for Disease Control and Prevention; C<sub>A</sub>: Concentration in Air; C<sub>F</sub>: Concentration in Field; Chry: Chrysene; DIN: Deutsches Institut für Normung / German Institute for Standardization; ECR: Excess Cancer Risk;  $\Sigma$ ECR: Cumulative Excess Cancer Risk; ED: Exposure Duration; EF: Exposure Frequency; EF<sub>do</sub>: Daily Exposure Frequency; EPA: Environmental Protection Agency; Fl: Fluorene; Flt: Fluoranthene; HI: Hazard Index; HQ: Hazard Quotient; IA: Interested Area; IR: Inhalation Rate; LADD: Lifetime Average Daily Dose; PAH: Polycyclic Aromatic Hydrocarbons; PEF: Particulate Emission Factor; Pyr: Pyrene; R<sub>D</sub>: Reference Dose; SBRr: Styrene:Butadiene Recycled rubber; SF: Slope Factor; TEF: Toxic Equivalency Factors; TEQ: Toxic Equivalent Quantity.

## Introduction

World population increase is accompanied by increasing consumption of resources. This makes recycling of materials extremely important to reduce waste. However, recycling itself is not enough, because it is necessary to understand if recycled materials have adverse effects on humans and environment, such as the case of used tyres, loaded of potentially toxic substances and recycled in synthetic turf. Today, synthetic turf is common in many sporting facilities. Created in the 1950s by the humanitarian Ford Foundation of New York and Chemstrand Corporation, it gained huge success in 1966 when used in the Astrodome stadium, Houston, Texas [1]. In the '70s and '80s, it was applied in many sports grounds in America and Canada, and was introduced into Europe in the mid-1980s. Softer new types of synthetic turf containing polyethylene were developed and introduced all over the world in the late 1990s [2]. Synthetic turfs differ in relation to their method of production and infill technique. Normally, the

layer of infill consists of rubber crumb, which in a typical application reaches a thickness of 3 cm, and is spread on a thin layer of sand [3]. The most common source of rubber crumb is recycled tyres (recycled styrene-butadiene rubber - SBRr); the diameter of the crumb can vary between 0.5 and 3 mm [4]. Hazardous substances in crumb rubber infill are primarily, volatile components (nitrosamines, xylenes), benzothiazoles, secondary amines, heavy metals (especially zinc) and polycyclic aromatic hydrocarbons (PAHs) [5]. In particular, the presence of zinc (Zn) is due to zinc oxide that is used as a vulcanization aid in the rubber production process and PAHs come from high-aromatic oil that is used as an additive in the production of tyres. In 2005, the Italian Ministry for the Environment allowed SBR crumb for synthetic grass courts in Italy [6], but there are still no European Union guidelines defining measures to protect the environment and human health in relation to SBRr in synthetic turf. The only standard to which manufacturers refer in producing SBRr crumb was published in 2002 by the German Institute for Standardization (DIN) establishing limits for certain heavy metals in soil, but with no reference to PAHs [7]. This standard was also chosen by the Italian National Amateur League (LND) in its "Regulations for the construction of latest generation artificial turf football fields", which defines soccer field parameters necessary for approval and use. Besides purely technical qualities, it

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also includes concentration limits for certain substances, including heavy metals and some high molecular weight PAHs (limits reflect those provided by Legislative Decree 152/2006 [8,9]). Sport grounds fitted with synthetic turf filled with crumb of recycled tyres may release dangerous particles in air, contaminate soil and groundwater with soluble contaminants leached by rain, and pose health hazards for residents and users due to inhalation of volatile substances [10]. Some coats for rubber granulates can effectively reduce emissions in the environment of these contaminants but they are not systematically used [11].

Though designed for sporting facilities, it is not uncommon to find synthetic grass in recreational parks and children's playgrounds. Synthetic turf may reach high temperatures: for example, on a day with an air temperature of 26°C in the early afternoon, synthetic surfaces may reach 60°C, making it difficult to play on them [2]. The U.S. Center for Disease Control and Prevention (CDC) has not yet assessed the risks associated with exposure to dust released by rubber crumb from playing fields. As a precautionary measure, it issued general recommendations for users to minimize any potential risk, such as wash aggressively hand and body after playing, do not eat and drink on the field and do not use clothes and shoes after the activity for normal life [12]. Some studies have focused on levels of heavy metals, such as Zn, or PAHs in tyre rubber, both in granulates and in leachate [3,13-15] evaluating also the ecotoxicological effects in different organisms and humans [14,16-19]. In response to concern about human exposure through direct contact or inhalation, the principal aims of this study were: 1) to quantify the PAHs and heavy metals contained in rubber crumb from recycled tyres, produced before 2010 [20], used in synthetic turf, to determine whether PAHs are released and at what concentrations, becoming bioavailable to synthetic turf users at high temperatures; 2) to estimate respiratory uptake by athletes training on these grounds.

## Materials and Methods

### Sample collection

Samples of nine different synthetic turfs from football fields in Tuscany and Lazio (Italy) were analyzed. Samples 1 to 5 were new and had not yet been spread on playing fields yet; samples 6 to 9 were obtained from fields that had been laid down for 1 to 8 years. The crumb of sample 5 was virgin rubber and not recycled tyres (Table 1). In the laboratory, the samples were kept at room temperature, in black bags, away from sunlight.

### Heavy metals analysis

The samples were mineralized in a microwave oven (EPA Method 3052 modified in the Lab. (Bianchi, p.c.)). About 0.3 g of rubber crumb sample was placed in Teflon containers, spiked with 8 mL nitric acid (HNO<sub>3</sub>) and 2 mL hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), then transferred to a microwave oven. The solutions thus obtained were cooled to a final volume of 50 mL and concentrations of lead (Pb), copper (Cu), nickel (Ni), zinc (Zn), chromium (Cr), cadmium (Cd) and iron (Fe) were evaluated. A blank was included in each series to check the purity of reagents and two tests of reference materials (ERM-EC680k and NIST-SRM2710) with concentrations certified by the Community Bureau of Reference were performed to check analytical accuracy. Cr, Cu, Ni, Pb and Cd concentrations were determined with PerkinElmer AAnalyst700 high-performance atomic absorption spectrometers with graphite furnace. Zn and Fe concentrations were determined with an Analytik Jena ContrAA700 acetylene flame atomic absorption

spectrophotometer. All metal concentrations were expressed as the mean of three replicates in µg/g on a dry weight basis.

### PAH analysis

**PAH extraction in rubber crumb:** PAHs were extracted according to Griest and Caton [21,22] and Holoubek et al [22], with some modifications [23]. About 1.0 g of rubber crumb was extracted with a mixture of KOH 2M/methanol (1:4) in a Soxhlet apparatus for 4 h at 75°C. The mixture was extracted by shaking in separator funnels with 200 mL of cyclohexane. Liquid/liquid separation was performed to bring the PAH fraction into the supernatant. The liquid recovered was concentrated in a Rotavapor system, resuspended with 10 mL acetone/hexane (1:1) and purified in a chromatographic column packed with 3 cm of Florisil, about 60–100 US mesh, previously set at 120°C for 2 h. Elution was carried out with 90 mL acetone/hexane (1:1). The organic fraction was concentrated and suspended in 0.5 mL acetonitrile for HPLC analysis.

**PAH Extraction in evaporates of rubber crumb:** Since synthetic fields can reach 60°C when the air temperature is about 25°C, a method to evaluate release of PAHs at this temperature was used. Small flasks (25 mL) were filled with a quantity of rubber crumb up to 3 cm high, in order to simulate their thickness in a synthetic field. Then, the following steps were applied: 1) a closed trap packed with a bottom layer of cotton/fiberglass and a 3 cm layer of Florisil, previously activated at 120°C for 2 h, was placed on every flask; 2) the flask/trap system was kept at 60°C for about 5 h (assumed to be the average period at 25°C in a day) to capture the evaporates of rubber crumb; 3) liquid chromatography was then immediately performed using the trap as a column by pouring in 10 mL acetone/hexane (1:1) and then a further 90 mL of the same mixture; 4) the extract thus obtained was concentrated in a Rotavapor system and resuspended in 0.5 mL acetonitrile for HPLC analysis. This procedure (steps 1-4) was repeated three times to obtain three consecutive readings for each sample, thus determining whether or not the release of PAHs was continuous. The efficiency of the traps was validated with two different evaporation tests: first evaporation of the standard EPA 610 in acetonitrile (1/100) and, second evaporation, with the same amount of EPA 610 (1/100) mixed with a rubber crumb sample 3 cm high. HPLC analysis showed that the efficiency of the traps was about the 90%. In fact, in the first case, summing the amount of PAHs found in the evaporated to those found in the sample left in the flask, the value was almost like to the original amount of the standard EPA 610. In the other case of the standard mixed with the rubber crumb, there was a little matrix effect because the amount of PAHs found in the evaporated was lower (5-10%) than those found in the evaporated of the standard alone.

**PAH analysis:** PAHs were analyzed by an HPLC/fluorescence system. PAHs were separated using a reversed-phase column (Supelcosil LC-18, 25 cm × 4.6 mm i.d., 0.5 µm particle size, pore size 120Å) with an acetonitrile/water gradient from 60% to 100% acetonitrile for 20 min, then isocratically for 10 min. The flow rate was 1.5 mL/min. The mobile-phase was degassed with a helium stream. An external standard consisting of 16 PAHs from Supelco (EPA 610) was used. Fourteen PAHs were analyzed and the results expressed in ng/g. Recoveries were 80–98%. The detection limit, calculated at a signal-to-noise ratio of three, was 0.1 ng/g for all PAHs. Assay reproducibility was determined by five replicate analyses of a single sample: the coefficient of variation was 1-3%, depending on the compound. Blanks contained undetectable amounts of PAHs.

Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
Years since installation	0	0	0	0	0	8	2	6	1

Table 1: Years of installation in sporting infrastructure of the rubber crumb samples analysed.

## Results and Discussion

### Heavy metal concentrations in rubber crumb

Table 2 shows the concentrations of heavy metals (cadmium, lead, chromium, nickel, copper, zinc and iron; mg/kg) in rubber crumb samples and the maximum admissible concentration set by the Italian National Amateur League [9]. These limits are identical to those of Dlgs. 152/2006 [8] for public parks and private and residential land.

Lead, chromium, nickel and copper were well below the limits in all samples. Three samples exceeded the limit for cadmium, two being new (samples 4 and 5) and the third already installed (sample 6). In the case of zinc, all samples recorded high concentrations: sample 1 showed the lowest concentration of zinc, exceeding the limit by a factor of more than 20; the worst case was sample 4, exceeding the limit by a factor of nearly 90. Concentrations were quite similar to those of the study of Bocca et al. [13], except for cadmium that was always below the limit in the cited study. Concentrations of iron were quite similar to each other, except for sample 2 that showed a particularly high peak.

Zinc values are in line with other studies concerned with it: Verschoor [3] not only assessed the quantity of zinc in the rubber infill, but also the amount released, showing that the aging of rubber has a high impact on the release of zinc, which the author estimated as an annual average of 50 mg/kg of rubber. The concentration of Zn found in leachate was 1.3 mg/L, which is above the limit imposed by the Dutch Soil Quality law [24,25].

Another study evaluated the bioavailability of certain metals and PAHs in human digestive fluids, assuming ingestion of crumb from synthetic fields [26]. Their results showed that Zn in particular exceeded the limits of the Department of Environmental Conservation (DEC) of New York State [27] for soil (2200 ppm), while the lead content in rubber crumb never exceeded these limits, but was very bioavailable in synthetic gastric fluid, thus representing a potential risk to athletes.

### PAH levels in rubber crumb

It proved possible to identify and quantify the PAHs in all samples. All were priority PAHs according to USEPA [28] and some are known to be powerful carcinogens (Table 3) [29-32]. The total PAHs in tables and graphs are the sum of individual PAHs, while the carcinogenic PAHs are only those which are carcinogenic according to at least three classifications. Although benzo(a)pyrene (B[a]P) only accounted for 10-20% of the carcinogenic compounds, it is used by the European Commission Regulation 1881/2006 as an indicator of contamination by the 16 priority PAHs [33].

Table 4 shows the levels of single PAHs (ng/g) detected in samples 1 to 9. Samples 1 to 5 were obtained before they were spread on playing surfaces, whereas the samples 6 to 9 were collected directly from the fields and had been in place for 1 to 8 years. The two last rows of Table 4 show total PAH levels, obtained by summing all the PAHs quantified, and carcinogenic PAH levels, obtained by summing carcinogenic PAHs of Table 3.

Figure 1 compares levels of total PAHs and carcinogenic PAHs in rubber crumb from the various football fields. Very high levels of total PAHs were found in samples 2, 9 and 1. Lower levels were found in

samples 3, 6, 7 and 8, indicating a difference between new samples and those already installed in soccer fields. Indeed, the load of PAHs was appreciably lower in samples 6, 7 and 8 (installed 3 to 8 years ago) than in the other samples. This shows that once installed, these fields lose part of their toxic load in the time. This fact is important for assessing toxicological hazard to athletes, therefore they are chronically exposed to these compounds.

Comparing the relative percentages of all PAHs on total PAHs of the different samples (Figure 2A-C), we noted that the highest PAHs in all samples, except sample 5, were benzo(b)fluoranthene (B[b]F) (samples 1, 2, 6 and 9) or pyrene (Pyr) (samples 3, 4, 7 and 8) but always followed by B[b]F. The fingerprint of sample 5 (natural rubber crumb, not recycled tyres) showed a high concentration of fluorene (Fl), followed by Pyr, fluoranthene (Flt) and B[b]F, unlike the other footprints. Although absolute levels of PAHs were high in this sample (Table 4), the three most abundant PAHs (Fl, Pyr and Flt) are not regarded as particularly hazardous or carcinogenic to humans and therefore this type of natural rubber crumb can be considered less toxic.

Table 5 shows the levels of those PAHs (mg/kg) of which the maximum admissible concentration is established [8], detected in the rubber crumb samples analyzed for this study. The Decree reported threshold values of concentration for some PAHs in soils and even if the comparison with the present data was not direct it could give some indications. All samples exceeded the limit for B[b]F and benzo(g,h,i)perylene (B[ghi]Per); in the case of B[b]F, sample 2 exceeded the limit by a factor of about 30, and samples 1 and 9 by a factor of about 20. No crumb exceeded the limit for chrysene (Chry).

### PAH levels in evaporates of rubber crumb

Table 6 shows the levels of benzo(a)anthracene (B[a]A), Chry, B[a]P and B[ghi]Per, among the most toxic high molecular weight PAHs detected in evaporates of nine rubber crumbs. We have taken only these PAHs because, when the evaporation test was repeated three times to obtain three consecutive readings for each sample, were the only PAHs which standard deviation (S.D.) was below the mean value in all nine samples. Among all samples, turf fields 9 and 1 released particularly high levels of all considered compounds. Evaporation tests showed that the releasing of four PAHs into the air by rubber crumb did not decrease with the time, suggesting chronic contamination in areas fitted with synthetic turf filled with rubber crumb.

It was also evaluated the mean times for total release of these four PAHs from the samples (Table 7). In theory, considering for each compound the total amount present in the rubber crumb samples and the amount found in the evaporated samples, we can estimate that for the new turf fields are necessary from a minimum of 811 times (sample 3) to a maximum of 4423 times (sample 2) to exhaust emissions of these compounds when the turf temperature reaches 60°C, then when the atmospheric temperature is 25°C. Regarding the used samples, in the same conditions of temperature, are required from a minimum of 346 times (sample 7) to a maximum of 655 times (sample 6). Assuming solar radiation keeps atmospheric temperature at 25°C for at least 5 h/day (heating experimental time in the Lab.) for 5 months of the year, there are 150 suitable days per year. Ignoring other sources of elimination, such as rainwater or washing that cause leaching and cooler days when the crumb still becomes warm, it would hypothetically take a minimum

	<b>Cd (mg/kg)</b>	<b>Pb (mg/kg)</b>	<b>Cr (mg/kg)</b>	<b>Ni (mg/kg)</b>	<b>Cu (mg/kg)</b>	<b>Zn (mg/kg)</b>	<b>Fe (mg/kg)</b>
<b>Sample 1</b>	1.81	27.86	7.92	26.12	46.42	<b>3474.00</b>	489.60
<b>Sample 2</b>	1.77	17.51	17.52	9.86	39.96	<b>3732.00</b>	7256.00
<b>Sample 3</b>	0.47	13.97	4.12	4.11	5.59	<b>5314.00</b>	129.12
<b>Sample 4</b>	<b>2.05</b>	33.58	3.34	5.27	84.49	<b>13202.00</b>	657.40
<b>Sample 5</b>	<b>2.68</b>	11.23	2.84	8.95	9.50	<b>6462.00</b>	355.40
<b>Sample 6</b>	<b>2.38</b>	22.84	2.95	5.43	27.47	<b>4866.00</b>	1577.40
<b>Sample 7</b>	0.47	10.76	3.58	5.14	5.49	<b>4168.00</b>	543.00
<b>Sample 8</b>	1.51	29.44	1.91	3.90	14.43	<b>6006.00</b>	262.20
<b>Sample 9</b>	1.53	38.99	5.37	5.75	65.11	<b>4194.00</b>	346.80
<b>Limit (LND, 2011)</b>	<b>2.00</b>	<b>100.00</b>	<b>150.00</b>	<b>120.00</b>	<b>120.00</b>	<b>150.00</b>	<b>N.D.</b>

**Table 2:** Levels (mg/kg) of cadmium, lead, chromium, nickel, copper, zinc and iron in samples of rubber crumb. The triple horizontal line separates new crumb (samples 1-5) and crumb sampled from sporting installations (samples 6-9). Values in bold exceeded the limits set by the Italian National Amateur League reported in the last row.

Compound	Abbreviation	Structure (# of rings)	Formula	Molecular weight (g/ mol)	Solubility (mg/L)	Melting point (°C)	Boiling point (°C)	Vapor tension (Pa) at 25°C	Coefficient octanol/H <sub>2</sub> O (log K <sub>ow</sub> )	Carcinogenicity IARC (2008)	Carcinogenicity NTP (2005)	Carcinogenicity IPCS (1998)	Carcinogenicity NRCC (1983)
Naphthalene (S)	Naph	2	C <sub>10</sub> H <sub>8</sub>	128.17	31	81	217.9	10.4	3.40	<b>2B</b>		(?)	0
Acenaphthene (S)	Ace	3	C <sub>12</sub> H <sub>8</sub>	154.21	3.8	95	279	2.9x10 <sup>-1</sup>	3.92	3		(?)	0
Fluorene (S)	Fl	3	C <sub>13</sub> H <sub>10</sub>	166.22	1.9	115-116	295	8.0x10 <sup>-2</sup>	4.18	3		-	0
Phenanthrene (S)	Phen	3	C <sub>14</sub> H <sub>10</sub>	178.23	1.1	100.5	340	1.6x10 <sup>-2</sup>	4.60	3		(?)	0
Anthracene (S)	Ant	3	C <sub>14</sub> H <sub>10</sub>	178.23	0.045	216.4	342	8.0x10 <sup>-4</sup>	4.50	3		-	0
Fluoranthene (C)	Flt	4	C <sub>16</sub> H <sub>10</sub>	202.26	0.26	108.8	375	1.2x10 <sup>-3</sup>	5.22	3		+	0
Pyrene (C)	Pyr	4	C <sub>16</sub> H <sub>10</sub>	202.26	0.132	150.4	393	6.0x10 <sup>-4</sup>	5.18	3		(?)	0
Benzo(a)anthracene (C)	B[a]A	4	C <sub>18</sub> H <sub>12</sub>	228.29	0.011	160.7	400	2.8x10 <sup>-5</sup>	5.61	<b>2B</b>	<b>Yes</b>	+	+
Chrysene (C)	Chry	4	C <sub>18</sub> H <sub>12</sub>	228.29	0.0015	253.8	448	8.4x10 <sup>-5</sup> (20°C)	5.91	<b>2B</b>	<b>Yes</b>	+	±
Benzo(b)fluoranthene (C)	B[b]F	5	C <sub>20</sub> H <sub>12</sub>	252.32	0.0015	168.3	481	6.7x10 <sup>-5</sup> (20°C)	6.12	<b>2B</b>	<b>Yes</b>	+	++
Benzo(k)fluoranthene (C)	B[k]F	5	C <sub>20</sub> H <sub>12</sub>	252.32	0.0008	215.7	480	1.3x10 <sup>-8</sup> (20°C)	6.84	<b>2B</b>	<b>Yes</b>	+	0
Benzo(a)pyrene (C)	B[a]P	5	C <sub>20</sub> H <sub>12</sub>	252.32	0.0038	178.1	496	7.3x10 <sup>-7</sup>	6.50	<b>1</b>	<b>Yes</b>	+	+++
Dibenz(a,h)anthracene (C)	D[ah]A	6	C <sub>22</sub> H <sub>14</sub>	278.35	0.0005	266.6	524	5.3x10 <sup>-8</sup> (20°C)	6.50	<b>2A</b>	<b>Yes</b>	+	+++
Benzo(g,h,i)perylene (C)	B[ghi]Per	6	C <sub>22</sub> H <sub>12</sub>	276.34	0.00026	278.3	545	1.4x10 <sup>-8</sup>	7.10	3		(?)	0
Indeno(1,2,3-cd)pyrene (C)	I[1,2,3-cd]P	6	C <sub>22</sub> H <sub>12</sub>	276.34	0.062	163.6	536	1.3x10 <sup>-8</sup> (20°C)	6.58	<b>2B</b>	<b>Yes</b>	+	+
										1 demonstrated carcinogenic 2A probable carcinogenicity 2B possible carcinogenicity 3 carcinogenicity not demonstrated	+ positive - negative ? uncertain ( ) insufficient evidence	0 not carcinogenic ± uncertain carcinogenicity + carcinogenic	

**Table 3:** PAH compounds detected in rubber crumb samples. Abbreviations: S – petrogenic; C – pyrogenic. Grey shades indicate carcinogenicity, determined in at least three published studies, and degree of carcinogenicity.

	<b>Sample 1 (ng/g)</b>	<b>Sample 2 (ng/g)</b>	<b>Sample 3 (ng/g)</b>	<b>Sample 4 (ng/g)</b>	<b>Sample 5 (ng/g)</b>	<b>Sample 6 (ng/g)</b>	<b>Sample 7 (ng/g)</b>	<b>Sample 8 (ng/g)</b>	<b>Sample 9 (ng/g)</b>
Naphthalene	774.28	2039.61	360.19	804.53	424.87	246.14	407.59	223.32	1136.00
Acenaphthene	7297.50	10148.88	352.12	4200.53	416.15	405.31	1309.41	508.71	6321.31
Fluorene	10367.21	11025.47	426.81	1347.92	4944.42	1152.60	528.52	1665.02	7145.12
Phenanthrene	708.74	1160.10	146.90	1560.01	149.00	247.79	76.03	37.92	1013.08
Anthracene	80.30	138.12	38.25	282.62	44.56	76.39	7.64	34.59	182.28
Fluoranthene	2939.37	3740.04	872.96	1979.53	2243.22	710.43	993.99	817.50	3244.74
Pyrene	5670.11	6729.04	3983.32	5974.83	3800.41	1643.56	2144.43	1909.15	10280.99
Benzo(a)anthracene	1166.03	1612.58	92.28	440.21	267.10	115.46	41.37	5.38	389.40
Chrysene	2898.05	3422.21	923.00	1396.91	700.38	243.57	921.07	622.18	916.56
Benzo(b)fluoranthene	11103.33	15715.42	1149.65	4569.85	1563.07	1899.14	1248.07	1440.33	10185.76
Benzo(k)fluoranthene	679.05	1203.44	68.25	504.87	353.09	126.77	224.24	611.64	3615.88
Benzo(a)pyrene	256.10	464.58	119.81	229.96	165.92	265.10	60.28	51.72	662.56
Dibenz(a,h)anthracene	464.36	362.12	192.90	72.75	426.97	344.52	109.13	134.76	573.26
Benzo(g,h,i)perylene	902.89	449.76	395.63	418.68	585.24	543.82	239.69	344.92	475.49
<b>Total PAHs</b>	<b>45307.32</b>	<b>58211.37</b>	<b>9122.05</b>	<b>23783.19</b>	<b>16084.40</b>	<b>8020.60</b>	<b>8311.45</b>	<b>8407.13</b>	<b>46142.43</b>
<b>Carcinogenic PAHs</b>	<b>16566.92</b>	<b>22780.35</b>	<b>2545.89</b>	<b>7214.55</b>	<b>3476.52</b>	<b>2994.56</b>	<b>2604.16</b>	<b>2866.02</b>	<b>16343.42</b>

**Table 4:** Levels of PAHs (ng/g) detected in nine samples of rubber crumb. The triple vertical line separates new crumb (1-5) from crumb sampled directly from sporting facilities (6-9).

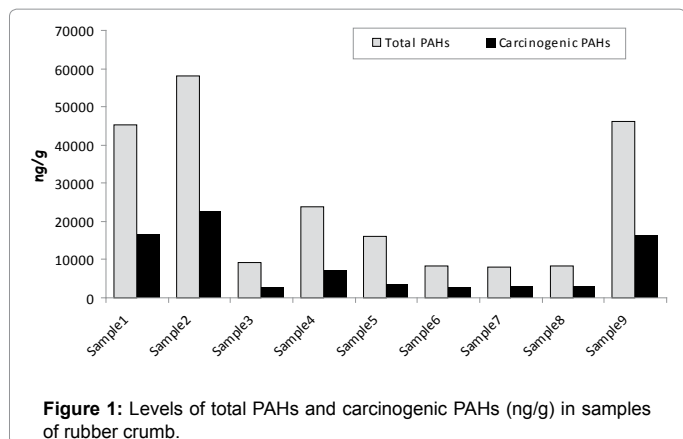


Figure 1: Levels of total PAHs and carcinogenic PAHs (ng/g) in samples of rubber crumb.

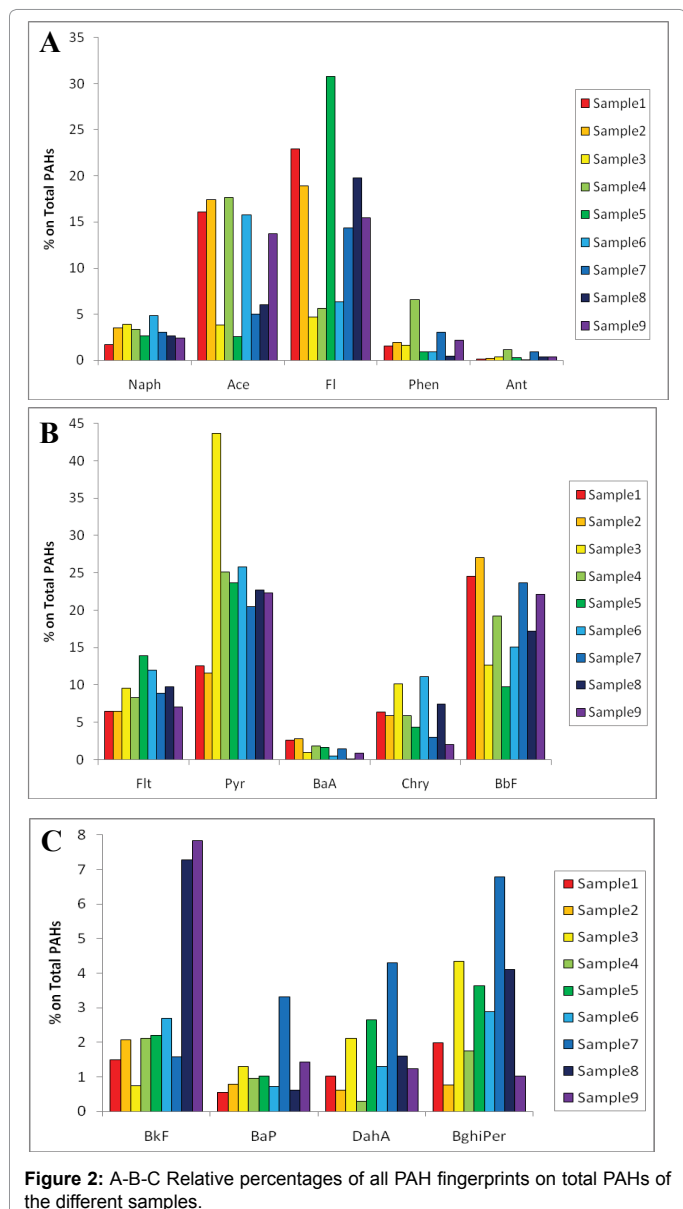


Figure 2: A-B-C Relative percentages of all PAH fingerprints on total PAHs of the different samples.

of 2 years (sample 7) to a maximum of about 29 years (sample 2) to reach theoretical zero concentration of PAHs.

### Risk assessment for PAH inhalation from synthetic fields

The approach to assess human health risks through the inhalation route in the synthetic turf fields, plans to consider field surface as soil surface [24]. Then, if field surface does not reach a temperature of 25°C, the contaminant release in air can be associated to wind erosion and volatilization and the inhalation risk must consider also the contaminated dust resuspension. This site-specific inhalation risk evaluation that we have conducted on the rubber granulates of the nine synthetic fields, follows the recommendations of the Dlgs. 152/06 [8] and the indication of the technical procedure issued by APAT [34]. This evaluation procedure is applied separately on each pollutant and, at the end, all individual risk values obtained are summed. In order to proceed to this estimation, it is important to know the particulate emission factor (PEF) of outdoor matter of the survey site. We considered PEF equal to  $PM_{10} \times 10^{-6}$  kg/mg, where  $PM_{10}$  are the levels of total inhalable dusts ( $mg/m^3$ ) potentially containing PAHs, assuming that all the particles present in the air as  $PM_{10}$  result from the volatilization of particles from the field, and not as an input from the wide variety of anthropogenic and crustal sources. Then, the following results are overestimated and they must be considered as extreme worst case screening. The precautionary principle is applied taking into account the highest average concentration of  $PM_{10}$  recorded in 2010 in Tuscany (since 8 turfs of 9 came from Tuscany) which is  $PM_{10} = 0.0517$   $mg/m^3$ . Considering a punctiform source of contamination, it is possible to evaluate the contaminant concentration in air ( $C_A$ ) given by  $C_A = \text{contaminant concentration in field } (C_F) \times PEF$ . In this way it is possible to calculate the Average Daily Dose (ADD), assumed by the athletes, expressed in terms of mass of contaminant per unit of body weight per day ( $mg/kg$  day). The ADD is calculated to evaluate toxic effects taking into consideration the  $C_A$  values, the inhalation rate (IR) of an athlete (3.6  $m^3/h$ ), the daily exposure frequency ( $EF_{do}$ ) (2 h/d), the exposure frequency (EF) in a year (208 d/year), the exposure duration (ED) (20 years), the body weight (BW) (70 kg) and the averaging time (AT) (20 years  $\times$  365 d/year):

$$ADD = (C_A \times IR \times EF_{do} \times EF \times ED) / (BW \times AT)$$

Furthermore, the Lifetime Average Daily Dose (LADD), used for the evaluation of carcinogenic effects, is calculated simply with the same parameters of ADD, except the Averaging Time (AT) that for carcinogenic effects considers 70 years (70 years  $\times$  365 d/year).

Starting from ADD and LADD values, in the last step it is possible to calculate a Hazard Quotient (HQ) as an indicator of risks associated with health effects other than cancer, and Excess Cancer Risk (ECR) as the incremental probability of an exposed person developing cancer over

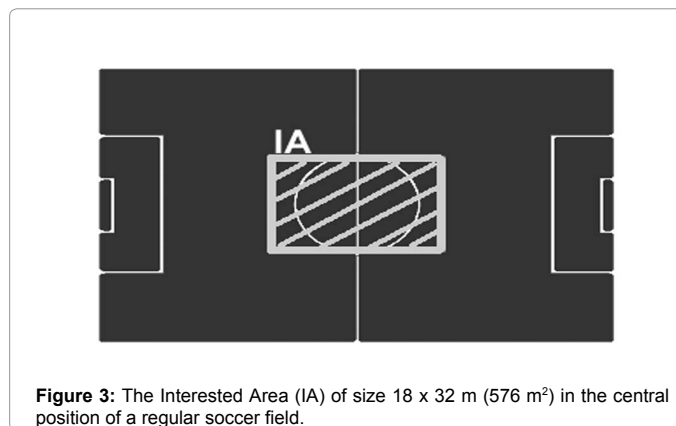


Figure 3: The Interested Area (IA) of size 18 x 32 m (576  $m^2$ ) in the central position of a regular soccer field.

	Pyr (mg/kg)	B(a)A (mg/kg)	Chry (mg/kg)	B[b]F (mg/kg)	B(k)F (mg/kg)	B(a)P (mg/kg)	D(ah)A (mg/kg)	B(ghi)Per (mg/kg)
Sample 1	<b>5.67</b>	<b>1.17</b>	2.90	<b>11.10</b>	<b>0.68</b>	<b>0.26</b>	<b>0.46</b>	<b>0.90</b>
Sample 2	<b>6.73</b>	<b>1.61</b>	3.42	<b>15.72</b>	<b>1.20</b>	<b>0.46</b>	<b>0.36</b>	<b>0.45</b>
Sample 3	3.98	0.09	0.92	<b>1.15</b>	0.07	<b>0.12</b>	<b>0.19</b>	<b>0.40</b>
Sample 4	<b>5.97</b>	0.44	1.40	<b>4.57</b>	0.50	<b>0.23</b>	0.07	<b>0.42</b>
Sample 5	3.80	0.27	0.70	<b>1.56</b>	0.35	<b>0.17</b>	<b>0.43</b>	<b>0.59</b>
Sample 6	1.64	0.12	0.24	<b>1.90</b>	0.13	<b>0.27</b>	<b>0.34</b>	<b>0.54</b>
Sample 7	2.14	0.04	0.92	<b>1.25</b>	0.22	0.06	<b>0.11</b>	<b>0.24</b>
Sample 8	1.91	0.01	0.62	<b>1.44</b>	<b>0.61</b>	0.05	<b>0.13</b>	<b>0.34</b>
Sample 9	<b>10.28</b>	0.39	0.92	<b>10.19</b>	<b>3.62</b>	<b>0.66</b>	<b>0.57</b>	<b>0.48</b>
Limit (Dlgs 152/2006)	<b>5.00</b>	<b>0.50</b>	<b>5.00</b>	<b>0.50</b>	<b>0.50</b>	<b>0.10</b>	<b>0.10</b>	<b>0.10</b>

**Table 5:** Levels of PAHs (mg/kg) with maximum admissible concentration known detected in samples and the limits set by the Legislative Decree 152/2006. The triple horizontal line separates new crumb (samples 1-5) from crumb sampled from sporting installations (samples 6-9). Values in bold exceeded the limit.

	Benzo(a)anthracene (ng/g)		Chrysene (ng/g)		Benzo(a)pyrene (ng/g)		Benzo(g,h,i)perylene (ng/g)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Sample 1	0.43	0.14	5.82	3.18	0.48	0.32	0.58	0.30
Sample 2	0.16	0.07	1.46	0.07	0.15	0.10	0.43	0.17
Sample 3	0.14	0.06	1.43	0.42	0.12	0.02	0.42	0.19
Sample 4	0.15	0.10	1.30	0.57	0.11	0.07	0.50	0.23
Sample 5	0.27	0.18	1.06	0.09	0.21	0.06	0.62	0.50
Sample 6	0.16	0.05	1.73	1.33	0.28	0.19	0.68	0.36
Sample 7	0.18	0.07	2.26	1.42	0.26	0.11	0.64	0.28
Sample 8	0.28	0.06	1.32	0.29	0.19	0.02	0.49	0.09
Sample 9	0.49	0.66	2.53	1.08	0.89	0.70	1.28	0.07

**Table 6:** Levels (ng/g) of benzo(a)anthracene, chrysene, benzo(a)pyrene and benzo(g,h,i)perylene in evaporates of rubber crumb samples at 60°C.

	Mean Time (days at atmospheric T=25°C)	SD
Sample 1	1325	1047
Sample 2	4423	3990
Sample 3	811	185
Sample 4	1734	967
Sample 5	846	150
Sample 6	655	396
Sample 7	346	136
Sample 8	410	229
Sample 9	568	234

**Table 7:** Estimated mean time (days) and standard deviation (SD) for total release of B[a]A, Chry, B[a]P and B[ghi]Per (sum of the four PAHs) from rubber crumb samples. The triple horizontal line divides new crumb (samples 1-5) from crumb sampled from sporting installations (samples 6-9).

a lifetime using for each pollutant the inhalation pathway toxicological parameters that are Reference Dose ( $R_D$ ) for HQ calculation ( $HQ = ADD/R_D$ ) and Slope Factor (SF) for ECR calculation ( $ECR = LADD \times SF$ ) (Table 8A-B). The values of these parameters are included in the ISS/ISPESL 2009 database [35] (Table 8A-B). HQs for all PAHs are summed to provide an overall Hazard Index (HI). When  $HI \leq 1$  there are no concern for potential adverse systemic health effects in the exposed individuals. Summing the individual ECR for all PAHs, it provides the Cumulative Excess Cancer Risk ( $\Sigma ECR$ ), that is acceptable if  $< 10^{-6}$  [36]. In the different rubber granulates samples was found a HI range that varies between a minimum of  $8.94 \times 10^{-7}$  in sample 4 and a maximum of  $1.16 \times 10^{-6}$  in sample 1 (Table 8A). The  $\Sigma ECR$  range goes from a minimum of  $4.91 \times 10^{-9}$  for sample 6 to a maximum of  $1.10 \times 10^{-8}$  for sample 1 again (Table 8B). All values were considered as acceptable. Menichini et al. [37] found an excess lifetime cancer risk of  $1 \times 10^{-6}$  for an athlete with an intense 30-years activity; then despite the different parameters considered for the athlete in this study, the results are very similar.

In reality, when the ambient temperature is 25°C and direct sunlight exposure is present on field, rubber granulates reach a mean

temperature of 60°C, where a chronic release of PAHs occur, as seen in section 3.3. According to the high evaporation which occurs in this condition and knowing that these fields are used anyway with such temperatures, despite it should be decreased by watering, we calculate an estimate of risk for outdoor fields at 60°C. Applying again the precautionary principle estimating the maximum risk, we consider only the central area of the field of size  $18 \times 32$  m ( $576$  m<sup>2</sup>), from now indicated as Interested Area (IA) (Figure 3), where the exchange of air at 2 m is irrelevant because it comes from surrounding perimeter and then it has the same toxicological characteristics. The air temperature at 2 m above the field is considered to have the same temperature as the granulates, according to the principle of the vertical temperature gradient. First, we calculated the quantity of crumb in a soccer field, averaging the specific weights ( $\gamma$ ), which were similar, of the various samples analyzed (mean 0.518 g/mL). Considering IA paved with synthetic turf 3 cm thick, the quantity of crumb of specific weight 0.518 g/mL is 8951 kg. To estimate risk to human health from exposure to PAHs, we expressed the toxicity of the various PAHs with respect to B[a]P, in other words as Benzo(a)Pyrene Equivalent ( $BaP_{eq}$ ). We calculated the Toxic Equivalent Quantity (TEQ) by multiplying the individual PAH levels in evaporates by their Toxic Equivalency Factor

A	RfD	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
		HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ	HQ
Pyr	3.00x10 <sup>-02</sup>	5.73x10 <sup>-07</sup>	6.80x10 <sup>-07</sup>	4.02x10 <sup>-07</sup>	6.04x10 <sup>-07</sup>	3.84x10 <sup>-07</sup>	1.66x10 <sup>-07</sup>	2.17x10 <sup>-07</sup>	1.93x10 <sup>-07</sup>	1.04x10 <sup>-06</sup>
B(a)A	2.85x10 <sup>-01</sup>	1.24x10 <sup>-08</sup>	1.71x10 <sup>-08</sup>	9.81x10 <sup>-10</sup>	4.68x10 <sup>-09</sup>	2.84x10 <sup>-09</sup>	1.23x10 <sup>-09</sup>	4.40x10 <sup>-10</sup>	5.72x10 <sup>-11</sup>	4.14x10 <sup>-09</sup>
Chry	3.00x10 <sup>-02</sup>	2.90x10 <sup>-07</sup>	3.46x10 <sup>-07</sup>	9.32x10 <sup>-08</sup>	1.41x10 <sup>-07</sup>	7.07x10 <sup>-08</sup>	2.46x10 <sup>-08</sup>	9.30x10 <sup>-08</sup>	6.28x10 <sup>-08</sup>	9.26x10 <sup>-08</sup>
B[b]F	2.85x10 <sup>-01</sup>	1.18x10 <sup>-07</sup>	1.67x10 <sup>-07</sup>	1.22x10 <sup>-08</sup>	4.86x10 <sup>-08</sup>	1.66x10 <sup>-08</sup>	2.02x10 <sup>-08</sup>	1.33x10 <sup>-08</sup>	1.53x10 <sup>-08</sup>	1.08x10 <sup>-07</sup>
B(k)F	2.85x10 <sup>-02</sup>	7.22x10 <sup>-08</sup>	1.28x10 <sup>-07</sup>	7.26x10 <sup>-09</sup>	5.37x10 <sup>-08</sup>	3.75x10 <sup>-08</sup>	1.35x10 <sup>-08</sup>	2.38x10 <sup>-08</sup>	6.50x10 <sup>-08</sup>	3.84x10 <sup>-07</sup>
B(a)P	3.14x10 <sup>+00</sup>	2.48x10 <sup>-10</sup>	4.49x10 <sup>-10</sup>	1.16x10 <sup>-10</sup>	2.22x10 <sup>-10</sup>	1.60x10 <sup>-10</sup>	2.56x10 <sup>-10</sup>	5.83x10 <sup>-11</sup>	5.00x10 <sup>-11</sup>	6.40x10 <sup>-10</sup>
B(ghi)Per	3.00x10 <sup>-02</sup>	9.12x10 <sup>-08</sup>	4.54x10 <sup>-08</sup>	4.00x10 <sup>-08</sup>	4.23x10 <sup>-08</sup>	5.91x10 <sup>-08</sup>	5.49x10 <sup>-08</sup>	2.42x10 <sup>-08</sup>	3.48x10 <sup>-08</sup>	4.80x10 <sup>-08</sup>
HI		1.16x10 <sup>-06</sup>	1.38x10 <sup>-06</sup>	5.56x10 <sup>-07</sup>	8.94x10 <sup>-07</sup>	5.71x10 <sup>-07</sup>	2.81x10 <sup>-07</sup>	3.71x10 <sup>-07</sup>	3.71x10 <sup>-07</sup>	1.68x10 <sup>-06</sup>
B	SF	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
		ECR	ECR	ECR	ECR	ECR	ECR	ECR	ECR	ECR
B(a)A	6.00x10 <sup>-01</sup>	6.06x10 <sup>-10</sup>	8.38x10 <sup>-10</sup>	4.79x10 <sup>-11</sup>	2.29x10 <sup>-10</sup>	1.39x10 <sup>-10</sup>	6.00x10 <sup>-11</sup>	2.15x10 <sup>-11</sup>	2.80x10 <sup>-12</sup>	2.02x10 <sup>-10</sup>
Chry	6.10x10 <sup>-03</sup>	1.53x10 <sup>-11</sup>	1.81x10 <sup>-11</sup>	4.87x10 <sup>-12</sup>	7.38x10 <sup>-12</sup>	3.70x10 <sup>-12</sup>	1.29x10 <sup>-12</sup>	4.86x10 <sup>-12</sup>	3.29x10 <sup>-12</sup>	4.84x10 <sup>-12</sup>
B[b]F	6.00x10 <sup>-01</sup>	5.77x10 <sup>-09</sup>	8.16x10 <sup>-09</sup>	5.97x10 <sup>-10</sup>	2.37x10 <sup>-09</sup>	8.12x10 <sup>-10</sup>	9.87x10 <sup>-10</sup>	6.48x10 <sup>-10</sup>	7.48x10 <sup>-10</sup>	5.29x10 <sup>-09</sup>
B(k)F	3.10x10 <sup>-02</sup>	1.82x10 <sup>-11</sup>	3.23x10 <sup>-11</sup>	1.83x10 <sup>-12</sup>	1.36x10 <sup>-11</sup>	9.48x10 <sup>-12</sup>	3.40x10 <sup>-12</sup>	6.02x10 <sup>-12</sup>	1.64x10 <sup>-11</sup>	9.71x10 <sup>-11</sup>
B(a)P	7.32x10 <sup>+00</sup>	1.62x10 <sup>-09</sup>	2.94x10 <sup>-09</sup>	7.59x10 <sup>-10</sup>	1.46x10 <sup>-09</sup>	1.05x10 <sup>-09</sup>	1.68x10 <sup>-09</sup>	3.82x10 <sup>-10</sup>	3.28x10 <sup>-10</sup>	4.20x10 <sup>-09</sup>
D(ah)A	7.30x10 <sup>+00</sup>	2.93x10 <sup>-09</sup>	2.29x10 <sup>-09</sup>	1.22x10 <sup>-09</sup>	4.60x10 <sup>-10</sup>	2.70x10 <sup>-09</sup>	2.18x10 <sup>-09</sup>	6.90x10 <sup>-10</sup>	8.52x10 <sup>-10</sup>	3.62x10 <sup>-09</sup>
ΣECR		1.10x10 <sup>-08</sup>	1.43x10 <sup>-08</sup>	2.63x10 <sup>-09</sup>	4.54x10 <sup>-09</sup>	4.71x10 <sup>-09</sup>	4.91x10 <sup>-09</sup>	1.75x10 <sup>-09</sup>	1.95x10 <sup>-09</sup>	1.34x10 <sup>-08</sup>

**Table 8.** Hazard Quotient (HQ) and Excess Cancer Risk (ECR) values calculated using the Reference Dose (R<sub>D</sub>) for HQ calculation (HQ = ADD/R<sub>D</sub>) (Table 8A) and Slope Factor (SF) for ECR calculation (ECR = LADD x SF) (Table 8B). The values of the R<sub>D</sub> and SF are included in the ISS/ISPEL 2009 database (ISS/ISPEL, 2009). HQs for all PAHs are summed to provide an overall Hazard Index (HI). When HI ≤ 1 there are no concern for potential adverse systemic health effects in the exposed individuals. Summing the individual ECR for all PAHs, it provides the Cumulative Excess Cancer Risk (ΣECR), that is acceptable if < 10<sup>-6</sup> (USEPA, 2009) [39].

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9
TEQ (ng/g)	0.59	0.19	0.15	0.14	0.25	0.30	0.32	0.24	0.98

**Table 9.** Toxicity Equivalent (TEQ) in benzo(a)pyrene equivalents (BaP<sub>eq</sub>) in evaporate of crumb samples.

(TEF). This data was only calculated for PAHs that showed limited variability in the three replicates of evaporates, as mentioned above. Thus, the TEQ is based on Chry (TEF=0.01), B[a]A (TEF=0.1), B[a]P (TEF=1) and B[ghi]Per (TEF=0.01) [38-40] making it underestimated, as many other compounds with known TEF were found in the evaporates. The TEQ for each sample (Table 9) was calculated using the following formula:

$$\text{TEQ (ng/g)} = \text{B[a]A} \times 0.10 + \text{Chry} \times 0.01 + \text{B[a]P} \times 1.00 + \text{B[ghi]Per} \times 0.01$$

IA use 8951 kg of rubber crumb and we estimated the TEQ in µg referred to the crumb evaporates of the different fields at an average air temperature of 25°C (Table 10A). Estimating evaporation up to a height of 2 m, we have a volume of 1152 m<sup>3</sup> (576 m<sup>2</sup> × 2m). Table 10B shows the results in µg/m<sup>3</sup> obtained dividing the TEQ of evaporates of the rubber crumb samples (µg) by the estimated volume of air (m<sup>3</sup>) above the field. Knowing that an athlete inhalation rate is around 3.6 m<sup>3</sup> per hour [41], the TEQ inspired by him in a standard two-hour workout was calculated on the basis of that assumption. In 2 h of training, the daily intake of BaP<sub>eq</sub> of an athlete is showed in Table 10C. If a player trains for 2 h a day, three times a week, five times for professionals, plus the match, his estimated intake of PAHs as TEQ ranged from 31.2 µg/week (sample 4) to 219.2 µg/week (sample 9), for an average weekly exposure of 8 h (Table 10D). Dividing this by 7 days we obtain 4.46 - 31.3 µg/day of BaP<sub>eq</sub> inhaled as daily mean dose, not considering other PAH inputs for the athletes (Table 10E). For a 70 kg athlete, we obtain an intake of 0.06 - 0.45 µg/kg bw of BaP<sub>eq</sub> per day (Table 10F). Since the release of PAHs is continuous and constant throughout the life of the field (Table 6), a chronic exposure of 0.06 to 0.44 µg/kg bw per day BaP<sub>eq</sub> for a 70 kg athlete should not be underestimated. In fact recent studies have shown that 0.57 - 5.00 ng/kg bw per day is a *virtually safe dose* of B[a]P in food, which implies a risk of 1x10<sup>-6</sup> (one person in a million will develop cancer after chronic exposure). Considering that,

generally, carcinogenic PAHs are about 10-fold higher than the B[a]P alone, the carcinogenicity increases and a *virtually safe dose* of B[a]P, as an indicator of carcinogenic PAHs in food, would be in the range 0.06 - 0.50 ng/kg bw per day [42], theoretically 1000 times lower than the range of 0.06 to 0.45 µg/kg bw per day found in this study.

## Conclusions

Rubber crumb derived from recycled tyres, like the tyres themselves, should be considered non-hazardous special waste. The literature and the present study show that crumb contains PAHs and heavy metals. Fine dust may become airborne and leachate may filter into the soil. The magnitude of human exposure depends on chemicals of concern concentration in field, exposure parameters describing human physiology (e.g. dermal contact, body weight) and population-specific parameters describing exposure behaviour (exposure frequency, duration). Randomly ingested crumb may release these compounds in the digestive tract. Most of all, evaporation at high temperatures may expose users of sports grounds, who are often children between 5 and 13 years of age, in a very sensitive phase of growth, to many of these toxic compounds.

The results of the present study demonstrate that PAHs are continuously released from rubber crumb through evaporation. Athletes frequenting grounds with synthetic turf are therefore exposed to chronic toxicity from PAHs. The main conclusion we can draw from this preliminary study, which will be validated by further field and laboratory research, is that although synthetic turf offers various advantages over natural grass, the quantity of toxic substances it releases when heated does not make it safe for public health. When we extrapolated the data obtained in laboratory, the toxicity equivalent (TEQ) of the different compounds evaporating from the crumb was far from negligible and would contribute substantially to an athlete's total daily PAH intake. In fact, all rubber crumb samples of this study exceeded the DIs. 152/2006 [8] for B[b]F, B[ghi]Per and Zn, but all



PAHs, except Chry, were over the threshold in almost one synthetic field. It must be underlined that this preliminary hazard assessment overestimates the PAH contribution of the field because the input from the wide variety of anthropogenic and crustal sources were not considered and then, this theoretical approach must be considered as an extreme worst case screening.

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