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Occupational exposure of firefighters to polycyclic aromatic hydrocarbons in non-fire work environments

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HIGHLIGHTS

- Firefighters' air exposures to PAHs in non-fire work settings were assessed.
- Obtained PAH levels fulfilled occupational limits and air quality guidelines.
- Congeners with 2–3 rings were the predominant contributors to total PAHs levels.
- Exposure sources were mixed ones (both pyrogenic and petrogenic origin).
- Incremental lifetime cancer risks exceeded WHO–based guideline at all fire houses.

GRAPHICAL ABSTRACT

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ABSTRACT

This work aims to characterize personal exposure of firefighters to polycyclic aromatic hydrocarbons (PAHs) in non-fire work environments (fire stations), and assesses the respective risks. Eighteen PAHs (16 considered by USEPA as priority pollutants, dibenzo[*a*,*l*]pyrene and benzo[*j*]fluoranthene) were monitored in breathing zones of workers at five Portuguese fire stations during a normal shift. The obtained levels of PAHs fulfilled all existent occupational exposure limits as well as air quality guidelines with total concentrations (ΣPAHs) in range of 46.8–155 ng m^{-3}. Light compounds (2–3 rings) were the most predominant congeners (74–96% of ΣPAHs) whereas PAHs with 5–6 rings accounted 3–9% of ΣPAHs. Fuel and biomass combustions, vehicular traffic emissions, and use of lubricant oils were identified as the main sources of PAHs exposure at the studied fire corporations. Incremental lifetime cancer risks were below the recommend USEPA guideline of 10^{-6} and thus negligible for all the studied subjects, but WHO health–based guideline level of 10^{-5} was exceeded (9–44 times) at all fire corporations. These results thus show that even during non-fire situations firefighters are exposed to PAHs at levels that may promote some adverse health outcomes; therefore the respective occupational exposures to these compounds should be carefully controlled.

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1. Introduction

Firefighters (IARC, 2010a) represent one of the most hazardous occupation (Baxter et al., 2014). During their professional conduct, firefighters are exposed to a complex mixture of pollutants including particles (fine and respirable particulate matter) and a wide range of gaseous chemicals (such as carbon monoxide and dioxide, nitrogen oxides, carbonyls, volatile and semi-volatile organic compounds; Estrellan and Lino, 2010; Lemieux et al., 2004; Lewtas, 2007; Miranda et al., 2010; Reisen et al., 2006). Among them polycyclic aromatic hydrocarbons (PAHs) are especially relevant due to their mutagenic and genotoxic properties (Annesi-Maesano et al., 2007; IARC, 2002, 2010a, 2010b; Tuntawiroon et al., 2007), some of them being considered as endocrine disrupting chemicals (WHO, 2013). Occupational exposure to PAHs has been associated with increased risks of various cancers (lungs, bladder, skin, urinary and gastrointestinal systems; Boffetta et al., 1997; Diggs et al., 2011; Rota et al., 2014); cell damage via gene mutation (Kamal et al., 2015; Kuang et al., 2013; Poirier, 2004), oxidative stress and cardiovascular diseases (Burstyn et al., 2005; Jeng et al., 2011; Kim et al., 2013; Lee et al., 2011) and cardiovascular mortality (Brucker et al., 2014). Concerning potential exposure and adverse health effects, United States Environmental Protection Agency (USEPA) has identified 16 priority congeners (USEPA, 2014).

From chemical perspective, PAHs are compounds containing only hydrogen and carbon that are composed of multiple aromatic rings. They are abundant in soils and marine sediments, fresh water, and in atmosphere where the more health hazardous congeners (WHO, 2010) are predominantly bound to fine (i.e. $PM_{2.5}$) particles (Castro et al., 2011; Slezakova et al., 2011, 2013b). Fire emissions and smoke are the most relevant sources of PAHs exposure for firemen (Booze et al., 2004; Fent et al., 2013, 2014; Kirk and Logan, 2015a), but the compounds are formed by other man-made sources such as industrial processes, incinerators, coal-fired boilers and power plants, and last but not least, by traffic emissions (Hanedar et al., 2014; Ravindra et al., 2008; Slezakova et al., 2013a, 2013b). In confined spaces, second–hand tobacco smoke, combustion emissions (from cooking stoves and fireplaces) and infiltration of ambient air emissions are responsible for the presence of PAHs (Chen et al., 2012; Qi et al., 2014; Shen et al., 2012; Slezakova et al., 2014). The toxicity of PAHs is largely attributed to their reactive oxygenated metabolites, potential of causing oxidative stress (Kamal et al., 2015) and the adducts of their metabolites with DNA (Rengarajan et al., 2015). The DNA-binding is considered to be essential for the carcinogenic effect (Pratt et al., 2011; Tarantini et al., 2011) with DNA adducts being identified in various human tissues (Ziech et al., 2011); cancer is the primarily risk for PAHs exposure (Boström et al., 2002; Kim et al., 2013) and in that view International Agency for Research on Cancer (IARC) has categorised benzo[*a*]pyrene (B[*a*]P; a marker of PAHs exposure) as known human carcinogen (Group 1) (IARC, 2010b) whereas other congeners are classified as probable and/or possible ones (Group 2A and 2B, respectively). Further scientific evidence has also linked exposure to PAHs with cardiovascular diseases (Lewtas, 2007; Korashy and El-Kadi, 2006). Adverse health outcomes (hemotoxicity and carcinogenicity; Fabian et al., 2014; Fent and Evans, 2011; Robinson et al., 2008) and also excess morbidity and mortality have been reported for firefighters' occupational exposure, with cardiovascular diseases being the primary cause for the deaths (in approximately 45% of firefighters) and a major cause of the increased morbidity (Gaughan et al., 2014a, 2014b; Soteriades et al., 2011); the additional exposure to PAHs may promote and/or worsen the existent cardiovascular diseases of firefighters (Lewtas, 2007). Because of the relevance of this topic, data regarding firefighters' exposure to PAHs have been emerging. The most extensive studies that assessed exposures in various combat situations and scenarios (i.e. training sessions, mainly prescribed burns management, suppression and overhaul of controlled structure burns) have been conducted in USA (Baxter et al., 2014; Bolstad-Johnson et al., 2000; Booze et al., 2004; Fent et al., 2013, 2014; Fent and Evans, 2011; Pleil et al., 2014; Robinson et al., 2008) and Australia (Kirk and Logan, 2015a). In addition, some authors reported that fire-generated contaminants were tracked back to fire stations through firefighters' protective gear (gloves, boots and turnout equipment) and vehicles (Alexander and Baxter, 2014; Fabian et al., 2014; Fent et al., 2013; Kirk and Logan, 2015a, 2015b; Laitinen et al., 2010; Shen et al., 2015) but only few studies investigated occupational exposure to PAHs at fire stations (being mainly conducted in USA). Due to the geographical differences such different materials and construction techniques used for building houses and structures, and due to differences in the firefighting practices (which can influence the smoke emissions and consequently the respective exposure; Reinhardt and Ottmar, 2004; Reisen and Brown, 2009; De Vos et al., 2009), these reported exposure data may be significantly different from those of European firefighters. Furthermore, the seasonal trends of PAHs (Liu et al., 2008; Melymuk et al., 2012; Ravindra et al., 2006) may lead to further differences. This study aimed to investigate firefighters' exposure to PAHs in work (non–fire incident) settings. The levels of 16 PAHs considered by USEPA as priority pollutants, dibenzo[*a*,*l*]pyrene (D[*a*,*l*]P) and benzo[*j*]fluoranthene (B[*j*]F; a monitoring is suggested by Directive 2004/107/EC, 2005) were measured in the breathing air zone of firefighters in five Portuguese municipalities. The potential emission sources in the work settings were identified by diagnostic ratios and the occupational risks due to PAHs exposure in the respective environments were assessed.

2. Material and methods

2.1. Sample collection

Portugal belongs to the five Southern European Member States which every year suffer the most forest fires (Joint Research Centre, 2011). Typically, central and northern region of the country are affected the most by forest fires; in 2014 these two regions exhibited a burnt area of 14,938 ha (~75% of the total) with northern region also registering the prevailing number of fire occurrences (40% of the total number of fires) (Joint Research Centre, 2015). The sample collection was thus conducted in northern region in Braganza district (Fig. 1) where annual average air temperature was 12.7 °C and precipitation was 900.2 mm (INE, 2015); summer was hot and dry (average temperature of 28.2 °C, precipitation: 3.6 mm).

The personal sampling was conducted during a period of 28 days (May–June 2014) in subjects (Table 1) who worked as professional firefighters at corporations of five different municipalities: Vimioso (VMS), Macedo de Cavaleiros (MCC), Izeda (IZD), Vila Flor (VFR), and Alfândega da Fé (AFF). All fire corporations were located in central zones of rather small towns with relatively low populations (between 1212 and 15,776 at IZD and MCC; Table 1) and were considered as urban background sites. Each fire station was composed of track/car garages that were in general indirectly connected with working areas, control room and offices, as well as with an area of living quarters (Figs. 1S and 2S). For each subject, additional information (age, weight, gender, education, duration of employment; Table 1) was collected by means of structured questionnaire (WHO, 2016). All participating firemen were non-smokers. Information on further PAH exposures such as transportation to work, smoking and diet habits were also registered (Table 1) with participants reporting the most frequently consumed meals as: boiled > roasted > grilled.

The study included 18 $PM_{2.5}$–bound PAHs, namely naphthalene (Nap), acenaphthylene (Acy), acenaphthene (Ace), fluorene (Flu), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fln), pyrene (Pyr), benz[*a*]anthracene (B[*a*]A), chrysene (Chry), benzo[b + j]fluoranthene (B[b + j]F), benzo[*k*]fluoranthene (B[*k*]F), benzo[*a*]pyrene (B[*a*]P), dibenz[*a*,*h*]anthracene (D[*a*,*h*]A), benzo[*ghi*]perylene (B[*ghi*]P), indeno[1,2,3–cd]pyrene (InP), and dibenzo[*a*,*l*]pyrene (D[*a*,*l*]P). Sampling was conducted in breathing zones of the selected