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Indoor release of asbestiform fibers from naturally contaminated water and related health risk

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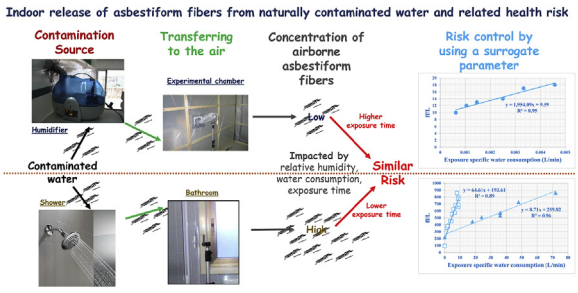
HIGHLIGHTS

- Asbestiform fibers (AFs) can be transferred from water to air by humidifier or shower.
- The concentration of AFs in air is higher by using the shower than the humidifier.
- Using the humidifier or the shower may result in similar health risk.
- A surrogate parameter to monitor the exposure to the airborne AFs is proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigates the occurrence of airborne asbestiform fibers released in indoor ambient due to the use of asbestos naturally contaminated water. Some experiments employed a laboratory physical model using an ultrasonic humidifier charged with contaminated groundwater. Other experiments were carried out at full scale to assess the release of asbestiform fibers during showering. Obtained results show that the concentration of the airborne asbestiform fibers released in the bathroom during showering is higher than the limit value set by the European and Italian Regulations, while the concentration of fibers released by the humidifier is much lower. However, it is noteworthy that the use of the humidifier at high exposure time results in similar health risk. Strong correlations were found between the concentration of the airborne asbestiform fibers and a novel surrogate parameter (i.e. the exposure-specific-water-consumption). These correlations can be used to monitor the asbestiform fibers concentration at varying operating conditions and therefore, to control the resulting health risk.

1. Introduction

The first evidence that asbestos fibers inhalation cause pleural malignant mesothelioma was in 1960 (Wagner et al., 1960). Later, asbestos was indicated as one of the main occupational risk factors for lung cancer (IARC , 1987). Thus, since the beginning of the 80s, many countries started banning production and use of asbestos containing products. However, asbestos containing products are still present in private and public buildings and need appropriate management and treatment for their disposal (Hwang and Park, 2016; Spasiano and Pirozzi, 2017).

Both anthropogenic and non-anthropogenic processes contribute to the presence of asbestos fibers in air, soil and water of urban, rural, and remote environments (Ansari et al., 2007; Harper,

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2008; Donovan et al., 2012; Noonan, 2017). Therefore, also non-occupational or environmental exposure may generates malignant mesotheliomas (Gardner and Saracci, 1989; Hillerdal, 1999; Magnani et al., 1995; Pan et al., 2005; Turci et al., 2016).

Naturally occurring asbestos refers to asbestos found as a natural component of rocks and soils but may include fibrous minerals that do not meet the regulatory definition of asbestos (Harper, 2008). It is the case of Biancavilla town (Catania, Italy), where the discovery of a cluster of cases of malignant pleural neoplasm was linked to the exposure of the population to a new asbestiform fiber. This novel fiber, named fluoro-edenite ($NaCa_2Mg_5(Si_7Al)O_{22}F_2$), was found in the stone quarries located in Monte Calvario (Paoletti et al., 2000; Gianfagna and Oberti, 2001; Bruno et al., 2006; Bruni et al., 2006). Such stone quarries were largely used in the local building industry. Therefore, the Biancavilla site was defined as National Priority Contaminated Site (NPCS) in 2002. Hence, on site characterization and remedial action were conducted as well as monitoring programs were carried out. Fluoro-edenite fibers were found in air, water and top soil at the Biancavilla NPCS confirming their environmental spreading due to the wide use of stone quarries from Monte Calvario in the local building industry (e.g. for road paving and in buildings construction) (Famoso et al., 2012). Recently, the presence of pleural plaques in the lungs of construction workers exposed to fluoro-edenite fibres was demonstrated (Rapisarda et al., 2015). Furthermore, a higher presence of women with pleural plaques was observed (Ledda et al., 2016).

Several studies have addressed the toxicity or carcinogenicity of fluoro-edenite fibers (Loreto et al., 2008; Miozzi et al., 2016). A comparison between fluoro-edenite and crocidolite effects on different types of cells, showed oxidative stress in the cultured cells, even though the effects induced by crocidolite were higher and a different mechanism of action was hypothesized (Cardile et al., 2004). In particular, in lung epithelial cells, fibrous fluoro-edenite behaved similarly to the unrelated asbestos type crocidolite, whose connection with severe inflammation and cancer of the lung is well known (Travaglione et al., 2006). The involvement of retinoblastoma (Rb) protein in the pathogenesis of the lung diseases induced by fluoro-edenite was reported (Musumeci et al., 2011). As a result, fluoro-edenite fibrous amphibole was classified as carcinogenic to humans (Group 1) on the basis of sufficient evidence in humans that exposure to fluoro-edenite causes mesothelioma (Grosse et al., 2014). Its carcinogenesis is probably based on a close relationship between inflammatory process, DNA damage and apoptosis, which leads to the classic honeycombing of alveolar cells and fibrosis, but the mechanisms remain to be further elucidated (Szychlinska et al., 2014).

Regardless of the chemical structure, it is well known that diameter and length of fiber are the most important determinants of its toxicity (Stanton et al., 1981). For instance, fibers with a diameter of $\leq$1 μm can be inhaled and may travel over the ciliated epithelium, while the length of fibers can play a significant role in fibre deposition and in turn in relative pathogenicity (Miozzi et al., 2016). Indeed, several studies demonstrated that fibers of >8 μm in length pose a higher pathogenic hazard (Stanton et al., 1981; Donaldson et al., 1989, 1992; Donaldson and Golyasnya, 1995; Boulanger et al., 2014). As a result, asbestiform fibes are defined as particles longer than 5 μm, with a width less than 3 μm, and with a length to width ratio greater than 3:1 (WHO, 1997). The human exposure to asbestiform fibers may be related to the presence of those fibers in different environmental matrices (soil, air and water). Although the epidemiological studies have shown that asbestos-like fibers cause bronchial carcinoma and pleural mesothelioma by inhalation, the association of asbestos with an increased risk of malignancies other than lung cancer and mesothelioma has not been confirmed in animal studies and has not been observed consistently in human studies (National Research Council, 1984). However, there is no unequivocal evidence of the carcinogenicity of these fibers by ingestion (Kjærheim et al., 2005; Bruni et al., 2006; Di Ciaula and Gennaro, 2016; Di Ciaula, 2017).

Even though the ingestion is the main route of exposure associated to asbestos-like fibers in water, other scenarios can occur. For instance, the release of fibers in the air by evaporation or humidification, and the deposition on textiles during washing and rinsing processes and subsequent release of fibers during wearing/use of cloth (Webber et al., 1988; Hardy et al., 1992; Highsmith et al., 1992). Ultrasonic humidifiers are considered a source of inhalation exposure to minerals and pathogens dissolved in water (Schoen and Ashbolt, 2011; Chattopadhyay et al., 2017; Sain et al., 2018; Estrada-Perez et al., 2018). The shower may also be a source of airborne asbestiform fibers because particle emissions have been reported during showering (Cowen and Ollison, 2006). To the author's knowledge, the release of asbestiform fibers from contaminated waters during showering has not been explored so far. Therefore, this study investigates for the first time the release of asbestos-like fibers from naturally contaminated water in the air during showering. The goal of the study is to compare the concentration of airborne asbestiform fibers released by the shower and by using an ultrasonic humidifier charged with contaminated groundwater. The evaluation of the human exposure to airborne asbestiform fibers during such scenarios is also compared. Finally, a novel surrogate to monitor the airborne asbestiform fibers concentration at varying operating conditions is developed.

2. Materials and methods

2.1. Experimental methods

A part of the experimental work was carried out using an experimental chamber. Indeed, a 20 m^3 polyethylene chamber was constructed over a wood frame in order to approximate the size of a bedroom. A high-volume vacuum system with a high efficiency particulate filter (Nilfisk Alto ATTIX 350-0H class H) was used to provide a chamber air change rate of 2.0 h^{-1}, typical for bedrooms (Hardy et al., 1992; Du et al., 2012; Canha et al., 2017). A room fan was used to maintain the typical residential room condition and an ultrasonic portable home humidifier charged with asbestos contaminated groundwater was employed. The concentration of asbestiform fibers naturally present in humidifier charging water was 24687 f/L. Other experiments were conducted in the bathroom of a residential house and in the bathroom of a sport center, containing one and four showers, respectively. The concentration of the asbestiform fibers naturally occurring in the tap water of the residential house and of the sport center were 8229 and 7917 f/L, respectively. It is noteworthy that the three naturally contaminated waters used in this study were collected in different seasons and from different locations in the Biancavilla NPCS before the implementation of remedial action. No asbestos-cement pipes were employed in the municipal water system supply. After the implementatation of remedial action a strong decrease of fibers concentration in groundwater was observed.

The airborne asbestos-like fibers released either from the humidifier or from the shower were collected by a digital constant air sampler (mod. ZB1, Zambelli, Italy) equipped with an esters mixed cellulose membrane (25 mm diameter and 0.8 μm porosity). The air sampler was used at a flow rate of 1 L/min during all the experiments. In order to have similar initial ambient conditions inside the bathroom, prior to starting each test, the room was ventilated opening the window for a few hours.

Experiments were carried out at varying operating conditions (Table 1) in order to maintain a target value of relative humidity