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An analysis of the radioactive contamination due to radon in a granite processing plant and its decontamination by ventilation

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ABSTRACT

This work focuses on studying concentration distribution of ^{222}Rn radioisotope in a granite processing plant. Using Computational Fluid Dynamic Techniques (CFD), the exposure of the workers to radiation was assessed and, in order to minimise this exposure, different decontamination scenarios using ventilation were analysed. Natural ventilation showed not sufficient to maintain radon concentration below acceptable limits, so a forced ventilation was used instead. Position of the granite blocks also revealed as a determining factor in the radioactive level distribution. Thus, a correct layout of the stored material and an adequate ventilation system can guarantee free of exposure to radiation zones within the studied workshop. This leads to a drastic fall in the exposure of the workers and consequently minimises their risk of developing aggressive illness like lung cancer.

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1. Introduction

The three main decay chains observed in nature (called thorium, uranium and actinium series) contain radon gaseous element (^{220}Rn, ^{222}Rn and ^{219}Rn isotopes respectively). The half-live of these isotopes are 55.6 s, 3.82 d and 3.96 s, respectively, then, ^{222}Rn isotope is the only one that has a long enough life to be able to permeate through the rock into the air (Ferrero, 2013).

It is well known that inhalation of radon and their decay products constitute the largest fraction (52%) of radiation dose received by humans from natural background radiation (UNSCEAR, 2006, 2000a, 2000b). Indoor radon exposure has been linked to lung cancer cases in several studies (BEIR, 1999; Castren et al., 1985; Chen et al., 2010; WHO, 2009).). According to the United States Environmental Protection Agency, radon is the number one cause of lung cancer among non-smokers (ATSDR, 1990; U.S. EPA, 2003). This serious associated illness, the difficulty in detecting the gas (it is colourless, odourless and tasteless) and its zero chemical reaction make radon a highly dangerous gas (El-Hussein, 2005; Higgy et al., 2000).

There are many rocks that emit natural radiation, particularly those of metamorphic origin such as granite which contain all the radioisotopes of the mentioned half-life chains (Righi and Bruzzi, 2006; Taylor and McLennan, 1985). Therefore, a confined space containing metamorphic rock such as granite -material widely used in construction for ornamental purposes-poses a serious potential danger in the long term for human beings (Chao et al., 1997a; Gil-Lopez et al., 2013a; Stoulos et al., 2003).

Given the seriousness of exposing workers to high levels of radon concentration, there are extensive regulations (European Commission, 2001; WHO, 2009), as well as indications on the repercussions of these levels of concentration on workers' health (IAEA, 2006). These regulations are mandatory at international (ICRP, 2009; UNSCEAR, 2006; WHO, 2007), European (European

Abbreviations: Ac, concentration of radon, Bq·m^{-3}; *M*, molecular mass of ^{222}Rn, 222.01752 g/mol; *m*, mass of ^{222}Rn present in 1 m^3 of contaminated air, pg; *N*, number of ^{222}Rn atoms in the whole volume of the plant; N_{av}, Avogadro number, $0.60225 \cdot 10^{24}$ atoms/mol; *R*, ventilation rate in the plant, h^{-1}; *t*, time, s; *T*, ^{222}Rn escaped from granite to the surrounding air, 26.85 atoms of ^{222}Rn /(s·kg); $T_{1/2}$, half-life period of ^{222}Rn, 3.82 days; V_g, volume of granite, 200 m^3; V_r, plant volume, 15 640 m^3; λ, decay constant of ^{222}Rn, $2.10014 \cdot 10^{-6}$ s^{-1}; ρ, granite density, 2880 kg m^{-3}.

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Commission, 2001, 1999a, 1999b, 1997) and Spanish levels (RD 1439, 2010). In most cases, the permissible levels of radon in places of work, residence and leisure are set according to the term of exposure.

Studies for understanding radon release and for developing systems to control it are crucial for exposure control research. The information on radon emission processes, as well as on how it is transported and distributed in the environment, is essential for determining the permissible exposure limits to radon sources and radiation dose calculation due to the impact of radon on indoor air quality and consequent inhalation hazard. On the other hand, development of various mitigation techniques is crucial for controlling the dose due to radon and its progeny (Cavallo et al., 1996).

In confined volumes, radon has a nonuniform concentration distribution that depends on the flow field established in the volume, which is in turn governed by the airflow rate, the geometry of the volume, the inlet and outlet positions, etc. (Agarwal et al., 2016).

The radon distribution and its state of mixing inside the volume, is best simulated using software based on Computational Fluid Dynamics (CFD). Some works exist wherein CFD has been used to study radon distribution in rooms and dwellings (Agarwal et al., 2014; Urosevic et al., 2008; With and Jong, 2011; Zhuo et al., 2001).

Traditionally, indoor radon levels have been measured by passive methods using dosimeters and active methods using electronic devices, for example, continuous radon monitors. Some mathematical models are also developed to estimate the indoor radon concentration (Jelle et al., 2011; Stoulos et al., 2003). In recent times, CFD has taken outstanding position for simulation of indoor radon problems. CFD solves the governing fluid equations and provides spatial and temporal field solution of variables such as pressure, temperature and concentrations. It also provides velocity flow field and the dispersion pattern of indoor pollutant (Chauhan et al., 2014; Gil-Lopez et al., 2014, 2013b). Ability of commercially available CFD software to simulate a wide range of geometrical and environmental conditions is one of its striking advantages over other existing tools. Many CFD based studies have been carried out to model the entry of soil gas radon into buildings (Andersen, 2001; Loureiro, 1987; Wang and Ward, 2002, 2000, 1997). But limited CFD based studies have been performed to investigate indoor radon dispersion (Akbari et al., 2013; Urosevic et al., 2008; Zhuo et al., 2001).

This research uses a CFD model to analyse the concentration of radon in a granite processing plant and the performance of different alternatives of ventilation used to keep radon concentration level below the permissible levels.

2. Material and method

The purpose of this work is to measure the concentration of radon (^{222}Rn isotope) in the air that may be potentially inhaled by the workers in a granite handling plant. In the research, only the radon emitted by the granite blocks has been considered. Atoms emitted from the walls, floor or other construction material have not been taken into account.

For the purpose of determining the mass of ^{222}Rn and its distribution throughout the building, the characteristics of the plant and the material properties (volume, morphology, density and exhalation rate of the granite) have to be previously addressed.

A granite handling and processing plant was chosen as granite is a rock that is in wide commercial use and has a high rate of ^{222}Rn atoms escaped to the air (Sakoda et al., 2011; Chen et al., 2010).

2.1. Characteristics of the plant

The activity in the studied plant is the production of granite slabs out of 2 × 5 × 2 m granite blocks.

The plant comprises two closed workshops and a central space designed to store granite blocks. In the right hand workshop the granite blocks are cut and in the left hand one, they are transformed into slabs of thicknesses between 2 and 5 cm.

Each of the workshops has a rectangular shape of 80 × 22 m and is 9 m high. In one of the shorter sides there is an 8 × 8 m door (64 m^2), protected by a strip curtain with an air permeability of 80 m^3/h·m^2 for a pressure difference of 100 Pa. The top part of the building has a longitudinal ventilation opening of 80 × 0.8 m (64 m^2).

The study focuses on one of the workshops since both have the same shape and dimensions.

2.2. Material characteristics

In order to find the contamination produced by the radioactive decay products of radon inside the workshops, the dimensions and characteristics of the granite blocks are first analysed (IAEA, 2003; Taylor and McLennan, 1985).

The granite that is handled in the plant is of the Rojo Sayago variety. It was chemically analysed by an ICP − MS (Inductively Coupled Plasma Mass Spectrometry), by the Chemical Analysis Service of Salamanca University to define its elements and traces. The granite's chemical composition is set out separately depending on whether its components are higher than 1‰ (Table 1) or lower (Table 2). The concentration of the major components is expressed as a percentage in weight of the corresponding oxides of which the sum of the percentages must be approximately 100.

The most relevant chemical element found in the analysis is ^{238}U, the first radioisotope in the natural chain of radioactive decay. The remainder of the radioisotopes in the series, like ^{226}Ra (direct predecessor of ^{222}Rn) can be calculated from the secular radioactive equilibrium, considering that all radioisotopes have equal activity.

2.3. Adopted methodology

The decontamination of the radon radioactive decay products has some characteristics that make it markedly different from other types of decontamination. The radon passes into the air from the rock slowly and gradually. It cannot be detected by smell or colour. Being a noble gas it has a zero chemical reaction, which means that techniques based on chemical capture or combination with reagents are not viable. The only feasible technique for decontaminating is to dilute the gas with air, that is to say, using a ventilation-extraction technique (Chao et al., 1997b; NCRP, 1997).

One of the conditioning factors of the problem is that an extremely small amount of radon present in the air can be highly dangerous for health.

Table 1
Main components of the granite.

Components	Quantity (%)
Al_2O_3	14.32
CaO	1.06
Fe_2O_3	2.05
K_2O	7.18
MgO	1.48
MnO	0.04
Na_2O	6.05
P_2O_5	0.31
SiO_2	66.14
TiO_2	0.32
Volatile	2.43

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