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Analysis of the main factors affecting the evaluation of the radon dose in workplaces: The case of tourist caves

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Abstract

High concentrations of radon exist in several workplaces like tourist caves mainly because of the low ventilation rates existing at these enclosures. In this sense, in its 1990 publication, the ICRP recommended that high exposures of radon in workplaces should be considered as occupational exposure. In developed caves in which guides provide tours for the general public great care is needed for taking remedial actions concerning radon, because in some circumstances forced ventilation may alter the humidity inside the cave affecting some of the formations or paintings that attract tourists. Tourist guides can work about 1900 h per year, so the only option to protect them and other cave workers from radon exposure is to apply an appropriate system of radiation protection mainly based on limitation of exposure by restricting the amount of time spent in the cave. Because of the typical environmental conditions inside the caves, the application of these protecting actions requires to know some indoor air characteristics like particle concentration, as well as radon progeny behaviour in order to get more realistic effective dose values In this work the results of the first two set of radon measurements program carried out in 10 caves located in the region of Cantabria (Spain) are presented.

Keywords: Radon; Radiation dose; Tourist cave

1. Introduction

Inhalation of radon and its decay products is responsible of about half of the annual average effective dose received by the human due to natural sources of radiation [1]. Outdoor radon do not represent a significant health hazard because high concentrations are never reached. However, it becomes a problem when released into a closed or poorly ventilated enclosures like dwellings, buildings and also caves and mines. Indoor concentrations of radon and its short-lived progeny depend on several factors mainly related with the entry or production rate from various sources and the ventilation rate.

Many workplaces both above and below ground may be affected by high radon concentrations. On its 1990 publication, the International Commission of Radiological Protection, ICRP recommended that exposure to high radon levels should be considered as occupational exposure and remedial actions have to be taken in such situations [2]. Concerning the Spanish situation regarding radiation coming from natural sources, in 2001 the Spanish law incorporated EURATOM basic standards for radiological protection, which include a request at the EC Member States to determine the working places on which exposure to natural radiation is significant. On Title VII (BOE 178/2001) radiation coming from natural sources plays the same role than radiation emitted from artificial sources.

Tourist caves represent a case of workplace with particular environmental conditions that might be affected by high radon concentrations [3,10]. In these places in which guides provide visits for the general public, typical remedial actions like forced ventilation, sealing or reducing pressure in the source rock cannot be used because of conservation reasons. For example, forced ventilation could alter the humidity inside the cave thus affecting the paintings or geological formations that attract tourists. So in most of the cases the only way to reduce radon exposure to guides and other workers is to apply a radiation protection system based on restrictions in the amount of time spent in the cave.

The information needed for carrying out the above-mentioned protecting actions is related with the specific characteristics of the cave concerning the behaviour of radon

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and it decay products. In order to perform a precise effective dose calculation, factors like unattached progeny fraction (f_p), equilibrium factor (F) and particle concentration (Z) are of main importance. One of the specific characteristic of the caves is the high unattached fraction due to a particle concentration far below from the usual value in dwellings. The f_p values can be higher than 0.1, for places with low ventilation and without additional aerosol sources, with $Z < 4 \times 10^3$ particle cm^{-3}. In this work the results of the two-stage 10-month radon measurements within an annual program carried out in 10 caves located in the region of Cantabria (Spain) are presented. Additionally in two of them the results concerning particle concentration, continuous radon measurements and their implications in dose calculations are discussed.

2. Material and methods

Radon measurements were carried out in 10 caves located in the region of Cantabria in the North of Spain (Fig. 1). Radon detectors were exposed on 2005 from February to June in the first stage, and from June to December in the second one, and placed inside of each cave following criteria related with most probable risk situations for workers. The exposition time for this type of detectors was 6 months, which is a routinary period in order to avoid CR39 saturation when high radon concentrations can be expected. The analysed points were those in which guides usually spent longer periods giving explanation to the public.

CR39 track-etched detectors were used for integrating measurements. Every CR-39 detector was fastened under the cap of a cylindrical polypropylene container 55 mm high and 35 mm diameter which prevents radon decay products and also ^{220}Rn from entering. Then, only alpha particles from radon that has diffused into the container, and from the polonium produced inside can strike the detector. After the exposure time an etching process is done, and radon concentration can be determined by counting the tracks in a given area. Accuracy and precision of this method has been tested in a National intercomparison exercise [11], as well as in a recent European intercomparison with good results (not yet published).

Fig. 1. Location of the caves in the Cantabria region in Spain.

In two of the caves called “El Castillo” and “Las Monedas” continuous 10 days measurements were carried out using the device DOSEman radon dosimeter from SARAD GmbH. This system use semiconductor detector technology and is based upon the use of alpha spectrometry of the radon progeny (^{218}Po and ^{214}Po) present inside the detector chamber, and cover a measurement range of radon concentrations from 10 to 4×10^6 Bq m^{-3}. Radon concentration can be recorded each hour in a non-volatile memory.

Also in the two above-mentioned caves particle concentration was also measured by means of a condensation particle counter CPC ISI 3007. Air is pumped at a rate of 100 cm^3 min^{-1} and pass throughout a porous wick containing liquid isopropyl alcohol. After the exposure of the sample to the alcohol vapour, particles grow by condensation and can be detected optically with a laser light and a detection unit. With this device particle concentrations in the range of 0–500,000 particle cm^{-3} can be detected.

Mean annual effective doses coming from radon inhalation have been estimated by using ICRP65 dose assessment methodology [4]. The dose conversion factor (DCF) used for radon exposure was 5 mSv per WLM at work, assuming an equilibrium factor of 0.4 and indoor occupancy 2000 h per year. On the other side, the effective dose can be determined using the respiratory track model of ICRP 66 [5]. For doing so, the measurement of unattached fraction f_p is essential. The dependence of the f_p as a function of particle concentration Z can be approximated by the semi-empirical equation [6]:

$$f_p = 400/Z(\text{cm}^{-3}) \quad (1)$$

on the model of ICRP 66, DCF$_u$ for inhalation of the unattached short-lived radon progeny in mSv per WLM can be calculated from equation:

$$\text{DCF}_u = 8.4 + 64 \times f_p \quad (2)$$

3. Results and discussion

Table 1 summarizes the results concerning radon concentration and annual average effective dose calculated using the DCF from epidemiological. Taking as a reference value 1000 Bq m^{-3}, which is the action level for radon concentration in workplaces established by IAEA in 1996 [7] it can be observed that only about 18% of the measurements are above this value. With this reference, the caves of Castillo, Chimeneas, Hornos de la Peña and El Pendo could present radon problems.

Figs. 2 and 3 show the continuous radon monitoring in the cave of Castillo and Monedas, respectively. As it can be seen no significant variations in radon concentrations could be observed

Table 1
Integrated radon concentration and mean annual effective dose in several places inside each cave

Cave	Detectors placement	Average radon concentration ($Bq\,m^{-3}$)	Annual average effective dose (mSv)
Castillo	1st room	999	6.35
	1st panel	985	6.27
	2nd panel	657	4.25
	Ewe room	121	0.78
	End of gallery	1402	8.92
Monedas	Reindeer panel	323	2.05
	End of gallery	96	0.61
Chimeneas	Chimeneas viewpoint	117	0.74
	1st Deer	1461	9.29
	End of gallery	1395	8.87
La Pasiega	Intersection gals A/B	289	1.83
	End of gallery A	319	2.03
	Middle of gallery B	545	3.46
	End of gallery B	665	4.23
	Middle of gallery C	580	3.69
	End of gallery C	97	0.61
Hornos de la Peña	Central roundhouse	203	1.30
	End of the gallery	1408	8.95
El Pendo	Middle course	908	5.77
	End of the gallery	1070	6.80
Covalanas	Entry	600	3.82
	Middle course	103	0.66
	End of the gallery	60	0.38
Haza	End of the gallery	155	0.99
Sopeña	Centre of the big room	569	3.71
Chufín	Centre	43	0.27
	Inner panel	423	2.69

between night and day in a 10-day period measurements. This fact is usual inside the caves mainly due to low temperature variations and poor ventilation rates. However, radon concentration shows monthly variations in caves [8,13] so these continuous measurements also indicate the adequacy of long-term integrated measurements.

From ICRP's human respiratory model point of view, the differences on aerosol conditions can modify the dose conversion factors. For the most usual aerosol conditions in homes of $f_p = 0.08$ and equilibrium factor of 0.4, a DCF of 14 mSv per WLM has been obtained by Marsh et al. [9]. This DCF can significantly increase in caves, where particle concentration is very low and subsequently values of f_p as high as 0.8 can be found. The uncertainties in the calculation of DCF can be high using the dosimetric model because it involves the use of parameters like weighting factors for alpha particles and lung tissues which are difficult to determine accurately. In spite of this consideration, the great differences observed between the DCF's obtained from both models show the main relevance on unattached fraction of radon progeny in the dose calculations.

In the present work, particle concentration was measured in the caves of Monedas and Castillo. In these places Z values were

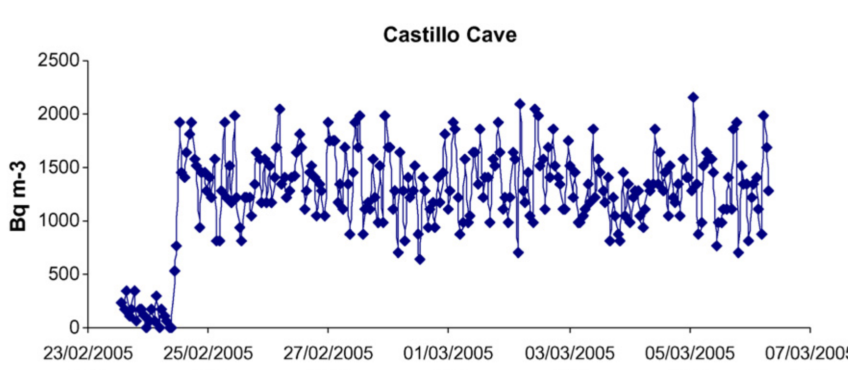

Fig. 2. Continuous radon measurements in the Castillo cave during a 10 days period.

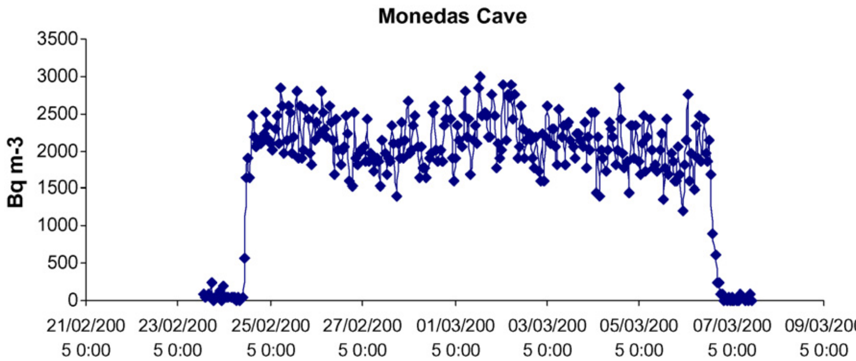

Fig. 3. Continuous radon measurements in the Monedas cave during a 10 days period.

of 464 particle cm^{-3} in Castillo cave and 1514 particle cm^{-3} in Monedas, which represents by means of Eq. (1) an unattached fraction values f_p of 0.862 and 0.264, respectively. By using Eq. (2), a DCF_u for inhalation of the unattached short-lived radon progeny for each situation of 63.6 and 25.3 mSv WLM^{-1}, respectively, was calculated. These values represent 12 and 5 times the one used in dose estimation from epidemiological evidences.

As a final conclusion, in order to carry out remedial actions in workplaces when high radon levels are detected, an accurate dose assessment is needed [12]. Tourist caves present monthly variations in radon concentration, so integrating passive methods appear to be adequate measurement solution. On the other hand, the extremely low particle concentration inside the caves can lead to higher doses than those received by people in workplaces with similar radon levels.

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