

## **Uncertainties in the evaluation of the dose coming from radon in tourist caves**

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### **Abstract**

Indoor radon poses a health risk confirmed by a variety of studies. High concentrations of this gas can be found in closed enclosures depending on several factors like activity of source term, permeability of the source/indoor air inter-phase, as well as the interchange rate of external air. Low ventilation rates together with the presence of <sup>226</sup>Ra in rocks, make the tourist caves a place where medium and high radon concentrations can typically be found. With the incorporation of EURATOM basic standards for radiological protection, into the national European legislations radon have been recognised as a health risk to be controlled in workplaces. The transfer of EURATOM standards to the Spanish legislation came out on Title VII (BOE 178/2001) where radiation coming from natural sources has an analogous role as radiation emitted from artificial ones.

The most significant exposure to radon in show caves is received by tourist guides who work providing tours for the general public. The implementation of an efficient radiological protection system for this kind of workplaces must take into account that in some circumstances forced ventilation may alter the humidity inside the cave affecting some of the formations or paintings. For this reason the best option to protect workers from radon is a system based on limitation of exposure by restricting the amount of time spent in the cave. For doing so, the knowledge of main uncertainty sources in dose evaluation is of main importance.

The principal variability sources in dose assessment are the integration intervals for radon measurements and the aerosol conditions related with the unattached fraction of radon progeny. The first factor takes into account the daily and monthly variations in radon concentrations and can not be fully addressed in caves with the seasonal correction factors proposed for the determination of radon doses in houses. On the other hand, mainly due to the low particle concentration usually present inside the caves, the unattached fraction of radon progeny can be higher than in other workplaces. This factor is significant when dose assessment is approached from the dosimetric respiratory track model of ICRP.

In this work the results of radon measurements carried out monthly in different points of 7 caves located in the region of Cantabria (Spain) as well as estimations of the dose received by workers approached from different integration intervals are presented. Also the results concerning particle concentration and its relationship with unattached progeny fraction together with their implications in dosimetric calculations are discussed for some of the caves.

***KEYWORDS: radon, dose, tourist caves***

## 1. Introduction

When we breathe in air with a concentration of radon and radon progeny, several alpha radioactive decays take place inside the lung. This irradiation is responsible of about half of the annual average effective dose received by the human due to natural sources of radiation. [1]. Outdoor radon does 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 type of workplace with particular environmental conditions that might be affected by high radon concentrations [3, 10]. In these places in which guides host visits for the general public, typical remedial actions like forced ventilation, sealing or reducing pressure in the source rock can not be used for conservation reasons. For example, forced ventilation could alter the humidity inside the cave thus affecting the paintings or geological formations that attract the 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 abovementioned protecting actions is related with the specific characteristics of the cave concerning the behaviour of radon and its 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  $Z < 4 \cdot 10^3$  particle  $\text{cm}^{-3}$ .

In the present work, the results of radon measurements carried out monthly in different points of 7 caves located in the region of Cantabria (Spain), showed in Fig. 1, as well as estimations of the dose received by workers and general public are presented. Radon exposure values are calculated from different measurement integration intervals in order to stress its importance as a source of variability in dose assessment. Additionally the results concerning particle concentration and its relationship with

unattached progeny fraction together with their implications in dosimetric calculations are discussed.

## 2. Material and methods

Radon measurements were carried out within 7 caves located in the region of Cantabria in the North of Spain (Fig. 1). Radon detectors were exposed monthly along 2008 and placed inside of each cave following criteria related with most probable risk situations for workers. 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  $^{220}\text{Rn}$  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 performed, and the radon concentration 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).

Also particle concentration was also measured by means of a condensation particle counter (CPC ISI 3007). In this device, air is pumped at a rate of  $100\text{ cm}^3\text{ min}^{-1}$  and passed 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 system particle concentrations in the range of 0 to  $500,000\text{ particle cm}^{-3}$  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 and 4 mSv per WLM for the general public, and the dose assessment is usually performed by assuming an equilibrium factor of 0.4 and indoor occupancy 2000 hours per year. In the special case of workers in tourist caves it must be taken into account that the occupational time is significantly lower than 2000 hours per year. For this reason, doses have been estimated from the real distribution of time spent by tourist guides inside each cave. On the other hand, the singular atmospheric conditions characterized by high indoor humidity and very low particle concentrations makes more appropriate the use of an equilibrium factor of 0.6.

From an alternative approach, 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]:

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

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

$$DCF_u = 8.4 + 64 * f_p \quad (Eq. 2)$$

### 3. Results

#### 3.1 Radon concentration

It is known that radon concentration shows monthly variations in caves [8,12]. As an illustration, Fig. 2 represents the variation in radon levels at different sectors inside the cave of Las Monedas. As it can be seen, seasonal variations are clearer at specific sectors more influenced by external changes in meteorological parameters. In each cave, from the set of values obtained monthly at different points, the annual average radon concentration has been calculated. In order to assess the influence of the integration interval in the estimation of the annual effective dose, average radon concentrations were calculated from three and six month measurements.

In Table 1, a comparison of three-month integrated values with the annual mean is showed. Taking as a reference value  $1000 \text{ Bq m}^{-3}$ , which is the action level for radon concentration in workplaces established by IAEA in 1996 [7] it can be observed that all the studied caves present some points above this value, although all the annual means are below. It can be found significant relative differences as high as 90 % with the annual mean. In some cases, when the measurements are carried out in summer period, the annual exposition to radon can be overestimated by factors up to 2. On the other hand, mean values coming from winter or spring seasons can lead to an underestimation of similar magnitude. Fig. 3 illustrates the abovementioned differences.

As it would be expected, integrated values obtained from six-month measurements fit better to the monthly averaged annual radon concentration, as it can be seen in Fig. 4. However, also in this approach, overestimations up to 75 % can occur when the measurements are carried out during the second half of the year, and underestimations up to 400 % can be observed when the measurements are performed during the first half of the year.

#### 3.1 Dose assessment

According to the above mentioned ICRP65 methodology and to the information available about the real time spent by each tourist guide at different sectors of the studied caves, the annual effective dose was estimated. As it can be seen in Table 2, only three workers received doses above the general public's limit of 1 mSv per year. In the same way, Table 3 shows the dose coming from radon inhalation received by public in one typical visit for each cave.

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 monthly at different sectors inside the caves. Table 4 shows a summary of values together with the corresponding dose conversion factors for the unattached fraction ( $DCF_u$ ) according to dosimetric model. Particle concentrations as low as  $100 \text{ cm}^{-3}$  were found in some points, which mean  $DCF_u$ 's from 3 to 8 times higher than that obtained from epidemiological approach. This would mean that in some work cases, radiological protection actions should be taken because doses up to 6 mSv per year could be possible.

#### **4. Conclusions**

With this study the annual mean radon concentration have been determined from monthly measurements at different points of several tourist caves. The results indicate that for an accurate dose assessment for workers under realistic situations the most detailed knowledge of the indoor radon levels evolution is needed. Approximations made from usual longer integration intervals as 3 or 6 months can lead to over or underestimations of the dose received by people working in the caves.

On the other hand, the extremely low particle concentrations found inside the caves can lead to higher doses coming from radon progeny inhalation than those received by people in workplaces with similar radon levels. Finally, in some cases particle concentrations lower than  $400 \text{ cm}^{-3}$  have been found which would mean an unattached fraction higher than 1. Maybe the relationship used in Eq. 1 can be questioned under special environmental conditions like those present in some tourist caves. This issue is now under analysis with new measurements of the unattached fraction in the studied caves.

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## Captions of figures and tables

Figure 1: Location of the studied caves in the Cantabria region in Spain

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

Figure 3: Continuous radon measurements in the Monedas cave during a 10 days period

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

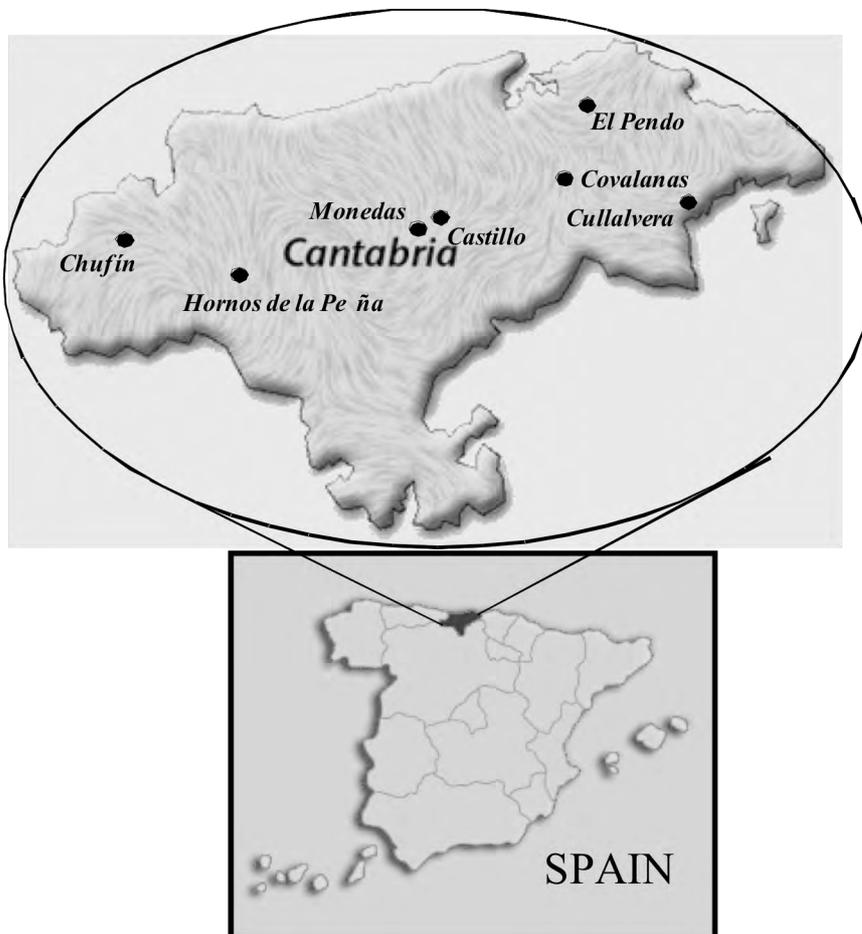


Figure 1

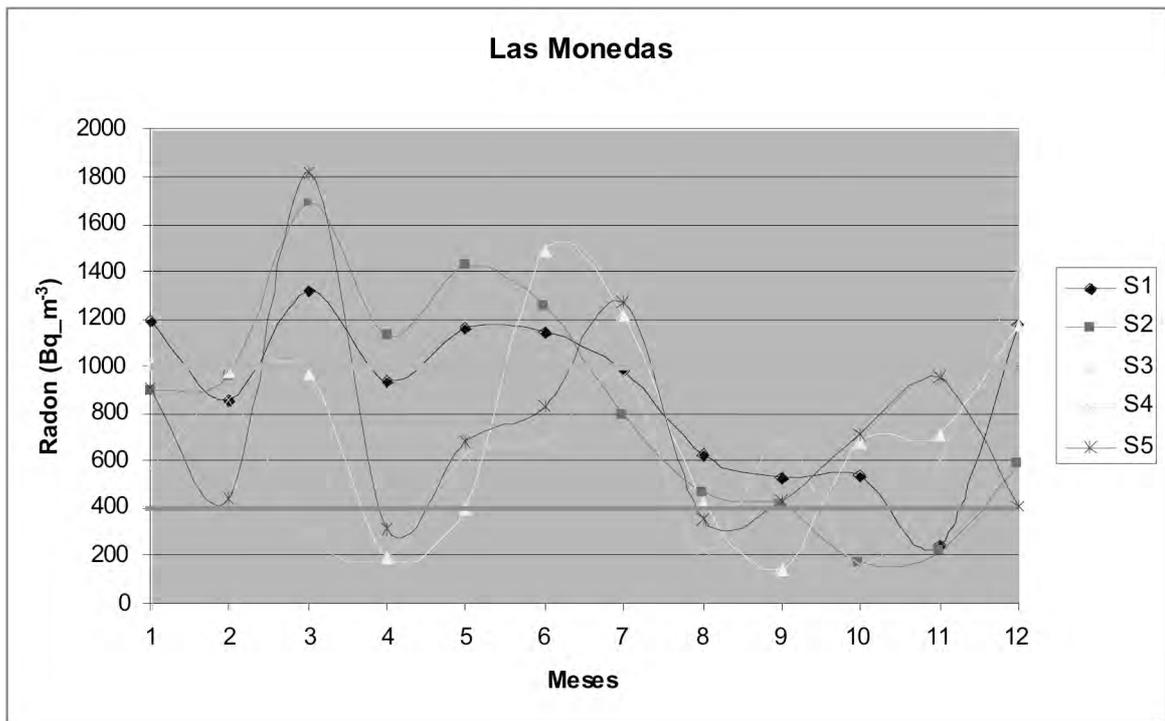


Figure 2

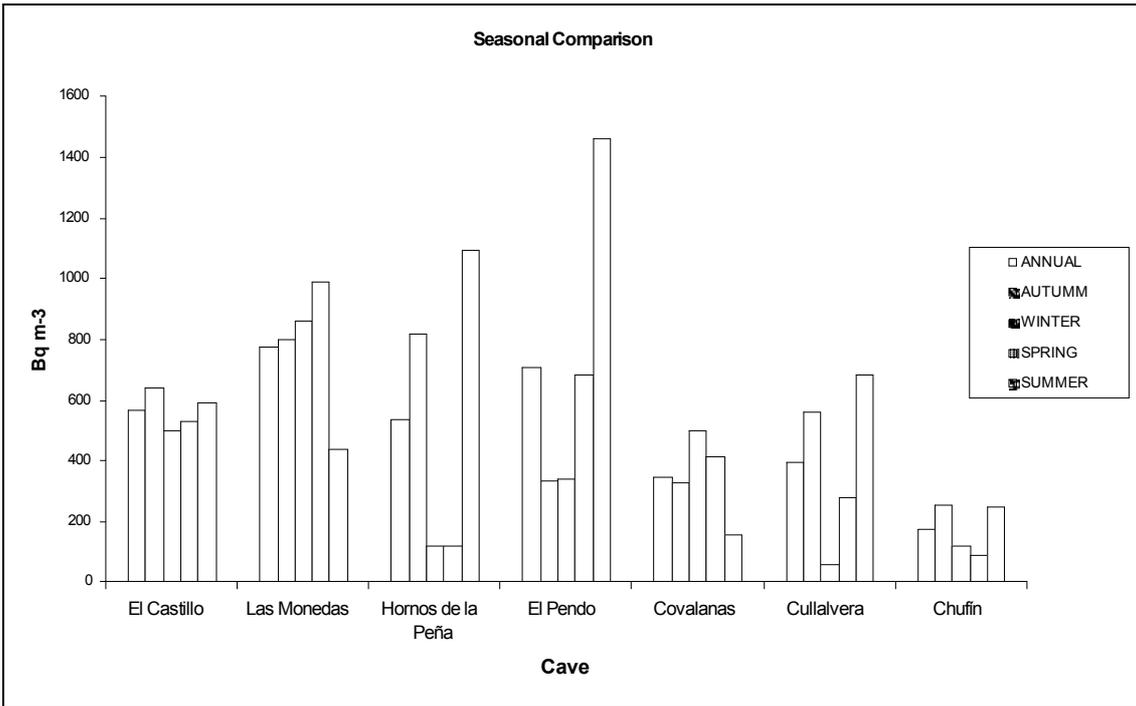


Figure 3

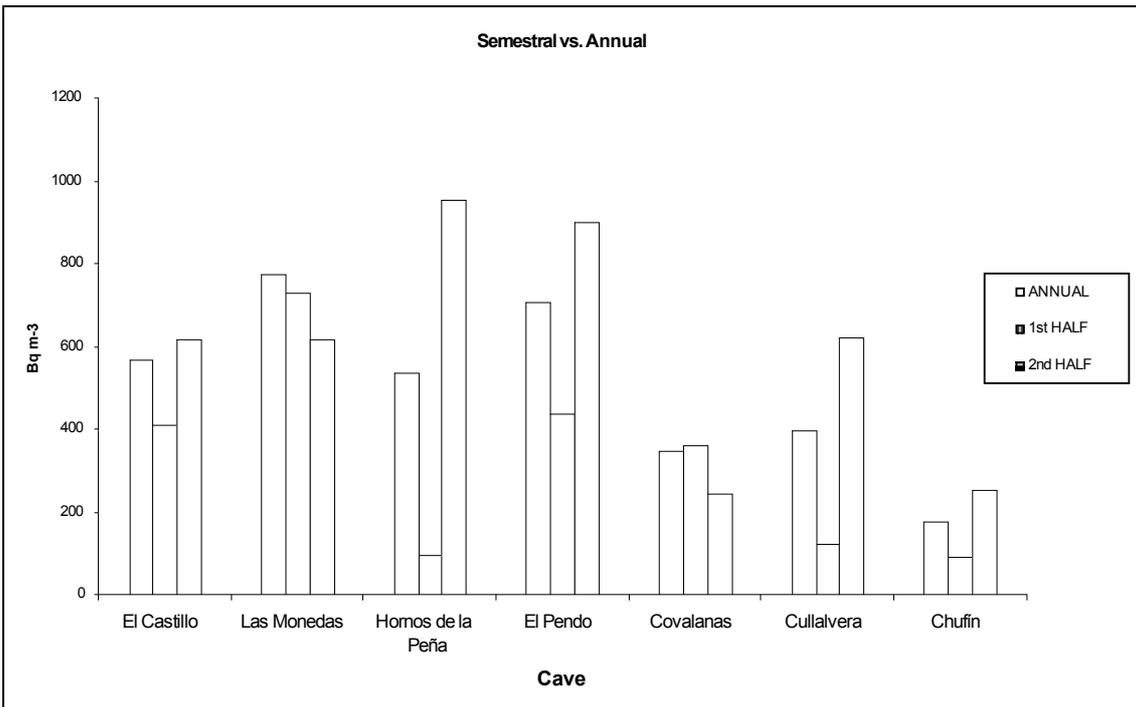


Figure 4

CAVE	MEAN RADON CONCENTRATION (Bq m <sup>-3</sup> )				
	ANNUAL	AUTUMN	WINTER	SPRING	SUMMER
<b>El Castillo</b>	571 (40- 1600)	643	500	534	595
<b>Las Monedas</b>	775 (170-1700)	804	863	995	438
<b>Hornos de la Peña</b>	539 (80-5300)	817	121	123	1096
<b>El Pendo</b>	707 (80-1700)	337	342	683	1465
<b>Covalanas</b>	350 (25-1110)	332	500	413	157
<b>Cullalvera</b>	397 (20-1600)	564	60	281	684
<b>Chufin</b>	179 (25-530)	256	121	88	250

Table 1

<b>Workers Tourist Guides</b>	<b>Dose (mSv y<sup>-1</sup>)</b>
<b>1</b>	<b>0.85</b>
<b>2</b>	<b>0.05</b>
<b>3</b>	<b>0.38</b>
<b>4</b>	<b>0.02</b>
<b>5</b>	<b>0.37</b>
<b>6</b>	<b>0.66</b>
<b>7</b>	<b>0.28</b>
<b>8</b>	<b>0.47</b>
<b>9</b>	<b>0.31</b>
<b>10</b>	<b>0.61</b>
<b>11</b>	<b>0.79</b>
<b>12</b>	<b>0.01</b>
<b>13</b>	<b>1.12</b>
<b>14</b>	<b>0.52</b>
<b>15</b>	<b>1.66</b>
<b>16</b>	<b>1.18</b>
<b>17</b>	<b>0.06</b>
<b>18</b>	<b>0.70</b>
<b>19</b>	<b>1.06</b>
<b>20</b>	<b>0.76</b>
<b>21</b>	<b>0.64</b>
<b>22</b>	<b>0.56</b>
<b>23</b>	<b>0.04</b>
<b>24</b>	<b>0.63</b>
<b>25</b>	<b>0.47</b>
<b>26</b>	<b>0.34</b>
<b>27</b>	<b>0.06</b>
<b>28</b>	<b>0.62</b>

Table 2

<b>Cave</b>	<b>Dose to the Public in one visit (mSv)</b>
El Castillo	0.0027
Las Monedas	0.0031
Hornos de la Peña	0.0088
El Pendo	0.0037
Covalanas	0.0021
Cullalvera	0.0023
Chufin	0.0015

Table 3

<b>Cave</b>	<b>Mean particle concentration (cm<sup>-3</sup>)</b>	<b>DCF<sub>u</sub> (mSv WLM<sup>-1</sup>)</b>
El Castillo	868 (100-350)	37,89
Las Monedas	1154 (600-3000)	30,58
Hornos de la Peña	3508 (440-19000)	15,70
El Pendo	1903 (400-5400)	21,85
Covalanas	1912 (370-16000)	21,79
Cullalvera	3106 (950-12000)	16,64
Chufin	3428 (1100-14000)	15,87

Table 4