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CONTRIBUTION OF RADON DOSE TO THE PATIENT EXPOSURE IN THE MOFETTE OF COVASNA SANATORIUM, ROMANIA

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Abstract: The purpose of this research is to present the results of in situ radiation dose measurements for patients treated in the mofette of Covasna Sanatorium, Romania. The vertical distribution of the radon activity concentration was monitored indoor, in the treatment room and the staff room of the sanatorium respectively. The effective dose that may be received by patients during one cure of treatment is situated in the interval of 0.026-0.19 mSv. During these treatments the curative effects of the exposure to mofette gas may be correlated to the radon concentration at the nose level. The radiation dose on patients under our measurement conditions is below the reference level. The annual effective dose for workers may reach up to 0.768 mSv, indicating the necessity of personal dosimeters for a reliable monitoring of the occupational exposure.

Keywords: radon, radon dose, mofette.

1. INTRODUCTION

The mofettes are natural gas exhalations at relatively low temperature, usually found in post-volcanic areas. The main component of the gas is carbon dioxide (CO_2) which is found in high concentrations, other components are methane, nitrogen, oxygen, helium, hydrogen, carbon monoxide, hydrogen sulfide and radon. During wet seasons the mofettes are characterized by mud and bubbles expulsions (Koch et al., 2000).

Mofettes can have gas flux of more than 20000 L/h and the gas mainly consists of CO_2 that can reach up to 99.8% by volume (Vaselli et al., 2002). Rainwater, snow or ice can close the small fissures in the topsoil and/or increase the resistance to a free discharge rate, thus short-term disturbances in the flow rate may occur (Heinicke et al., 2006).

The geological periods that are associated with the mofettes areas are Pliocene-Quaternary, strongly related with volcanic activities (Vaselli et al., 2002; Heinicke et al., 2006). Mofettes are always associated with active tectonics, the gas emissions are found in intraplate regions, tectonic windows and intersection of fault zones (Bissig et al., 2006; Somlai et al., 2007; Néda et al., 2008 a and b).

Following the postvolcanic activity, high amounts of CO_2 emanations reach the earth surface, potentially carrying radioactive gases, such as radon. Radon are continuously produced in the Earth's crust migrate together towards the surface mainly through diffusion and advection processes (Papp et al., 2010). The geogenic radon can be useful in other issues as in earthquakes, faults presence or dating (Vasiliniuc et al., 2011). Depending upon local geology, upward following gas may appear at the surface either as dry CO_2 emanations (mofettes) or as CO_2 mineral water.

The natural CO_2 springs are used in countries like Hungary or Romania in treatment of cardiovascular and rheumatic disorders. Although the curative effect is attributed to the carbon dioxide, several studies observed positive effects of radon upon the health of people living in high background radiation environments, demonstrating a potential effect on the immune system (Pratzel, 1997).

By inhalation or transcutaneous resorption of radon dissolved in water, depending on the type of treatment, the radon enters the body and is dissolved in the bodily organs. The intake of radon may be enhanced by concomitant heat or carbon dioxide. The energy produced by the disintegration of radon and its short-lived daughters generates ionization with production of oxidizing radicals that act at cells level (Pratzel, 1997).

In Europe, specific constructions of facilities with strict natural CO_2 dry bath treatment purpose can be found in Hungary - Matraderecske (Lazar et al., 2003; Kovacs et al., 2003) and Romania (Néda et al., 2008 a and b).

In addition to the CO_2 rich gas (95-98%), the high radon levels (higher than 125 $Bq \cdot m^{-3}$) may cause potential health problems (Néda et al., 2008 a and b). Therefore it is very important to know the level of radon in the mofette.

In this study, results of in situ radiation dose measurements for patients treated in the mofette of Covasna Sanatorium (Romania) are presented, in order to evaluate the effective dose that may be received by patients during one cure of treatment.

2. THE GEOGRAPHICAL AND GEOLOGICAL SETTING

The mofette of Covasna sanatorium is genetically related with The Neogene Volcanic range of the East Carpathians (Neda et al., 2008 a). The western (inner sector) side of the Eastern Carpathians contains also a large number of soda springs. Their location is mainly on the southern border of the Călimani-Gurghiu-Harghita volcanic chain (Pliocene–Quaternary origin). This zone exhibits the strongest heat-flow anomaly in Romania (85–120 $mW \cdot m^{-2}$; Vaselli et al., 2002). Geothermal heat flow anomalies describe the areas of natural CO_2 emissions (Bissig et al., 2006; Tank et al., 2008). Analysis of gas composition and $^{13}\delta C$ in CO_2, together with heat flow data, indicate that the CO_2 origin lies in mantle derived processes and the alteration and hydrothermal metamorphism of marine carbonates (Vaselli et al., 2002).

The geological background of the Covasna area consists of Paleocene and Cretaceous sedimentary deposits (Cretaceous Flysch) (Néda et al., 2008a). Covasna city is situated in Covasna County, in south from the southern end of the volcanic range, approximatively 260 km North from Bucharest, at 560 m height above sea level. Emanations of dry carbonic gas (mofettes) together with mineral water springs are a natural factor of Covasna, used with various therapeutically purposes. In order to benefit from the presence of all these natural factors, a sanatorium for patients with heart and cardiovascular diseases was created here with a modern ''artificial mofette'' where the dry CO_2 gas is introduced in a gas pool through a pipe from a deep borehole. A treatment consists of gas cures, as well as mineral water cures and other treatments provided under the supervision of medical staff**.**

A large study, made on 1000 patients suffering from arterial hypertension, was carried out here, evidencing favorable results. Other positive consequences of mofette therapy were obtained in peripheral ischemia, gynecological diseases, sterility and rheumatism (Pratzel, 1997; Brassai, 1999; Néda et al. 2008 b).

3. PRACTICAL USE OF MOFETTES

The mofettes are used for therapy purposes. Hence they are specifically adapted for the accumulation of the gas such that the patients can be exposed to appropriate concentrations (Franke et al., 2007).

Figure 1 presents a section of the mofette treatment room from Covasna sanatorium. The gas is applied in an auditorium shape room designed specifically as a "Roman Auditorium" with a different number of steps for different heights. The patients are placed on steps such that the lower half of their body is immersed into the gas, for a 20 minutes period in orthostatic position or seating on a chair. The CO_2 level in figure 1 represents the height of toxic CO_2 concentration. Under this level the patients are forbidden to inhale.

The gas is introduced through the inferior side of the mofette where the CO_2 concentration is 98% (Brassai, 1999). A detailed description of the design and utilization of mofettes can be found elsewhere (Néda et al., 2008 a and b).

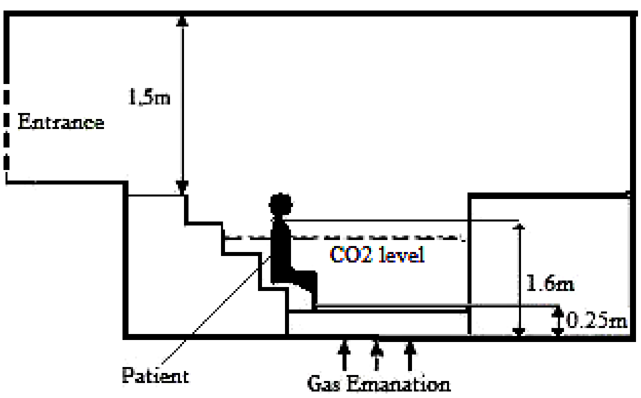

Figure 1. Schematic view of the Covasna Sanatorium mofette, Romania, with indication on vertical distribution of detectors (adapted from Néda et al., 2008a).

4. MATERIALS AND METHODS

This study measured indoor radon concentration in the sanatorium of Covasna in order to determine the magnitude of radon exposure and the effective dose received by the patients during a cure.

4.1. Radon Measurements

In situ measurements were performed during 2008-2010, according to the NRPB Measurements Protocol (Miles & Howarth, 2008). In order to determine the radon activity concentrations, integrated measurements were conducted in the treatments room, in the staff room and in outdoor air using 65 CR-39 track-etched detectors.

The height levels of the exposed detectors upon the patient's body are indicated in figure 1. In the treatment room, the detectors have been exposed on two vertical levels corresponding to the ankles and nose of 6 patients. For every patient and at each level a number of 5 detectors have been used, at a height of 0.25 m above the level of emanation and 1.6 m respectively (Fig. 1). Background correction was applied by using 5 detectors outdoors exposed.

The vertical distribution of the radon activity concentration was measured over a period of 15 treatment sequences, with a total exposure time of 5 hours and 8 minutes, a complete cure period.

After exposure the detectors were processed in laboratory using Radosys equipment. The measurements protocol has already been described elsewhere (Sainz et al., 2009; Cosma et al., 2009; Cucoş (Dinu) et al., 2012; Cosma et al., 2013; Papp et al., 2013).

4.2. Estimating the effective doses

Based on the measured radon concentration in the mofette's air, we calculate the effective dose received by a patient during treatment.

The radiation dose originating from the inhalation of radon and its daughter elements was computed by the following equation:

$$E_{Rn} = C_{Rn} \cdot K \cdot F \cdot t \qquad (1)$$

where, E_{Rn} is the effective dose (Sv) due to radon, C_{Rn} is the average radon concentration (Bq·m^{-3}), F is the equilibrium factor (0.4), t is the time spent in the investigated room (h), and K represent the dose conversion factor [ICRP and UNSCEAR - 9 and 12 nSv (Bq h m^{-3})$^{-1}$, respectively – were considered (ICRP, 2010; Harrison & Marsh, 2012).

5. RESULTS AND DISCUSSION

Table 1 shows the mean radon concentrations and effective radiation dose received by the patients during a cure in the sanatorium of Covasna. The individual error of radon measurements was estimated at less than 10%.

From this table, one can remark that above the CO_2 emission level, in the bath air at 1.6 m height (respiration level) the radon activity concentration is smaller than the concentration determined for 0.25 m height.

The radon mean activity concentration vary between 1437 and 8023 Bq·m^{-3} in indoor air of the mofettes, depending on the vertical level of the measurements. Our results are lower than the values of 125 kBq·m^{-3} obtained in the mofette of Matraderecske (Néda et al., 2008 a), located in Hungary in a similar geological background with Neogene Volcanic range.

The effective dose received by patients during a treatment cure in the mofette cave range between 0.026 and 0.19 mSv depending on the vertical level of measurements, as well as the radon concentration. The effective dose that may be taken into account as the effect of radon during the exposure to mofette gas is the one estimated from the concentration at nose level. Thus, the effective dose received by the patients in the mofette from the Covasna Sanatorium is 0.026 mSv respectively 0.035 (using UNSCEAR and ICRP dose conversion factors) for a cure composed by 15 treatment sessions of 5-23 min (total exposures time 5 hours and 8 minutes).

Table 1. Radon mean activity concentrations in the mofette from the Covasna Sanatorium and the effective dose received by patients and employees during a cure by using UNSCEAR and ICRP dose conversion factors.

Locations, Height	Nr. of measurement	$t_{exposure}$ [h]	C_{Rn} [Bq·m^{-3}]	E_{Rn} [mSv]
Treatment room, at 1.6 m height	30	5	**1437**	**0.026** (UNSCEAR 2010)
				0.035 (ICRP 2010)
Treatment room, at 0.25 m height	30	5	**8023**	**0.14** (UNSCEAR 2010)
				0.19 (ICRP 2010)
Staff room	5	168	**80**	**0.048** (UNSCEAR 2010)
				0.064 (ICRP 2010)

*** C_{Rn}= mean radon activity concentration; E_{Rn}= effective dose

This value is below the reference level (ICRP, 2010; Harrison & Marsh, 2012) and lower than 1% of the natural annual dose received by Romanian population, which was estimated to be 2.69 mSv (Iacob & Botezatu, 2000; Cosma et al., 2009). These values are significantly lower than the admissible annual dose limit. Thus, our results confirm that radon exposure during mofette therapy does not represent a public health problem. Moreover, in addition to the therapeutic effect of the CO_2, the effect of radon exposure on the patient's health could be also considered. As revealed the references (Néda et al., 2008 b; Baias et al., 2010), radon therapy may induce a positive effect on pain in rheumatic diseases.

Concerning the occupational exposure, the radiation dose resulting from the inhalation of radon and its daughter elements in the airspace should be taken into account. In this case, considering 2000 hours per year at work time (Van Deynse et al., 1999; ICRP, 2010; Harrison & Marsh, 2012), the annual effective dose could have a value of 0.576 mSv by using UNSCEAR dose conversion factors and 0.768 according ICRP dose conversion factors, respectively. Based on these results, the contribution to the annual dose for the medical staff can be estimated to represents about 2.5% of the natural annual dose received by Romanian workers previously reported (Cosma et al., 2009).

The results were also analyzed taking into account the geological context of the mofette's area. High CO_2 values are associated with elevated radon values because CO_2 has a role of a carrier for radon and both are being transported together from depth. In generally volcanic areas are particularly rich in radon gas emanation because the magma of feeding volcanic activity and its product are common sources of both CO_2 and radon (Papp et al., 2010). In addition, the Covasna Sanatorium is located in a Cretaceous sedimentary environment with relatively high radon potential.

Therefore, a more accurate radon risk assessement for both patients and medical staff exposed in moffete should be achieved.

6. CONCLUSIONS

Our results evaluate the effective dose received by patients during one cure of treatment in the mofette of Covasna Sanatorium (Romania). The radon mean activity concentration were found to be in the range of 1437 to 8023 $Bq \cdot m^{-3}$, which is comparable with the values previously reported by reference (Néda et al., 2008 a) but lower than the average values obtained for the mofette of Matraderecske, Hungary.

The effective dose received by patients during a treatment cure in the mofette cave range between 0.026 and 0.19 mSv depending on the vertical level of measurements. Comparing them with the recommended values to limit annual exposure can be seen that these values do not represent a health problem for patients. Furthermore, considering the possible health effects that radon from these dry emanations may have upon patients, research in this direction is offering supporting proof that concentrations of this magnitude may have a therapeutic effect for certain diseases, especially its long term pain relief after the treatment.

Regarding the dose received by medical staff, the contribution to the annual dose is about 2.5 % of the natural annual dose received by Romanian workers. Our estimated value is under considerable increase if the workers are exposed for significant time in the treatment room. A dose assessment using personal dosimeters would be suitable.

The results were also correlated with the geological context of the mofette's area. High levels of radon are due to both local soil geology and high CO_2 values, which plays the role of transporter for radon gas to the surface. Besides the Neogene Volcanic range located in the vicinity, the Covasna Sanatorium is located in a Cretaceous sedimentary environment with relatively high radon potential. As well as the therapeutic effect of the CO_2, the positive effect of radon exposure on the patient's health must be also considered.

As a continuance of the present study, more specific research will be conducted concerning the health effect of professional exposure for medical staff in moffetes.

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