RADON AND HYDROTHERAPY : APPLICATION TO FRENCH SPAS

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Introduction

From the earliest times, the human being is exposed to ionizing radiation from various natural sources. Radon, natural radioactive gas, takes an important part in this exposure. Recent international recommendations have included exposure to natural radiations as one of the sources to monitor in certain occupationally exposed groups. Among those mentioned are workers in thermal spas who may be exposed to high radiation doses due to high concentration of radon in indoor air of the spa. The European Community has set limits on radon concentrations in its 1996 OJEC directive and these must be incorporated into national legislation. This additional radiation burden due to radon in indoor environment of spa facilities has been studied by many researchers except in France (Uzunov *et al.*, 1981)(Steinhäusler, 1988)(Szerbin *et al.*, 1994)(Soto et Gomez, 1999). Whereas several studies were conducted about radon exposure in French homes, few studies have been driven on the occupational doses received in thermal spas. At present, there are almost 100 places in France used as health spas. Some of these have a long history going back to their use as baths in the times of the Romans.

Generally, the main source of radon entry in buildings is the soil underneath, with building materials as the second most important source. Its entry depends on the driving forces and on the characteristics of the interface between the soil and indoors. In the particular case of spa buildings, thermal water is the most relevant radon source, even in low water radon concentration situations, because of the great amount of water used during treatment period.

The aim of this study was to investigate the levels and variations of radon concentrations during treatment in two French thermal spas, a modernized and an old one. This paper presents the results of radon and decay product concentrations measurements and dose assessment.

Spa description

Although it is difficult to represent all spas in a single model, they can be considered to share a number of characteristics. All spa facilities under study comprise : treatment rooms; thermal water infrastructure where the water emerges either naturally or piped from the spring and across which the water is channeled from the spring to the baths or other installations such as pools and showers; and administration rooms however the building structure differentiates. The spa A was renovated during the last decade and a mechanical ventilation system was installed in all treatment rooms with the exception of the inhalation treatment rooms. The principal treatments are on rheumatic and respiratory courses. The spa B is an old facility, built in the 19th century on a radon rich ground, without mechanical ventilation system. All rooms are ventilated through window openings after treatment process. The administration room is built adjacent to the treatment area.

Pathologies treated in this spa facility concern the rheumatology, phlebology and gynaecology.

Materials and Methods

At the beginning stage, radon concentration measurements of the thermal waters of the spas under study were conducted in order to estimate their radon potential since no such measurements existed. Sampling was performed at the water supply site of the spas, following strict protocol to avoid radon gas loss. Water radon concentrations were measured using an ionizing chamber called AlphaGUARD[1] equipped with an appropriate unit (Aquakit), following a protocol proposed by the manufacturer. For measurement with Aquakit, the water samples were forced to degas their radon content within a radon tight assembly, which consists of two glass vessels and the AlphaGUARD unit. The water samples were taken at the source of the spring water, at faucets and at other points of use in the thermal facilities. Measurements of the ^{226}Ra concentration in water were also performed by gamma spectrometry.

The determination of the average concentration value in this type of facility presents the same general problems as measurements in homes (wide variation in the indoor radon concentration over time) plus other specific problems which arise as a result of high temperatures and high relative humidities which reduces the efficiency of sampling method based on filters for decay product determination. In order to determine long-term average indoor air radon concentration, integrating radon measurements were performed with open alpha-track-detectors, called Kodalpha[2], exposed for a 2-month period. Because bare alpha-track-detectors are sensitive to both radon and its progeny, they are sensitive to the equilibrium factor of room air. The Kodalpha detector is nominally calibrated for an equilibrium factor of 0.4, but because of unusual atmosphere conditions (high relative humidity) equilibrium factor has to be experimentally determined. Open detectors were displayed at a few representative places, where personnel spend most of their working time. In the spa A, thermoluminescence dosemeters were hung during the same period time to measure long-term gamma average dose rates.

In addition to the integrating Rn-measurements, indoor radon concentrations were continuously monitored in the indoor environment of spas by AlphaGUARD in 60-min data sampling cycles simultaneously with relative humidity during 3 weeks.

Short-term radon decay product measurements were carried out at a few representative places where different atmosphere conditions are encountered, using a MEAP III[3] monitor. It consists of air filtering method and subsequent count of the gross alpha activity of the filter over different time intervals. Radon daughters concentrations are calculated according to Rolle's method (Rolle, 1972).

Results and discussion

The results of the water radon and radium concentrations measurements are summarized in table 1. The radon concentrations in water measured at spring range from 236 to 420 $Bq.l^{-1}$. These concentrations are within the range of measurements reported for other

[1] Saphymo, 5 rue du Théatre 91884 Massy cedex, France.
[2] Dosirad, Villa Parc, Le Chêne, rue Lech Walesa, 77185 Lognes, France
[3] Algade, 1 Ave. du Brugeaud - B.P.46 - 87250 Bessines sur Gartempe, France

spas for France (Améon, 2003)(Rémy and Lemaitre, 1990) and they are elevated enough to indicate rather high radon potential to therapy rooms. The concentrations of radium dissolved in the water range from 250 to 2 750 $mBq.l^{-1}$. As with most deep waters there is a great difference between the radium and radon concentrations in the water. Remarkable is the fact that the average radon concentrations obtained at bathtub water tap are less than those found at spring by a factor of 6. An explanation is that radon gas escapes during piping of water along the water distribution channels. Measurements made to characterize daily and yearly variations in radon concentrations at spring showed that variations were below 10% of the mean value.

Location of water sampling		Mean ^{222}Rn concentration in water ($Bq.l^{-1}$)	Mean ^{226}Ra concentration in water ($mBq.l^{-1}$)	water temperature (°C)
Spa A	Spring	421 ± 48	2 750 ± 680	66
	Water reservoir	157 ± 22	2 450 ± 570	60
	Bathtub water tap	72 ± 8	2 550 ± 300	28
Spa B	Spring 1	269 ± 32	250 ± 50	61
	Spring 2	236 ± 32	290 ± 60	60
	Water reservoir	124 ± 27		50
	Bathtub water tap	46 ± 18		28

Table 1 : Average radon and radium concentration in thermal water with water temperature

The results of the indoor air radon measurements are summarized in Table 2. The integrated radon concentration values (50 – 3 000 $Bq.m^{-3}$) cover a wide range, depending on the different occupationally-defined sites. Though the highest values were expectedly found in water therapy rooms, very high radon concentrations were also detected at the water infrastructure rooms directly related to continuous radon emanation from spa water during periods of low ventilation rate.

Elevated indoor radon concentrations, higher than the French reference level of 400 $Bq.m^{-3}$, were measured in the spa B facilities. This seems to be in accordance with the high radon potential of the water and the lack of mechanical ventilation system. Even in the quite large entrance hall, radon concentration values were recorded higher than 800 $Bq.m^{-3}$. On the other hand, the radon concentrations in the treatment rooms of spa A are lower due to better ventilation, excluding the not ventilated inhalation rooms. Actually, efficient forced ventilation in underwater therapy rooms ensures low radon concentrations despite high degassing of radon rich thermal water. Ventilation appears effectively to prevent the accumulation of radon. Similar average levels were recorded in all rooms of the spa A therapy building with the only exception of both inhalation and water supply rooms, which have an unusual low air exchange rate. Therefore average radon levels, ranging from 250 $Bq.m^{-3}$ to 7 500 $Bq.m^{-3}$, were recorded at the inhalation rest rooms of both spas. For both French spas under study, the gas inhalation room, where the thermal water emerges naturally, simulates the thermal gallery atmosphere with warm, moist, radon-rich air. In this room, short-term measurements indicated unusually high radon concentration of up to 33 000 $Bq.m^{-3}$ during treatment period. This treatment is completed with a 30-minute rest, in the rooms adjacent to the treatment area. In these rest rooms, continuous measurements showed a daytime radon concentration increase correlated to the working activities due to constant influx of radon from the gas inhalation room into these adjacent rest rooms. In the aerosol inhalation rooms, aerosols can be generated by dispersion of thermal water with varying size distribution. Short-term radon concentration measurements performed in the inhalers showed that the air inhaled by the patients contains up to 3 000 $Bq.m^{-3}$. The high radon levels in the administration room of spa B are probably due to the low ventilation rate and to radon diffusion from the water distribution channel, a part of which crosses underneath this room.

Location	Indoor Rn concentration in Spa A		Indoor Rn concentration in Spa B	
	Mean§ ($Bq.m^{-3}$)	Range* ($Bq.m^{-3}$)	Mean£ ($Bq.m^{-3}$)	Range* ($Bq.m^{-3}$)
Administration	50		856	500 – 2 800
Entrance Hall	100		879	
Pools	260	25 – 250	1 310	90 – 1 940
Aerosol inhalation room	800	50 – 2000		
Gas inhalation rest room	2940	250 – 4 500		1 600 – 7 500
Underwater bath-tub	200	50 – 600	1 300	500 – 3 500
Fango room	250	25 – 350		
Water supply room	1 200	250 – 3 500		

§ from 30/06/03 to 15/09/03 * issued from continuous measurements £ from 5/04/00 to 29/05/00

Table 2 : Average and range of indoor radon concentration in 2 French thermal spas

The continuous measurements demonstrated that there is a marked daytime variation, dependent on working activities yielding very high daytime levels due to constant radon emanation from spa water (Fig 1). In water supply rooms, temporal variation of the radon levels is significant, showing extreme dynamics due to water using during treatment period. During the continuous measurement period, encompassing 18 days, a periodical radon concentration pattern could be observed. This pattern consists of continuous buildup of radon during the application period, between 6 a.m. and 12 noon, followed by a fast decrease when ventilation was intensified in the non-application period, in the afternoon. In aerosol inhalation rooms, the daytime increase of radon is governed by the continuous addition of radon from water spreading, reaching maximum levels close to 2 000 $Bq.m^{-3}$. Daytime increase without the influence of water application can be observed on Sundays when facility is not in operation. The daily variation of indoor air radon concentration seems to depend on a combination of radon emanation from the water and ventilation.

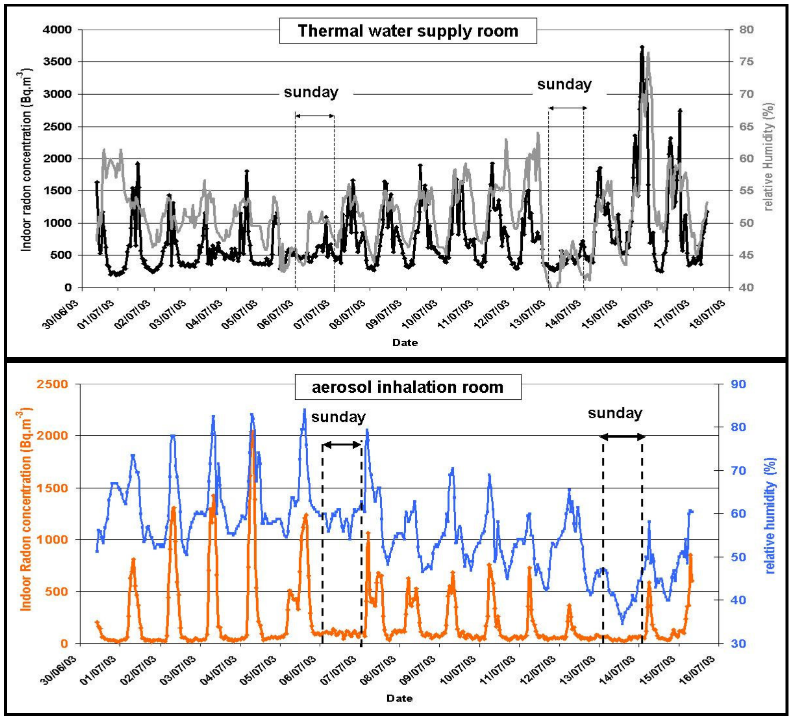

Fig 1 : continuous radon measurements at both thermal water supply and aerosol inhalation rooms (spa A)

Figure 2 shows the course of the hourly average radon concentration calculated with data continuously collected over three weeks at two treatment rooms in the spa B. Underwater therapy applied in tub-bath room, is one of the most efficient types of massage as it is performed by means of a water jet at different pressures. In this tub-bath room, temporal variation of the radon levels is significant, showing dynamics because of high radon degassing from thermal water due to jet-bubbling. In fact, baths are applied lasting not longer than 20 min. After each bath, the tub is emptied, and the water refilled for the next patient. For both water and inhalation therapy, a fresh radon-rich water is used, resulting in the working period radon level being higher than the whole-day average. In that case, the average radon concentration, determined by continuous measurements increased during working time (6 a.m. – 12 noon) between 60 % (inhalation) and 45 % (underwater tub-bath) compared to the total average for the measurement period and to the integrated radon concentration despite of another increase during night-time due to constant exhalation from the radon rich soil underneath the building.

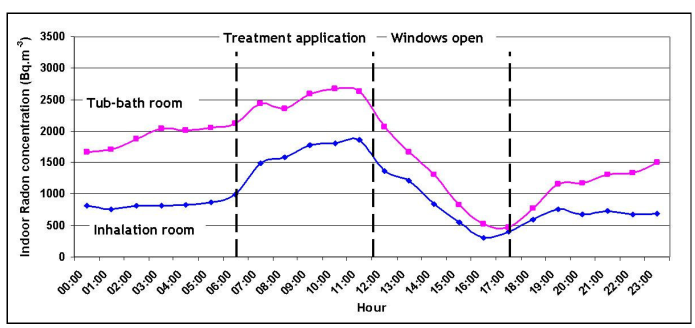

Fig 2 : hourly average radon concentration at two treatment rooms in the spa B

The main results of the indoor potential alpha-energy concentration of radon decay products are summarized in Table 3. The potential alpha-energy concentration values (0.3 – 38.8 µJ.m^{-3}) cover a wide range, depending on the different occupationally-defined sites. The highest values were found in gas inhalation therapy rooms where very high radon concentrations were also detected. The values measured at the water infrastructure rooms can be significant in unfavorable conditions (continuous radon emanation from spa water and low ventilation rate).

Location	**Range of potential α-energy concentration (µJ.m^{-3})**
Aerosol inhalation room	0.3 – 0.6
Gas inhalation rest room	1.8 – 7.9
Gas inhalation room	14.1 – 38.8
Water supply room	0.3 – 3.4

Table 3 : range of measured potential alpha-energy concentration of radon decay products in thermal spa A

Average gamma dose rates (in nSv.h^{-1}) in the period from June 30th 2003 to September 15th 2003 were 170 at water supply room, 150 at water therapy room, 175 at the aerosol-inhalation room, 235 at the gas inhalation rest rooms and 71 at the administration room. It seems that average gamma dose rates raise with increasing indoor radon concentration.

For the calculation of the occupational dose for the different rooms, measured equilibrium factor F values ranges from 0.14 to 0.6 were used. F value has a significant tendency to be low in humid conditions, in accordance with other authors (Lettner *et al*., 1996) (Reichelt, 1996) (Vaupotič and Kobal, 2001). For the evaluation of the annual effective dose to the staff, we have considered a working period of 210 days per year for 7 hours per day (because both spas are closed in the winter period). Considering that patients spend only a relatively short time in the spa during thermal treatment, dose calculations were only performed for spa workers.

The estimated doses, based on ICRP 65 recommendations, are presented in Table 4. These doses are biased by the variability of the radon activity concentration in indoor air with time. Therefore the mean values of integrated radon concentration over the measured time periods were used. However, considering that the average 2-month integrated radon concentrations are lower that the average radon concentration during working hours, this last one should be taken into account for accurate dose assessment.

In general, occupational exposure to radon in therapy rooms is subject to the different treatment procedures controlling temporal variation of radon concentrations. This is very important in gas inhalation therapy rooms where no ventilation is applied. The calculated doses for the water supply workplaces are rather overestimated if considering that technical workers move throughout the spa facility where radon concentrations can be lower particularly in the spa A.

Facility	Exposure situation	F measured	Effective annual dose ($mSv.y^{-1}$)
Spa A	administration	0.4	0.4
	Water therapy	0.5	1 – 2.8
	Aerosol Inhalation room	0.14	1
	Gas inhalation rest room	0.23 – 0.6	8.4 – 13.7
	Water supply room	0.3 – 0.5	1.4 – 3.4
Spa B	administration	0.4	1.4
	Water therapy		4.3 – 6.9
	Inhalation room		3.9

Table 4 : Dose estimate for occupational exposure to radon in 2 French spa facilities

According to the French legislation, reference levels for radon exposure in public buildings are expressed in terms of radon concentration. 400 $Bq.m^{-3}$ in averaged annual value is considered as the basic French reference level and 1 000 $Bq.m^{-3}$ is referred as the French warning threshold. In order to reduce radon staff exposure and considering the high radon levels measured in all rooms of the spa B, it was proposed to implement a mechanical intake and outlet ventilation system with heat exchanger of the treatment rooms in the spa. This mitigation technique applied in the course of the facilities restoration, resulted in a significant reduction of radon concentrations by about 80%.

In the case of the spa A, the highest exposure situation is found in gas inhalation room. Considering the fact that no ventilation system can be applied in this part of the building, it was proposed to move workers through the various treatment rooms.

Conclusion

The results of this study have shown that in a number of cases the radon concentrations measured in spa buildings are above the French reference level of 400 $Bq.m^{-3}$. Modern facilities with good ventilation systems give lower radiation exposure to workers even when higher radon concentrations in water are found. For an accurate assessment of the occupational exposure, the average radon concentration during working hours should be taken into account because of the great difference between those values and the average 2-month integrated radon concentration. The implementation of an appropriate ventilation of the treatment rooms and the mobility of spa workers through various treatment rooms can result in a significant reduction of staff exposure.

Average equilibrium factor values in both treatment and water supply rooms, determined from instantaneous measurements, range between 0.14 and 0.6, with a tendency to be low in high humid conditions.

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