Occupational Exposure to Radon in French Treatment Spa Facilities

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1. Abstract

From the earliest times, the human being is exposed to ionising 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 radon concentrations in indoor air through degassing from thermal water. The European Union set limits on radon concentrations in its 1996 OJEC directive and these have been incorporated into French national legislation. The implementation of the French regulation on radiation protection in thermal spas required the determination of a particular measurement methodology due to specific indoor environments (wide variation in the indoor radon concentration over time, warm and moist atmosphere). Two ways are proposed depending on the type of exposed people: public or workers. The first one is an improved version of the French AFNOR standard (NF M60-771) describing the protocol for radon mapping in buildings in order to detect radon concentrations higher than the French reference levels. The second way deals with both accurate radon concentration measurement during working hours and workstations' analysis.

2. Regulatory context applicable to treatment spa facilities

French regulations distinguish between exposures due to radon, managed through action levels expressed in activity concentration (Bq.m^{-3}), from those due to other sources, based on a dosimetric criterion (mSv.yr^{-1}).

The 22nd July 2004 order, relating to the management of risks linked to radon in public buildings, provides for radon measurements to be implemented in spa facilities located in the 31 departments ranked as priority (mean indoor Rn concentration measured in dwellings > 100 Bq.m^{-3}). These measurements must be performed in conformity to AFNOR standard NF M60-771 in force, and by approved organisations. This decree calls for two action levels: 400 and 1 000 Bq.m^{-3}, in average annual value, beyond which counter measures must be implemented in order to reduce the indoor radon concentrations.

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In the framework of the management of workers' exposure, 2003-296 decree provides for two application rules. The first (25th May 2005 order) for the work activities, which includes naturally occurring radioactive material (NORM) with a reference level fixed at 1 $mSv.yr^{-1}$. Hydrotherapy is concerned by NORM since radioactive thermal water is used. The second (order not published) for those where workers are exposed to radon because of underground workplaces other than mines (caves, mushroom growing, etc.) with an action level of 400 $Bq.m^{-3}$.

In short, workers radon exposure in French spa facilities must be managed in respect of both regulation with different action levels (400 $Bq.m^{-3}$ and $1mSv.y^{-1}$).

3. Main sources of radiation exposure in spa facilities

In spa facilities, the main sources of exposure are, in order of importance: inhalation of radon and its decay products and exposure to ambient gamma radiation, to which can be added, for the patients, the ingestion of radioactive thermal water (drinking treatment). In fact, the high radon concentrations in spas is a source of risk mainly for staff and to a lesser extent (due to lower occupancy) to the patients or visitors.

4. Inhalation of radon and its decay products

Generally, the main source of radon entry into buildings is the soil underneath, with building materials as the second most important source. In the particular case of spa buildings, radioactive 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 indoor radon activity concentration depends on both two potential radon sources (soil underneath and thermal water) and the ventilation of the various premises.

4.1 Radon sources in thermal spa buildings

The potential of the soil in contact with the building's slab and walls, as a radon source, varies according to the nature of the soil; its texture (permeability) and its radioactive characteristics (radium 226 content). Radon entry into a building depends on the driving forces and on the characteristics of the interface between the soil and indoors. Small depressurisation of the house, compared with the soil underneath, due to wind and indoor-outdoor temperature differences is enough to make the radon entering into the building.

Thermal water is a radon source, which varies according to its degree of use in the treatment buildings. In fact, indoor Rn continuous measurements demonstrated a marked daytime variation, dependent on working activities yielding very high daytime levels due to constant radon emanation from spa water. Non-existent after treatment has finished or when the facility is not in operation, the impact of thermal water on the Rn concentration enrichment is highest while treatment is being dispensed (see Figure 1)

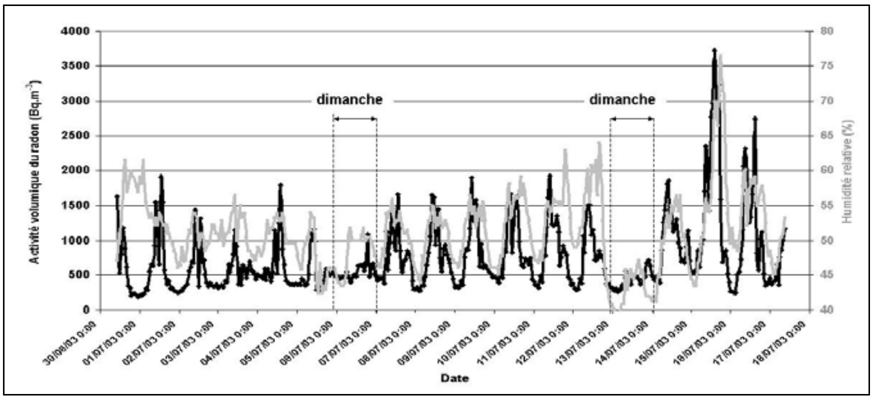

Figure 1. Example of Rn activity concentration evolution in the pipe gallery of a French thermal spa over 18 days duration.

The Rn degassing from water and consequently the air Rn concentration build-up occur rapidly (less than one hour) compared to Rn diffusion from the soil underneath (several hours). Its importance depends on:

1) the water radon content: the radioactivity of thermal waters, coming from the uranium, thorium and actinium in the Earth's crust, is directly related to the geological nature of the rocks through which the water passes. The values of radon activity concentration in French thermal waters, measured at the spring, vary considerably and range from 10 $Bq.l^{-1}$ to 1 400 $Bq.l^{-1}$ (Améon, 2003);

2) the water supply mode: thermal cures can be supplied in water directly from the point of emergence or indirectly via a storage reservoir or heat exchangers. Transferring thermal water from the spring to the various places where it is used in spa buildings may cause a decrease of the initial radon content due to degassing. A loss of around 80 % of radon activity concentration can be measured between the spring and the baths, after storage of the water (Fontan *et al*, 1980)(Améon, 2004). On the other hand, when the water is supplied directly to the points of use (well chambers or fountains, inhalation rooms) from the spring, the water radon content remains stable. Some treatments, such as baths, walking lanes, pools, may be supplied continuously with fresh thermal water (permanent source of radon) or recycled water (largely radon depleted);

3) the type of treatment dispensed: release of Rn from water occurs naturally but is accelerated when air flows through the water (injection of compressed air) or when it is moved (water jets in the baths, movements of the patients, vaporisation). At contrary, pelotherapy (with mud) uses few thermal water supplied indirectly yielding in a slight contribution to enrichment in radon.

4.2 Ventilation conditions of spa buildings

Ventilation, which plays a major role in the accumulation or not of radon in indoor air, is of special importance in the case of thermal buildings, due to the intensive and variable nature of the radon source linked to the thermal activity. Thus, the smallest radon concentrations are recorded in the summer period and in modern facilities with mechanical ventilation systems that ensures low radon concentrations despite high degassing of Rn rich water. Ventilation systems can run continuously or only during treatment application (Améon, 2003). Some facilities with seasonal thermal activity stop their ventilation system and confine the buildings when the facility is not in operation, despite the presence of workers.

Also, certain treatments, particularly for rheumatic pathologies, require a very warm, moist atmosphere partially obtained by confinement of the treatment rooms, and incompatible with any ventilation. These atmospheres – natural (thermal galleries or caves) or artificial (steam rooms) - are therefore highly radon rich, and contribute to enrich the air of adjoining rooms (e.g. restrooms) (Lettner *et al.*, 1996) (Améon, 2004).

In conclusion, indoor Rn concentrations in thermal buildings are conditioned by a combination of the following three factors; subjacent soil, thermal waters, and ventilation. Both direct supply of radon rich thermal water to the treatment area and lack of ventilation have a major impact on the radon enrichment of any atmosphere. However, even in case of indirect water supply, the contribution of radioactive thermal water to a potentially significant increase of air radon concentration, is generally very high, due to great quantities of water used during treatment periods.

5. Exposure to gamma radiation

Apart from terrestrial radiation, exposure to gamma radiation in spa facilities is due to

1) the radon decay products present in indoor air. their contribution varies according to the thermal activity via the indoor radon concentration variation, the air renewal rate and to the level of humidity;

2) deposits of radionuclides from the water in the various parts of the water circuit (pipes, pumps, heat exchangers, tanks, filtration sand). The share attributable to these deposits, especially important in the water infrastructure rooms (like pipe galleries), varies according to the water radionuclides content, and to how frequently the pipes are cleaned or changed.

Staff exposure to gamma radiation in spa facilities is far less than what is attributable to radon inhalation. However, radon rich places can contribute to enhance external exposure of workers to gamma radiation with dose rates up to 200 $nSv.h^{-1}$, this value being three times higher than the mean absorbed dose rate measured in French air indoors (Améon, 2004) (Billon *et al*, 2004).

6. Metrological aspects

According to AFNOR standard NF M60-771, determining long-term average indoor Rn concentration in a building must be performed by integrating radon measurements with passive devices such as alpha-track detectors (Solid-State Nuclear-Track Detector) and “electret” ion chambers.

In case of thermal buildings, several problems occur. First, measuring instruments suitable for application in warm and humid places may have to be employed. Second, equilibrium factor F values, measured in thermal rooms atmosphere range from 0.14 to 0.6 with a significant tendency to be low in humid conditions (Lettner *et al.*, 1996)(Reichelt, 1996) (Vaupotič and Kobal, 2001)(*Améon, 2004*). Because bare alpha-track-detectors are sensitive to both radon and its progeny, they are sensitive to the equilibrium factor of room air (the French Kodalpha detector is nominally calibrated for an equilibrium factor of 0.4). In fact, if equilibrium factor can not be experimentally determined, the simplest way to measure Rn is to use closed alpha-track-detectors. Third, due to extreme temporal variations of the air radon levels linked to water changing procedures, integrating Rn measurements may underestimate by 20 to 50 % the indoor Rn concentration just during the period of using water in a not ventilated building (Améon, 2004). On the other hand, they may overestimate it when the radon, accumulates in the rooms/areas during night-time, when the ventilation is shut down, due to constant exhalation from the radon rich soil underneath the building.

7. Natural radioactivity measurement methodologies

7.1 Public exposure

Determining average Rn concentrations in buildings must be performed using the methodology described in AFNOR standard NF M60-771 to which amendments will need to be made to take into account the peculiarities of thermal facilities (two potential radon sources; very humid atmosphere, seasonal activity) (Table 1).

Radon mapping in a building is performed using Rn integrating measurements over a minimum period of two months (between 15th September and 30 th April of the year n+1) during which the spa facility is unoccupied during consecutive days for no more than 20 % of the time. Measurements are performed using passive detectors implemented in homogeneous zones HZ (occupied more than one hour per day). A homogeneous zone is a zone with identical characteristics as regards the Rn entry (soil in contact with the building, thermal water, building materials, building's interface) and their distribution within the volumes of this zone (continuous or partial ventilation or non-existent). In each occupied HZ, the number of devices to set up is at least 1 device per 200 m^2 section with at least two dosimeters per building.

If the building is not involved in the thermal activity (administration), only the lowest occupied level is studied. In treatment facilities, all the floors must be studied but setting up the dosimeters will be conditioned by the use of thermal water and the minimum occupation rate defined above.

In order to determine the HZ in therapeutical or technical facilities, radioactive characterisation (^{226}Ra and ^{222}Rn) of thermal water has first to be conducted at the spring, at faucets and at other points of use. Then, treatments are classified according to how they are supplied with water (directly, indirectly, continuously) and their water radon degassing mode (agitation, vaporisation, etc.).

Table 1. Rn measurement methodology for spa buildings.

Type of building:	**Administration**	**Technical installations**	**Therapeutical facilities**
Determination of HZ	Soil/indoors interface Ventilation Thermal Gradient		
		Use of thermal water	Therapeutic agents used (water, gas, mud, etc.) Water supply (direct, indirect) Type of treatment
Measuring device	Rn Integrating measurement		
	Open or closed passive detector (SSNTDs), ion electret chamber	Closed passive detector (SSNTDs)	
Implantation of devices	Occupied HZ (occupation rate > 1hr/day)		
	Lowest occupied level of the building	All occupied levels. Implantation is conditioned by the use of thermal water for the highest floors	
Number of devices	1 per 200 m^2 section in each occupied HZ At least 2 per building		
Exposure of the devices Duration Recommended period	At least 2 months with unoccupied period less than 20% of the time Between 15 th September of year n and 30 th April of year n+1. Possible dispensatory period (except for summer period) if the spa is closed in winter.		
Result	Average activity Rn concentration measured per HZ or the highest measured value, when the measurement results show a disparity higher than the uncertain factors. This value is compared to the action level values		

7.2 Workers exposure

Spa staff exposure can be considered as an occupational exposure for medical doctors, bath attendants and maintenance workers who can be subjected to increased levels of radon daughter exposure in the course of their duties. On the other hand the administration staff is exposed mainly to radon issued from the soil subjacent to the building (administrative rooms/areas with no direct communication with thermal activity while the facility is in operation) as well as the public.

In the first case, the best way to assess occupational dose consists in performing accurate radon measurements during working period and workstations analysis. Indeed, using conventional integrated measurement (over several months without interruption) underestimates the radon concentrations to which workers are exposed during working time. Moreover, some staff members (maintenance workers, cleaning staff) divide their time between several working areas leading to a complex reconstitution of real exposure.

If the action level of 400 $Bq.m^{-3}$ has to be considered, radon personal dosimeters based on a device to be turned on and off at monitoring sites with diffusion alpha track detectors have to be used. The exposure period has to be set for three months during working hours and the result is expressed as radon activity concentration in ($Bq.m^{-3}$).

For the administration staff, Rn integrated measurements can be performed as well as the methodology developed for the public excepted the exposure duration, which can be extended to 3 months in order to be in line with the individual Rn dosimeters.

If the action level of 1 $mSv.y^{-1}$ has to be considered, monthly measurements of radon decay products and gamma radiation have to be performed at monitoring sites with personal dosimeter.

8. Conclusion

People exposure to natural sources of ionising radiation in French spa facilities must be managed in respect of both regulations related to the general public and employees.

The main sources of exposure, which need to be taken into account are in order of importance: the inhalation of radon from both the soil underneath the building and the radioactive thermal water and exposure to ambient gamma radiation from the radon decay products in air and deposits of radionuclides from the water in the pipes, pumps, heat exchangers, tanks and filtration sands.

Two ways for Rn measurement methodologies are proposed depending on the type of people exposed in thermal spa facilities.

In the framework of public protection, determining average Rn concentrations in buildings must be performed using the methodology described in AFNOR standard NF M60-771 to which amendments will need to be made (type, implantation and exposure period of the measuring devices) to take into account the peculiarities of thermal facilities (two potential radon sources; moist and warm atmosphere, seasonal activity).

French rules to be applied to hydrotherapy for occupational exposure are contradictory. Two different action levels of 400 $Bq.m^{-3}$ and 1$mSv.y^{-1}$, can be considered. However, spa workers are concerned with internal and external exposures. Because of the marked daytime Rn concentration variation dependent on the working activities, individual (radon or radon decay products) monitoring has to be performed for thermal staff, maintenance workers and cleaning staff.

9. References

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