Assessment of the Indoor Gamma Dose Rates in 15 Portuguese Thermal Spas

A. S. Silva and M. Lurdes Dinis

Abstract In Portugal, most of the average annual dose to which the population is exposed by natural sources is from radon (57%) and terrestrial gamma radiation (18%). In this study, the indoor gamma radiation dose rates were evaluated in 15 Portuguese thermal spas between 2011 and 2015. Gamma radiation dose rates were measured with a Geiger counter type GAMMA SCOUT® (GS3). The readings of the dose rate were hourly collected during a period of time ranging between 25 and 45 days, in different treatment rooms within each one the selected facilities: inhalation treatment rooms, thermal pools and vapors areas. All registered values for the gamma dose rates were lower than 1 mSv/year, and therefore the contribution of the external dose to the calculation of the annual effective dose is negligible.

Keywords Radon · Thermal spa · Gamma radiation · Distribution

1 Introduction

Radioactivity does not result exclusively from anthropogenic action, since the Earth has always been subject to cosmic radiation, forming part of some radionuclides.

Natural radiation includes cosmic radiation as well as the radiation arising from the decay of naturally occurring radionuclides. These, include the primordial

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radioactive elements in the earth's crust, their radioactive decay products, and radionuclides produced by cosmic-radiation interactions [2, 23].

The exposure to natural radiation occurs mainly in two ways: from external sources, which includes radionuclides in the earth and cosmic radiation, and by internal radiation from radionuclides incorporated into the body. The main routes of radionuclide intake are ingestion of food and water and inhalation. A particular category of exposure to internal radiation, in which the bronchial epithelium is irradiated by alpha particles from the short-lived progeny of radon, constitutes a major fraction of the exposure from natural sources [3, 6, 24].

In Portugal, most of the average annual dose to which the population is exposed by natural sources is from radon (57%) and terrestrial gamma radiation (18%) [5, 8].

Natural radiation from external sources is variable worldwide and this is due mainly to high or low soil concentrations of radioactive minerals. In particular, high concentrations of radioactive minerals in soil have been reported in several countries such as Brazil, India, and China. The high variations in doses received by the public from natural sources results from the fluctuations of concentrations in buildings [6].

Many human activities such as mining and milling of ores, extraction of petroleum, use of groundwater for diverse applications such as therapeutic treatments in thermal spas, modifies the natural background by concentrating the radionuclides in the exposure environment which can enhance significantly the radiation exposure [4, 9, 11, 12].

In thermal spas, the exposure to natural radiation occurs mainly from radon dissolved in water, which may be released to the indoors air, and its solid decay products but also from external gamma radiation, although the radon exposure will be of much higher magnitude. Water supplies makes only a small contribution to the indoor radon concentration but can be the predominant source in areas where the radon content of groundwater is unusually high [6].

In Portugal, the radiological surveillance of the environment is carried out through the Network of Continuous Monitoring of Radioactivity of the Environment (RADNET). The highest annual values of the gamma radiation rate in the national territory are recorded in area 1 and area 4 (Fig. 1).

Amaral et al. [1] conducted a study to determine the doses of gamma radiation in the external environment throughout the Portuguese territory, and verified that the dose of gamma radiation is higher in the districts of Braga, Viseu and Porto, due to the geological characteristics of these regions.

Silva et al. [17, 18] carried out a detailed study on exposure to external gamma radiation for indoor environments where high radon concentrations were observed [10, 13–22, 25]. Solid radon decay products are alpha and beta emitters but also gamma and they can contribute to the external dose from gamma radiation exposure [7].

The Decree-Law no. 222/2008 of 17 November, transposing Directive 96/29/Euratom of the Council of the European Union (repealed by Directive 2013/59/Euratom) lays down the basic safety standards for protection health and safety of

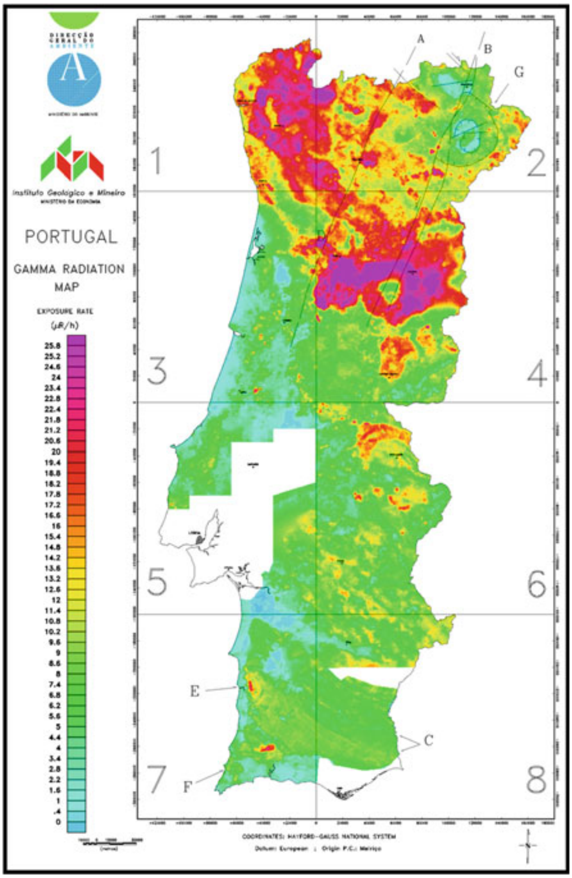

Fig. 1 Gamma radiation map Portugal natural gamma radiation letter from continental Portugal. A-fault of RéguaVerin; B-fault of Vilariça; C-flysch units of the Mira and Mértola formations are clearly visible in the radiometric image; D-São Pedro do Sul; E-volcanics mapped with the same geological behavior; Sienitic complex of Monchique, shows different geochemical characteristics, E and W a major fault; Morais Vinhais basic and ultra-basic G-complex

the general public and workers against the dangers arising from ionizing radiation, including work involving exposure to sources of natural radiation, such as thermal spas.

The objective of this study was to evaluate the indoor gamma dose rate in particular environments, such as thermal spas, and evaluate the contribution to total exposure dose. The assessment was carried out within 15 Portuguese thermal spas where both high and low indoor radon concentrations were registered.

2 Materials and Methods

The study was developed in 15 Portuguese thermal spas, distributed in the following districts: Viseu (4), Guarda (3), Braga (3), Porto (2), Castelo Branco (1), Aveiro (1) and Bragança (1).

Most of the occurrences of natural minerals in Portugal (with emergency temperatures between 20 °C and 76 °C) are located in the North/Center of the Country, due to the different geological and specific structural characteristics of the rest of the Portuguese territory.

To measure the indoor gamma dose rate in the selected thermal spas, a calibrated instrument able to measure either γ radiation, $\alpha + \beta$ and $\alpha + \beta + \gamma$, as well, was used (GAMMA SCOUT®—GS3). The equipment was used in the option gamma radiation dose rate measurements.

The Gamma-Scout is a Geiger counter with a wide measuring range and can be used to take instantaneous or time-integrated measurements.

The measurements were carried out for an exposure period comprising 25 and 45 days, within different treatment rooms of each ones of the thermal spas inhalation treatment rooms (ORL); thermal pool (TP); steam area room (SA) between 2011 and 2015.

Measurements of the gamma radiation dose rate almost always occurred simultaneously with measurements of radon concentration in indoor air.

In relation to the gamma radiation dose rate data, two tests for normality were applied to the data obtained for this variable: Chi-square test and Kolmogorov-Smirnov test.

The aim of this study was to analyze if the data of this variable presented a standard, to be followed later on another type of approach, namely the construction of a model, that would be applicable to all the Portuguese thermal spas and that explained the behavior of this variable foreseeing the risk of occupational exposure to radon for spa workers.

From the data collected for the radon concentration in indoor air it was possible to calculate the dose resulting from internal exposure by inhalation of radon and the annual effective dose combining the first dose with the dose resulting from external exposure given by the dose rate of gamma radiation.

3 Results and Discussion

The dose rate of gamma radiation was measured at 15 Portuguese thermal spas in the following places: TP, ORL and SA. The results are shown in Figs. 2, 3 and 4, respectively.

Gamma radiation dose rates were measured in the thermal pool of thermal spa 1 (TS1), 3 (TS3), 10 (TS10), 11 (TS11) and 14 (TS14) (Fig. 2).

The mean dose rate of gamma radiation in the thermal pool was 0.148 (TS1), 0.644 (TS3), 0.551 (TS10), 0.295 (TS11) and 0.332 (TS14) μSv/h, respectively. The highest value for the mean dose rate of gamma radiation was obtained in the thermal pool of TS3 (Fig. 2).

Regarding the variation of the gamma radiation dose rate data, it was found in the TS3 and TS10 thermal spas that the values obtained had the greatest variation.

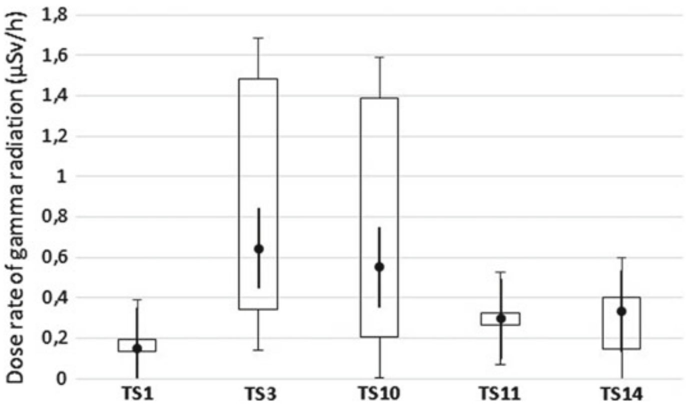

Fig. 2 Gamma radiation dose rate in TP

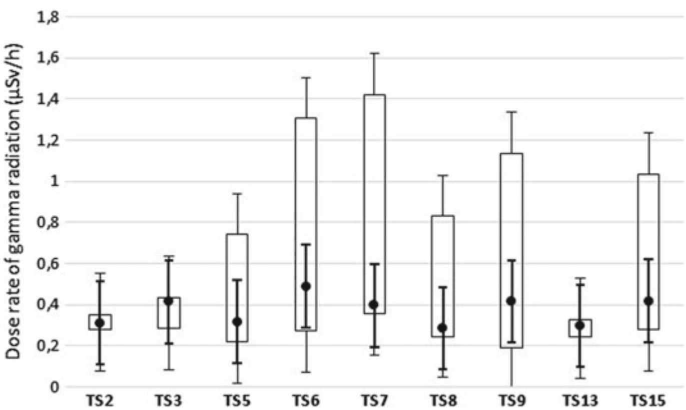

Fig. 3 Gamma radiation dose rate in ORL

However, it was in thermal spa TS1 that the data presented a lower variation, 0.132 and 0.192 µSv/h, respectively.

On the other hand, the gamma radiation dose rate values measured at the thermal spas TS2, TS3, TS5, TS6, TS7, TS8, TS9, TS13 and TS15 are very similar, in terms of data amplitude, to the values obtained for the dose rate of gamma radiation measured in the thermal pool of TS1, TS3, TS10, TS11 and TS14. This can be explained by the values of indoor air radon concentration and type of ventilation (mechanical ventilation) obtained at each spa site.

The highest value of the gamma radiation dose rate obtained in the TS6 ORL (0.490 µSv/h) is slightly lower than the highest mean value obtained in the TS3 thermal pool (0.644 µSv/h) (Fig. 3).

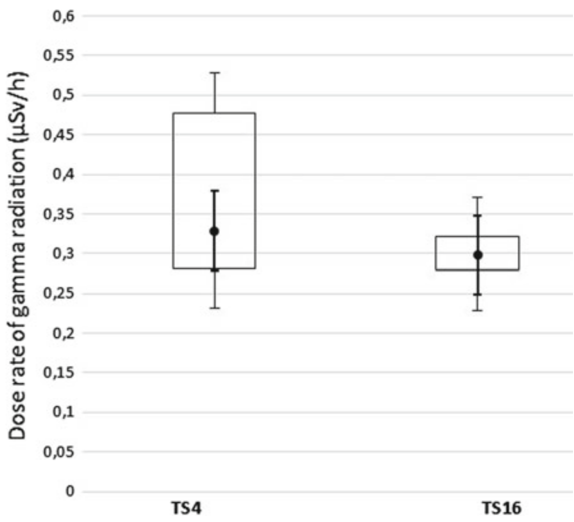

Fig. 4 Gamma radiation dose rate in SA

It is also verified that the values of the dose rate of gamma radiation in the ORL have a greater amplitude of values (TS6, TS7, TS9 and TS15) than the values of the dose rate of gamma radiation of the thermal pools. The reason for this data is the concentration of radon in indoor air, radon concentration in the water and type of ventilation (natural ventilation).

In relation to the dose rate values of the dose rate of gamma radiation obtained in SA, it is verified that the range of values is lower than the values obtained in the thermal pool and ORL. Gamma dose rate values range from 0.279 (TS16 minimum) to 0.478 (TS4 maximum) µSv/h (Fig. 4). This data can be explained by the type of ventilation (mechanical and natural) and radon concentration values in indoor air

For the values of the gamma radiation dose rate in the SA of the TS16, the data distribution is symmetric, since the median value (0.298 µSv/h) is identical to the mean value (0.298 µSv/h) (Fig. 4).

Considering the values of the dose rate of gamma radiation obtained in the TP, ORL and SA of the thermal spas, the distribution tests.

The adjustments to different types of distribution (Normal, Log-Normal) for the gamma radiation dose rate values were tested using the Kolmogorov-Smirnov (KS) test, and a significance level of 0.05 was adopted for the value of alpha (α).

In the case of the measurements of the gamma dose rate performed in the thermal pools, it was verified that the values obtained in the thermal spas TS1 and TS11, follows a normal distribution (Figs. 5 and 6).

On the other hand, the values of the gamma radiation dose rate measured in the ORL that followed a normal distribution were the values obtained in the thermal spas TS4, TS7, TS8, TS13 and TS15.

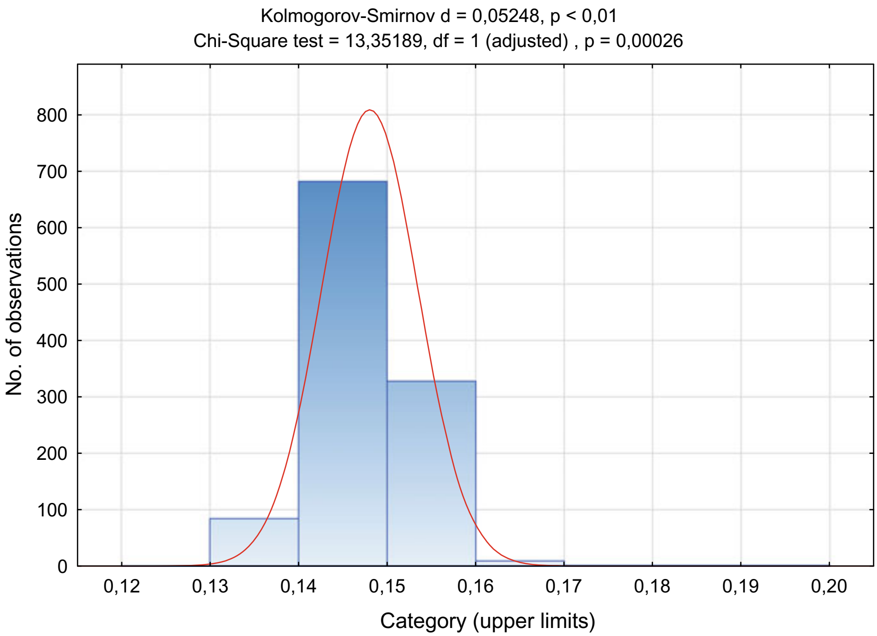

Fig. 5 Normal distribution for the gamma radiation dose rate values obtained in the TS1 thermal pool

4 Conclusions

No abnormal or too high values were detected for gamma dose rates in any situation and, therefore, the contribution of the external dose to the calculation of the effective annual dose is negligible.

Portuguese legislation (Decree-Law 222/2008) stipulates that professional activities in thermal spas may result in an annual effective dose higher than 1 mSv, and in these cases workers should be considered within an "existing exposure situation". Depending on the values of the annual effective dose, workers are classified into two categories (A and B) and specific measures are previewed for each one of these situations.

The purpose of Directive 2013/59/Euratom is to improve the radiological protection of workers who are or may be exposed to radiation, including workers who are exposed to natural radiation in the course of their professional activities, such as thermal spas. Therefore, according to the legislation, measures should be taken to monitor and control the radiation exposure in these professional activities, such as: (i) implementation of a monitoring system for the radiological protection of

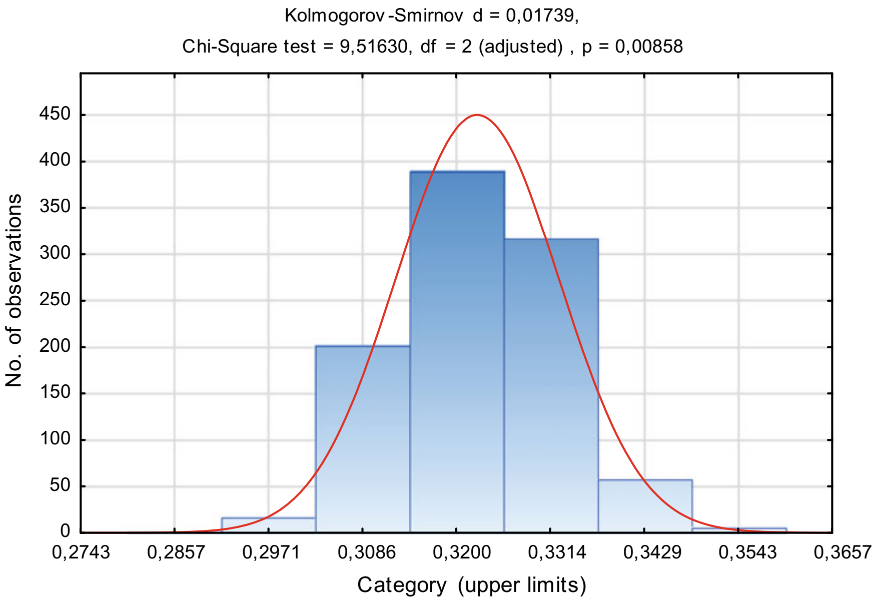

Fig. 6 Normal distribution for the gamma radiation dose rate values obtained in the TS11 thermal pool

workers; (ii) implement a radiological control plan for the facilities; (iii) ensure that these facilities have adequate and effective ventilation; (iv) health surveillance programs for workers.

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