The National Radon Action Plan – a Strategy for the Management of Radon Exposure in Thermal Establishments

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Abstract: The National Radon Action Plan (NRAP), prepared by the Portuguese Environment Agency (APA), meets the recommendations made by the international organizations (WHO, IAEA, UNSCEAR, ICRP) and presents a set of requirements and actions that aim to reduce the long-term risks arising from exposure to radon in homes, public buildings and workplaces. According to the WHO, radon is the second leading cause of lung cancer. The present work aims to frame the studies on indoor radon levels carried out in Portuguese thermal establishments with the guidelines of the Portuguese NRAP. For the preparation of this study, the Portuguese NRAP and previous studies on occupational exposure to radon in thermal establishments were analyzed. These studies concluded that thermal establishments are located in places with a high susceptibility to elevated radon exposure, as the indoor radon concentrations are above the reference level of 300 Bq/m^3, originating in most of the situations an effective annual dose above 6 mSv/year.

Keywords: Radon, Thermal establishments, Occupational exposure, Radon action plan

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1. Introduction

The legal regime of protection against the hazards resulting from exposure to ionizing radiation established by the Directive 2013/59/Euratom, transposed in Portugal through the Decree-Law No. 108/2018 of 3 December, provides for the mandatory development and implementation of a National Radon Action Plan (NRAP) by the competent authority, Portuguese Environment Agency (APA). The first version of this document (under public consultation up to the 1st of April) presents a set of requirements and actions that aim to reduce the long-term risks arising from the exposure to radon in dwellings, public buildings and workplaces.

The NRAP is divided into four chapters. The first chapter characterizes the radon gas and the health risks inherent to its exposure, including a brief international and national regulatory framework. The second one addresses the situation regarding radon exposure in Portugal. The third one defines the objectives, vision, and pillars that guide the development of the NRAP, and the last one describes the means and instruments of implementation, monitoring, and reviewing the NRAP.

The NRAP is in line with the recommendations made by the international organizations responsible and involved in radiation protection matters, namely: the World Health Organization (WHO), the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Radiation (UNSCEAR), and the International Commission on Radiological Protection (ICRP).

According to the WHO, radon is the second leading cause of lung cancer death (WHO, 2009; WHO, 2008; WHO, 2007; WHO, 2006; WHO, 2002; WHO, 2001; UNSCEAR, 2008a; UNSCEAR, 2008b; UNSCEAR, 2000; USEPA, 2007; USEPA 2001; IAEA, 205; IAEA, 2014; IAEA, 2010; IAEA, 2004;IARC, 2001), accounting for 21 000 lung cancer deaths annually, with 2 900 of these deaths occurring among people who have never smoked (EPA, 2013), the risk of lung cancer from radon exposure is higher in smokers (Silva & Dinis, 2021; Du et al., 2019; Chen, et al., 2016, EPA, 2013; Erdogan et al., 2013, ICRP, 2014; ICRP, 2010; Ferlay et al., 2007; Jacob et al., 2007; Darby et al., 2005). The WHO (2009) estimates that exposure to radon causes between 3% and 14% of all lung cancers in a country, depending on the average concentration of radon and the prevalence of smoking and that the risk of lung cancer increases by about 16% for every 100 Bq/m^3 increase in indoor radon concentration.

The present work aims to frame the studies on radon carried out in Portuguese thermal establishments with the guidelines of the Portuguese NRPA.

1.1. Indoor radon levels in Portugal

In 1987, a national study was carried out by the Department of Radiological Protection and Safety of the former National Laboratory of Industrial Engineering and Technology to evaluate the indoor radon concentration using 4 200 dosimeters and estimate the resulting annual effective dose. The results from this study showed an average indoor radon concentration of 37 Bq/m^3 and an effective dose of 1.9 mSv/year (Faísca, 1992). This study was used to produce a map of the distribution of radon concentrations in Portugal. In 2005, the map was published (ITN, 2005) presenting the results of the indoor radon concentration grouped by levels: i) < 25 Bq/m^3; ii) 25-50 Bq/m^3; iii) 50-200 Bq/m^3 (Figure 1).

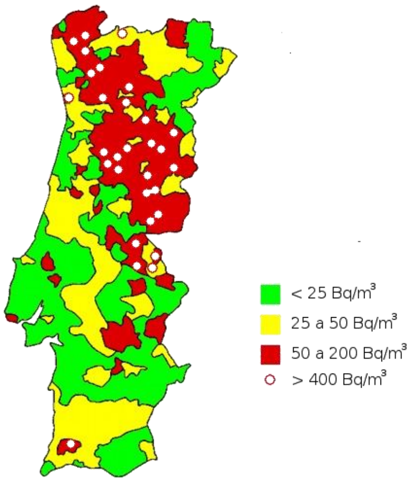

Fig. 1. Annual mean values of radon concentration in Portugal (ITN, 2005).

In 2020, a new national survey was carried out by the Natural Radiation Laboratory of the University of Coimbra in dwellings located in geological units with little or no characterization of the indoor radon concentrations (Domingos el at., 2021). A total of 2 224 passive detectors were analysed. In addition to the measurement of the indoor radon concentrations, data on radon concentration in soils, uranium concentration in rocks, Ra-226 activity concentration in rocks and ambient gamma radiation dose rates were included in this study.

This study was used to identify and classify the national territory according to the risk of indoor radon exposure, such as low, moderate and high-risk areas (Figure 2) and represent areas of susceptibility to elevated indoor radon divided by parishes (Figure 2) (Domingos, et al., 2021).

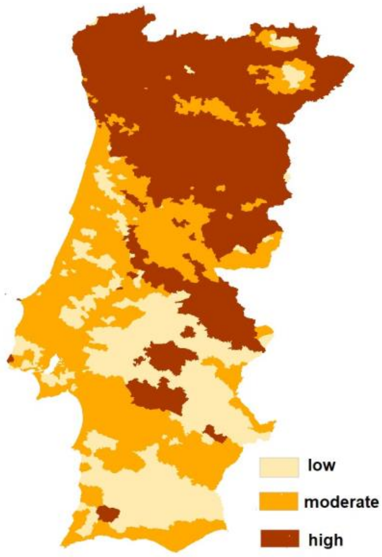

Fig. 2 Areas at risk of exposure to radon (Domingos et al., 2021).

It is important to keep in mind that these risk maps give an indication of the average levels of radon in a given area since the indoor radon concentration depends on several variable factors (Gruber et al., 2021; Miles & Appleton, 2005).

1.2. Radon management in workplaces

According to DL 108/2018 of 3 December it is the responsibility of employers to ensure that the level of indoor radon concentration at workplaces is as low as possible and below the reference level, 300 Bq/m^3. To effectively manage radon exposure in workplaces, creating conditions to implement the National Radon Action Plan is necessary. For workplaces involving groundwater extraction, such as those in spas and thermal establishments, the frequency for monitoring the indoor radon should not exceed 12 months, contrary to what happens in workplaces located in areas of low and moderate susceptibility to radon, where the periodicity is every five years. In addition, if the diagnostic monitoring (first measurement) or effectiveness monitoring (when implementing mitigation measures) is inferred to the reference level and below 250 Bq/m^3, the periodicity should be every five years (APA, 2022).

For workplaces where the effective dose to workers is less than or equal to 6 mSv per year or the exposure is less than the corresponding time-integrated radon exposure value, it is required that the exposures are kept under review. On the other hand, for workplaces where the exposure of workers is liable to exceed an effective dose of 6 mSv per year or a corresponding time-integrated radon exposure value, these shall be managed as a planned exposure situation in accordance with the DL 108/2018, requiring a protection strategy always articulated with the competent authority, the APA.

2. Materials and Methods

For the preparation of this study, the Portuguese "National Radon Action Plan" was analyzed, which was under public consultation between 21-02-2022 and 01-04-2022. The studies on occupational exposure to radon carried out in Portuguese thermal establishments by Silva & Dinis (2020), Silva & Dinis (2016) and Silva (2016) between 2014 and 2019, were also taken into consideration, as summarized below.

These studies were developed in two phases. The first phase took place between 2013 and 2016, where the exposure to indoor radon and gamma dose rates were assessed in 16 Portuguese thermal establishments through two measurements campaigns (November 2013 - June 2014, and July 2014 - September 2015).

The second phase took place between 2018 and 2019, addressing three particular thermal establishments. The assessment for indoor radon concentration and gamma dose rates were carried out in two measurements campaigns (April - August 2018 and August - November 2018).

The evaluation of the indoor radon concentration was performed with passive detectors CR-39, and the hourly gamma dose rates registers (μSv/h) were obtained with a geiger count equipment, the GAMMA SCOUT® (GS3), which measures γ, $\alpha + \beta$, and $\alpha + \beta + \gamma$ radiation. Finally, the annual effective dose was estimated combining the internal exposure due to radon inhalation with the external exposure due to gamma radiation (Silva & Dinis, 2019a; Silva & Dinis, 2019b; Silva & Dinis, 2018a; Silva & Dinis, 2018b; Silva & Dinis, 2017a; Silva & Dinis, 2017b; Silva & Dinis, 2016a; Silva & Dinis, 2016b).

3. Results

3.1. Radon sustainability index

Table 1 represents the location of the thermal establishments studied in the first phase of the previous study and the respective susceptibility index to elevated indoor radon concentration.

Table 1. Location of the thermal establishments and the respective susceptibility index to elevated indoor radon concentration.

TS	District	County	Parish	Sustainability Index
TS1	Viseu	Nelas	Canas de Senhorim	High
TS2	Guarda	Manteigas	S. Pedro	High
TS3	Leiria	Caldas da Rainha	N.ª Sr.ª Pópulo	Moderate
TS4	Porto	Santo Tirso	Areias	High
TS5	Bragança	Carrazeda de Ansiães	Pombal	High
TS6	Braga	Guimarães	Caldelas	High
TS7	Viseu	Viseu	S. João Lourosa	High
TS8	Braga	Amares	Caldelas	High
TS9	Guarda	Sabugal	Rapoula do Côa	High
TS10	Porto	Penafiel	Eja	High
TS11	Guarda	Meda	Longroiva	High
TS12	Aveiro	Mealhada	Luso	High
TS13	Braga	Terras do Bouro	Moimenta	High
TS14	Viseu	Tondela	Lajeosa do Dão	High
TS15	Viseu	S. Pedro do Sul	Várzea	High
TS16	Castelo Branco	Covilhã	Unhais da Serra	High

TS – Thermal establishments

According to the sustainability map published by APA (APA, 2022), all thermal establishments involved in the study on occupational exposure to radon (Silva, 2016) have a high sustainability index, with the exception of thermal establishment number three (TS3). These results are coherent with the geological characteristics of the region where TS3 is located. With the exception of TS3, all thermal establishments are located in geological areas composed of granite, characteristic of the geological composition of the north and center regions of Portugal.

3.2. Indoor radon concentration

Table 2 presents the indoor radon concentrations measured in the three thermal establishments participating simultaneously in the two phases of the study (2013 - 2019).

Table 2. Indoor radon concentrations in three thermal establishments (phase 1 and phase 2)

TS	Loc.	222Rn (Bq/m^3)						
		WI		SP	SU	AU	SP - SU	SU-AU
		2014	2018	2014	2014	2019	2019	2019
		1st phase	2nd phase	1st phase	1st phase	2nd phase	2nd phase	2nd phase
TS1	BT	674	--	--	436	--	--	--
	ORL	3479	1283	--	3119	--	1941	1083
	TP	449	344	--	333	--	305	286
	SP	784	437	--	--	--	383	333
	VS	--	801	--	--		1175	491
	NS	--	1649	--	--	--	1310	1147
	Bertholet	--	1747	--	--	--	1133	958
	WC	--	415	--	--	--	366	295
	R	--	313	--	--	--	280	202
TS2	AC TS1	566	--	--	--	--	187	191
	TP TS1	517	--	--	267	--	131	156
	TA TS1	692	--	--	--	--	147	187
	VS TS1	724	--	--	258	--	144	171
	ORL TS1	329	-	-	187	-	92	114
	VS 1* TS2	--	--	--	155	--	161	187
	VS 2* TS2	--	--	--	137	--	--	--
	ORL 2* TS2	--	--	--	152	--	89	126
	TP TS 2	--	--	--	159	--	52	67
TS3	NS	--	--	1130	-	--	992	1212
	VS	--	--	1971	2873	--	1400	961
	ORL	--	--	2298	1643	--	937	1146
	TP	--	--	1494	2808	--	1679	1750
	TZ	--	--	1145	--	--	1130	1474

Access corridor to the thermal pool (AC), bathtubs (BT), ORL, thermal pool (TP), Vichy shower (VS). nozzle shower (NS); whirlpool cabin (WC); reception (R) Spa pool (SP) technical zone (TZ); 1* ground floor (1*); 2nd floor (2*)

3.3. Occupational exposure to radon in thermal establishments

Table 3 presents the annual effective doses (mSv/year) of three thermal establishments participating simultaneously in the two phases of the study (2013 - 2019).

Table 3. Annual effective doses (mSv/year) of three thermal establishments (phase 1 and phase 2)

TS	**Loc.**	**mSv/year**	
		2014	**2019**
		1st phase	**2ndphase**
TS1	ORL	25,65	26,41
	TP	5,26	5,02
TS2	ORL 2* TS2	1,60	2,61
	TP TS 2	1,70	--
TS3	TP	20,90	--

4. Discussion

Regarding the assessment of the indoor radon concentration in TS1, during the first phase of the study (2014) and second phase (2018 and 2019) it was observed that the radon variation is higher during the winter compared with the results obtained during the summer season. On the other hand, all the values obtained for the radon concentration in the indoor air are higher than the reference level (300 Bq/m^3). The lower indoor radon levels obtained in the second phase of the study may be explained by the improvement of the ventilation system, although it is not enough to meet the reference level (300 Bq/m^3). At the reception, the values obtained for the indoor radon concentration were lower than the reference level, both during spring and autumn seasons (280 and 202 Bq/m^3, respectively) and the value obtained between spring and summer in the WC (295 Bq/m^3).

In TS2, the indoor air radon concentrations were measured in one building (1) during the winter and summer seasons and in other facilities (2) only during the summer season (2014). All values of indoor radon concentration measured in winter (2014), in building 1, exceeded the reference level (300 Bq/m^3), but the same was not verified during the summer (2014) nor in the second phase of the study (Spring to October 2019). In the second phase of the study, all values of radon concentration were lower than the reference level. Although TS2 is located in a region predominantly composed of granite substrate, it was expected to have higher radon levels. However, the efficient ventilation system (natural and artificial) may explain the low radon levels during the summer in the second building.

In the case of TS3, the indoor radon concentrations obtained in the first phase of the study were much higher than the reference level (300 Bq/m^3) in all situations. In the second phase of the study (2019), the radon concentration values are slightly lower than those recorded in 2014, but above the reference level (300 Bq/m^3). This thermal establishment is located in an area classified as high risk for elevated radon levels. In addition, the ventilation system existent in TS3, mostly natural, is not sufficient to prevent the accumulation of indoor radon.

In relation to the annual effective dose for TS1, it was found that the values obtained in the two phases (2014 and 2019) exceed the effective dose limit value for exposed workers (20 mSv/year). As these workers are likely to be exposed to an effective dose above 6 mSv/year, employers must comply with surveillance, monitoring and radiological protection requirements.

In the case of TS2, the annual effective dose in both phases of the study (2014 and 2019) is lower than the effective dose limit value for exposed workers (20 mSv/year) in ORL and TP of building 2, as the indoor radon concentration levels obtained in the ORL are always below 300 Bq/m^3. In this case, TS2 workers are classified as category B. Since the dose is below 6 mSv/year (DGS, 2016), the responsible employer for this thermal establishment must monitor the dose quarterly. In TS3, the annual effective dose was only calculated for the first phase of the study (2014), and it was found that it was higher than the annual effective dose for workers classified with category A (6 mSv/year).

5. Conclusions

The regions where the spa establishments are located have a high susceptibility index to elevated radon exposure, which may lead to indoor radon concentration above the reference level (300 Bq/m^3) and an annual effective dose above 6 mSv/year. In the view of this scenario, it is up to employers to make all necessary efforts to ensure that the concentration of radon in the workplace is below the reference level, such as, for example, implement remedial measures (improvement of natural and mechanical ventilation, positive pressurization inside the building, etc.). But it implies beforehand the identification of workplaces where radon exposure might occur, establishing and implementing radiation protection requirements, applying a graded approach and optimization of protection and safety (APA, 2022).

For workplaces where the effective dose is above 6 mSv/year, the situation should be managed as a planned exposure, requiring measures to be taken following the principle of radiation protection, in particular with the principle of optimization. The process of optimization involves the continuous review of the workplace situation. This includes the application of controls to verify whether the levels of radon are as low as reasonably achievable under the circumstances. According to Decree-Law No. 108/2018 of 3 December, it is up to the owner of the thermal establishment to carry out the radiological safety assessment and implement protective measures for exposed workers.

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References

Agência Portuguesa do Ambiente (2022). National Radon Action Plan. https://participa.pt/contents/consultationdocument/PNR_consulta%20publica.pdf

Chen, J., & Ford, K. (2016). A study on the correlation between soil radon potential and average indoor radon potential in Canadian cities. Journal of Environmental Radioactivity, 166(1), 152-156.

Darby, S., D., H., & al, e. (2005). Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. BMJ, 330, 223-227.

DGS (2016). Guia Técnico N.º 1 – vigilância da saúde dos trabalhadores expostos a radiação ionizante, Edição Direção-Geral da Saúde – Divisão de Saúde Ambiental e Ocupacional.

Domingos, F., Seco, S., & Pereira, A. (2021). Monitorização da atividade de radão no interior de edifícios em Portugal Continental: Avaliação de Risco. Laboratório de Radioatividade Natural, Universidade de Coimbra.

Du, L., Leivo, V., Prasauskas, T., Täubel, M., Martuzevicius, D., & Haverinen-Shaughnessy, U. (2019). Effects of Energy Retrofits on Indoor Air Quality in Multifamily Buildings. Indoor Air, 29(4), 686-697.

EPA. (2013). United States Environmental Protection Agency. Consumer´s Guide to Radon Reduction, How to fix your home. URL:http://www.epa.gov/radon, EPA 402/K-10/005 | March 2013.

Erdogan, M.; Ozdemir, F.; Eren, N. (2013). Measurements of radon concentration levels in thermal waters in the region of Konya, Turkey. Isotopes in Environmental and Health Studies 49(4), 567–574. doi:10.1080/10256016.2013.815182.

Faisca, M., Teixeira, M., & Bettencourt, A. (1992). Indoor Radon Concentrations in Portugal - A National Survey. Radiation Protection Dosimetry, 45(1-4), 465–467.
Ferlay, J.; Autier, P.; Boniol, M.; Heanue, M.; Combet, M.; Boyle, P. (2007). Estimates of the cancer incidence and mortality in Europe in 2006. Ann Oncol. 2007, 18, 581–592.
Gruber, V., Baumann, S., Alber, O., Laubichler, C., Bossew, P., Petermann, E. et al., (2021). Comparasion of radon mapping methods for the delineation of radon priority areas – an exercise. Journal of the European Radon Association, 2: 5755
IAEA. (2015). Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation. IAEA Safety Standards Series No. SSG-32. Viena: IAEA.
IAEA. (2014). Radiation Protection and Safety Sources: International Basic Safety Standars. General Safety Requirements Part 3, No. GSR Part 3. Viena: IAEA.
IAEA. (2010). Analytical Methodology for the Determination of Radium Isotopes in Environmental Samples, IAEA Analytical Quality in Nuclear Applications Series No. 19. Vienna.
IAEA. (2004). Radiation Protection against Radon in Workplaces other than Mines. Safety Reports Series No. 33. Viena: IAEA.
IARC (2001). Ionizing radiation, Part 2: some internally deposited radionuclides. IARC Monogr Eval Carcinog Risks Hum, 78: 1-599. PMID:11421248.
ICRP. (2014). Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. (Vol. 43(3)). ICRP.
ICRP. (2010). Lung Cancer Risk from Radon 286 and Progeny and Statement on Radon. ICRP Publication 115, Ann. ICRP 40(1).
ITN. (Setembro de 2005). Radão: Um Gás Radioactivo de Origem Natural. Obtido em 2021, de www.ctn.tecnico.ulisboa.pt:http://www.ctn.tecnico.ulisboa.pt/docum/relat/radao/itn_gas_rado.pps
Jacob, P., Meckbach, R., Sokolnikov, M., et al., (2007). Lung cancer risk of Mayak workers: modelling of carcinogenesis and bystander effect. Radiat Environ Biophys, 46: 383-394. doi: 10.1007/s00411-007-0117-0 PMID:17562061
Miles, J., & Appleton, J. (2005). Mapping variation in radon potential both between and within geological units. J Radiol Prot, 25(3), 257-76.
Silva, A.S., Dinis, M.L. (2021). An overview of the Development and Implementation of the Radon Action Plans in European Countries. Occupational and Environmental Safety and Health, Edited by Pedro M. Arezes, João Santos Baptista, Mónica P.Barroso, Paula Carneiro, Patrício Cordeiro, Rui B. Melo, A. Sérgio Miguel and Gonçalo Perestrelo, CRC Press/Balkema 2019, pp. 225-235, Vol 406. Publisher Name Springer, Cham. Print ISBN 978-3-030-89616-4, ISBN 978-3-030-89617-1.https://doi.org/10.1007/978-3-030-89617-1
Silva, A.S. & Dinis, M.L. (2020). Indoor radon levels in thermal spas and the compliance with the European BSS Directive: A Portuguese case study. Book chapter in: Occupational Safety and Environmental Safety and Health II, Eds. P. Arezes, J. S. Baptista, M. Barroso, P. Carneiro, P. Cordeiro, N.; Costa, R.; Melo, A. S.; Miguel, G. Perestrelo, pp. 163-171, doi: 10.1007/978-3-030-41486-3.
Silva, A.S. & Dinis, M. L. (2019a). Assessment of the Indoor Gamma Dose Rates in 15 Portuguese Thermal Spas. Occupational and Environmental Safety and Health. Studies in Systems, Decision and Control, Edited by Pedro M. Arezes, João Santos Baptista, Mónica P. Barroso, Paula Carneiro, Patrício Cordeiro, Rui B. Melo, A. Sérgio Miguel and Gonçalo Perestrelo, CRC Press/Balkema 2019, pp. 221-2. https://doi.org/10.1007/978-3-030-14730-3_24
Silva, A.S. & Dinis, M. L. (2019b).Distribution of the gamma dose rate measured in 15 Portuguese thermal establishments. Proceedings of the Seventh International Conference on Radiation and Application in Various Fields of Research, RAD2019, Herceg Novi, Montenegro, 10-14 June, 2019.
Silva, A.S. & Dinis, M. L. (2018a). Main mitigation measures — occupational exposure to radon in thermal spas. Occupational Safety and Hygiene VI, Edited by Pedro M. Arezes, João Santos Baptista, Mónica P. Barroso, Paula Carneiro, Patrício Cordeiro, Rui B. Melo, A.

https://www.taylorfrancis.com/chapters/main-mitigation-measures—occupational-exposure-radon-thermal-spassilva-dinis/e/10.1201/9781351008884-75

Silva, A.S. & Dinis, M. L. (2018b). Radiological characterization of the occupational exposure in hydrotherapy spa treatments. Occupational Safety and Hygiene VI, Edited by Pedro M. Arezes, João Santos Baptista, Mónica P. Barroso, Paula Carneiro, Patrício Cordeiro, Rui B. Melo, A. Sérgio Miguel and Gonçalo Perestrelo, CRC Press/Balkema 2017, pp. 406-412. Print ISBN: 978-1-138-54203-7. https://www.taylorfrancis.com/chapters/radiological-characterization-occupational-exposure-hydrotherapy-spatreatments-dinis-silva/e/10.1201/9781351008884-72

Silva, A.S. & Dinis, M. L. (2017a). Indoor radon in dwellings: An increment to the occupational exposure in Portuguese thermal spas. Occupational Safety and Hygiene V, Edited by Pedro M. Arezes, João Santos Baptista, Mónica P. Barroso, Paula Carneiro, Patrício Cordeiro, Rui B. Melo, A. Sérgio Miguel and Gonçalo Perest https://doi.org/10.1201/9781315164809-76

Silva, A.S. & Dinis, M. L. (2017b). Variability of Indoor Radon Level Accumulation: a Study in Portuguese Thermal Spas. Proceedings of Fifth International Conference on Radiation and Application in Various Fields of Research, RAD2017, pp. 141-148, Budva, Montenegro, 12-16 June 2017.https://doi.org/10.21175/RadProc.2017.29.

Silva, A.S. (2016). Occupational Exposure to Radon in Thermal Spas, PhD. FEUP, University of Porto.

Silva, A.S. & Dinis, M.L. (2016a). Measurements of indoor radon and total gamma dose rate in Portuguese thermal spas. Occupational Safety and Hygiene IV (P. Arezes, J.S. Baptista, M. Barroso, P. Carneiro, P. Cordeiro, N. Costa, R. Melo, A.S. Miguel, G. Perestrelo, Eds.), pp. 485-489. Taylor & Francis, London.

Silva, A.S. & Dinis, M.L. (2016b). Evaluation of Total Gamma Radiation and Dose Rate of Gamma Radiation in Portuguese Thermal Spas. Edited by: Arezes, P; Baptista, JS; Barroso, MP; et al. Proceedings of International Symposium on Occupational Safety and Hygiene (SHO 2016), Guimarães, PORTUGAL, MAR 23-24, 2016 SHO2016: INTERNATIONAL SYMPOSIUM ON OCCUPATIONAL SAFETY AND HYGIENE, pp. 323-325.

Silva, A.S.; Dinis, M.L. & Pereira, A.J.S.C. (2016). Assessment of indoor radon levels in Portuguese thermal spas. Radioprotection, pp. 249-254, doi: 10.1051/radiopro/2016077

UNSCEAR (2000) United Nations Scientific Committee on Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation. United Nations, New York, United Sales publication E.00.IX.3.

UNSCEAR. (2008a). Sources and Effects of Ionizing Radiation, UNSCEAR 2008 Report, Vol. I. United Nations Publication.

United Nations Scientific Committee on the Effects of Atomic Radiation. (2008b). Sources and Effects of Ionizing Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to the General Assembly with Scientific Annexes. (Vol 1, Annex B: Exposures of The Public and Workers from Various Sources of Radiation, p. 404.) New York, 2010.

United States Environmental Protection Agency. (2007). Communicating Radiation Risks. 301 USEPA Publication, 402-F-07-008, USEPA Office of Radiation and Indoor Air.

United States Environmental Protection Agency. (2001). Find Information About Local Radon Zones and State Contact Information. Indoor Environments Division, Office of Radiation and Indoor Air, Office of Air and Radiation, USEPA. Last updated on January 14. www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information.

WHO. (2009). Handbook on Indoor Radon, A Public Health Perspective. Hajo Zeeb and Ferid Shannoun.

World Health Organization. (2008). Report on the Global Tobacco Epidemic-The MPOWER package. 321.

World Health Organization. (2007). Effective Media Communication during Public Health Emergencies.

World Health Organization Health. (2006). Hazards and Public Debate: Lessons for risk communication from the BSE/CJD saga, Regional Office for Europe.
World Health Organization Health. (2002). Radon and Health. Information Sheet.
World Health Organization Health. (2001). https://www.who.int/data/gho/indicator-metadata registry/imr-details/5611