

Indoor radon measurements and annual effective dose estimation in different university workplaces in Urbino (Central Italy)

Raffaella Campana¹, Alessandra De Benedittis, Vincenzo Musumeci, Alessandro Gambarara

Affiliation

¹ University of Urbino Carlo Bo, Prevention and Protection Office, Via Veterani 36, Urbino, Italy

Keywords: workplaces, University, radon exposure, methodology, dose estimation

ABSTRACT

Background and aim. Radiation is a natural part of the environment, and radon gas is a critical source of exposure due to its abundance and mobility. Indeed, radon can reach and accumulate in confined living and working places. Inhalation of radon and its decay progenies is a significant risk factor for human health. This investigation aims to measure the annual average of radon concentration in different workplaces of Urbino University.

Methods. The study was carried out for two consecutive semesters in 48 workplaces using CR-39-type detectors.

Results. The data revealed a mean value of radon concentration of 113.10 Bq/m³, higher than the national average value of 70 Bq/m³ but below the 300 Bq/m³ threshold indicated by Directive 96/29 EURATOM 2013. In the locals with higher radon levels (>300 Bq/m³), the effective dose estimation showed values below the limit of 6 mSv (from 3.27 to 5.12 mSv), except for one workplace identified as a technical room (no frequented by personnel).

Discussion. Overall, in this investigation, 85.4% of the examined premises were below the reference level for indoor radon concentration (300 Bq/m³), while 14.6% showed radon concentration higher than 300 Bq/m³ but in areas little or no frequented by staff at all, such as technical rooms (21.4%) and archives (20%), or libraries (37.5%) respectively.

Conclusions. Our results confirm the presence of indoor radon in underground workplaces of Urbino University below the national reference level for indoor radon concentration in the air. In cases where radon values exceed this limit, the necessary interventions will be carried out, as well as new measurements to verify the effectiveness of the applied radiation protection procedures.

Introduction

The term “radon” typically refers to the combination of Radon (Rn) and its short-lived decay products (RnDP). Radon is a radioactive noble gas belonging to the ²³⁸Uranium radioactive chain, produced by the decay of ²²⁶Ra (Radium), widely distributed in soil and rocks throughout the earth’s crust, water, and in many building materials [1]. The

radioactive gas, formed underground, can move freely inside buildings; in the case of locals with good ventilation, the indoor radon concentration can remain low even when radon emanation from the earth's crust is high, but in confined spaces, radon concentration can reach harmful levels for the occupants [2]. It's well-known that Rn concentration in air depends on the source's intensity and dilution factors, both influenced by weather conditions, such as humidity, atmospheric pressure, and wind conditions [3].

Indoor radon has been identified to be the second leading risk factor for lung cancer after tobacco smoking [4]. Radon is almost completely exhaled after inhalation for its long half-life (3.82 d). On the contrary, its progenies ^{218}Po and ^{214}Po have a shorter half-time (27 min) and, being electrically charged, can be attached to dust or smoke particles in indoor air. In the lung, during the breathing process, they reach the bronchial tissue, where they decay, emitting radioactive alpha particles that can damage the pulmonary epithelium and cause lung cancer [5]. World Health Organization [1] has established that most radon-induced lung cancers are caused by low and moderate radon concentrations rather than high radon concentrations. In 2009, the WHO report established an action level of 100 Bq/m³ for residential radon with the recommendation not to exceed 300 Bq/m³. In 2013, the European Union issued the European Directive 59/2013 [6], indicating 300 Bq/m³ as a reference level for dwellings and workplaces. This European directive was implemented in Italy in 2020 [7], confirming the 300 Bq/m³ reference level for workplaces and dwellings. In our country, according to Italian Legislation, measurements of radon concentration in underground workplaces and on the ground floor of workplaces located in identified radon-prone areas are mandatory. In this direction, surveys of occupational radon exposure have been performed on local scales in Italy [8-11] but an updated map on indoor radon levels in workplaces is not yet available [12].

This study aims to determine the indoor radon concentration in different workplaces of Urbino University (Marche, Central Italy). Specifically, the experimental design was divided into two proceeding steps: i) the elaboration of the sampling plan, including the choice of the workplaces to be monitored; ii) the exposure of CR-39 detectors for two consecutive semesters in the selected sites and related data analysis.

2. Materials and Methods

2.1. Sampling sites

The confined workplaces to be monitored were selected by the Prevention and Protection Office of Urbino University, and regardless of their intended use, underground floors, basements and ground floors were monitored. Among the structures of Urbino University, six typologies of workplaces were selected for a total of 48 different zones of each site: technical rooms (n=14), laboratories (n=11), classrooms (n=8), libraries (n=8), archives (n=5) and offices (n=2).

2.2. Monitoring, dosimeters and data analysis

Specifically, the survey was conducted in two half-year periods during 2022-2023 (the first including August 2022-February 2023, the second March 2023-September 2023) via the use of passive dosimeters of the CR-39-type detectors that respond to nuclear tracks (UNI ISO 11665-4:2021). In each monitored workplace, the dosimeters were exposed for two

consecutive semesters to obtain a year of exposure. The detectors were positioned about 2 m from the floor and, when possible, approximately 20 cm from the internal wall so as not to record the contribution from the Thoron. This distance could not be respected on some premises, and as a maximal precaution, the dosimeters were positioned near the wall. To ensure accurate measurements, the detectors were not placed near ventilation systems, doors, or electrically powered appliances. In the case of premises with a surface area equal to or less than 100 m², multiple sampling points were identified (one every 50 m²). On the other hand, in rooms larger than 100 m², at least one sampling point has been provided for every 100 m² or fraction thereof, as per the guideline of Annex II of Legislative Decree 101/20 [7]. After each exposure period, all the dosimeters were collected and sent to Tecnorad s.r.l. (Verona, Italy) for chemical analysis following UNI ISO 11665-4. The ²²²Radon concentration was expressed as Bq/m³ with a 300 Bq/m³ threshold as indicated in Council Directive 2013/59/Euratom [6].

The annual effective dose *H* to the workers due to the radon and its progeny was calculated as suggested by the Italian Legislation⁷ using the Equation:

$$H(\text{mSv/y}) = C \times T \times D$$

where *C* is the radon concentration (Bq/m³), *T* is the occupancy factor, and *D* (6.7 x 10⁻⁹ Sv per Bq hm⁻³) is the dose conversion factor assuming an average equilibrium factor between radon and its daughters of 0.4 [8,13].

3. Results and Discussion

Many reports on radon concentration in different European workplaces are available in the literature. Indeed, the investigation of Clouvas and Xanthos (2012), carried out in schools and public offices as well as private enterprises in Greece, stressed that the radon concentrations varied in a building depending on the variations of the ventilation conditions and air exchange between rooms [14]. Bochicchio et al. (2014) performed a systematic survey in 334 primary schools in Southern Serbia [15], Azara and collaborators (2018) assessed radon concentration (45-140.3 Bq/m³) in schoolrooms in the Midwest of Italy [16] and Martin-Gisbert et al. (2023) examined private and public workplaces in Spain [17].

On the contrary, a few data on the radon survey in European University workplaces are available in the literature [18,19]. In this context, our investigation can help add new information on radon diffusion in the Marche Region and, more importantly, in university workplaces. For the research, 48 workplaces of Urbino University were selected, grouped into six categories (technical rooms, laboratories, classrooms, libraries, archives and offices) and monitored for the annual indoor radon concentration measurement (Table 1). The annual radon average concentration is 113.10 Bq/m³ (Table 2), higher than the national average value of 91 Bq/m³ and that of the average level of the Marche Region (40- 60 Bq/m³) for underground workplaces [20]. However, values higher than the national average of 91 Bq/m³ were evidenced only in 35.4% of the monitored workplaces and, among these, 76.5% mainly in environments little frequented (such as archives and technical rooms).

Regarding the radon survey in the Marche region, no significant measurement activities were carried out after the generic information report of the Regional Agency for Environmental Protection of the Marche (ARPAM in Italian) on the radon problem in

2003 (updated in 2007), indicating the radon level in the range 20-40 Bq/m³ (<https://www.arpa.marche.it/radiazioni-ionizzanti/radon>) [21]. In this direction, our data, even if not comparable with other relatively recent ones, results novel and in line with the indication of Council Directive 2013/59/Euratom [6]. The high annual average radon level measured in Urbino workplaces (113.10 Bq/m³) could be related to different factors, from the geomorphological characteristics of the territory, the building materials used in the selected premises to differences between day and night in long-term measurements, varied ventilation conditions (opened/closed doors), pressure and temperature conditions or the presence of minimal cracks, etc... Unfortunately, recent maps of indoor radon at a regional scale are unavailable in the literature for Marche.

As mentioned above, the radon survey was conducted in different types of workplaces. Table 2 summarizes the percentages of each type of workplace presenting an annual average of radon concentration higher than 300 Bq/m³ as indicated by the Italian Legislation [7]. Overall, 85.4% of the examined premises were below the national reference level for indoor radon concentration in the air. Only 14.6% of the samples showed radon concentration higher than 300 Bq/m³, in any case in areas that are little or no frequented by staff at all, such as technical rooms (21.4%), archives (20%) or libraries (37.5%) respectively. The distribution of the average radon concentrations in the different workplaces related to the floor level was presented in Figure 1, considering three subranges of radon concentration: < 240 Bq/m³, 240 – 300 Bq/m³ and > 300 Bq/m³. As shown, 64.3% of underground floors, 72.2% of basements and the totality of ground floors presented radon concentrations < 240 Bq/m³. Only 14.3% and 5.5% of underground floors and basements revealed radon concentrations between 240 and 300 Bq/m³, respectively, while 21.4% and 22.2% of the same workplaces showed radon concentrations > 300 Bq/m³.

The Italian Regions are responsible for mapping natural radioactivity in their respective areas, and effectively, some surveys have already been started in the past years using different protocols [16,20, 22-24]. The Italian implementation of European Council Directive 2013/59/Euratom in 2020 [6] indicates as mandatory the radon concentration measurements in underground workplaces such as caves, tunnels, cellars and mines, in spas and on the ground floor of workplaces located in identified radon prone areas. Indeed, in the recent literature, reports on Italian radon monitoring in different regions are available [9,25]. In particular, Loffredo and Quarto (2023) presented data on radon concentration in several workplaces in the Campania Region (Southern Italy), involving about 695 workplaces conducted from September 2018 to February 2022 [10]. Similarly, Lupiano and collaborators (2023) have analysed a set of 1434 average annual indoor radon measurements between 2010 and 2021 in the Calabria Region (Southern Italy), obtaining an updated specific map for a possible relationship between radon concentrations and geology [11]. In general, it can be stated that radon distribution is not uniform throughout Italy, with a high variability among regions and intra-region but a low spread among rooms belonging to the same workplace.

In the present investigation, the maximum effective dose was calculated when the radon concentration resulted between 240 to 300 Bq/m³ or higher, hypothesizing 2000 hours spent in a year in each workplace (Table 3). As reported, the effective dose resulted below 6 mSv (from 3.27 to 5.12 mSv), except for one workplace identified as TR07 (technical room) with 6.39 mSv. It can be noted that the considered worker occupancy time was

overestimated because most of the seven premises are little or no frequented by personnel (technical rooms, archives and library) and, moreover, in these locals the CR-39-type detector's distance from the wall of 20 cm was not respected. This way, the radon concentration was certainly overestimated compared to the real concentration in the rooms, anyway indicating no risk for the occupants (ever below 6 mSv). Indeed, the Italian Legislation [7] sets the dose limit for radon exposure in workplaces equal to 6 mSv/y; beyond this limit, the worker is considered professionally exposed with the consequent dose monitoring actions to be acted.

The characteristics of building materials or those of the rocks may play an essential role in the radon diffusion in these situations. Our findings agree with those of Ruano-Ravina (2023), who reported that the radon concentration increases with height [2]. Moreover, radon levels in buildings can vary according to season and housing characteristics, with higher concentrations in colder months on premises with poor ventilation and on the lower floors of houses [26,27].

In conclusion, the results of the present work confirm the presence of indoor radon in underground workplaces of Urbino University but, in most cases, at a level below the reference level of 300 Bq/m³ for indoor radon concentration in the air. In all the situations with radon values exceeding the limit, investigations are ongoing to identify the possible way by which radon is introduced, such as cracks in walls, floors, cavities, piping, cable routes for electrical systems, etc., as well as the impact of ventilation systems and air exchange rates. At the end of the investigation, the necessary interventions will be carried out, and new measurements will be performed to verify the effectiveness of the interventions and/or the need to undertake further remediation actions and radiation protection procedures.

Authors' contribution

R. Campana: Conceptualization, Writing – original draft, Data curation, Writing – review & editing. A. De Benedittis: Methodology, Formal analysis, Writing – review & editing. V. Musumeci: Review & editing. A. Gambarara: Project administration, Funding acquisition, Review & editing.

Acknowledgments

All the authors kindly thank Mrs. Susanna Piergiovanni for her administrative support during the survey period.

Declaration of competing interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Table 1 Type and number of the examined Urbino university workplaces according to the floor level

Workplaces type	Basement	Underground	Ground floor
Technical rooms (n=14)	6	6	2
Laboratories (n=11)	3	2	6
Classrooms (n=8)	2	3	3
Libraries (n=8)	5	0	3
Archives (n=5)	2	3	0
Offices (n=2)	0	0	2
Total premises (n=48)	18	14	16

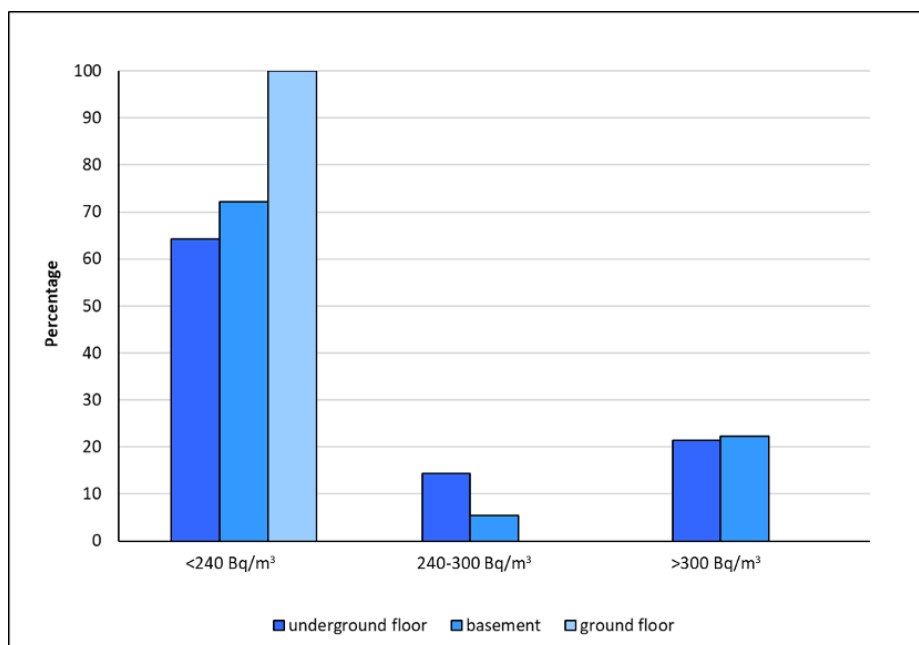
Table 2 Annual average of radon concentration (Bq/m³) in the different types of examined Urbino university workplaces

Workplaces type	Radon Concentration	> 300 Bq/m ³ (%)
Technical rooms (n=14)	147.5	21.4
Laboratories (n=11)	34	0
Classrooms (n=8)	33.125	0
Libraries (n=8)	182.75	37.5
Archives (n=5)	244.2	20
Offices (n=2)	21	0
Total premises (n=48)	113.10	14.6

Table 3 Annual effective dose (mSv) received by the workers in the workplaces showing annual radon average concentration from 240 to more than 300 Bq/m³, assuming an occupancy factor of 2000 h/y for a worker

ID Workplace	Floor level	Annual radon average concentration (Bq/m ³)	Annual effective dose (mSv)
TR07	basement	477	6.39
TR13	underground floor	343	4.60
TR14	underground floor	382	5.12
LR01	basement	310	4.15
LR02	basement	354	4.74
LR03	basement	304	4.07
LR04	basement	260	3.48
AR03	underground floor	315	4.22
AR04	underground floor	269	3.60
AR05	underground floor	244	3.27

Figure 1 Distribution of the average radon concentrations in the different examined workplaces related to the floor level (underground floor, basement, ground floor). Three subranges of average radon concentration were considered: < 240 Bq/m³, 240 – 300 Bq/m³ and > 300 Bq/m³



References

1. World Health Organization. WHO handbook on indoor radon: a public health perspective. Geneva, Switzerland: World Health Organization. p. 94, 2009.
2. Ruano-Ravina A, Martin-Gisbert L, Kelsey K, Pérez-Ríos M, Candal-Pedreira C, Rey-Brandariz J, Varela-Lema L. An overview on the relationship between residential radon and lung cancer: what we know and future research. Clin Transl Oncol. 2023;225(12):3357-3368. doi:10.1007/s12094-023-03308-0
3. Friedmann H, Baumgartner A, Bernreiter M, Gräser J, Gruber V, Kabrt F, Kaineder H, Maringer FJ, Ringer W, Seidel C, Wurm G. Indoor radon, geogenic radon surrogates and geology - Investigations on their correlation. J Environ Radioact. 2017;166:382-389. doi:10.1016/j.jenvrad.2016.04.028
4. International Agency for Research on Cancer (IARC). Manmade mineral fibres and radon. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans 1988;43:1-300.
5. Mozzoni P, Pinelli S, Corradi M, Ranzieri S, Cavallo D, Poli D. Environmental/Occupational Exposure to Radon and Non-Pulmonary Neoplasm Risk: A Review of Epidemiologic Evidence. Int. J Environ Res Public Health. 2021;18:10466. doi:10.3390/ijerph181910466
6. Council Directive 2013/59/Euratom on basic safety standards for protection against the dangers arising from exposure to ionising radiation. Off J Eur Union. 2014;57:1-73.

7. Italian Government. Decreto Legislativo 31 Luglio 2020, n. 101, in Italian. <https://www.gazzettaufficiale.it/eli/id/2020/08/12/20G00121/sg> (accessed on 20 February 2021).
8. Loffredo F, Savino F, Amato R, Irollo A, Gargiulo F, Sabatino G, Serra M, Quarto M. Indoor Radon Concentration and Risk Assessment in 27 Districts of a Public Healthcare Company in Naples, South Italy. *Life*. 2021;11:178. doi:10.3390/life11030178
9. Sabbarese C, Ambrosino F, D'Onofrio A, Pugliese M, La Verde G, D'Avino V, Roca V. The first radon potential map of the Campania region (Southern Italy). *Appl Geochem*. 2021;126:104890. doi:10.1016/j.apgeochem.2021.104890
10. Loffredo F, Quarto M. Indoor radon concentration measurements in workplaces and their impact on health risk assessment. *Indoor Built Environ*. 2023;32(4):777-782. doi:10.1177/1420326X221135840
11. Lupiano V, Procopio S, Buttafuoco G, Rago V, Iovine G. Indoor radon measurements in Calabria (Southern Italy). *J Maps*. 2023;19:1. doi:10.1080/17445647.2022.2132883
12. Decreto Del Presidente Del Consiglio Dei Ministri (DPCM) 11 gennaio 2024. Adozione del piano nazionale d'azione per il radon 2023-2032. (GU Serie Generale n.43 del 21-02-2024 - Suppl. Ordinario n. 10). <https://www.gazzettaufficiale.it/eli/id/2024/02/21/24A00877/sg>
13. ICRP. Occupational Intakes of Radionuclides: Part 3. ICRP 137. *Ann ICRP*, 2017;36:1-487.
14. Clouvas A, Xanthos S. A comparison study between radon concentration in schools and other workplaces. *Radiat Prot Dosimetry*. 2012;149(2):207-210. doi:10.1093/rpd/ncr224
15. Bochicchio F, Žunic ZS, Carpentieri C, Antignani S, Venoso G, Carelli V, Cordedda C, Veselinovic N, Tollefsen T, Bossew P. Radon in indoor air of primary schools: A systematic survey to evaluate factors affecting radon concentration levels and their variability. *Indoor Air*. 2014;24:315-326. doi:10.1111/ina.12073
16. Azara A, Dettori M, Castiglia P, Piana A, Durando P, Parodi V, Salis G, Saderi L, Sotgiu G. Indoor radon exposure in Italian schools. *Int J Environ Res Public Health*. 2018;15:749. doi:10.3390/ijerph15040749
17. Martin-Gisbert L, Candal-Pedreira C, García-Talavera San Miguel M, Pérez-Ríos M, Barros-Dios J, Varela-Lema L, Ruano-Ravina A. Radon exposure and its influencing factors across 3,140 workplaces in Spain. *Environ Res*. 2023;239(Pt 2):117305. doi:10.1016/j.envres.2023.117305
18. Calvente I, Núñez MI, Chahboun Karimi R, Villalba-Moreno J. Survey of Radon Concentrations in the University of Granada in Southern Spain. *Int J Environ Res Public Health*. 2021;18:2885. doi:10.3390/ijerph18062885
19. Günay O, Aközcan S, Kulali F. Measurement of indoor radon concentration and annual effective dose estimation for a university campus in Istanbul. *Arab J Geosci*. 2019;12:171. doi:10.1007/s12517-019-4344-x
20. Rossetti M, Esposito M. Radon levels in underground workplaces: a map of the Italian regions. *Radiat Prot Dosimetry*. 2015;164 (3):392-397. doi:10.1093/rpd/ncu268
21. Agenzia Regionale per la Protezione Ambientale delle Marche (ARPAM). Radiazioni ionizzanti. Il Radon. <https://www.arpa.marche.it/radiazioni-ionizzanti/radon>

22. Sarra A, Nissi E, Palmeri S. Residential radon concentration in the Abruzzo region (Italy): a different perspective for identifying radon prone areas. *Environ Ecol Stat.* 2012;19(2):219-247. doi:10.1007/s10651-011-0183-y
23. Trevisi R, Orlando C, Orlando P, Amici M, Simeoni C. Radon levels in underground workplaces - results of a nationwide survey in Italy. *Radiat Meas.* 2012;47(2):178-181. doi:10.1016/j.radmeas.2011.11.004
24. Vimercati L, Fucilli F, Cavone D, DeMaria L, Birtolo F, Ferri GM, Soleo L, Lovreglio P. Radon levels in indoor environments of the University Hospital in Bari-Apulia Region Southern Italy. *Int J Environ Res Public Health.* 2018;15:694. doi:10.3390/ijerph15040694
25. D'Avino V, Pugliese M, Ambrosino F, Bifulco M, La Commara M, Roca V, Sabbarese C, La Verde G. Radon survey in bank buildings of Campania region according to the Italian Transposition of Euratom 59/2013. *Life.* 2021;11(6):1-12. doi:10.3390/life11060533
26. Stanley FK, Zarezadeh S, Dumais CD, Dumais K, MacQueen R, Clement F, Goodarzi AA. Comprehensive survey of household radon gas levels and risk factors in southern Alberta. *CMAJ Open.* 2017;28:E255-E264. doi:10.9778/cmajo.20160142
27. Lee C, Lee D. Review of domestic and international methods of measuring radon in residential buildings. *Ann Occup Environ Med.* 2016;28:14. doi:10.1186/s40557-016-0097-0

Corresponding author

Raffaella Campana, PhD

University of Urbino Carlo Bo

Prevention and Protection Office

Via Veterani 36, 61029 Urbino, Italy

tel. +39 0722 303543

e-mail: raffaella.campana@uniurb.it