INDOOR RADON SURVEY IN UNIVERSITY BUILDINGS: A CASE STUDY OF SAPIENZA – UNIVERSITY OF ROME

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ABSTRACT
The indoor radon concentration in underground workplaces pertaining to Sapienza – University of Rome have been monitored since the 1990s according to the prescription of the Italian Legislative Decree 230/95. In the last few years, the recommendations contained in the Council Directive 2013/59/Euratom have shifted the focus to all indoor exposure situations by promoting actions to identify workplaces and dwellings with radon concentrations exceeding the reference level of 300 Bq/m^3. In response to the upcoming transposition into national legislation, Sapienza has promoted the first Italian survey addressing workplaces in university buildings, regardless of the position with respect to the ground floor. The survey has interested more than 300 workplaces, i.e. administration and professors' offices, research and educational laboratories, conference rooms and classrooms, distributed in 15 different buildings. Places monitored are strongly heterogeneous in terms of users' habit, occupancy pattern and building characteristics. The influence of these parameters into seasonal variation have been addressed by organizing the survey into four quarters. The indoor radon concentration is measured by solid state nuclear track detectors, CR39. The aim of the paper is to present features, methods and intermediate results of the survey. The work, relying on the analysis of previous measurements interesting underground workplaces, focuses on methodology followed during all the preliminary and preparatory phases: active measurements by ionization chamber radon continuous monitor, radon progeny equilibrium factor estimations by radon daughters monitor, strategies for occupants' awareness, positioning protocol and provisions to maximize representativity of results.
Keywords: indoor radon, survey, university, radon in school, radon in workplace.

1 INTRODUCTION

Inhalation is the primary patter for public exposure to natural radiation [1]. The main contribution is given by isotope 222 of radon (in the following referred to simply as "radon" or "Rn") and its progeny [2]. This nuclide is showed to be the primary cause of lung cancer among people who have never smoked (i.e., the second cause of lung cancer after cigarette smoke). The percentage of lung cancer attributable to radon exposure is estimated to range between 3% and 14% [3]: in Italy, the annual average of lung cancer deaths attributable to radon is 3,326 (1,118–5,882), ranging between 3% and 18% of total lung cancer deaths [4].

Radon concentration in Italy has been addressed, from 1989 to 1998, by a representative National Survey aiming to evaluate the exposure in dwellings of all the 21 Italian regions. According to the results of such survey, Lazio was found to be one of the region with the highest mean radon concentration (>100 Bq/m^{-3}) [5]. Since then, several studies have been carried out in Italian workplaces and dwellings (e.g., [6]).

The current Italian Legislative Decree 230/95, transposing recommendation of Directive 96/29 Euratom, demands radon measurements in underground workplaces only. Nevertheless, exposure in schools (i.e., kindergarten, primary, and secondary school) has been studied due to the peculiar building characteristics (schools are generally at the ground

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and first floor) and due to the age of population generally frequenting such buildings (e.g., [7]–[10]).

The need of performing and documenting design and methods of a survey addressing university buildings arises from: (i) no case study interesting such buildings in Italy, and very few in other countries (e.g., [11]), are available; (ii) due to the dimension and the spatial distribution of such buildings, specific protocols should be considered; and (iii) Council Directive 2013/59/Euratom (transposition into national legislation is in progress) will require measurements in workplaces and buildings with public access without restriction on floors [12].

In this paper, the survey on indoor radon concentration in Sapienza – University of Rome will be described in detail. The materials and methods will be discussed in depth with respect to radon detectors used, number of buildings (and rooms) involved, and deployment–removal protocols. The inner representativity, in terms of intended use and occupancy factor, of such survey will be analyzed. Moreover, the results of measurements addressing radon equilibrium factor F and unattached fraction f_p will be reported.

2 MATERIALS AND METHODS

The survey has been completely designed and managed by Sapienza – University of Rome and Italian National Institute for Insurance against Accidents at Work (INAIL). The indoor radon measurements interested 18 buildings, all of pertinence of the Department of Basic and Applied Sciences for Engineering (SBAI).

2.1 Rooms census

A comprehensive and systematic census of rooms to be considered within the survey has been carried out. Such analysis is mandatory to allow a proper estimation of dose for students and workers. Ten intended uses have been considered, each to be associated to a correspondent occupation factor, T (expressed in terms of fraction of weekly working hours, i.e., 40 h, for the occupant maximally exposed to indoor radon). For offices, workshops, porter's lodges, and research laboratories, T=1 is considered. Reading rooms, libraries, classrooms, and teaching laboratories are assumed to have T=0.5. Storage rooms, kitchens, archives, and copy rooms are all considered unattended rooms (T=1/20). Public toilets, stairways, corridors and elevators have been excluded from the survey due to the low occupancy factor (generally lower than 1/40) and the high air exchange rate.

The results of the census are reported in Table 1.

A total of 335 rooms have been censed: as expected, offices (156) and research laboratories (111) cover the large majority of rooms. As a consequence of the census, three buildings (12, 13 and 16) have been excluded from the survey due to the lack of rooms satisfying requirements about minimum occupancy factors.

2.2 Radon detectors

CR-39 solid state nuclear track detectors (SSNTD) have been used. The sizes of the plastic polymer chosen, manufactured by TASL Ltd, are 37x13 mm. The CR-39 has been coupled with NRPB/SSI holder made of conductive plastic.

Results of studies by Tokonami et al. [13], [14] show a thoron sensitivity for such holders of 0.1 cm^{-2} kBq^{-1} m^3 h^{-1} (0.05 in relative terms). Thus, the Rn-220 penetration into NRPB/SSI holders should not be neglected when deploying the passive dosimeter in rooms. If no

Table 1: Results of intended use census for building interested by the survey. Columns two and three report the distribution of rooms according to the intended use. Columns four and five report the maximum value for occurrences (absolute and percentage respectively) of the intended use in row in the 18 buildings. Columns six and seven report the mean value for the same occurrences. The minimum values are not listed because equal to zero for each row.

	No.		Max.		Mean	
	(#)	(%)	(#)	(%)	(#)	(%)
Office	156	47	33	96	9	38
Workshop	1	0	1	3	0	0
Reading room	8	2	2	13	0	2
Lodge room	5	1	1	13	0	1
Kitchen	1	0	1	3	0	0
Copy room	1	0	1	14	0	1
Archive	3	1	1	3	0	0
Classroom	25	7	11	100	1	28
Teaching lab	24	7	6	100	1	21
Research lab	111	33	93	84	6	8

attention is paid to the position of detectors, this may result in incorrect estimates. From several scientific findings, in fact, it was clarified that radon readings by radon detectors were overestimated by the presence of thoron [15]. If the indoor radon activity concentration is roughly uniform in rooms, the spatial distribution of thoron decreases exponentially from the wall surface [16]–[18]: according to this, a minimum distance of 30 cm between CR-39 and the closer wall has been adopted during the current survey.

According to scientific findings concerning CR-39 detectors background [19], a chemical etching of the detectors has been performed prior to their exposure to radon in order to make easier and more accurate the discrimination of true tracks (i.e., due to interaction of radon and its progeny) from those of the background (i.e., due to surface defects, micro-voids and alpha interactions before exposure).

2.3 Design of the survey

A long-term periodicity in indoor radon concentration is acknowledged [20]: radon follows usually a seasonal cycle with higher levels in cooler months and lower levels in warmer months. The magnitude of the resulting cycle depends on temperature and weather condition of the area. Such periodicity may be modified by: living habits (i.e., changes in the house's ventilation rate), occupancy pattern and building characteristics. Thus, the correlation between Rn concentration and meteorological parameters is far from simple. Results from the Italian National Survey [5] showed several evidences of winter to summer Rn concentration ratio lesser than one. In order to verify if such *inverse* seasonal variation could affect the buildings addressed, it has been decided to divide the survey into four 3 month periods, nearly coincident with the four seasons. The measurements started at the beginning of spring 2019.

Such approach has also the aim of collecting data to estimate the average (with respect to the site) seasonal correction factors. These coefficients allow to perform measurements shorter than one year (e.g., three months [21]), thus estimating the annual mean on the basis of previous observation of seasonal variations in the same area. This approach, followed by several Countries, provides strong reduction of time and cost efforts to manage regulatory requirements. The same approach could be applied to Italy: the current Italian Legislation expresses, in fact, the radon limit in term of annual mean concentration (i.e., 500 Bq/m^{-3}).

2.4 Dosimeters deployment

Dosimeters have been deployed by a trained team according to the following main criteria: (i) the instrument should be placed in a safe position to reduce the risk of manumissions, accidental falls or hits; ii) the instrument should be placed far from heat sources, including surfaces with direct solar radiation; (iii) the instrument should be placed far from air conditioner, windows or doors; and (iv) the instrument should be placed at least 30 cm far from the bearing walls and 1 m from floors and ceilings [22].

In each room one CR-39 detector has been placed, except for rooms larger than 100 m^2 whose radon concentration is being monitored by two dosimeters.

During the deployment procedures, the content of the holder has been showed to the rooms occupants. Such an expedient is aimed to avoid manumissions of the instruments during the measurements period, whose main cause is represented by the desire to know what is inside the holder.

The dosimeters have been coupled with a flyer containing concise information about the nature of measurements taking place and the contacts of survey directors always available for answering questions. On or two reference persons for each building (according to the number of rooms and occupants) have been informed and trained about radon risk, regulatory legislation, and kind of measurements being performed. Then, the information has been transmitted to all the workers by the reference persons themselves. All these precautions are aimed to make the workers feel confident about the measurements taking place in their rooms. In fact, occupant’s cooperation is mandatory in checking and saving the dosimeter during the measuring period, so reducing the number of missing results. The cleaning company has been informed about the rooms interested by such measurements together with the positions of each dosimeter deployed.

2.5 Equilibrium factor and unattached fraction

The evaluation of dose arising from radon progeny inhalation is often related to the gas exposure only due to the supposed compensation between doses from attached and unattached fraction. [23] shows that such a self-compensation is not fully realized, and for the same radon gas concentration, the effective dose can vary by a factor up to 2: thus, equilibrium factor and unattached fraction should be evaluated for proper doses evaluation.

According to the ICRP recommendations, an equilibrium factor of 0.4 can be assumed. However, since this factor depends largely on human-related and environmental conditions (e.g., living habits, occupancy pattern, humidity), 7 rooms, contemporary monitored by CR-39 detectors, have been also sampled to host measurements of equilibrium factor and unattached fraction. Rooms choice aimed to make the samples representative with respect to intended use.

Two instruments have been used to evaluate such parameters: an active ionization chamber radon detector (AlphaGUARD DF2000), and a double channel radon progeny monitor (Tracerlab BWLM-2S PLUS). The potential alpha energy concentration (PAEC) of each radon daughter has been determined by alpha spectrometry considering attached and unattached fraction individually.

Each measurement lasted more than 24 hours in order to superimpose short term aperiodic fluctuations and periodic diurnal cycle of radon-related parameters.

3 RESULTS AND DISCUSSION

Dosimeters have been deployed in a total of 178 rooms, with a prevalence of offices (66%), research and teaching laboratories (8% and 16%, respectively). The distribution of CR-39 detectors, according to intended uses of monitored rooms, is reported in Table 2.

Table 2: Summary of rooms whose indoor radon concentration is being measured, i.e., CR-39 detectors have been placed inside actually. Columns two and three report the distribution of rooms according to the intended use. Columns four and five report the maximum value for occurrences (absolute and percentage respectively) of the intended use in row in the 18 buildings. Columns six and seven report the mean value for the same occurrences. The minimum values are not listed because equal to zero for each row.

	No.		Max.		Mean	
	(#)	(%)	(#)	(%)	(#)	(%)
Office	118	66	33	100	7	47
Workshop	1	1	1	3	0	0
Reading room	5	3	2	13	0	2
Lodge room	2	1	1	13	0	1
Kitchen	1	1	1	3	0	0
Copy room	3	2	1	14	0	2
Archive	1	1	1	3	0	0
Classroom	5	3	4	27	0	3
Teaching lab	14	8	6	100	1	31
Research lab	28	16	14	100	2	12

Four other buildings have been excluded from the survey during this phase: they are all mainly hosting classrooms characterized by large areas (more than 150 Bq/m^{-3}) and high air exchange rates.

Inner representativity of rooms sampling during the procedure of dosimeter deployment is discussed with respect to two parameters: intended use (Table 3) and floor level (Table 4).

Rooms actually being measured are well representative of the whole "population" of rooms censed, considering both the occupancy factor and the floor level. Tables 3 and 4 show maximum differences of 4% and 6%, respectively.

3.1 Equilibrium factor and unattached fraction

As shown in Table 5, the average equilibrium factor for offices is 0.52 which is nearly equal to the suggested value, 0.5, of [24], but 30% higher than the traditionally assumed value, 0.4, of [25] (still considered appropriate by [2], showing a range from 0.1 to 0.9). The F value increases for libraries, usually characterized by small surface to volume ratios, and decreases for archives and storage rooms due to their very small free inner volume.

Table 3: Analysis of inner representativeness with regards to rooms occupancy factor expressed in terms of hours spent there in one year: (i) offices, workshops, porter's lodges, and research labs, 2000 h $year^{-1}$; (ii) reading rooms, libraries, classrooms, and teaching labs, 1000 h $year^{-1}$; (iii) storage rooms, kitchens, archives, and copy rooms, 100 h $year^{-1}$.

	Rooms censured		Rooms measured	
	(#)	(%)	(#)	(%)
2000 h/year	273	81%	149	84%
1000 h/year	57	17%	24	13%
100 y/year	5	1%	5	1%

Table 4: Analysis of inner representativeness with regards to floor levels of rooms hosting indoor radon concentration measurements.

	Rooms censured		Rooms measured	
	(#)	(%)	(#)	(%)
PS1	68	10	40	11
PTE	55	8	48	13
PR1	115	17	39	11
P01	77	11	51	14
P02	4	1	0	0
P03	5	1	0	0
P04	11	2	0	0

Table 5: Summary of measurements results about equilibrium factor F and unattached fraction f_p during the first three month period (corresponding to spring).

	Equilibrium factor		Unattached fraction	
	Mean	σ (k=1)	Mean	σ (k=1)
Office 1	0.49	30%	0.09	68%
Office 2	0.39	32%	0.14	49%
Office 3	0.51	33%	0.14	51%
Office 4	0.48	26%	0.13	28%
Porter's lodges	0.52	29%	0.12	76%
2000 h $year^{-1}$	0.48	10%	0.12	16%
Library	0.66	34%	0.08	28%
1000 h $year^{-1}$	0.66	34%	0.08	28%
Archive	0.33	15%	0.20	21%
100 h $years^{-1}$	0.33	15%	0.20	21%

The average unattached fraction for the offices considered is 0.12, greater than the central value of the unattached fraction in houses, 0.05, reported by [2]. Despite what expected, measurements in archives and storage rooms, usually characterized by higher aerosol concentrations (so attachment rates), return higher values of unattached fraction (0.2). Similar considerations should be extended to the reduction (with respect to 0.4) of the equilibrium factor in such places: indeed, a value of 0.33 is generally associated to lower aerosol concentration than the average house.

4 CONCLUSION

A survey addressing measurements of radon concentration in university buildings (at Sapienza – University of Rome) has been described and discussed in depth. The survey aims to provide information about radon exposure in workplaces (e.g., offices, research laboratories) and places attended by students (e.g., classrooms, teaching laboratories and libraries).

The sample of rooms being measured has been proved to be representative of all the rooms censed at the beginning of the survey. Two main variables have been considered in representativity analysis as parameters potentially influencing indoor radon concentration: occupancy factor coupled with the intended use for rooms (i), and the floor level (ii).

Measurements are well under way since April 2019 being designed to be divided according to seasons in order to appreciate the periodicity, direct or inverse, in radon seasonality.

The paper also shows the results of a preliminary study addressing the evaluation of equilibrium factor F and unattached fraction f_p in 7 rooms sampled within the places interested by radon measurements. Such measurements will be repeated in the following three month monitoring periods (i.e., summer, autumn, and winter) extending the number of rooms considered.

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