

Article

Radon survey in bank buildings of Campania Region according to the Italian transposition of Euratom 59/2013

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Abstract: Radon gas represents the major contributor to human health risk from environmental radiological exposure. In confined spaces radon can accumulate to relatively high levels so that mitigation actions are necessary. The Italian legislation on radiation protection has set a reference value for the activity concentration of radon at 300 Bq/m³. In this study, measurements of the annual radon concentration in 62 bank buildings, spread on Campania region (Southern Italy), were carried out. Using CR-39 solid-state nuclear track detectors, radon level was assessed in 136 confined spaces (127 at underground and 9 at ground floors), frequented by workers and/or the public. The survey parameters considered in the analysis of the results were: floor types, wall cladding materials, number of openings, door/window opening duration for air exchange. Radon levels were found to be between 17 and 680 Bq/m³, with an average value of 130 Bq/m³ and a standard deviation of 120 Bq/m³. About 7% of the results gave a radon activity concentration above 300 Bq/m³. The analysis showed that the floor level and air exchange have the most significant influence. This study highlighted the importance to assess the indoor radon levels, even in particular environments, to protect public and workers by radon-induced effects on health.

Keywords: CR-39 detector, Euratom 59/2013, Italian radiation protection legislation, radon indoor, radon survey

1. Introduction

Radon is the heaviest and the only radioactive noble gas present in nature everywhere, generated in rocks and soils throughout the earth's crust. Its main unstable isotopes namely ²²²Rn (radon), ²¹⁹Rn (actinon) and ²²⁰Rn (thoron) are produced in the intermediate steps of the three primordial decay chains of ²³⁸U, ²³⁵U and ²³²Th respectively. The radiological importance of each radon isotope depends on its relative abundance and half-life. Due to the isotopic ratio of ²³⁵U/²³⁸U=0.0072 and the short half-life ($T_{1/2}$ =3.98 s), ²¹⁹Rn is always ignored. ²²²Rn, having the greatest half-lives ($T_{1/2}$ =3.82 d), also respect to ²²⁰Rn ($T_{1/2}$ = 56.83 s), has received the most attention for the scientific community and for radiation protection.

Radon and its progenies are amongst the major sources of population's exposure to natural radiation; indeed, they constitute the main contributor to the annual effective radiation among all sources of ionizing radiation [1]. Radon is chemically inert so it does not react with other elements or compounds and it can easily escape from the ground into

the air where it can be inhaled. However, health hazards related to radon issue are not caused directly by radon, but by its progenies. In fact, being the lifetime of ^{222}Rn longer than the air change time in the human respiratory system, most of the inhaled radon is exhaled rather than decaying in it. On the contrary, the short-lived radon progeny (^{218}Po and ^{214}Po) is solid and so reactive that they can attach to atmospheric dust and water droplets forming clusters (attached fraction). Similarly, if inhaled, the decay products of ^{222}Rn (unattached fraction) attach themselves to the epithelium of the respiratory system and, due to their short duration, decay. In this way, the alpha particles ionize the DNA structures increasing the probability that, due to the stochastic effect, they can generate carcinogenic processes [2,3].

Since 1988, based on scientific evidences, the International Agency for Research on Cancer (IARC) defined radon as a human carcinogen (group 1) [4] and some decades later, the International Commission on Radiation Protection (ICRP) in 2007 [5] and the World Health Organization (WHO) in 2009 [6], identified radon as the second leading causes of lung cancer after cigarette smoking.

Radon, due to its chemical characteristics which allow it to escape easily through rocky substrates and native soils, enters buildings through cracks in the foundations or walls and accumulates in indoor environment where it could be breathed by humans.

In addition to the soil, a significant contribution to the accumulation of radon in indoor environments is due to exhalation from building materials of natural origin, in particular with a porous matrix (such as tuff) [7,8].

Furthermore, its indoor concentration is affected by environmental changes such as the frequency of air exchange in a closed environment and as changes in pressure, temperature, humidity outside. For this reason, long-term measurements (from 3 to 12 months) that take into account daily and seasonal variations are recommended to evaluate the radon concentration inside a building [9,10]. Thus, the annual average of radon activity concentration provides a representative estimate of indoor radon level.

Population exposure to radon occurs both in workplaces and dwellings, since people usually spend a lot of their time in these confined spaces. It has been estimated that people generally spend more than eight hours a day in their workplace, therefore monitoring workers exposure is essential [11]. In addition, it is important to assess exposure in confined spaces other than houses (such as schools, shops, offices, banks, hospitals, universities) where significant levels of radon can be observed [12].

Subsequently to the classification of radon among carcinogens, many countries and international organizations have issued norms or recommendations for managing exposure. The WHO recommends a reference level of 100 Bq/m^3 for houses, and the ICRP has also recommended a level not exceeding 300 Bq/m^3 [5,6]. In Italy, the protection against the dangers arising from exposure to ionizing radiation, has recently become more prominent with the Legislative Decree 101/2020 [13] which transposed the Basic Safety Standards (BSS) Directive - 2013/59/Euratom Directive [14]. Compared to the previous legislation (Legislative Decree 241/2000), [15] the great novelty introduced by the Directive lies in the establishment of protection measurements against the ionizing radiation not only for workers but also for general population in living environments (Article 19). Furthermore, the Legislative Decree 101/2020 replaced the 'national action level' of 500 Bq/m^3 with the 'reference level' of 300 Bq/m^3 both for workplaces and dwellings (Article 12 comma 1) [13]. The Italian legislation commits employers to evaluate the occupational exposure in fully underground workplaces (e.g. caves, tunnels, cellars, mines, galleries, metro stations, car parks), in thermal structures and in basements and ground floor workplaces of buildings placed in 'radon-prone areas' identified and declared by the Regions according to the National Radon Action Plan (Article 10). Remedial actions are required if the annual average activity concentration of radon exceeds the reference level. In the event that the assessment of the effectiveness of the remedial actions adopted determines a level even higher than the reference value, then the employer is asked to calculate the annual effective dose for workers. Hence, if this estimation results lower than 6 mSv , (Article 12 comma 1, letter d) no further actions are required. In this context, the present work

presents an extensive measurement survey of radon activity concentration in 62 buildings of a bank company throughout Campania Region, Southern Italy. This region, in accordance with the 2013/59/Euratom Directive and pending for its transposition in the national regulation, approved the Regional Law no. 13/2019 [16] which establishes the reference limit level for the activity concentration of radon gas activity at 300 Bq/m³ in all underground rooms, basement, ground floor of closed environments opened to public as well as in buildings intended for education and in so-called strategic buildings as declared by the Ministry of Infrastructure [17]. The measurement campaign began in October 2019 and ended in September 2020. The aim of the present study was first of all to estimate the annual average radon levels in the underground and ground floors of the banks and then to evaluate remedial actions for these indoor environments where necessary. In order to perform a multifactorial study, data on several factors affecting radon concentration in confined spaces were collected and analysed. To assess the possible influences and correlations, the results of radon activity concentrations were combined with data on building characteristics, construction standards, building materials, ventilation conditions and systems, number of doors and windows and habits of the occupants.

2. Materials and Methods

2.1 Study area and sampling design

Banks involved in the measurements survey are 62 buildings spread across the five provinces of Campania Region: Napoli (44), Salerno (7), Caserta (6), Avellino (3), Benevento (2).

Campania is a very interesting area since its territory is characterized by a large variety of geological environments and a high population density. Geological features, soil characteristics and extensive use of stones of volcanic origin (yellow tuff, green tuff, etc.) in the traditional building construction systems [18] can be considered responsible for the indoor radon mean activity concentration value higher than the national average (around 70 Bq/m³) [19-21].

A typical bank building consists of a ground floor serving to public as banking halls, offices, conference rooms and office spaces with a daily human occupation of at least eight hours and eventually an underground floor arranged in rooms serving as caveat, deposit, archive and more rarely office. The building sample object of the study consisted of a total of 136 confined environments, 9 of which in the underground level.

A CR-39 detector was placed in each measurement point by the responsible for safety at work, appropriately trained by our team for correct positioning. Radon measurements were conducted following the recommendations established by the UNI ISO 11665: 2020 standard. A data collection form on building characteristics and occupants' habits (ventilation system, number of openings, floor and wall cladding materials, number of hours per day of opening doors/windows for air exchange) was requested to complete.

2.2 Radon activity concentration measurement method

Radon concentration was measured in 136 environments of 62 bank buildings for two consecutive six-month periods. The first period was October 2019 - March 2020 and the second period April - September 2020. The mean annual radon activity concentration was calculated as the time-weighted average concentration of the two periods, using detector exposure time as weights.

Radon activity measurements were performed using Solid-State Nuclear Track Detectors (SSNTDs) of poly-allyl-diglycol-carbonate commercially known as CR-39.

The CR-39 detector is widely used for integrated and long-term measurement of the radon levels because of its material stability, good ionization sensitivity, stability against various environmental conditions and ease of use [22-25]. The detection system consists of a closed chamber (Radout®, holder for CR-39 produced by Mi.am srl) in which it diffuses ²²²Rn, but not ²²⁰Rn and ²¹⁹Rn isotopes, dust particles and humidity are excluded. During the exposure time, the α particles emitted by radon and their daughters interact with the aggregate state of the CR-39 polymer causing damage along its path. The traces

of the α particles are then made visible by an optical microscope after a chemical etching of the detector. The etching process consists of immersion the CR-39 detector in 25% weight/volume sodium hydroxide (NaOH) solution, at 98°C and 1.181 g cm⁻³ density for 1 h and then in 2% weight/volume acetic acid (CH₃COOH) solution for 30 min. At last, the detector is rinsed in distilled water for 1 h in order to stop further etching. A more detailed description of CR-39 tracks analysis methodology is available in [25]. The observed track densities were converted into radon activity concentrations using an appropriate calibration factor supplied by the manufacturer and subtracting the background track density determined by observing unexposed detectors etched under the same conditions.

2.3 Statistical analysis

Statistical analysis was carried by verifying the log-normal distribution of radon values using Kolmogorov-Smirnov test. The comparison of radon activity concentration values was performed for the categories 'ground' and 'underground' level with the non-parametric Mann-Whitney test. Descriptive statistics (median, mean, standard deviation, range, etc.) have been computed on radon annual averages estimated in the two groups. Thus, the rooms that showed an annual average radon activity concentration higher than the reference value were classified 'critical'. Statistical analyses were performed using the Statistical Package for the Social Sciences (IBM SPSS Statistic v.26).

3. Results

Frequency distribution of annual activity concentrations for the 136 rooms is shown in Figure 1a.

Descriptive analysis shows that data distribution is skewed (skewness = 0.45, kurtosis = 0.1), and it is well described by a log-normal model (Figure 1b), checked by the Kolmogorov-Smirnov test ($p > 0.05$, 95% confidence level). In the graph, the values of the geometric and arithmetic means are reported.

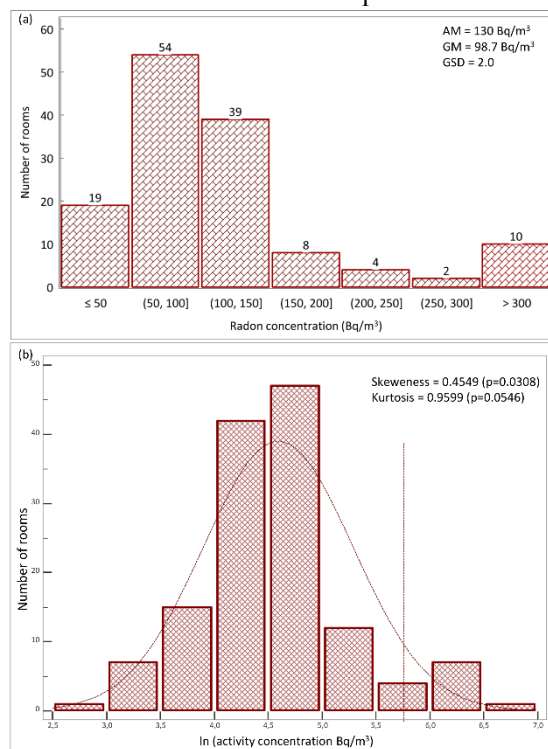


Figure 1. (a) Distributions of the annual average radon activity concentration for the full data set (136 bank rooms) expressed as Bq/m³. The final bin is an overflow bin that contains all results above 300 Bq/m³. Abbreviations: AM, arithmetic mean; GM, geometric mean; GSD, geometric standard deviation. **(b)** Normalized histogram for the natural log of radon measurements fitted with a normal distribution. Vertical dot line indicates the threshold at 300 Bq/m³.

Based on the result of the Mann-Whitney test, significant difference in the annual average radon concentrations between ground and underground level are observed ($p < 0.05$) at 95% confidence level. The variation of radon concentration with respect to the different floor level is reported in the box plot of Figure 2.

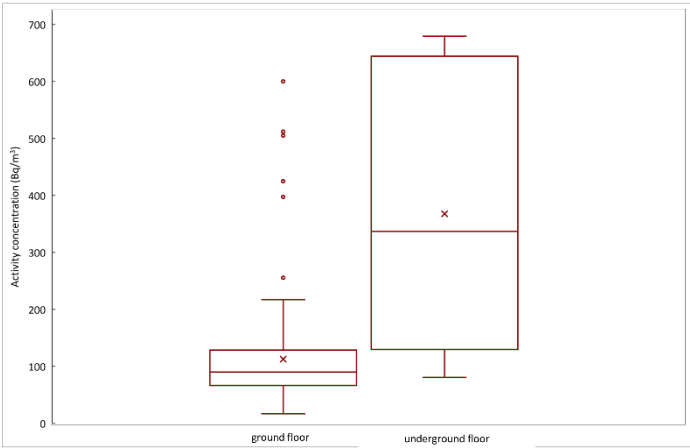


Figure 2. Comparison of annual average radon activity concentration obtained at ground and underground floors. The graph reports median, 25th and 75th percentile; the outside values are represented by dots. The cross marker represents the mean value.

Frequency distributions of the separate annual specific concentrations for ground and underground floors are reported in Figure 3.

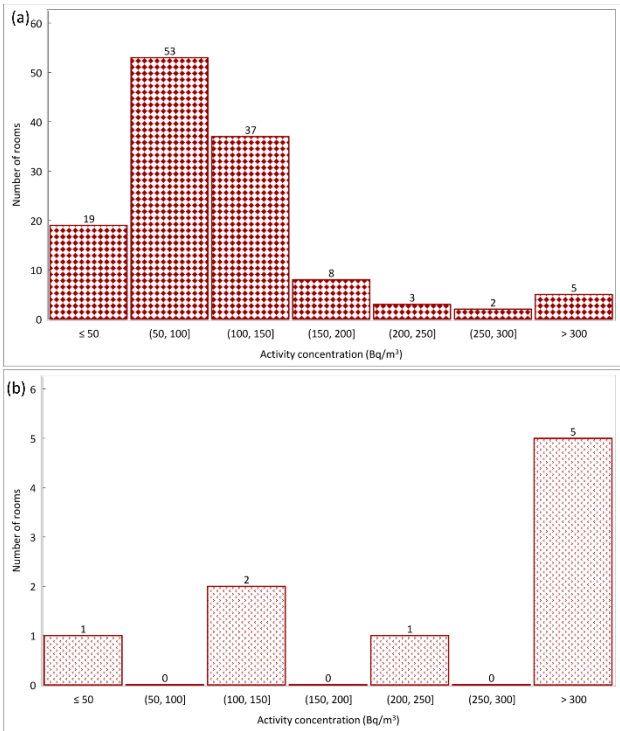


Figure 3. Distributions of the annual average specific concentrations in the (a) ground and underground (b) floor levels expressed as Bq/m³.

As reported in Figure 3, a total of 10 rooms, five for each category (representing 4% and 56% of the total rooms at ground and underground level respectively), belonging to

7 different buildings, showed a value of the radon concentration exceeding the reference value of 300 Bq/m³.

The rooms investigated, at ground and underground floors, showed values of the annual average activity concentrations included in 17 - 600 Bq/m³ and 80 - 680 Bq/m³, with an arithmetic mean of 113 ± 91 Bq/m³ and 368 ± 242 Bq/m³, respectively. The median value of radon concentration was found 90 Bq/m³ and 337 Bq/m³ for the ground and underground level, respectively. Since radon results distributions were skewed (Figure 3), the geometric mean was used to describe the central tendency. The results showed a geometric mean of 91.6 Bq/m³ and 286.3 Bq/m³ in ground and underground floors respectively. A synthesis of the statistic parameters and the number of rooms in which the radon value exceeds the reference level are shown in Table 1.

Table 1. Statistical data on annual average of indoor radon concentration (Bq/m³) in monitored banks by floor level.

Descriptive statistics	Ground level	Underground level
Range (Bq/m ³)	17 - 600	80 - 680
Median (Bq/m ³)	90	337
AM ± SD (Bq/m ³)	113 ± 91	368 ± 242
GM (Bq/m ³)	91.6	286.3
GSD	1.9	2.2
% ^a >300 (Bq/m ³) (no. of rooms)	4 (5)	56 (5)

Abbreviations: AM, arithmetic mean; SD, standard deviation; GM, geometric mean; GSD, geometric standard deviation.

^a = Percentage of results exceeding 300 Bq/m³.

Factors affecting radon concentration were investigated. To this aim, the rooms resulting to have a radon concentration level > 300 Bq/m³ were categorized as ‘critical’ for the analysis. To verify the existence of any significant difference between the critical rooms and the other ones, the Mann-Whitney test was used. No significant difference in the distribution of number of openings between the two groups was found, whereas significant change in the variable ‘opening time’ of windows/doors between ‘critical’ and ‘no critical’ rooms are found (*p* < 0.05) at 95% confidence level. As showed in Figure 4, the range of the mean value of opening time resulted 2.5 - 3 h/d in critical rooms group and 3 - 5 h/d otherwise.

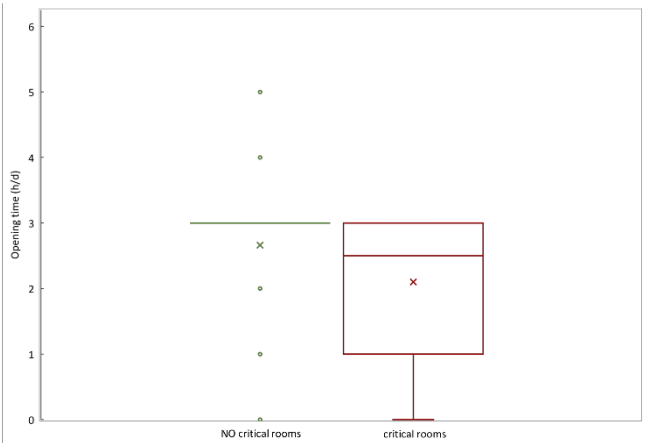


Figure 4. Variability of opening time (h/d) of windows/doors into the groups of 'critical' (radon concentration level $> 300 \text{ Bq/m}^3$) and 'no critical' rooms. The graph reports median, 25th and 75th percentile; the outside values are represented by dots. The cross marker represents the mean value.

The data on the wall cladding materials showed that almost all the analysed rooms both at ground and underground level are plastered (95% and 100% respectively). Similarly, no statistical significance was found with respect to the floor cladding materials for the critical and no critical rooms of the buildings included in the analysis.

4. Discussion

In this study, we analysed the radon activity concentration in 62 bank buildings spread on Campania region. A total of 136 measurement points (127 at ground and 9 at underground floor) were investigated for the annual radon monitoring. Despite the difference in the sample size between the rooms at underground and ground floors represents a limit for the statistics (it potentially induces a bias), the analysed sample is the description of the effective distribution of the environments since the monitored buildings belong to a single bank company. The results of overall data set, expressed in terms of annual average activity concentration, as expected [26,27] showed a skewed distribution well fitted by a log-normal curve (Figure 1). The distribution of radon activity concentrations is comparable with the results reported in several studies available in literature [19,21,27-31]. The geometric mean and the geometric standard deviation of the data have been used to describe the distribution and their knowledge resulted to be useful to evaluate the fraction of rooms that exceeds the reference value (300 Bq/m^3).

The legislative framework, that was the rationale for this work, plays a key role in the interpretation of the results. Campania Regional Law 13/2019 [16] requests to assess the radon level in underground, basement and ground floor of any building with public access, establishing the reference level of 300 Bq/m^3 . According to this law if radon activity concentration value exceeds the reference level, the employer must implement remedial actions. Furthermore, compared to the previous Italian Legislative Decree 241/2000, the "reference level" has been introduced replacing the "action limit" and has been reduced from 500 to 300 Bq/m^3 . During these measurements, the transposition of the Euratom 59/2013 directive came into force by Italy which, with respect to the regional law, incorporates all the basic safety standards for protection against the dangers arising from exposure to ionising radiation. In particular, for exposure to radon gas, the annual effective dose limit has been increased from 3 to 6 mSv/y and buildings, intended for residential use, are involved in the national regulation demanding to regional institutions the task to implement an investment policy in order to adopt radon reduction strategies also for radioprotection of people at home, if required.

Since the bank buildings include underground and ground confined spaces, occupied both by workers and public, according to Regional Law, strategy for radon mitigation should be implemented in order to reduce the radon concentration. The owner of the property presents a remediation plan which will be approved by the Municipality (Article 4 comma 3) [16].

The method of choice for mitigation depends on the required reduction factor and the type of floor [32,33]. In general, the best way in which to lower radon levels is to reduce the pressure difference that draws radon into a building [32] but structural interventions are not quick to apply and their feasibility depending by several factors including construction characteristics. One practical method immediately applicable is passive ventilation consisting in increasing number and frequency of opening doors and/or windows allowing at reduction indoor radon concentration by dilution (increased volume of fresh air dilutes radon concentration). Many literature papers investigated the impact of passive ventilation through manual airing on indoor radon concentration [34-36]. In our study, the significant difference of the hours per day of opening windows and doors between

'critical' and 'no critical' rooms, supports the potential effectiveness in enhancing the ventilation of the environments. To this regard, all buildings investigated are equipped both with air conditioners and at least one opening in each room. At the same time, it should be noted that behaviours of occupants including window opening are influenced by building type, ventilation strategy, heating system, energy characteristics and so on [37]. However, the type of buildings investigated represents a peculiar scenario: for example, inside banks, for security reasons, it is not possible to intervene by increasing the windows opening time, but it will be necessary to design forced ventilation systems that do not alter the degree of building security. Another aspect that plays a fundamental role in managing the risk of radon gas is the intended use of the environments. Our results showed that 6 rooms are bank archives (5 located at the underground floor) exceeding the reference level, the access of staff is 18 hours per year, so applying the criteria of Legislative Decree 101/2020 the annual effective dose is lower than the action limit of 6 mSv (Article 12 comma 1 letters c and d). Conversely, 2 rooms at ground floor with high radon concentration, are daily occupied by both workers and public, so according to the criteria of LR 13/2019 the building owner must submit a remediation plan.

From the point of view of the positioning of the rooms respect to the floor, the statistical analysis found a significant difference between the ground and underground floor (Figure 2). The reason for high levels of radon in cellars could be the contact with soil containing uranium. Many literature works reported high radon concentration levels in underground sites nearest to the source and usually poorly ventilated (mines, tunnels, underpasses, catacombs, caves, spas, caves) [21,31,32,38-41]. Radon gas enters the building from the ground through cracks, crevices and other leakages or exhales from the walls of the house and, through air flows, spreads and accumulates in the internal environment. The diffusion process and the radon level in a building depends on several factor such as concentration of radioactivity in the ground, permeability of the ground, nature of floor and coupling of building to the ground, ventilation conditions, lining materials. The highest radon levels occur where each of these factors contribute to increase the radon, but small changes in one or more of them can cause appreciable differences in the radon activity concentration value, even in adjacent buildings of apparently identical construction [42]. This can be the reason of the variability of radon activity concentration found in our data set ranging from 17 ± 7 to 680 ± 190 Bq/m³ with a geometric mean of 98.7 Bq/m³ and an arithmetic mean of 130 Bq/m³ (Figure 1). In order to reduce the radon concentration to the rooms at ground floor, specific barriers between cellar and ground floor could help to decrease the amount of radon entering the living areas [38].

Generally, the mean value of annual radon concentration found in the present investigation is higher than the mean national value (77 Bq/m³) [26,29,43]. Furthermore, is interesting to note that radon values occurred in underground rooms are higher also than the mean value reported in the extensive national survey on radon concentration in similar underground workplaces of bank buildings [31]. Conversely, the values of radon activity concentrations found in this study are comparable with other published results deriving from regional campaign of measurements [8,43]. We can speculate that combination of two factors affects the radon concentration in Campania region: the complex geological and structural setting of this region [44] and the building materials of volcanic rock origin and pyroclastic sediments (i.e. lavic stones, tuffs, pozzolana) presenting high ²²⁶Ra radioactivity level and used in recent and ancient constructions [8]. It is well known that radioactivity contents of building materials contribute to radiation exposure, and radon exhalation can increase the radon levels indoor depending on the type of material [7,45-47].

In this framework, the knowledge of building materials, construction techniques, occupancy time of the space, combined with a more extensive and homogenous survey involving bank buildings spread all through region, could be useful to individuate factors influencing the radon level in the geographical area involved in the survey.

Waiting for to enhance the work with future measurement campaigns that could potentially target areas and dwelling types where data are currently sparse, our study provides useful results in the perspective of the imminent implementation of National Radon Action Plan as stated by the Italian Legislative Decree 101/2020 [13]. The plan defines strategies and arrangements for managing exposure to radon in workplaces and homes moving from identification of radon-prone areas (where the radon concentration in a significant number of buildings is expected to exceed the relevant national reference level) by targeted radon measurement survey. Once radon-prone areas will be identified here the regulation will demand to perform radon measurement in underground, basement and ground environments both in workplaces and dwelling and, if necessary, to reduce radon levels within the reference values established for existing and new buildings (Article 12) [13]. In this context, the work focused on the radioprotection issue of workers and general population in underground and ground environments of buildings opened to public and where different working activities are performed.

5. Conclusions

This study reports the results of a survey carried out to evaluate the radon concentration in bank buildings in Campania region, southwester Italy. The survey covered 62 bank buildings in the five provinces including 136 closed environments in underground and ground floor. In each room, radon device was exposed for a period of 12 months. In the underground rooms (such as archives and other rooms not occupied daily by workers) and in poorly ventilated rooms located at ground floor, the average annual radon concentrations were found to be higher than regularly ventilated rooms or those on the ground floor. The difference in radon concentration levels between the two investigated floors confirmed that soil is the main source of indoor radon, as well as the results show the effectiveness of the increased aeration turnover as a radon reduction strategy. About 93% of the radon activity concentration is below the national reference level of 300 Bq/m³. Rooms that exceed the level of 300 Bq/m³ (7%), would need remedial actions, such as forced ventilation and specially designed barriers, could be useful to reduce the radon level. In conclusion, the results highlighted the necessity to increase the radon monitoring in workplaces with high occupancy factor to ensure protection against exposure to staff and public as well. Furthermore, the work suggests that the identification of radon-prone areas will provide valuable criteria to implement a targeted radon surveillance and mitigation in the workplaces and dwellings in accordance with the Italian radiation protection regulation.

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