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Italian National Radon Action Plan: New Challenges for Risk Assessment

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Abstract: Radon gas is one of the chemical pollutants with one of the most significant physical effects due to its impact on human health: it is a radioactive noble gas which, if inhaled, can stochastically induce lung cancer. For this reason, it is classified as a category A substance and is the second cause of cancer after tobacco smoking. The monitoring and management of indoor radon is based on international recommendations but also national regulations, which, in recent years, have been updated by lowering the reference levels. In this work, some radon activity concentration data were evaluated by comparing the criteria of old and new legislation to highlight how the radiation protection approach has completely changed. Specifically, this study focuses on measurements in Campania, which, due to its originally volcanic geological structure, requires crucial attention in the context of radon risk assessment, given the considerable number of dwellings built in tuff. This initial data processing enabled the identification of potential high-priority radon risk areas, serving as an important reference point for the extension of the monitoring activities in Campania.

Keywords: radon; legislation; radiation protection; risk management; air pollution; Italy; air quality observations

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Citation: La Verde, G.; Della Peruta, G.; Imparato, C.; Ambrosino, F.; Mottareale, R.; Gagliardo, G.; Pugliese, M. Italian National Radon Action Plan: New Challenges for Risk Assessment. *Atmosphere* **2024**, *15*, 846. https://doi.org/10.3390/atmos15070846

Academic Editor: Francisco Molero

Received: 10 June 2024
Revised: 25 June 2024
Accepted: 16 July 2024
Published: 18 July 2024

1. Introduction

The topic of air pollution is increasingly attracting the attention of the scientific community due to both a growing awareness of its impact on human health [1–3] and its close correlation with proven climate change [4]. Adding to this, very recently, the outburst of the COVID-19 pandemic strengthened the importance of air quality, especially indoors, nourishing the Indoor Air Quality (IAQ) sector in relation to different types of pollutants [5–8].

However, a particular chemical pollutant that has physical interactions with the biological system is radon gas. Radon (Rn) is a naturally occurring radioactive noble gas (colourless, odourless, tasteless and inert) whose isotopes come from the decay of the three natural radionuclide series in the Earth's crust in different rocks: U-238 (uranium), U-235 and Th-232 (thorium). From a human healthcare point of view, Rn-222 (from U-238) assumes relevance due to its half-life of about 3.8 days and its direct contribution to lung cancer development through the emission of alpha particles and/or the subsequent decay of its daughter nuclides following inhalation [9–13]. Once inhaled, radon and its daughters (Po 218-Po214) emit alpha particles which, especially at the level of the pulmonary alveoli, due to a stochastic effect, could cause DNA mutations that could, in turn, trigger carcinogenic processes. Indeed, the presence of radon indoors has been identified as a major risk agent for lung cancer development by the World Health Organization (WHO) [14], and Rn-222 has been classified as a Group I carcinogen radionuclide by the International Agency for Research on Cancer (IARC) [15].

For this reason, it is important to identify the sources of emissions and adopt all strategies for monitoring and managing indoor radon activity concentration. In addition to the Earth's crust lithology and geological structure [16], in fact, other sources of Rn-222, for which it is necessary to carry out radiometric characterizations, are building materials (especially igneous ones) [17–21] and water [22–24].

In this context, Italy has adopted different Legislative Decrees (L.D.) over the years for the monitoring of radon gas in buildings; since 2000, L.D. 241/2000 [25] has been the reference law concerning workplaces on ground floors and thermal spas. It was followed by L.D. 101/2020 [26], which represents the implementation of European Directive Euratom 59/2013 [27], introducing a new vision of radiation protection based on the graded approach methodology, which relates to the adoption of all measures aimed at guaranteeing the principle of optimization [28].

Furthermore, L.D. 101/2020, similarly to the Directive provisions (art. 103 and annex XVIII) [27], has introduced a National Radon Action Plan (NRAP) [29] which shows the necessity to adopt a specific plan for the measuring and monitoring of indoor radon and, finally, to identify radon-prone areas which will then need to be investigated further.

Therefore, the aim of this study was to highlight some challenges related to the introduction of new legislation and national instruments such as the NRAP, which each member state has or will have to adopt. This work reports a practical case related to the Italian legislative framework.

The aim of this study was to manage indoor radon activity concentration data by evaluating a risk assessment scenario for the municipalities of the extensive Neapolitan province. Campania represents a region of crucial relevance in terms of radon risk determination due to its originally volcanic geological structure [30] and the consequent widespread use of tuff as a building material [31–33], especially among older dwellings.

Firstly, the concentrations of radon activity in the municipalities of Naples are discussed considering the new NRAP guidelines, compared with the previous legislation. Additionally, the collected data allow for a preliminary identification of potential high-priority radon risk areas, establishing a solid foundation for the continuation of monitoring activities in the Campania region and the implementation of the planned national mapping activity.

2. Materials and Methods

2.1. Indoor Radon Measurements and Area of Sampling

Radon activity concentration measurements were performed using CR-39 solid-state nuclear track detectors provided by MI.AM S.r.l., Piacenza, Italy. They are 50 mm in diameter and 20 mm high, with an active surface of 25×25 mm^2. The measurements were conducted over the past twenty years and refer to rooms on the ground floors of residential buildings. The duration of each measurement was one year (two consecutive semesters). The sampling methodology was random, as homes were excluded from the decree [25] and were involved through citizen science campaigns. Holders were placed at least 1 m from the floor, away from doors or windows, in one or more rooms of the studied buildings. The material of the detectors was poly-allyl-diglycolcarbonate, which is very sensitive to the energy of highly ionizing particles, such as alpha particles, and which was housed inside a radon-permeable plastic holder (RADOUT®, from MI.AM S.r.l., Piacenza, Italy) in which radon gas diffuses and which prevents the radon daughters, produced outside the plastic box, from reaching the measurement volume. The alpha particles generated from the decay of radon damage the molecular bonds of the sensitive material inside the detectors, creating sub-microscopic latent tracks. A standard etching process of the detector (25% solution of NaOH, then 2% solution of CH3COOH) follows exposure to radon gas; the tracks can then be enlarged, permanently observed and, finally, counted and analyzed using a double-lens scanner reading system. More details are reported in [34]. By using a calibration curve, appropriately validated during international intercomparison campaigns at different known radon exposures, the number of tracks can be converted into radon activity concentration.

The measurement area is the Campania region in southwest Italy, characterized by very peculiar geological settings [35]. Naples is the Regional County seat of the Campania region, located in the southwest of Italy and occupying an area of about 13,600 km^2. Most of the population of the region (over 5.8 million inhabitants) is concentrated in this city, which is characterized by lava and pyroclastic rocks.

This is the soil type of almost the totality of the region, which is also characterized by a very complex geological and structural setting and is bordered to the west by the Tyrrhenian Sea. As mentioned in the Introduction, the presence of U-238 in volcanic rocks could lead to high Rn-222 concentrations, considering regional surveys using γ-spectrometry and soil permeability to detect U-238 distribution in Campania.

The distribution of U-238 is low (1.2–1.9 Bq) in densely cultivated areas over alluvial deposits and in outcrops of carbonate deposits, with these values increasing (1.9–3.4 Bq) in the four volcanic complexes of the region [36].

Due to radon gas exhalation from underground rocks, premises located on ground floors were ultimately chosen for monitoring, as higher concentrations are likely to be found there compared to upper floors. Regarding the data shown in Section 3, a table of different soil types with their relative codes is reported (Table 1). For greater homogeneity of data, some soil types have been grouped together because some municipalities include different lithological typologies.

Table 1. Soil type with respective code highlighting different types of geology in Naples province.

Soil Type	Code
Lava and pyroclastic rocks	1
Lava and sand	2
Alluvial clay, lapilli and ash	3
Alluvial clay and sand	4
Sand and marine clay	5
Tuff	6
Lava and pyroclastic rocks + alluvial clay	7
Alluvial clay and sand + limestone	8
Dolomite rocks	9

2.2. Data Management and Criteria

The data used in this study, relating only to the province of Naples, were selected from a larger database that includes measurements throughout the Campania region [37].

The dataset was identified by excluding from the analysis all municipalities in Campania with fewer than 10 measured dwellings, as, in such cases, the small sample size did not provide significant robustness for the evaluation of radon radiological risk.

The data were evaluated considering the differences between the two regulations to highlight how the number of residential buildings of radiological interest increases with the new RLs. In fact, L.D. 241/2000 explicitly excluded residential buildings (art. 1, 1-bis) by providing underground workplaces and thermal spas with an action level (AL) of 500 Bq/m^3 and managing it with an annual effective dose limit of 3 mSv.

L.D. 101/2020, instead, includes residential buildings (art. 19) with a reference level (RL) of 300 Bq/m^3 and 200 Bq/m^3 for those built after December 2024.

Furthermore, for a more up-to-date evaluation, the criteria of the NRAP were adopted. They were developed around three particular strategic axes: (1) measuring and identifying the priority areas and, thus, the main exposure scenarios; (2) acting through the implementation of remedial actions in buildings with activity concentration values higher than the reference level or through structural interventions to prevent the accumulation of indoor radon; (3) involving, educating and informing the population about radon and its risks.

Once a priority area had been identified and defined, the obligation of annual monitoring was also extended to all workplaces on the ground floor. For this reason, it was of fundamental importance to establish—but above all, to validate—the criteria and methodology of a tool that produces a result with significant socio-economic impact. In non-priority areas, the measurements had to be performed according to the indications of art. 16 of L.D.101/2020.

In this study, the application of axis 1 was explored in depth. Guidelines provided in the NRAP for measurements indicate that a proper sample should consist of a number of buildings equal to the number of inhabitants raised to the power of 0.3 for each municipality. Furthermore, for small municipalities, a minimum number of at least 10 measurements is required to avoid underestimations. Finally, the NRAP defines the criteria for the identification of radon-prone areas in the Italian national territory, such as those in which the number of monitored dwellings exceeding the RL of 300 Bq/m^3 is equal to or greater than 15% of the total number of measurements in residential buildings according to NRAP recommendations.

3. Results and Discussion

The whole sample of 2466 measurements was obtained from 27 municipalities out of a total of 92, corresponding to 29% of all municipalities in Naples (the Campania county seat).

Figure 1 illustrates how the legislative transition from L.D. 241/2000 to L.D. 101/2020 is reflected in a percentage increase in the number of dwellings at potential radiological risk from radon gas exposure. This is clearly related to the inclusion of a lower RL, which indeed decreased from 500 to 300 Bq/m^3. Changing this screening criterion results in a greater number of residential buildings being considered for redefining priority areas. In fact, the legislative transition from D.lgs 241/2000 to D.lgs 101/2020 has increased the percentage of dwellings at potential radon risk from 4.7% to 12.7% of the total number of residential buildings monitored in the Neapolitan province.

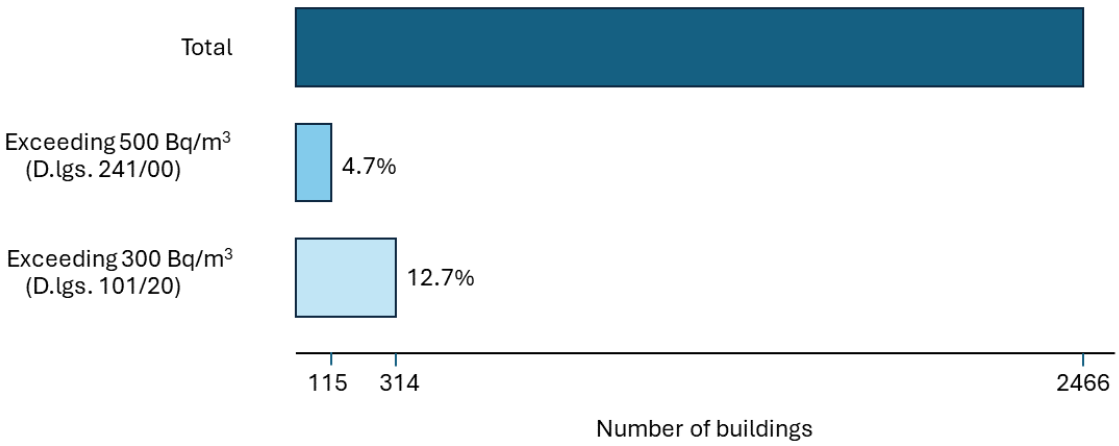

Figure 1. Comparative analysis of L.D. 241/2000 and L.D. 101/2020 in terms of the identification of residential buildings at radon radiological risk with respect to the total number of monitored dwellings in the past twenty years.

Table 2 shows the results in terms of minimum and maximum values of activity concentration (in Bq/m^3) for each municipality, along with the number of actual measurements carried out and the number necessary according to the indications of the NRAP. The number of dwellings representing 15% of the needed measurements according to NRAP criteria (see Section 2.2) and the number of measurements conducted in residential buildings exhibiting values over the RL of 300 Bq/m^3 are also included; the comparison between them allows the identification of radon-prone areas in the Neapolitan province.

Table 2. Radon activity concentration measurements for 27 municipalities of Naples. For each of these, we report the number of dwellings to be measured according to NRAP prescriptions (Needed) with the actual number of monitored dwellings (Done); specifically, municipalities with measurements conducted below the needed level are highlighted in gray in the first column. Radon activity concentration (Bq/m^3) is individuated in a range between the minimum (Min) and maximum (Max) level. The number of completed measurements with radon activity concentration values over the reference level of 300 Bq/m^3 is compared to the number of dwellings representing at least 15% of the number of needed measurements provided by NRAP recommendations; potential radon-prone areas are highlighted in bold.

Municipality (Soil Type Code)	Number of Measurements According to NRAP	Activity Concentration (Bq/m^3)	Number of Dwellings Representing 15% of NRAP Needed Measurements	Number of Completed Measurements over RL 300 Bq/m^3
Afragola (1)	Needed: 28 Completed: 37	Min: 20 Max: 52	4	0
Arzano (1)	Needed: 24 Completed: 19	Min: 168 Max: 755	4	**13**
Barano d'Ischia (2)	Needed: 16 Completed: 19	Min: 45 Max: 865	2	**11**
Boscoreale (1)	Needed: 22 Completed: 230	Min: 58 Max: 276	3	0
Brusciano (3)	Needed: 19 Completed: 15	Min: 46 Max: 185	3	1
Caivano (4)	Needed: 24 Completed: 11	Min: 86 Max: 198	4	0
Casamicciola Terme (2)	Needed: 15 Completed: 20	Min: 46 Max: 491	2	**8**
Cercola (1)	Needed: 19 Completed: 23	Min: 28 Max: 427	3	**3**
Forio d'Ischia (5)	Needed: 19 Completed: 58	Min: 31 Max: 770	3	**18**
Giugliano in Campania (1)	Needed: 34 Completed: 29	Min: 25 Max: 662	5	**15**
Grumo Nevano (1)	Needed: 19 Completed: 13	Min: 153 Max: 706	3	**11**
Ischia (2)	Needed: 20 Completed: 244	Min: 22 Max: 936	3	**18**
Lacco Ameno (2)	Needed: 13 Completed: 12	Min: 54 Max: 532	2	**3**
Marano di Napoli (1)	Needed: 27 Completed: 12	Min: 21 Max: 128	4	0
Marigliano (3)	Needed: 23 Completed: 17	Min: 39 Max: 283	3	0
Monterusciello (6)	Needed: 23 Completed: 16	Min: 29 Max: 167	3	0
Mugnano di Napoli (1)	Needed: 23 Completed: 36	Min: 24 Max: 226	3	0
Napoli (7)	Needed: 63 Completed: 974	Min: 20 Max: 990	9	**174**
Nola (8)	Needed: 23 Completed: 22	Min: 23 Max: 120	3	0

Table 2. *Cont.*

Municipality (Soil Type Code)	Number of Measurements According to NRAP	Activity Concentration (Bq/m^3)	Number of Dwellings Representing 15% of NRAP Needed Measurements	Number of Completed Measurements over RL 300 Bq/m^3
Piano di Sorrento (3)	Needed: 18 Completed: 25	Min: 61 Max: 353	3	**3**
Pollena Trocchia (1)	Needed: 18 Completed: 82	Min: 21 Max: 166	3	0
Portici (1)	Needed: 27 Completed: 23	Min: 25 Max: 473	4	**4**
Pozzuoli (6)	Needed: 31 Completed: 32	Min: 25 Max: 495	5	1
San Giorgio a Cremano (1)	Needed: 25 Completed: 28	Min: 20 Max: 117	4	0
Serrara Fontana (5)	Needed: 12 Completed: 25	Min: 32 Max: 866	2	**2**
Sorrento (3)	Needed: 19 Completed: 360	Min: 25 Max: 772	3	**21**
Torre del Greco (1)	Needed: 31 Completed: 83	Min: 33 Max: 680	5	**8**

From this preliminary study, the reported potential radon-prone areas according to NRAP recommendations are identified in the following municipalities: Arzano, Barano di Ischia, Casamicciola Terme, Cercola, Forio di Ischia, Giugliano in Campania, Grumo Nevano, Ischia, Lacco Ameno, Napoli, Piano di Sorrento, Portici, Serrara Fontana, Sorrento and Torre del Greco. In this report, municipalities with a number of measurements below the level prescribed by the NRAP (highlighted in gray in the first column of Table 2) were also considered; in fact, a portion of these incomplete samples were, regardless, labelled as potential radon-prone areas since the number of completed measurements over the RL had already exceeded the identified 15% NRAP threshold.

Another important aspect of reflection on the critical issues of the NRAP is the representation of the required data. In fact, representing data through averages results in a loss of information, and the only solution would, necessarily, be a weighted average. However, even in this case, the large difference in the number of measurements among municipalities would not allow it to be considered robust. It would be appropriate, however, to think of a way to report individual data in order to plan, based on the values obtained and the environmental and lithological parameters of the site, remedial actions that are effective and, at the same time, rational and targeted expenditures.

Likewise, the min and max values do not provide information on the distribution of values (with the exception of Naples) due to the small number of samples, which, however, are considered sufficient according to the NRAP criteria.

Even if projections, simulations and derivations of indoor radon concentration activity values are useful for an initial characterization of the territory to identify radon-prone areas, they certainly cannot be the basis on which to plan remediation interventions.

4. Conclusions

This work underlined the importance of adopting comprehensive and updated measures to monitor and mitigate indoor radon exposure and highlighted the challenges linked to the implementation of the National Radon Action Plan (NRAP). The NRAP, mandated by D.lgs 101/2020, which represents a transition from L.D. 241/2000 and was driven by the implementation of European Directive Euratom 59/2013, marks a significant shift in radiation protection strategies. This shift is evident in the increased identification of dwellings at potential radiological risk due to the lower reference level (RL) for radon concentration, which was decreased from 500 Bq/m^3 to 300 Bq/m^3.

While it might not be the general case, in a region like Campania, with its unique geomorphological features, this change resulted in an increment of 8% in the number of buildings at potential radon risk. This may pose challenges in the future performing of remedial actions, which would need to be implemented on a much larger scale.

The measurements conducted in the extensive and diverse province of Naples highlight to the entire scientific community the challenges associated with radon monitoring in such heterogeneous geological and morphological settings. Furthermore, the measurements carried out in the Neapolitan area can specifically aid the relevant authorities in laying the groundwork for mapping and identifying priority areas at radiological risk within the Italian national territory.

Author Contributions: Conceptualization, G.L.V. and M.P.; methodology, F.A., G.D.P., C.I. and G.L.V.; software, G.D.P., F.A., C.I. and G.L.V.; validation, G.L.V., G.D.P., C.I., F.A., R.M., G.G. and M.P.; formal analysis, F.A.; investigation, G.D.P., F.A., C.I., R.M., G.G. and G.L.V.; resources, M.P.; data curation, G.L.V., F.A. and M.P.; writing—original draft preparation, G.L.V., G.D.P. and C.I.; writing—review and editing, G.L.V., G.D.P., C.I., F.A., R.M., G.G. and M.P.; visualization, G.L.V., G.D.P., C.I., F.A., R.M., G.G. and M.P.; supervision, G.L.V. and M.P.; project administration, M.P.; funding acquisition, M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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