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Results of Indoor Radon Measurements in Campania Schools Carried Out by Students of an Italian Outreach Project

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Abstract: Outreach projects are often used to a limited extent for dissemination purposes and rarely have a significant impact on the student's teaching and technical skills. The RadioLab project requires a proactive interaction between researchers and students by experimental activities for measuring environmental radioactivity, in particular radon gas. Buildings considered to be of radiological interest, such as schools, have been selected to carry out radon gas activity concentration measurements using solid-state nuclear track passive detectors LR-115. The results of annual measurements, made over 6 years and involving a total of 952 rooms, distributed in 67 schools throughout the Campania region, were collected. These data, deemed scientifically reliable (i) can be overlapped over geological characterization data enhancing the relationship between lithology and radon, (ii) confirmed data from the radon potential map of the Campania region about the distribution of indoor radon, and finally (iii) contributed to the collection of radon indoor data of the Campania region. The results obtained highlighted the need and effectiveness of increasing the network of schools involved in the outreach activity and in the implementation of experimental activities with applicative effects in the scientific and research sectors.

Keywords: radon activity concentration; educational project; passive detectors

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1. Introduction

Radon (^{222}Rn) is a radioactive noble gas of natural origin with a half-life of 3.8 days, arising from the decay chain of uranium (^{238}U). For this reason, it is ubiquitous and is recognized as the main source of public exposure by background natural radioactivity (50% of the global mean effective dose) [1]. Although humans have evolved adapting also to environmental radioactivity, the negative biological effects of radon occur when the gas accumulates inside the body, thus increasing the probability that, in particular, radon daughters, polonium (^{218}Po and ^{214}Po) will all decay within the airways. The emitted alpha particles from short-lived radon progeny are deposited in the bronchial airways of the lung where they can affect the basal and secretory cells in the bronchial epithelium and induce cancerous development. This is why radon has long been considered the second cause of lung cancer after cigarette smoking [2] and, even nowadays, its effects are at the center of scientific interest [3]. Since radon is ubiquitous but with an uneven distribution, it is also essential to consider the geology of the area. The Campania region (in the southwest of Italy) is of volcanic origin and, therefore, its population is potentially exposed to high natural radioactivity [4–7]. In fact, the close correlation between geology and radon is well known [8–10], especially for volcanic areas [11]. As such, spreading knowledge of all these topics among the population plays a key role for risk management by inspiring the adoption of a more aware radiation protection strategy.

RadioLab is one of the Italian National Institute of Nuclear Physics (INFN) outreach activities [12,13] for students and teachers with the aim to promote scientific culture on nuclear physics. In particular, RadioLab is focused on environmental radioactivity issues involving high school students in radon activity concentration measurements [14–16]. The peculiarity of this project lies in the way in which scientific communication is intended; teaching is integrated with scientific research through training orientation actions that follow the development phases of a research work, thus creating a path between dissemination, teaching, and research on the specific topic of radioactivity. Awareness of the presence of environmental radioactivity of natural origin allows students, their teachers, and their parents to familiarize themselves with these issues and their participation also requires them to carry out indoor radon monitoring activities. The RadioLab project has created an effective program that includes work sessions in the laboratory (assembly of the detectors, selection and study of the environments where to carry out the measurements, planning of the experimental activities) and methodologies for data acquisition and experimental results processing. This required a remodeling of educational programs with the need to integrate the curriculum of mathematics, physics, chemistry, biology, and computer science with activities that allowed working on the key concepts of the various scientific disciplines. In this way, physics is not only "presented" to students, but is "done" by students, also involving teachers. The project proposes the creation of a model of "training orientation" in several steps inspired by the typical rigor of a scientific experimental activity. After a training and information course on the main topics of radioactivity and on the instrumentation to be used, annual radon activity concentration measurements were carried out, spread over a period of 6 years in 67 schools distributed throughout the Campania region. The measurements were performed using passive solid-state nuclear trace detectors (SSNTD) and selecting places of particular interest such as schools of every level of education.

In this work, the main results that were obtained are reported, comparing them with those that were obtained by our research group on a potential radon map in Campania [17].

2. Materials and Methods

2.1. Sampling and Design of Measurements

RadioLab involved around 150 students from eight high schools in all the provinces of the Campania region. The experimental measurement activity provided for a preliminary inspection and study of the places conducted by the students under the supervision of their teachers and researchers to define the scenarios of greatest potential exposure to radon gas (considered as exposed members the students, teachers, and part of the public). The students performed the indoor radon measurements not only in their own eight schools but also in another 59 schools throughout the Campania region, therefore, the schools involved in the monitoring are of every level of education. For this work, the rooms most frequented by this type of exposed population were identified, such as classrooms, administrative offices, gyms, and educational laboratories, etc., which were all located on the ground floor. This ensured that the measurements were performed in the places with the closest contact with the ground and, therefore, with the potential for a higher concentration of indoor radon. The detectors were positioned at a height of about 2 m from the floor and at least 20 cm away from the wall to exclude the addition contribution of thoron (^{220}Rn, half-life of 55.6 s) from building materials. Measurements were performed for 1 year (two consecutive semesters). In particular, the monitored rooms were grouped into three typologies of intended uses: (i) classroom, (ii) headmaster room/secretary/library, and (iii) educational laboratory/gym. Educational laboratories included computer labs, language labs, and science labs. This classification was made according to different staying times and ventilation rates of the rooms. For the successful outcome of the experiment, training seminars were held on the procedures to be adopted during the radon measurements (from the positioning to the surveillance of the detector, up to the withdrawal scheduled every 6 months). In the first phase of the project, meetings were planned between researchers and teachers. The researchers held seminars that were specially designed for high school students and focused on environmental radioactivity and measurement methods. At the end of this phase, the solid-state nuclear track detectors

(SSNTD), i.e., LR-115, began to be used. One detector was used for each small room, i.e., classroom, headmaster room, secretary, while for each large rooms, i.e., laboratory, gym, and library, two detectors were used. The final phase involved collecting and reading the detectors to determine radon-specific activities. General meetings were organized and the young people were invited to show (through talks, posters, and other forms of mass communication) and discuss, not only with their peers but also with experts, the results of their work and the problems that were encountered [15].

2.2. LR-115 Detectors

For measurement, a cellulose nitrate detector (LR-115 provided by Dosirad, France) was used, placed in diffusion chamber. At the end of each measurement, the detectors were brought to the radioactivity laboratory at Department of Physics "E. Pancini" of Federico II University (Naples), where the students performed the procedure for the traces analysis left by the alpha particles emitted on the LR-115 films [18]. As such, the students proceeded step by step to (i) disassemble the detectors, (ii) label them, (iii) prepare the chemical etching (NaOH 2.5M), (iv) stripping, (v) dry the films and prepare them for reading, (vi) acquire the traces, and finally (vii) calculate the radon concentration. Further details on the procedure are given in [19]. For each LR-115, an area of 2.25 cm^2 was selected and the residual thickness, in terms of brightness (due to chemical etching) and trace count (due to alpha decay) were then measured. For these parameters, an optical method with a dual illumination scanner was used and the processing of the acquired images was performed with the image processing software ImageJ (Image Processing and Analysis in Java, version 1.46r, National Institutes of Health, (Bethesda, MD, USA). The brightness was converted into residual thickness through a previously determined calibration curve, while the density of the detected traces was calculated by subtracting a number of background traces equal to 10 traces/cm^2. Finally, the radon concentration was computed using Equation (1):

$$C_{Rn} = \frac{R_{6.5}}{e \times h} \quad (1)$$

where C_{Rn} is the radon activity concentration measured (expressed in Bq/m^3), $R_{6.5}$ is the track density corrected by background track density and normalized to the nominal thickness of 6.5 μm, e is efficiency (see [19] for more details), and h is time (expressed in hours).

3. Results and Discussion

The RadioLab's main activity was to educate students about data management. This aspect is the experimental approach that brings the student closer to the activity of a researcher, as well as guaranteeing the validity of the data. A key challenge of RadioLab was understanding the complex range of features associated with the improvement of student outcomes through enhanced teaching performance and improved teaching practices. The focus was on important interrelated practices involving scientific knowledge in the field of nuclear phenomena, the way of doing science, and the relationship between science and society [15]. The students learned to understand features of radiation and radioactivity, discuss how radiation interacts with human tissues, monitor the environmental radiation from radon gas and describe the risks associated, evaluate scientific evidence and explanations, and manage and analyze data to understand scientific phenomena.

The first experimental activity was to install the detectors in all the schools that adhered to the proposal for measuring and monitoring indoor radon. Table 1 shows the number and representativeness of the schools in relation to the territory. For better data management, the students created a database in which to report the results. Table 2 shows the 67 schools (distinguished by provinces) and the annual average values of radon activity concentration. The average value is computed on all the detectors placed in each school.

Table 1. Registry of the number of schools involved, distributed among the five provinces of Campania (absolute number and percentage) compared to the total number in the area.

Province	Number of Schools Monitored	Percentage of Schools Monitored	Total Number of Schools of Each Province	Percentage of Schools Monitored on the Total Number of Each Province
Avellino	5	8%	694	0.7%
Benevento	7	10%	503	1.4%
Caserta	8	12%	1222	0.7%
Napoli	41	61%	3349	1.2%
Salerno	6	9%	1599	0.4%

Table 2. Annual mean values of radon gas activity concentration in schools throughout the Campania region (ID school identifies the province and the number of buildings; AV is Avellino, BN is Benevento, CE is Caserta, NA is Naples, and SA is Salerno).

ID School	Radon (Bq/m^3)	ID School	Radon (Bq/m^3)	ID School	Radon (Bq/m^3)
AV01	129 ± 20	NA04	42 ± 9	NA27	44 ± 7
AV02	176 ± 13	NA05	87 ± 10	NA28	18 ± 1
AV03	241 ± 78	NA06	580 ± 17	NA29	51 ± 12
AV04	45 ± 11	NA07	401 ± 53	NA30	379 ± 62
AV05	232 ± 24	NA08	1060 ± 31	NA31	160 ± 18
BN01	122 ± 11	NA09	386 ± 57	NA32	164 ± 23
BN02	40 ± 6	NA10	112 ± 27	NA33	249 ± 29
BN03	216 ± 15	NA11	103 ± 18	NA34	377 ± 19
BN04	59 ± 10	NA12	748 ± 260	NA35	52 ± 7
BN05	108 ± 16	NA13	79 ± 9	NA36	443 ± 21
BN06	86 ± 8	NA14	386 ± 26	NA37	112 ± 11
BN07	263 ± 16	NA15	130 ± 10	NA38	145 ± 12
CE01	43 ± 15	NA16	203 ± 14	NA39	75 ± 9
CE02	158 ± 7	NA17	687 ± 218	NA40	64 ± 32
CE03	49 ± 7	NA18	43 ± 5	NA41	244 ± 64
CE04	94 ± 10	NA19	250 ± 25	SA01	91 ± 10
CE05	417 ± 20	NA20	37 ± 11	SA02	104 ± 10
CE06	49 ± 7	NA21	174 ± 18	SA03	118 ± 11
CE07	62 ± 6	NA22	30 ± 5	SA04	66 ± 8
CE08	320 ± 18	NA23	106 ± 18	SA05	83 ± 13
NA01	101 ± 23	NA24	77 ± 9	SA06	337 ± 49
NA02	161 ± 62	NA25	247 ± 131		
NA03	355 ± 29	NA26	381 ± 54		

The variations of the mean values in the same province may be due to the different locations of the buildings and the building materials used (which notoriously contribute to the concentration of indoor radon). Another type of data processing was related to the different intended use of the rooms. Table 3 shows the number of rooms belonging to each typology that was selected for the monitoring, i.e., classroom, headmaster room/secretary/library, and educational laboratory/gym. In the same table, the radon activity concentration measured in the school rooms, divided according to the 3 typologies, with the correlated statistics is also reported. The activity concentration range is displayed, i.e., the minimum and the maximum value, the median, and the average value of all the detectors placed.

Table 3. Statistics on the results of radon activity concentrations in schools throughout the Campania region, grouped by the different typologies of rooms selected by different intended uses.

	Classroom	Headmaster Room Secretary/Library	Educational Laboratory Gym
N° rooms	636	143	173
Min-Max (Bq/m^3)	10–1168	10–1418	11–1889
Average (Bq/m^3)	166	181	190
Median (Bq/m^3)	113	76	84

The results show that the average concentration, as well as the maximum value, of radon in the laboratory/gym and in the headmaster room/secretary/library are higher than that in the classroom typology. This can most likely be attributed to the different rate of air exchange with the external environment in different rooms, depending on their intended uses. In fact, the ventilation in the classrooms is usually greater than that in the other two typologies, which are mostly closed environments (or poorly ventilated). On the other hand, based on the intended use, the type of people exposed also changes. In fact, classrooms and educational laboratories/gym are attended by students and teachers (therefore, it is also possible to adopt two different radiation protection approaches); while the headmaster room secretary/library are frequented above all by workers, student exposure can be considered negligible. The involvement of multidisciplinary skills required by the RadioLab was achieved with the graphical representation of the results obtained. This approach, which stimulates the development of transversal skills, fully adopts the most up-to-date European teaching guidelines. Note n. 7 of the European recommendation [20] fully describes the purpose of the RadioLab project itself: "In the knowledge economy, memorization of facts and procedures is key, but not enough for progress and success. Skills, such as problem solving, critical thinking, ability to cooperate, creativity, computational thinking, self-regulation are more essential than ever before in our quickly changing society. They are the tools to make what has been learned work in real time, in order to generate new ideas, new theories, new products, and new knowledge". Moreover, group work is an opportunity to socialize, respect interaction balances, learn, and include as each student processes information on the basis of their own resources and abilities. In the context of this research work, the results were graphically represented by a geographical elaboration. The data management and the realization of the radon concentration distribution map were performed using the 3D Map tool of Excel. Although the main purpose of the activity was the teaching and learning aspect, the data obtained were scientifically reliable. It is interesting to consider geological features, the information of the radon potential map processed with QGIS® software (https://www.qgis.org/en/site/, accessed on 6 April 2023), and the results in schools that were georeferenced (Figure 1). The results that were obtained from the measurements in the schools confirm a significant correlation between radon activity concentration values (Figure 1a) and the geological nature of the area (Figure 1b). Primary geological materials such as rocks and minerals that have a high ^{238}U concentration are the main sources from which radon is generated. Other geological factors contribute to increase its emission from the soil, including volcanic gaseous manifestations, secondary deposits of leaching products, the porosity of the rock, and the presence of faults. The presence of radon in the environment is due not only to geological factors, but also to meteorological factors (atmospheric P, T, humidity, season of the year, etc.).

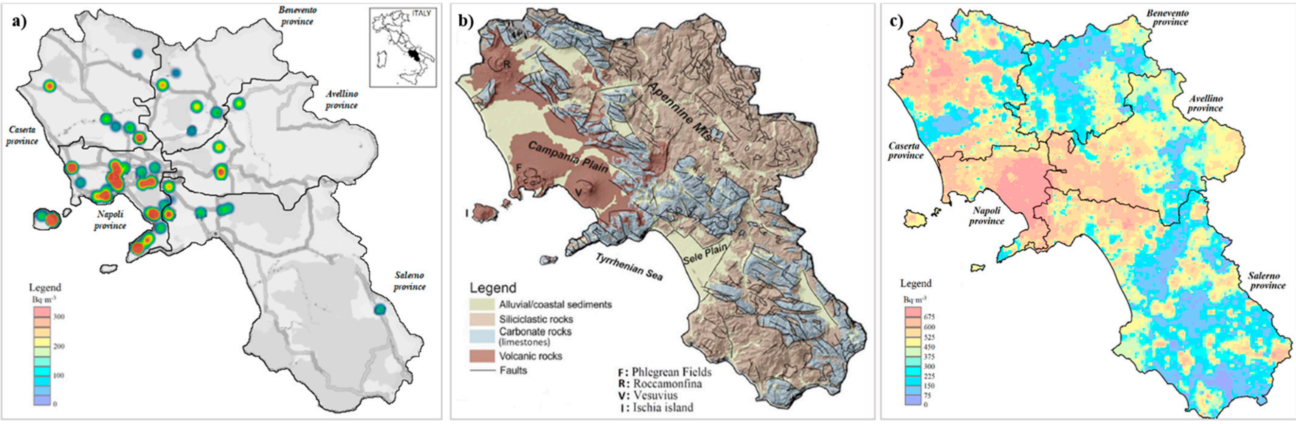

Figure 1. Comparison among (**a**) the maps of indoor radon activity concentration in schools, (**b**) geological map and fault network of the Campania region (adapted from [21]), and (**c**) radon potential map (adapted from [17]).

However, the concentration of outdoor radon is always very low due to the phenomenon of dilution of the gas in the air. On the other hand, radon can enter buildings (indoor radon) through physical processes such as pressure differences (outdoor–indoor) which create a suction effect, promoting its accumulation inside the building. The main entry routes are certainly the fractures between the floor and the walls of the ground floor, the contribution of the building materials used above are all of natural origin and, therefore, are also extracted from the ground, is not negligible. The parameter used for the data analysis has been the reference value of 300 Bq/m^3 indicated by the Italian Legislation, Legislative Decree 101/2020 [22], which, in turn, implements the European directive 59/2013 EURATOM [23]. In the schools of Avellino and Benevento provinces, mean annual radon activity concentration values lower than the reference level were obtained. This can probably be justified by the prevalent presence of siliciclastic and alluvial/coastal rocks characterized by a low concentration of ^{238}U. Of the eight school buildings in the Caserta province, only two, CE05 and CE08, have annual mean values of 417 $\pm$ 20 and 320 $\pm$ 18 Bq/m^3, respectively. Investigating the location of the schools on a geological map, CE05 falls within a border area between the provinces of Naples, Caserta, and Benevento, characterized by volcanic rocks and many faults. On the other hand, CE08, on the northern borders of the province of Caserta, is located on a fault in the Roccamonfina complex, also made of volcanic rocks. The 26% of schools in the Napoli province show values higher than 300 Bq/m^3 and, as can be seen, falls in the area between Vesuvius and Campi Flegrei and in particular also on faults (e.g., NA08 1060 $\pm$ 31 Bq/m^3). In the municipality of Salerno, all schools presented values lower than the reference one being a mixed area of alluvial/coastal, siliciclastic, and carbonate rocks, however, only one school, SA06 337 $\pm$ 49 Bq/m^3, is located on the border with the municipality of Naples on volcanic rocks. All results agree with the data reported on the radon potential map (Figure 1c). School buildings with a high concentration of radon gas activity have been subjected to more investigations to plan remedial actions, such as passive ventilation which is widely adopted due to its effectiveness [24], which is part of a wider range of solutions that are normally used [25–27]. Techniques for reducing indoor radon levels range from simply increasing the overall ventilation of the investigated environment to sealing radon entry points (e.g., cracks in the foundation, gaps around a sump pump), or also installing an active soil depressurization system that actively draws radon out from under the basement and vents it outside where it quickly dilutes to harmless levels. The students learned that the first and effective remedial action, and one that is immediate to implement, is the increase of the ventilation rate. This aspect highlights the importance of the RadioLab project in disseminating knowledge of radioactivity and the related hazards in order to make students aware of how to apply safety measures and take necessary action to control risk and hazards. In conclusion, it is worth mentioning that the obtained map in Figure 1a is part of a larger project of indoor radon mapping in Campania [28].

4. Conclusions

Science outreach projects usually aim to raise awareness of scientific research activities, educating students on topics that could potentially inspire their professional careers. RadioLab is an INFN project which, over the years, has contributed to spreading knowledge on the issues of natural environmental radioactivity, in particular on exposure to radon gas, actively involving high school students. This activity translates into seminars by expert researchers in the field, workshops, measurements, data processing, and so on. The didactic approach has allowed and promoted cooperation between different learning contexts (schools-universities), contributing to the acquisition of key skills that are necessary for the individual's integration into society. In this work, it has been demonstrated that educational activities can also be useful for scientific purposes. The students were guided by the researchers in experimental activity and in output elaboration, while retaining a certain autonomy required with the study and deepening knowledge of the topic. Annual measurements of radon gas activity concentration were made in 67 schools distributed throughout the Campania region using LR115 passive detectors. The results obtained contributed to an improvement in the collection of data relating to the concentration of radon gas activity in the Campania region. The mapping of the territory is one of the milestones of the National Radon Plan, planned by the Italian legislation, which has the aim to identify the "radon prone areas" and so to define specific radiation protection actions. In addition, these results had a two-fold purpose: (i) to educate students on the rigor of research in order to obtain reliable results; and (ii) to contribute to providing data for the radiological characterization of territory. The quality of these data is even more amplified by the intended use of buildings that were selected for monitoring: schools. Although they are not places where radon measurement is mandatory, they represent one of the few places where the exposure is greater for children/teenagers, who constitute the most radiosensitive part of the population. RadioLab's outlook could be to increase the network of schools involved in the outreach activity and in the realization of experimental activities with applicative effects in the scientific and research sectors.

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References

1. United States Environmental Protection Agency (US EPA). *Assessment of Risk from Radon in Homes*; United States Environmental Protection Agency: Washington, DC, USA, 2003; EPA 402-R-03–003 (2003).
2. International Agency for Research on Cancer (IARC). IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. *World Health Organ.* **1988**, *43*, 173–259.

3. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources, effects and risks of ionizing radiation. In *UNSCEAR 2020/2021 Report to the General Assembly, with Scientific Annexes*; United Nations: New York, NY, USA, 2021; Volume III.
4. Sabbarese, S.; Ambrosino, F.; D'Onofrio, A.; Roca, V. Radiological characterization of natural building materials from the Campania region (Southern Italy). *Constr. Build. Mater.* **2021**, *268*, 121087. [CrossRef]
5. La Verde, G.; Artiola, V.; D'Avino, V.; La Commara, M.; Panico, M.; Polichetti, S.; Pugliese, M. Measurement of Natural Radionuclides in Drinking Water and Risk Assessment in a Volcanic Region of Italy, Campania. *Water* **2021**, *13*, 3271. [CrossRef]
6. 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*, 533. [CrossRef]
7. Guarino, A.; Cicchella, D.; Lima, A.; Albanese, S. Radon flux estimates, from both gamma radiation and geochemical data, to determine sources, migration pathways, and related health risk: The Campania region (Italy) case study. *Chemosphere* **2022**, *287*, 132233. [CrossRef] [PubMed]
8. Florică, Ş.; Burghele, B.D.; Bican-Brişan, N.; Begy, R.; Codrea, V.; Cucoş, A.; Catalina, T.; Dicu, T.; Dobrei, G.; Istrate, A.; et al. The path from geology to indoor radon. *Environ. Geochem. Health* **2020**, *42*, 2655–2665. [CrossRef] [PubMed]
9. Hahn, E.J.; Gokun, Y.; Andrews, W.M., Jr.; Overfield, B.L.; Robertson, H.; Wiggins, A.; Rayens, M.K. Radon potential, geologic formations, and lung cancer risk. *Prev. Med. Rep.* **2015**, *2*, 342–346. [CrossRef]
10. Friedmann, H.; Baumgartner, A.; Bernreiter, M.; Gräser, J.; Gruber, V.; Kabrt, F.; Kaineder, H.; Maringer, F.J.; Ringer, W.; Seidel, C.; et al. Indoor radon, geogenic radon surrogates and geology–Investigations on their correlation. *J. Environ. Radioact.* **2017**, *166*, 382–389. [CrossRef] [PubMed]
11. Cinelli, G.; Tositti, L.; Capaccioni, B.; Brattich, E.; Mostacci, D. Soil gas radon assessment and development of a radon risk map in Bolsena, Central Italy. *Environ. Geochem. Health* **2015**, *37*, 305–319. [CrossRef]
12. Colalillo, R.; Aramo, C.; Alemanno, F.; Aloisio, R.; Altomare, C.; Antolini, R.; Arcaro, C.; Barbato, F.; Battaglieri, M.; Battisti, M.; et al. "A scuola di Astroparticelle": A synergy between school education and scientific research. In Proceedings of the POS PROCEEDINGSOF SCIENCE, Virtual, 18 March 2022; Volume 395, pp. 1–9.
13. INFN Outreach's Projects. Available online: https://www.na.infn.it/divulgazione (accessed on 10 March 2023).
14. Pugliese, M.; La Verde, G.; Roca, V. Dissemination about natural radioactivity through work-based learning experiences. *Nucl. Part. Phys. Proc.* **2019**, *306*, 183–188. [CrossRef]
15. De Cicco, F.; Balzano, E.; Limata, B.N.; Masullo, M.R.; Quarto, M.; Roca, V.; Sabbarese, C.; Pugliese, M. Radon measurement laboratories. An educational experience based on school and university cooperation. *Phys. Educ.* **2017**, *52*, 065003. [CrossRef]
16. Groppi, F. Radon Laboratory for secondary schools. *Il Nuovo Cim. C* **2018**, *41*, 1–9.
17. 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. [CrossRef]
18. La Verde, G.; Roca, V.; Pugliese, M. Quality assurance in planning a radon measurement survey using PDCA cycle approach: What improvements? *Int. J. Metrol. Qual. Eng.* **2019**, *10*, 2. [CrossRef]
19. De Cicco, F.; Pugliese, M.; Roca, V.; Sabbarese, C. Track counting and thickness measurement of LR115 radon detectors using a commercial image scanner. *Radiat. Prot. Dosim.* **2014**, *162*, 388–393. [CrossRef] [PubMed]
20. Council of the European Union. *Council Recommendation of 22 May 2018 on Key Competences for Lifelong Learning (Text with EEA Relevance)*; Council of the European Union: Brussels, Belgium, 2018.
21. Petrik, A.; Albanese, S.; Lima, A.; De Vivo, B. The spatial pattern of beryllium and its possible origin using compositional data analysis on a high-density topsoil data set from the Campania Region (Italy). *Appl. Geochem.* **2018**, *91*, 162–173. [CrossRef]
22. Decreto Legislativo n. 101 del 31 Luglio 2020, e Successive Integrazioni Correttive. Attuazione Della Direttiva 2013/59/Euratom, che Stabilisce Norme Fondamentali di Sicurezza Relative alla Protezione Contro i Pericoli de-Rivanti Dall'Esposizione Alle Radiazioni Ionizzanti, e Che Abroga le Direttive 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom e 2003/122/Euratom e Riordino della Normativa di Settore in Attuazione dell'Articolo 20, Comma 1, Lettera a), Della Legge 4 Ottobre 2019, n. 117. GU Serie Generale n. 201 del 12-08-2020—Suppl. Ordinario n. 29, e GU Serie Generale n.2 del 03-01-2023. Available online: https://www.gazzettaufficiale.it/eli/id/2020/08/12/20G00121/sg (accessed on 6 April 2023).
23. European Union. Laying down basic safety standards for protection against the dangers arising from exposure to ionis-ing radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, council directive 2013/59/Euratom. *Off. J. Eur. Union* **2013**, *13*, 1–73.
24. D'Avino, V.; Pugliese, M.; La Verde, G. Effectiveness of passive ventilation on radon indoor level in Puglia Region according to European Directive 2013/59/EURATOM. *Indoor Built Environ.* **2021**, *30*, 1580–1586. [CrossRef]
25. Barazza, F.; Murith, C.; Palacios, M.; Gfeller, W.; Christen, E. A national survey on radon remediation in Switzerland. *J. Radiol. Prot.* **2017**, *38*, 25. [CrossRef]
26. Sicilia, I.; Aparicio, S.; González, M.; Anaya, J.J.; Frutos, B. Radon Transport, Accumulation Patterns, and Mitigation Techniques Applied to Closed Spaces. *Atmosphere* **2022**, *13*, 1692. [CrossRef]

27. Khan, S.M.; Gomes, J.; Krewski, D.R. Radon interventions around the globe: A systematic review. *Heliyon* **2019**, *5*, e01737. [CrossRef] [PubMed]
28. Ambrosino, F.; La Verde, G.; Sabbarese, C.; Roca, V.; D'Onofrio, A.; Pugliese, M. The first indoor radon mapping in the Campania region, Italy. *Isot Environ. Health Stud.* **2023**. [CrossRef] [PubMed]