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ISOradioLAb: an educational project on environmental radioactivity for Italian minor islands—the case study of Lampedusa and Linosa

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Abstract ISOradioLAb is an educational project for schools of the Italian minor islands promoted by the Italian National Institute of Nuclear Physics. It aims to increase the population awareness of natural radioactivity by involving the students of the high schools in the measurement of indoor radon activity concentration in their schools and in some representative buildings. Within this project, questionnaires about risk perception and radon knowledge are also dispensed. With this approach students learn-by-doing and share their knowledge with friends and relatives. In this paper, we present the activities performed during the first year of the project, focused on the case study of the minor island of Lampedusa and Linosa, Agrigento (Italy). Questionnaires and radon measurements (using CR-39 and Electret) results are reported.

1 Introduction

ISOradioLAb is an Italian National Institute of Nuclear Physics (INFN) school project, born in 2021 as a complementary part of the RadioLAB project that has the aim to increase the awareness of natural radioactivity, and in particular radon gas and at the same time it has the aim of disseminating scientific culture starting from young people as a point of diffusion toward family members and society [1–3]. The topic of the natural radioactivity is presented by the INFN researchers to the students and their teachers, connecting the risks to the possible solutions and effective protection routes, and clarify the doubts that may occur during the discussions. The RadioLAB project, which represents an evolution of previous projects (ENVIRAD-INFN, LABORAD, SPLASH, ENVIRAD-SPLASH), nowadays involves 9 Italian Regions and it has been exported in Albania and Ecuador too [4–8]. On the other hand, ISORadioLAB involves the Italian minor islands: Lampedusa and Linosa, Pantelleria, Aeolian islands in Sicily, San Pietro Island in Sardinia and Elba in Tuscany. The purpose of this latest project is to include places which, due to their geographical position, would be excluded being small islands. Mainly these projects are dedicated to high school students, but also involve middle school students and the general population, declining and extending themselves as citizen science projects. Citizen science is a form of research that require the active participation of the population to scientific issues [4, 9, 10]. Several benefits for both population and researcher arise from the application of the citizen science paradigm. From the point of view of the researcher, a large participation in the measurements permits to obtain a big set of data that otherwise would require more effort to be collected. Moreover, it allows to overcome the common preconception that sees the universities and the research centers as realities that are far from the everyday life. The population gain the possibility to understand how science work, to enhance their scientific skills and to become aware of the problems that science is trying to solve being active part in the solution, not only by participating to the projects but sometimes also modifying their personal behavior with respect to the problem [11–13]. In this framework, the approached issue is the exposure to natural source of ionizing radiation: gas radon, its measurement, and the risk perception. Risk perception is an important parameter to evaluate since unlike knowledge, it is the result of a personal and subjective perception of a real risk, regardless of real knowledge of the nature of the risk itself [14, 15]. Radon (^{222}Rn) is a radioactive noble gas with a half-life of 3.8 days, arising from the decay chain of uranium-238, which is present throughout the Earth's crust. Radon indoor is recognized as the main sources of public exposure by natural radioactivity, contributing for nearly 50% of the global mean effective dose to the general population [16]. Radon was classified as a human lung carcinogen by the International Agency for Research on Cancer (IARC) in 1988 [17], and EPA 2003 [16] has reported that the radon is the second risk factor for lung cancer after smoking.

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In this work, we mainly focus on the outcomes of ISOradioLAb on the Italian minor islands of Lampedusa and Linosa, carried on by the INFN sections of Milan and Naples in collaboration with the respective universities, and with the involvement of the High School Istituto Omnicomprensivo "Luigi Pirandello" of Lampedusa and Linosa. These islands are particularly interesting for the geological characteristics of their soils. In fact, these two islands are in the southern Mediterranean Sea, between Sicily and Tunisia. They are part of the same archipelago, the Pelagie Islands, from administrative point of view they belong to the same municipality of Agrigento, but they are geologically extremely different. Lampedusa is the largest island of the archipelago, it is located on the edge to the Tunisian platform, and it is mainly composed by white to creamy limestone (carbonates) [18]. On the contrary, Linosa is completely formed of volcanic rocks and lies on the Pantelleria rift [19, 20]. In this work, the preliminary results of indoor radon measurements are presented, together with the evaluation of the knowledge and perception of the risk associated with ionizing radiation. The potential of this project is to become a standard model of citizen science, spreading knowledge of issues relating to natural radioactivity in a capillary way throughout the national territory.

2 Materials and methods

Twenty-five high school students from the "Istituto Omnicomprensivo Luigi Pirandello" of Lampedusa and Linosa have been involved in the project. As a collaborative project [21], the students are the main actors of ISOradioLAb. Students are aware of the characteristic of their territory, and they know the structure of their schools and public buildings, so that, after some lessons about the item or radioactivity and the origin of radon gas they actively participated to the determination of the locations where the measurements took place. They performed all the measurement process under the supervision of their teachers, and of the university staff in the most complex parts. The experimental techniques used for the determination of the indoor radon concentration are reported in Sect. 2.1. To overcome the initial technological and experimental gap, preliminary meetings between teachers and researchers took place so that the teachers will be able to follow the students during their work. The students are involved in all the decisions regarding the location of the measurement, the procedure of displacement of the detectors, the processing and the data analysis. Together with the researchers, they are the leading actors in taking conclusion and in the dissemination of the results. The presence of teachers is crucial to ensure that all experimental procedures are carried out with care, respecting all the protocols that allow to reach reliable scientific results.

Moreover, students, teachers and in general the population of Lampedusa and Linosa have been involved to reach the other aim of ISOradioLAb: the awareness about the natural radioactivity and to the perception of the ionizing radiation risk. This goal has been achieved through two anonymous questionnaires that evaluate their level of knowledge as well as that of other students not involved in the project, the parents and more generally the population.

2.1 Experimental techniques for radon concentration determination

Indoor radon concentration has been determined in the High School of Lampedusa and in different public buildings of the Linosa island. The measurements have been performed using passive detectors for a total time of six months. In each selected room two detectors have been placed: a CR-39 (Sect. 2.1.1) and an Electret Ion Chamber (EIC) (Sect. 2.1.2).

Each detector was labeled, given the identification number and matched to the location where it was exposed. The detectors have been placed at a distance higher than one meter from the walls to avoid the contribution of thoron (^{220}Rn) and in general of the natural radioactivity present in the building materials. The measurements have been properly notified to prevent perturbation caused by external people that could touch and move the detectors. Three detectors for each type have been stored and used to determine the background.

2.1.1 CR-39 nuclear track detectors

CR-39 (Columbia Resins 39) is a plastic nuclear track detector (allyl diglycol carbonate). The detection principle is based on the traces that the alpha particles, which are produced by the decay of radon, produce in the plastic. These traces have a dimension of the order of few nm and therefore cannot be observed with an optical microscope, much less with the naked eye. It is necessary to carry out a chemical etching using sodium hydroxide (NaOH) which widens the areas of the plastic where the chemical bonds have been damaged by the passage of the particles. The CR-39 detectors and the Radout® plastic chambers where the detectors are placed have been purchased from Mi.am Srl (Piacenza, Italy).

The etching process has been performed in a solution 6 M at 80 °C for 6 h of NaOH that has been purchased from Merck (Darmstadt, Germania). The CR-39 were positioned on a sample holder that was able to keep about 20 samples per time and immerged in a glass beaker filled with NaOH up to 1 cm over the sample holder. A thermal bath has been realized by immersing the beaker in a commercial fryer filled with water once the latter reached the desired temperature that was then kept almost constant by regulating the power of the fryer.

For the data acquisition a Motic RED-100 monocular optical microscope, purchased from Motic Europe S.L.U. (Barcellona, Spain), has been employed. For each dosimeter 30 captures have been randomly taken using the integrated wireless camera of the microscope. The tracks have been counted manually by two students per detector to improve statistic. The calibration factor to convert the number of tracks per square cm to radon concentration in Bq m^{-3} has been obtained experimentally for the same batch of detectors by exposing a set of dosimeters in a calibration chamber to different certified radon concentrations and building a calibration curve. The slope of the curve corresponds to the calibration factor of (19.4 ± 0.7) Bq m^{-3}/(traces cm^{-2}). The entire procedure is well and in detail described in [5, 6].

2.1.2 Electret ion chambers

Electret Ion Chamber (EIC) E-Perm® system, manufactured by Rad. Elec. Inc. (Frederick, MD, USA) [22, 23], has characteristics that make it extremely versatile for different types of radon gas activity concentration measurements [24–30], and for exposure times ranging from a few days up to a year thanks to different combinations of configurations. The electrets have plates that are electrostatically charged and have a different composition which results in a different sensitivity, inversely proportional to the thickness of the disks: (i) polytetrafluoroethylene (PTFE) TeflonTM disks, 0.152 cm thick, used for short-term measurements (Short-term configuration -ST); (ii) the Tetrafluoroethylene (FEP) TeflonTM disks, 0.0127 cm thick, used for long-term measurements (Long Term configuration -LT). The electrets are coupled to dome-shaped diffusion chambers, also available in two different configurations: (i) 210 mL (Short Term configuration -S); (ii) 50 mL (Long Term configuration -L). So, it is possible to obtain more combinations. In this work the LLT configuration was used. The radon concentration was calculated applying calibration factor (CF) and the exposure time, according to Eqs. (1) and (2)

$$C_{\mathrm{Rn}} = \left[\frac{(V_{\mathrm{i}} - V_{\mathrm{f}})}{\mathrm{CF} \cdot T} - \mathrm{BG} \right] \tag{1}$$

$$\mathrm{CF} = \left(A + \mathrm{B} \cdot \frac{(V_{\mathrm{i}} + V_{\mathrm{f}})}{2} \right) 1/37 \tag{2}$$

where V_{i} and V_{f}: electret voltage readings before and after exposure, respectively; T: exposure time in days; $A = 0.02383$, $B = 0.0000112$ constants given by the manufacturer depending on configuration and volume of the E-Perm chamber [31]. BG: equivalent radon concentration due to the ambient gamma background obtained from $\mathrm{BG} = C \cdot R\gamma$, where R_{γ} is gamma dose rate in nGy/h; C is a constants given by the manufacturer depending on configuration and volume of the E-Perm chamber. In this case $C = 0.59$.

The charge loss of the electret was measured using an electrometer (Rad. Elec. Inc. Mod. 6383-01, Frederick, MD, U.S.A.).

2.2 Questionnaires

Scientific divulgation plays a key role in the frame of the ISOradioLAb project, and it is performed at different levels. First, the university staff helps the students and their teachers to understand what the radioactivity, starting from the natural one, is. Then, students themselves start to play the role of the researchers that not only perform the experiment, but that are also in charge of discussing, sharing the results and informing the population about these items.

Each of the two phases starts with two preliminary anonymous questionnaires: the first is about the knowledge of the radon, while the second deals with the perception of the risk related to the ionizing radiations. This allows, over the years, to collect a rich set of data that can depict the state of the awareness in the population and, from a dynamic point of view, to evaluate the effectiveness of ISOradioLAb.

The results are reported in Sect. 3, while the two questionnaires are reported in the supplementary materials (Tables S.1 and S.2).

3 Results and discussion

Indoor radon activity concentration has been measured in different rooms located in the High School of Lampedusa and Linosa. The comparison between the results obtained using the CR-39 and the EICs is reported in Sect. 3.1. The analysis of the questionnaires is reported in Sect. 3.2.

3.1 Radon concentration measurements

To map the radon concentration in the schools of Lampedusa and Linosa, 8 CR-39 and 8 electrets have been exposed for six months, according to the following criteria:

- A student responsible for the positioning, the control and the recovery of each dosimeter was designed;
- In each room one CR-39 and one EIC were placed, considering that the results can depends on the position of the detector. Particular attention has been paid to avoid interference with radioactivity coming from the building materials and to make sure that the measurement is not altered by ventilation processes.

Table 1 Comparison between the results obtained with CR-39 and EICs in the locals of the schools of Lampedusa and Linosa during the first semester of measurements (from 15/11/2021 to 21/5/2022)

Island	Location	Floor	CR-39 (Bq m^{-3})	Electrets (Bq m^{-3})
Lampedusa	Classroom	1st	77 ± 24	99 ± 11
Lampedusa	Classroom	1st	116 ± 6	121 ± 12
Lampedusa	Classroom	Raised	78 ± 14	95 ± 1111
Lampedusa	Administration office	Ground	43 ± 13	60 ± 9
Lampedusa	Administration office	Ground	16 ± 6	19 ± 4
Linosa	Classroom	Ground	22 ± 8	26 ± 10
Linosa	Classroom	Ground	58 ± 12	91 ± 9
Linosa	Library	Ground	87 ± 14	85 ± 11

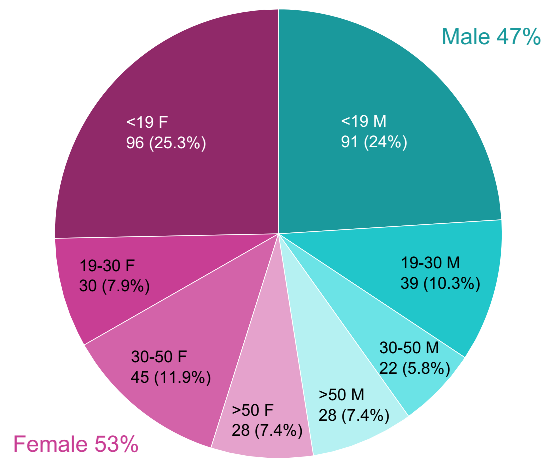

Fig. 1 Distribution of the gender and the age of the people that answered the questionnaires. Within each slice the age, the sex and the number of people involved are reported. Within brackets the percentage with respect to the total of participants is reported

The period of measurement lasted from 15/11/2021 to 21/05/2022. In Table 1, the details of the measurements and the results are reported.

The results obtained with the two methods are almost in agreement with each other. The radon activity concentration values are not high, and wherever lower than the limit of reference imposed by the Italian regulatory of 300 Bq m^{-3} [32]. Further measurements are required to find whether radon activity concentration could be related to the geological differences between these two investigated islands.

However, it is important to remark that over the results, what students get during this activity is learning how to perform a real scientific experiment with all the connected difficulties, such as dealing with the measurements and their uncertainties, performing the experiments in a rigorous way and adopting the safe behaviors that are mandatory in a scientific laboratory. In other words, the goal of the measurements was not so much the scientific result but to teach a methodology, the scientific approach, the understanding of the link of different disciplines that they encounter during their educational training like mathematics, physics, chemistry, statistics, biology, geology, earth sciences, civics education, etc. that are all part of the same book of the life.

3.2 Environmental radioactivity knowledge and risk perception

Two questionnaires, one on the radon awareness and one on risk perception, have been dispensed anonymously to a sample of 380 people. The distribution of the age and the gender of the sample is reported in Fig. 1.

There is an almost perfect gender balance, while it is predominant the presence of people younger than 19 years old. This is a bias caused by the fact that the questionnaires have been administered by the students themselves that preferred to share the experience with their school colleagues and to a lesser extent with people older than them. However, the number of answers in each group is sufficient for a preliminary analysis. From the analysis of the first questionnaire, only the 26% of people (25% female, 27% male) declare the radon knowledge. Figure 2 shows the percentage of radon knowledge splitted by ages (<19, 19–30, 30–50, >50 years): a deeper knowledge of radon is declared by people with age 19–30 years, while there is a decrease at higher ages; the same trend is shown both for male and female people.

A significant trend is presented in Fig. 3, where the knowledge of what radon is has been reported as a function of the education level of the participants. Education plays an important role: knowledge of radon increases as the level of education. However, it is important to continue promoting dissemination actions to the public regardless of their cultural background to obtain an overall increase in knowledge of what radon gas is.

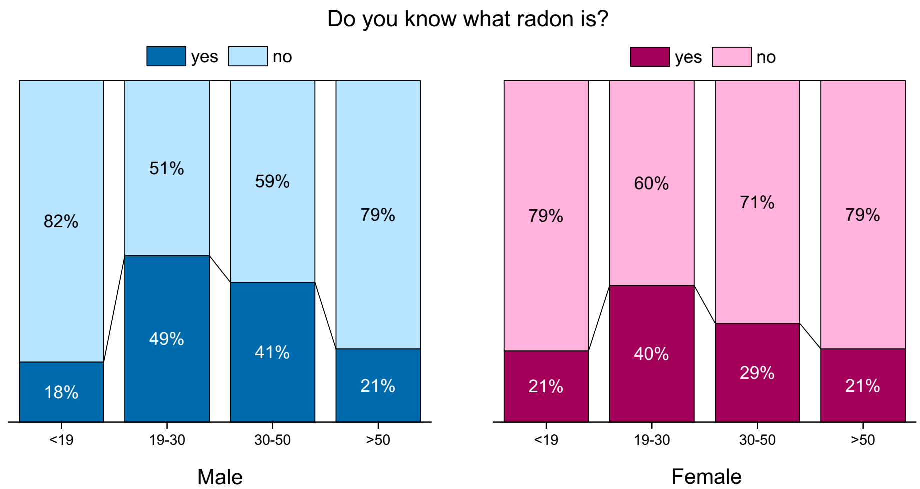

Fig. 2 Answers to the question "Do you know what radon is?". The results have been presented as a function of gender and age

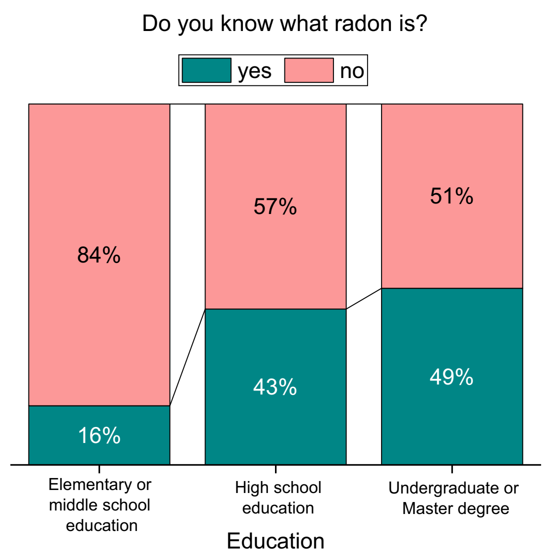

Fig. 3 Level of knowledge of radon versus the education level

Another question is 'Do you want to carry out radon measurements in your own home?'. Figure 4 shows the analysis of this parameter: (i) people ignoring radon are divided almost equally between those willing or not to carry out radon measurements; (ii) on the contrary, people knowing radon declare a strong interest in carrying out such measurements (about 78%). Finally, the source of knowledge of radon was also investigated: 32% from newspapers/TV/web; 4% from popular events; 30% from school projects (such as ISOradioLAb); 34% from other sources.

Unlike knowledge of radon, risk perception is the result of a personal and subjective perception of the real risks, regardless of real knowledge of the nature of the risk itself. For this reason, a second survey was conducted, starting from the assumption that the population underestimates the risk associated with exposure to the natural background of ionizing radiation [33, 34], which represents the major contribution to the environmental radioactive background as reported by UNSCEAR 2008 [35]. With this assumption, same participants were asked whether the main source of exposure to ionizing radiation was of natural or man-made origin. Therefore, the distribution by sex and age is the one shown in Fig. 1: about 70% of the participants assert that ionizing radiation produced or enhanced by human activities is the main source of their exposure, regardless of education level and age (Fig. 5).

Participants were asked to rank sources of radioactivity (Cosmic rays, medical X-Rays, electromagnetic pollution, natural radioactivity, nuclear plant) from least to most dangerous by assigning a score of 1 to 5, respectively—it is not allowed to assign the same grade to different answers. The results were compared to the real danger classification by UNSCEAR 2008 [35] (Table 2).

It is interesting to note that there is a tendency to consider safer the things that one is used, like the medical X-rays that are considered safer than the other risks. This tendency has been also described by Fischhoff et al. [36] with the psychometric effect. The greatest evidence is that the ranking of the nuclear plant is considered by the population to be the most dangerous source of radiation more than the environmental background. This is probably because the perception of risk is linked to many factors which

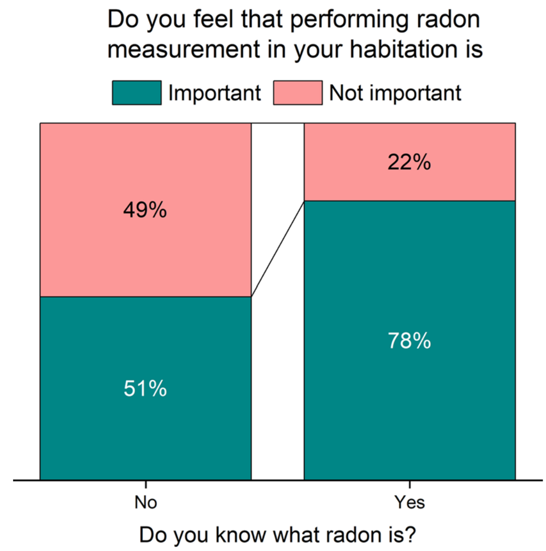

Fig. 4 Relation between the knowledge of radon and the interest in performing measurement of its activity concentration in the house of the participant

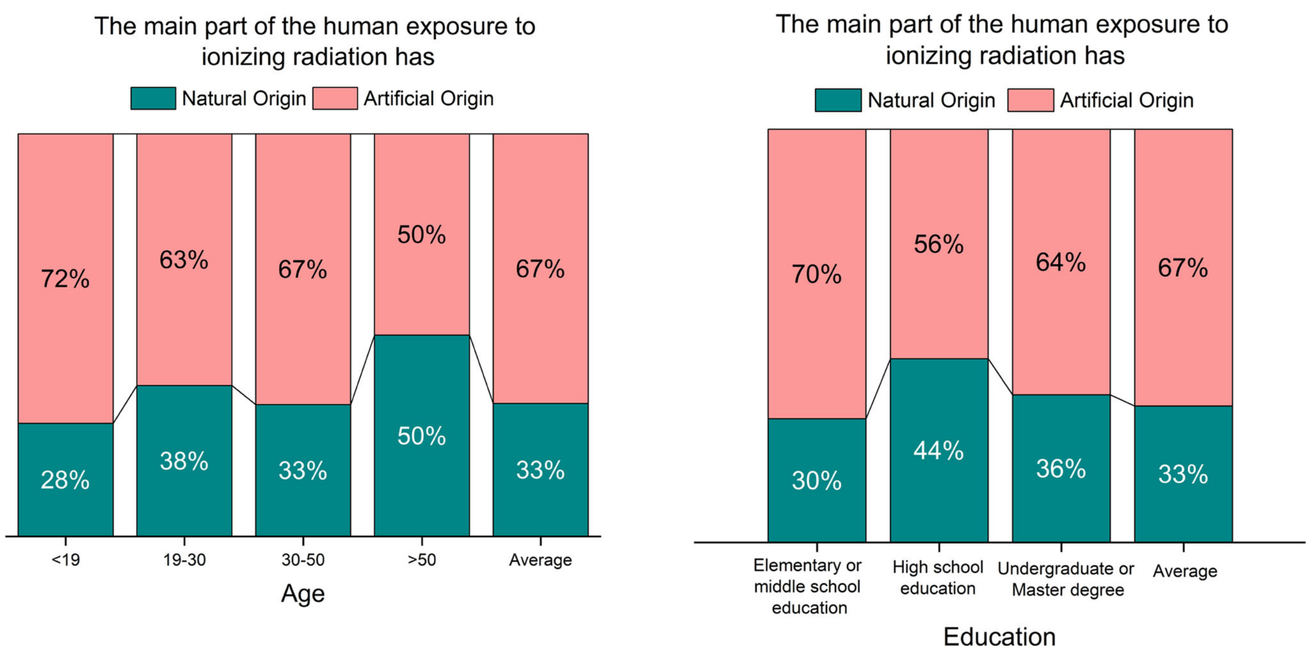

Fig. 5 Answer to the question "Do you think that the main part of the human exposure to ionizing radiation is due to artificial or natural radioactivity?": distribution of the answer as a function of the age (left); as a function of the education grade (right)

may also concern the personal sphere [37]. Surprisingly, natural radioactivity has been positioned as one of the most dangerous sources, as UNSCEAR classification.

4 Conclusions

ISOradioLAb project involves students from the high schools of Lampedusa and Linosa islands in Italy, in the measurement of radon concentration in their schools. With this project we wanted to focus on students from the smaller Italian islands who, owing to their geographical location, naturally have fewer opportunities to carry out projects proposed by universities and research centers compared to their peers from the Italian mainland peninsula. They have shown themselves eager to integrate into the project demonstrating a great desire driven by the curiosity that pervades them for subjects that are not commonly treated at school. The experimental results obtained are related to measurements of the activity concentration of radon in school rooms that during the analyzed period is significantly lower than the reference values of 300 Bq m^{-3} imposed by the Italian regulatory. It is achieved the objective to involve the students in a real scientific project through which they understood a study method of learning by doing. They also learned how

Table 2 Comparison between population's ranking and UNSCEAR 2008's one [35]

Sources of radioactivity	Danger classification	
	UNSCEAR 2008	Questionnaire
Cosmic rays	3	3
Medical X-Rays	4	2
Electromagnetic pollution	1	1
Natural radioactivity	5	4
Nuclear plant	2	5

to present and discuss the topics of this project in a rigorous but simple scientific language to be understood by ordinary people. Moreover, two questionnaires were dispensed on the radon knowledge and risk perception. The analysis of two questionnaires is the following: (i) people who know radon topic is 26%; (ii) knowledge of radon increases with the level of education; (iii) the artificial radiation is perceived as more dangerous than natural one. These preliminary results are important because highlight the need of dissemination, starting from the students and reaching through them the whole population. It must be kept in mind that the size of the islands and the number of inhabitants allow a real and very capillary distribution and dissemination. Moreover, it would be interesting to evaluate the impact that projects like ISOradioLAb can have on risk perception by repeating the questionnaire before and after the project, and this will be certainly done in future work. It will be also possible to compare the results obtained in different part of the Italian territory.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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