

## Article

# First Steps towards a National Approach for Radon Survey in Romanian Schools

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**Abstract:** Schools are a category of public buildings with a high radon exposure risk, due to their high occupancy factor. In Romania, the elaboration of a methodology for radon measurements in schools is a necessity imposed both by the European legislation and by the relatively high percentage (about 10%) of the mapped territory with a potential increased risk of exposure to the action of ionizing radiation emitted by radon. In order to optimize the design of a national survey aimed to evaluate radon exposure of children in Romanian schools, we conducted a pilot study in two schools in Cluj-Napoca, following the screening measurements carried out in 109 schools and kindergartens from five counties. The specific steps that must be followed were described, taking into account the international protocols and particularities of Romanian territory. The proposed approach could act as a guide for other large buildings and is implicit for the implementation of National Radon Action Plan, approved by HG no. 526/12 July 2018 in accordance with Council Directive 2013/59/EURATOM. The obtained results indicate that a high probability of annual radon concentration above the national reference level is to be expected in schools.



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**Keywords:** radon; public buildings; schools; protocol for radon measurements; radon measurement approach Romania

## 1. Introduction

It is well known that long-term exposure to radon and its decay products increase individual's risk of developing lung cancer [1,2]. Radon ( $^{222}\text{Rn}$ ) is a naturally occurring colorless and odorless radioactive gas. It comes from the decay chain of uranium ( $^{238}\text{U}$ ), which is found in soils and rocks all over the world. Radon can enter into buildings through cracks/holes in foundation and other pathways. Once indoors, radon can accumulate to significant levels, depending primarily on the building's construction and the amount of radon in the underlying soil. Design, construction, and ventilation of the building affect the pathways and migration patterns of radon and its indoors concentration level. Radon levels are generally highest in basements and ground floor rooms that are in direct contact with the soil [3,4], but this should not be regarded as an exclusive behavior [5].

On the basis of scientific findings, policies are being developed worldwide to reduce indoor radon levels in existing buildings and in new constructions with a common objective to decrease the health risk for exposed people [2–7]. The Basic Safety Standards of the European Union (EU-BSS 2013/59/EURATOM) are radioprotection regulations that include radon in workplaces and buildings [2]. These regulations had to be implemented into national law by all Member States starting in 2018. The first requirement under the national legislation must be to set up a national reference level for radon concentration in air of buildings. The World Health Organization (WHO) guidelines, being based on the ALARA principle (“as low as reasonably achievable”), recommend a national reference level of  $100\text{ Bq/m}^3$ , and wherever this is not possible, the chosen level should not exceed  $300\text{ Bq/m}^3$  [7]. According to the Directive 2013/59/EURATOM [2], the Member States are

required to establish in the national legislation reference levels for the annual average of the radon concentration in the air of buildings that does not exceed  $300 \text{ Bq/m}^3$ , both for existing and new dwellings, workplaces, and buildings with public access.

One of the items that have to be considered by the EU Member States in preparing its national action plan to address long-term risks from radon exposures, included in Annex XVIII (paragraph 3) is “*identification of types of workplaces and buildings with public access, such as schools, underground workplaces, and those in certain areas, where measurements are required, on the basis of a risk assessment, considering for instance occupancy hours*” [2].

The indoor air of schools constitutes a particular cause of concern, since children are extremely sensitive and vulnerable to unhealthy indoor environmental pollutants [8,9]. Their bodies are highly susceptible to low air quality that could cause serious health problems. Epidemiological studies have demonstrated the prevalence of the health burden of respiratory diseases associated with poor indoor air quality in schools [9,10].

Furthermore, children spend more time in school than in any other place, except home. For most of school children and staff, the second largest contributor to their radon exposure could, therefore, be represented by their school. Consequently, international attention is paid to the monitoring of this gas in such closed, public buildings, in compliance with measurement protocols that tend towards harmonization at the European Union (EU) level, while respecting the specificities of each territory.

Due to the fact that school buildings are workplaces of high occupancy, monitoring indoor radon levels is of utmost importance for an adequate risk assessment [8,11–18]. Many countries have already defined protocols for radon measurements in schools. In 1989 and 1990, the United States Environmental Protection Agency (EPA) conducted the *School Protocol Development Study*, a nationwide effort to further examine how best to conduct radon measurements in schools [19]. In order to guide the types of measurement devices, devices placement, measurement duration, and the interpretation of measurements in public buildings, including schools, Health Canada has elaborated the *Guide for Radon Measurements in Public Buildings (Workplaces, Schools, Day Cares, Hospitals, Care Facilities, Correctional Centres)* [20]. In Norway, measurements are carried out according to the Protocol for Radon Measurements in Schools and Kindergartens [21] established by the Norwegian Radiation Protection Authority (NRPA) in 2015. Systematic surveys in schools are thus considered a significant component of a national radon program, and numerous countries have already carried out such surveys, on the basis of the protocols or national/international recommendations [22]. In Europe, radon surveys have been carried out in schools from different parts of *Italy* [12], *Slovenia* [13], *Serbia* [14], *Greece* [15–17], *Ireland* [18], *Macedonia* [11], and others. Overall, these surveys provide overwhelming evidence that radon may pose a real problem in schools in many European countries.

Available data from Romanian homes [3,4,23–26] and preliminary studies in schools [27,28] suggest that both environments are likely to have radon concentrations higher than  $300 \text{ Bq/m}^3$ . Moreover, previously results indicate that between 1200 and 1800 lung cancer cases can be attributed to indoor radon exposure for the Romanian population every year [29], showing clear evidence that appropriate public policies are needed. Starting from 2017, the radon problem in Romania was assumed at national level by a Working Group formed to prepare the National Radon Action Plan (NRAP) [1]. In this context, Law no. 63/13 March 2018 brings important radon related legal amendments to Law no. 111/1996 on the safe deployment, regulation, authorization, and control of nuclear activities [30,31].

This regulation sets down a national reference level for indoor radon concentrations of  $300 \text{ Bq/m}^3$  [30]. The NRAP approaches the long-term risks of exposure to radon in dwellings, public buildings, and workplaces for any radon source (soil, water, building materials), according to the specific methodology approved by Order CNCAN 185/2019 [32]. In workplaces, such as schools, the radon issue could be even more pressing.

In order to define the best way to conduct future radon measurements in schools, we divided the present study into the several stages. The first step was to perform screening surveys of radon measurement in schools throughout Romania. In a second stage of

the study, two pilot schools from Cluj-Napoca were selected for investigation meant to assess the particularities of Romanian schools in defining survey methodology. The last step was represented by the implementation of remediation solutions and the follow-up regarding the radon mitigation efficiency. These steps would ultimately lead to facilitating implementation of actions defined by NRAP through the recommendation of a protocol for radon measurements in schools.

## 2. Materials and Methods

### 2.1. Measurement Technique

Indoor radon measurements were performed using passive radon detectors, CR-39-based detectors, provided by Radosys Ltd., Budapest, Hungary. Each detector was exposed in frequently occupied rooms (classrooms or offices), of all available floors, for 3 months during the cold season (between January to March) in Romania. All measurements were conducted using calibrated techniques, standards, and reference materials with the highest degree of confidence according to international guidelines [33,34]. After the exposure, the chemical processing and the automatic reading of all detectors were performed in the LiRaCC laboratory. The working protocol has been described elsewhere [3,4,23,27]. The annual radon concentration for each school was calculated, taking into consideration the seasonal correction factor imposed by legislation [32].

### 2.2. Radon Surveys in Romanian Schools

Between 2010 and 2018 radon screening measurements were carried out in 109 schools and kindergartens located in five Romanian counties: Alba (Alba-Iulia, Sebeş, Vinţu), Bacău (Oneşti), Cluj (Cluj-Napoca), Satu-Mare (Satu-Mare), and Sibiu (Agnita).

The selection criteria were based on the existing published results regarding indoor radon levels in residential buildings [3,4,23–29]. Schools and kindergartens were selected to cover different areas living environments (i.e., in the center and outskirts of the city) as well as all radon areas, namely, high-radon areas from Cluj and Alba counties, and moderate and low radon risk areas from Sibiu, Bacău, and Satu-Mare regions. A standardized questionnaire collected information regarding the distance from the crowded areas, the location of the room in the building, ventilation and occupation patterns of classes, etc.

An average of three measurements per school was performed in order to assess the radon level.

### 2.3. Pilot Study

The results of the screening survey outline the necessity of radon in school measurements on the basis of a comprehensive protocol and approach. As a subset of the above-mentioned radon survey in Romanian schools performed in 109 schools, a pilot study was initiated in order to analyze the variability of radon concentration between two different schools in the same city, Cluj-Napoca. Two different aspects were assessed: radon variability based on location of investigated room (i.e., rooms located on the same floor versus different floors) and the variation due to intended use of the rooms (classrooms, laboratories, offices). The first school (S1) was composed of three distinct buildings, while the second school (S2) had in its administration only two distinct buildings. A total number of 22 CR-39 passive detectors were distributed in the five distinct buildings, on different levels.

## 3. Results and Discussion

### 3.1. Overall Results—Radon Survey in Romanian Schools

Table 1 presents the statistical parameters of annual radon concentration in schools and kindergartens for each analyzed county.

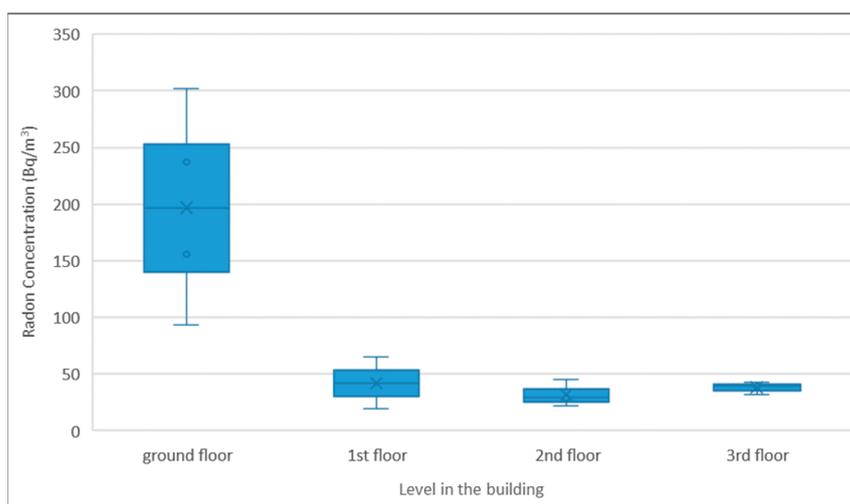
**Table 1.** Summary statistics of annual radon concentration in schools and kindergartens.

County	N	AM (Bq/m <sup>3</sup> )	SD (Bq/m <sup>3</sup> )	Min (Bq/m <sup>3</sup> )	Max (Bq/m <sup>3</sup> )	Median (Bq/m <sup>3</sup> )	GM (Bq/m <sup>3</sup> )
Alba	20	262	277	86	1121	360	313
Bacau	15	119	62	29	237	116	103
Cluj	34	141	124	23	460	97	99
Satu-Mare	15	127	19	85	167	125	125
Sibiu	25	68	35	27	174	69	60

N—number of schools and kindergartens; AM—arithmetic mean; SD—standard deviation; GM—geometric mean.

The annual average radon concentration for the 109 schools and kindergartens was 143 Bq/m<sup>3</sup>, with radon concentrations varying from 23 to 1121 Bq/m<sup>3</sup>. As expected, due to the geology of underlying area and building particularities, the radon concentration was not homogeneous. Nevertheless, the study indicated that high concentrations of radon gas could be found not only in dwellings, but also in schools. The percentages of schools with annual concentration higher than national reference level was 18%, whereas by applying the WHO recommendation for indoor radon reference level of 100 Bq/m<sup>3</sup>, we found that the percentage rose to 65%.

Comparison of radon data obtained in the pilot study to the data in Figure 1 and the available data obtained for dwellings [3,4,23–26] indicate a similar behavior of indoor radon levels, regardless of building usage. For example, in Alba County, the residential radon concentration varied between 5 and 2592 Bq/m<sup>3</sup>, while school results were in the range of 86–1121 Bq/m<sup>3</sup>. In Cluj county’s schools, the radon concentration ranged between 23 and 460 Bq/m<sup>3</sup>. The percentage of schools as well as houses (data is being published elsewhere in the frame of SMART\_RAD\_EN project) from the Cluj metropolitan area showing radon concentrations exceeding the recommended level of 300 Bq/m<sup>3</sup> was 21%. Overall, comparing radon levels in dwellings to the one in schools, the trend follows the same pattern [3,4,23]. The recommended value for indoor radon was not exceeded in schools and kindergartens from Sibiu County.



**Figure 1.** The distribution of annual indoor radon concentration according to floor level—school 1.

### 3.2. Results of Pilot Study

In school 1, the radon detectors were exposed in three school buildings on different levels, as shown in Table 2. The radon concentration showed an expected decreasing tendency with the elevation. On the other hand, similar levels of radon were observed within the same floor.

**Table 2.** Location of rooms and the variation of indoor radon concentration in school 1.

Building	Room Usage	Floor	$C_{Rn}$ (Bq/m <sup>3</sup> )	Uncertainty
D	secretariat	ground	237	8
D	classroom	ground	302	7
D	classroom	1st	19	4
D	head office	1st	65	5
D	classroom	2nd	29	4
D	classroom	2nd	22	4
D	classroom	3rd	32	4
D	classroom	3rd	39	5
C	department of economics	ground	93	6
C	classroom	2nd	45	4
C	classroom	3rd	43	5
Gym	gym office	ground	156	7

The radon concentration in both buildings (D and C) with upper floors was higher at the ground floor level. The third building (Gym), containing only a ground floor level, presented a lower radon concentration compared to the ground floor levels of building D and C. On the other hand, radon concentration measured on the upper floors varied from 21 Bq/m<sup>3</sup> to 73 Bq/m<sup>3</sup>, with no statistically significant variations between floors, as can be observed in Figure 1.

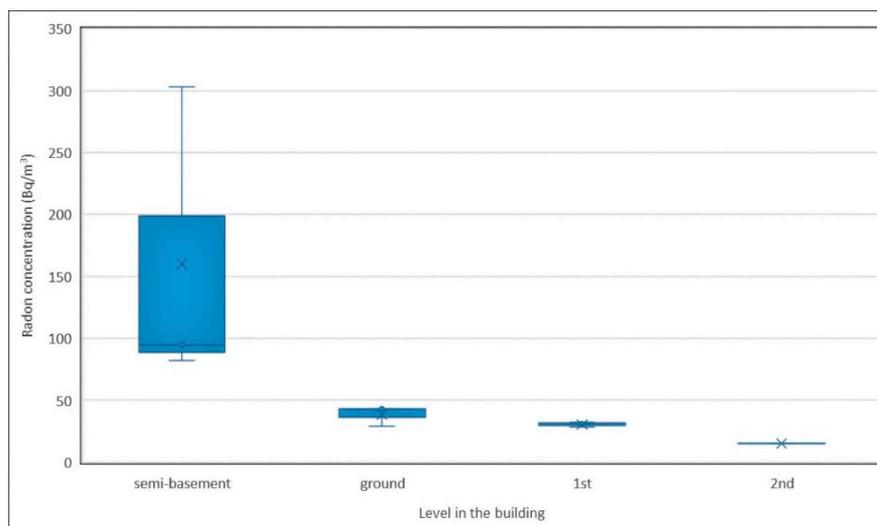
Figure 1 shows the distribution of annual indoor radon concentration measured in school 1 and associated uncertainty. The results display the fact that only in one case was the maximum admissible value of 300 Bq/m<sup>3</sup> exceeded.

The second school (S2) had two buildings in which the CR-39 detectors were exposed. In Table 3, the results of the radon measurements carried out and associated uncertainty are listed. Both of the school's buildings have classrooms at the semi-basement level. A similar behavior to S1 was observed, wherein higher radon concentrations were identified in rooms located in closer contact with the soil.

**Table 3.** Location of rooms and the variation of indoor radon concentration in school 2.

Building	Room Usage	Floor	$C_{Rn}$ (Bq/m <sup>3</sup> )	Uncertainty
A	secretariat	semi-basement	82	4
A	classroom	ground	29	5
A	classroom	1st	32	4
A	classroom	2nd	15	5
D	classroom	semi-basement	95	6
D	classroom	semi-basement	303	8
D	library	ground	43	4
D	secretariat	ground	43	4
C	classroom	1st	31	5
C	classroom	1st	28	4

The distribution of annual radon concentration in S2, presented in Figure 2, indicate a tendency of continuous decrease of the concentration with the increase of the level in the building. In only one classroom, located in a semi-buried level, the reference level of 300 Bq/m<sup>3</sup> was exceeded.



**Figure 2.** The distribution of annual indoor radon concentration according to floor level—school 2.

Radon measurements indicate high values for indoor radon concentration at the lowest levels of buildings, indicating its seepage from the soil and accumulation in the basement or rooms where floors are in contact with the ground. The decrease in concentration towards the upper part of the building indicates that the contribution from building materials is negligible, the main radon source being geogenic. Besides building materials, the stack effect also has a low impact in terms of increasing the radon level (coming from the soil) at floors higher than basement/ground floor [27,28].

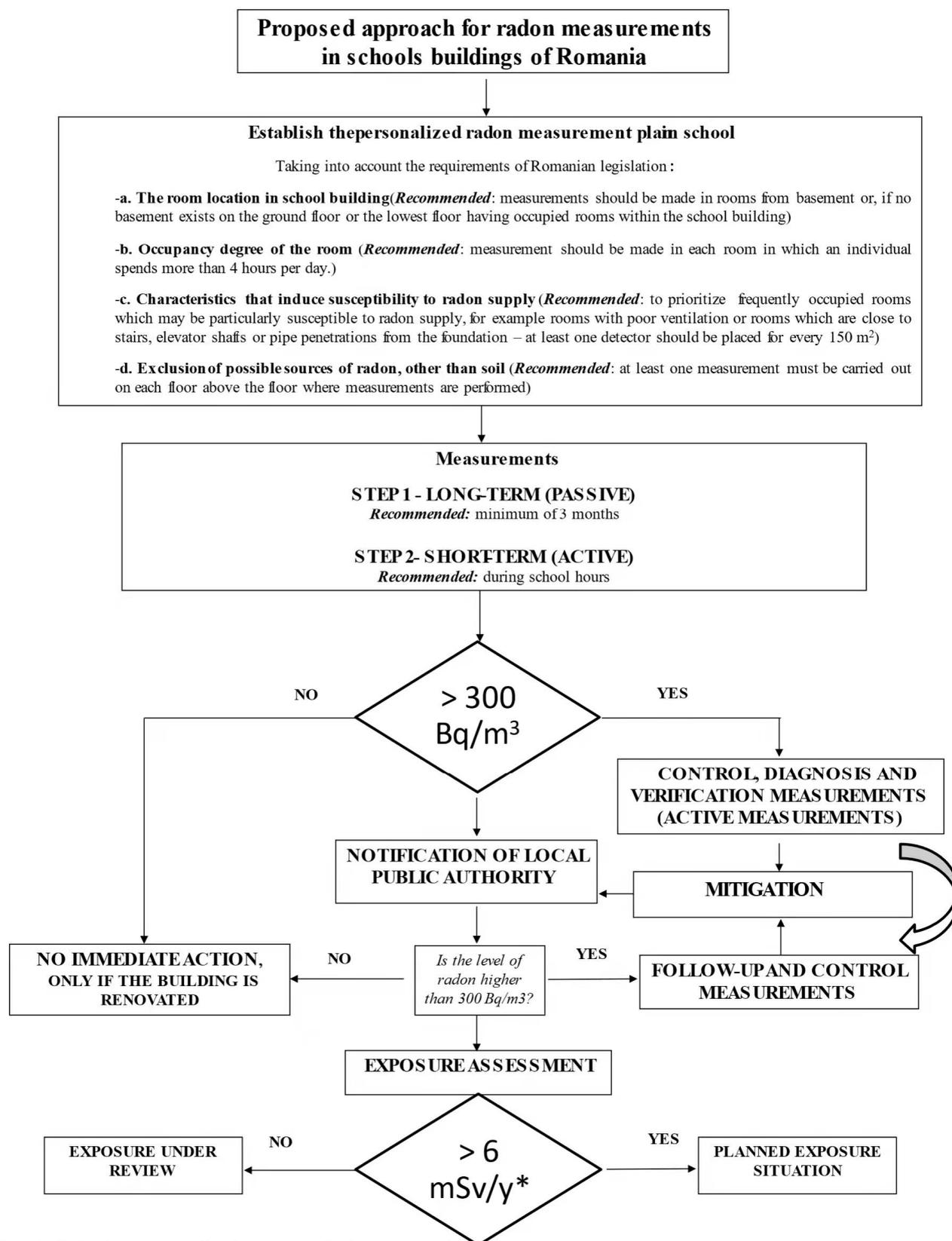
Air conditioning systems were not installed in the investigated schools. Natural ventilation in school rooms, by opening windows, affects the concentration of radon, resulting in a decrease during the time when windows are open and an increase when they are closed. Thus, weather conditions as well as heating and airing habits can have a significant impact on radon levels in schools with natural ventilation, as shown our previously results [27,28].

All these observations conclude that radon measurements should be mandatory for all frequently occupied rooms located on buried or ground floor levels or the basement level. This should be the first step in radon monitoring of schools, according to the specific Romanian requirements, measurement protocols, and national radon action plan [1,2,30–32].

The above-mentioned results sustain the need of follow-up measurements in the school rooms with the annual mean radon concentration above the reference level in order to highlight radon levels during school hours. It is extremely important to determine the concentration of radon activity during working hours through control and diagnostic measurements, as defined in specific national requirements [32]. Determination under normal conditions of occupation may prove the determining anthropogenic factor and the need/degree of urgency to implement remedial action.

### 3.3. Proposal for an Approach for Radon Measurements in Schools

In order for accurate, consistent, and relevant radon measurements to be ensured in Romanian schools, radon measurements need to be based on a standardized protocol. On the basis of international and national references and the results of radon studies, we proposed an approach for radon measurement in Romanian schools. The proposed approach for radon measurements in schools is presented, in the form of a flow chart, in Figure 3, taking into account the decision-making procedure and prioritization of actions on the necessary level of regulatory control in Romania according to Council Directive 2013/59/Euratom [1,2,32,35].



\* Annual effective dose corresponding time-integrated radon exposure value

**Figure 3.** The proposed approach for radon measurements in Romanian schools, according to the international recommendations.

Figure 3 indicates that long-term passive measurements in schools should be supplemented by active short-term control measurements, which show whether radon accumulation occurs during busy hours. If the reference level is exceeded, remedial measures shall be applied in accordance with the optimization principle set out in Article 5 (b) of Council Directive 2013/59/Euratom and international recommendations [34,35], followed by verification measurements. It is also important to inform the public authority whether radon exposure occurs at the reference level. Exposures will be monitored in notified workplaces where the exposure of workers is less than or equal to 6 mSv per year or less than the corresponding value of the integrated exposure over time [35].

#### 4. Conclusions

This survey represents a pilot study to enhance and organize a national approach on indoor radon concentration in schools and kindergartens. The preliminary analysis of variation between radon concentration in schools and homes showed considerable similarities. In order for accurate, consistent, and relevant radon measurements to be ensured in Romanian schools, a standardized measurement approach is required, combined with a larger study area. On the basis of radon experience of LiRaCC Laboratory, this paper proposes an approach for radon measurements in schools. At the same time, this approach can also act as a guide for other large, public buildings. The proposed national approach is a necessity imposed by the new Romanian legislative requirements in the context of the Council Directive 2013/59/EURATOM.

Two steps have been set for defining this approach. One step is to determine the possible presence of high radon levels (passive measurements). The second step is to investigate the radon levels during school hours (active measurements), but only in the rooms where the radon concentration exceeds the reference level ( $300 \text{ Bq/m}^3$ ). Knowing that (1) ventilation is a particularly crucial factor with respect to variation in radon concentration; (2) in the Romanian schools, mainly natural, not mechanical, ventilation is used; and (3) higher radon levels are usually observed during winter months (heating season) when buildings are sealed up, the most appropriate period for proposed measurement is between the middle of October and the middle of May.

In order to reduce the high radon concentrations in buildings with recording schools  $> 300 \text{ Bq/m}^3$ , appropriate control and diagnostic measures must be implemented, according to the legislation in effect.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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