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Effectiveness of Radon Remedial Action Implemented in a School on the Island of Ischia

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***Abstract*—**The aim of this study is to evaluate the efficacy of radon remedial action in a school on the Ischia island, South Italy, affected by indoor radon concentration higher than the value of 500 Bq/m^3. This value is the limit imposed by the Italian legislation, to above which corrective actions in schools are necessary. Before the application of remedial action, indoor radon concentrations were measured in 9 rooms of the school. The measurements were performed with LR-115 passive alpha detectors (SSNTDs) and E-Perm. The remedial action was conducted in one of the office affected by high radon concentration using a Radonstop paint applied after the construction of a concrete slab under the floor. The effect of remedial action was the reduction of the concentration of radon of 41% and moreover it has demonstrated to be durable over time. The chosen method is cheap and easy to apply and it could be designed for various types of building. This method can be applied to new and existing buildings that show high dose values.

***Keywords*—**E-Perm, LR 115 detectors, radon remediation, school.

I. Introduction

RADON is a naturally radioactive gas, it belongs to the natural series of ^{238}U and it is generated by the decay of its immediate parent ^{226}Ra in rocks and soil. Successively, the radon gas emanates from the soil and from underground water and it easily diffuses out of soil in the atmosphere where it is quickly diluted. Instead, it can accumulate to harmful levels in confined spaces such as homes and office buildings [1], [2]. The radon can seep into buildings from the soil through concrete slabs, cracks and crevices in the foundation and through the pipes of water, gas and sewer [3]. Radon and its progeny accounts for almost 50% of radiation dose received by people from natural sources [4].

Really after inhalation, radon is almost completely exhaled due to its long half life (3.82 d). Instead its progenies, in particular two radon daughters with short half-life, ^{218}Po and ^{214}Po, being electrically charged, can be attached to dust or smoke particles in indoor air. During breathing process, they reach the bronchial tissue and there they decay, emitting radioactive alpha particles capable of damaging the pulmonary epithelium and thereby causing lung cancer. Studies on miners showed a statistically significant association between exposure to radon and increased lung-cancer risk and the data extrapolation of these studies suggest that the residential radon may cause a considerable fraction of lung cancers among general population [5]-[12].

For occupational exposure to radon, the Italian authorities require employers to limit the exposure of workers in all underground workplaces and in the schools by imposing the action level for the values that are higher to 500 Bq/m^3. If the average annual radon concentration in workplace is higher than action level and the effective annual dose to workers exceed 3 mSv, the workplace must be subjected to mitigation measure to reduce the indoor radon concentration using proper technologies, but if the annual effective dose to the workers is less than 3 mSv, the mitigation measures are not mandatory except for schools [13]. On the contrary, in Italy there is no legislation for protection against exposure to radon in dwellings. Currently only the elaboration of a legislative proposal to that effect is as part of the National Radon (PNR) [14] was drafted. In recent years, many studies have been conducted in order to develop appropriate mitigation and prevention techniques [15]-[17]. The techniques currently employed are substantially i) natural and forced ventilation, ii) the sealing of the main access ways radon, iii) the depressurization of the subsoil, iv) the realization of very cheap sumps. These interventions that can be applied separately or in combination must be designed for each building, taking into account its architecture, the nature of the subsoil on which it is built and construction features. Some of these such as positive ventilation and depressurization, although effective, are extremely expensive. The floor sealing alone can be effective, but it may not be durable and hard to realize if considerable mitigation is required [18]. The aim of this study was to evaluate the effectiveness of a radon remediation method implemented in a school on the isle of Ischia which showed an indoor radon concentration exceeding the action level. The method applied consisted in the use of a Radonstop paint to apply in order to seal the floor to prevent the entry of the radon in the building from the subsoil which is remarkable because of the presence of the many fumaroles. This method can be considered a valuable tool for the significant reduction in the radon concentration and consequently in the radiation dose received by people. Furthermore, the stability in time of the action of a remedy has been evaluated.

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II. Materials and Methods

The island of Ischia (40°43'N 13°54'E) is situated to 35 km from Naples and it belongs to Phlegreo Archipelago of Campania region, southern Italy. It presents a surface area of 46.5 km^2 and a maximum elevation of 787 m of Mt. Epomeo and it has a population density of 1358 inhabitants/ km^2. From the geologic point of view, the island of Ischia has volcanic character and it was formed successively by various eruptions in approximately 150.000 years. Its territory is made up of both effusive (lava flow) and explosive volcanic products (green tuff, Citara tuff) whose composition is constituted mainly by trachybasalt to latite, trachyte, alkali-trachyte and phonolite. It is characterized by the widespread presence of eruptive centers, many of which are concentrated mainly in the eastern part of the island. The dynamics of the lifting of the plates is due to a cutting mechanism that generated a multiplicity of faults throughout the island [19]. Numerous springs are also present, many of which present high concentration of radon gas, and multiple fumarolic emissions, that are significant expression of secondary volcanism. The High School building was built in the '60s on an area covered by the Arso lava flow produced by the eruption of 1302. This area is rich of fumaroles, some of which have vapor emission at temperatures above 100 °C and the thermal waters of the springs near the building have a concentration of Rn above 1000 Bq/L. The building construction has taken place at different times, adding plexuses in time. The building is essentially on the ground floor and only a small zone is on the first floor. On the ground floor are allocated various classrooms and offices, as well as an auditorium and gymnasium while only 8 classrooms are on the first floor. The place in which the radon remediation was performed is constituted by a single environment on the ground floor, which was placed on a small slab at the bottom lying on the bare ground, with no crawlspace or solid cement screed, which offered no insulation from underground. The remedial action was performed using a Radonstop paint. This is a sheathing continuous liquid composed by Radonstop paint and synthetic resin that is generally used to eliminate the radon gas problem. To obtain about 3.0 mm of thickness about 30 kg of mixture was used. Once stretched, the mixture prevents the passage of alpha particles emitted by radon decay occurs under the mixture itself.

A. Measurements of Radon Concentration with LR-115 Detectors

The time-integrated measurements of indoor radon activity concentrations were carried out with passive alpha detectors (SSNTDs) LR-115 in 2004-2005. The LR 115 was exposed for two consecutive semesters in the six offices, four classrooms and one laboratory. After exposure, all detectors were chemically etched using a solution of 2.5 N NaOH at 60 °C for 110 min. In the LR-115 detectors, the number of tracks increase linearly as the residual thickness decreases so the determination of the residual thickness is necessary for the normalizing the observed track density to the nominal final thickness (6.5 μm). In our study, the residual thickness was measured with an optical method. The image of the detector has been acquired by means of a scanner with double lighting and its mean brightness in the gray scale was determined using a suitable software for image processing ImageJ software (Image Processing and Analysis in Java, version 1.46r, National Institutes of Health, USA). Using a calibration curve previously determined, the brightness was then converted into residual thickness. Also the automatic counting of tracks was performed using the ImageJ software. The background track density was estimated to be 10 tracks/cm^2 and it was determined counting the tracks of unexposed LR-115. Finally, the radon activity concentration was calculated using:

$$C_{Rn} = \frac{N}{E \times T} \quad (1)$$

where N is the track density corrected by background and normalized to the nominal thickness of 6.5 μm, E is the calibration factor and T is the exposure time [20].

B. Measurements of Radon Concentration with E-PERM Detectors

During the remedial action, the radon concentration was monitored using commercially available E-perm detectors in long-short configuration (LST) (Rad. Ele. Inc, Frederck, Maryland USA) [21], [22]. This device consists of a 50 ml conducting plastic chamber in which there is an electrostatically charged insulator (electret). Through filtered inlets, the radon gas passively diffuses into the chamber. The alpha particles emitted by the gas and its daughters induce ionisation of air molecules [23]. The ions produced inside chamber are collected onto a surface of the electret generating a reduction of the charge of the surface. The electret voltage decreases proportionally to the integrated radon concentration. In order to achieve the knowledge of its value, the loss of the electret net voltage was measured by a voltage reader (Rad. Ele. Inc, Frederck, Maryland USA) using appropriate calibration factors and exposure time. The radon concentration was calculated from:

$$C_{Rn} = \left[\frac{(V_i - V_f)}{CF * T} - (G_{gamma} C_1) \right] \times 37 \quad (2)$$

$$CF = C_2 + C_3 (V_i + V_f)/2 \quad (3)$$

where: V_i and V_f are initial and final electret voltages, respectively, T is the exposure time in days, G_{gamma} is the gamma background in μR/h; and C_1, C_2 and C_3 are constants that are given by the manufactured and they depend on the E-Perm configuration and on the volume of the conducting plastic chamber.

III. Results and Discussion

During the period 2004 – 2007, radon concentration measurements were performed in some rooms of the school

"Liceo Classico Scotti Ischia". In particular, the PC laboratory, six offices, the classrooms on the ground floor and two classrooms on first floor were monitored. The results of pre-remedial measurements in the classrooms and offices of High School are summarized Table I. As can be observed, all the rooms of the ground floor radon concentration exceeded the action level of 500 Bq/m^3. These values are certainly to be attributed to the fact that the building rests directly on the soil without any insulation, and therefore the radon emitted from the soil easily penetrates into the local ground floor.

TABLE I
RADON CONCENTRATION IN ROOMS OF SCHOOL BEFORE RADON MITIGATION

Room	Floor	Radon Concentration (Bq/m^3)
PC Laboratory	ground	1186 ± 65
Office 1	ground	1311 ± 40
Office 2	ground	925 ± 44
Office 3	ground	1142 ± 38
Office 4	ground	1437± 81
Head Office	ground	1190 ± 56
Classroom 1	ground	575 ± 25
Classroom 2	first	436 ± 12
Classroom 3	first	432± 17

To mitigate indoor radon concentrations, the natural ventilation was applied as first approach. The diurnal opening contributed to reduce the radon levels, but the closure of the windows during the night increased the radon levels. So this remediation was not effective. For this reason, in December 2007, during the Christmas holiday, the use of Radonstop paint as remedial action in the office 1 of the school was implemented. The used remediation method was chosen because it was faster to be carried out. The choice to remediate the office 1 was determined by the fact that most people work there for a long time per day. Although having high radon concentration values, other rooms are used as archives and thus they do not constitute a danger to worker's health. Of course, to reduce the whole building exposure, it is necessary to mitigate the high concentrations in all remaining rooms. This remedial action consisted in:

1. removing the existing floor and the old screed;
2. installation of a welded wire mesh;
3. construction of new slab of adequate size;
4. application of the Radonstop paint on the screed both on the walls and ceiling;
5. application of the new floor;

During and after remediation action, the radon concentration of office 1 was measured with electret E-Perm to test the efficacy of Radonstop. The first measurements were performed for three days before the beginning of radon mitigation. The radon concentration value was 1311 ± 40 Bq/m^3. This value is higher than that reported in Table I for office 1 because during the last measurement, the doors and the windows were closed.

The second measurement was performed after the removal of the floor for two days. The results of the measurement gave an indoor radon concentration of 3717 ± 371 Bq/m^3. This high value is due to the fact that the radon concentration increased significantly because after the removal of the floor there was no insulation of the subsoil. In this way the radon gas easily enters in the building and rapidly reaches harmful concentration also due to the closed windows and doors during the measurements.

After laying the screed, but before laying the floor, the radon concentration was monitored for eleven days and its mean value was of 1177 ± 129 Bq/m^3. This reduction of 68% is due to the fact that the screed acts as a barrier to the gas released from the soil preventing this from penetrating inside the building.

The subsequent measurement performed after the application of Radonstop paint on the walls and the slab shows a further reduction of radon concentration up to 41% compared to the value prior remediation action reported in Table I for office 1 as shown in Table II.

TABLE II
INDOOR RADON CONCENTRATIONS MEASURED BEFORE, AFTER AND AFTER FOUR MONTHS FROM THE ACTION OF THE REMEDY

Room	Radon concentration before mitigation action, Bq/m^3	Radon concentration after mitigation action, Bq/m^3	Radon concentration after four months from mitigation action, Bq/m^3
Office 1	1311 ± 40	774± 93	636± 70

After four months from the action of the remedy, the reduction of radon concentration is maintained and the radon concentration was almost stable with a value of 636 ± 70 Bq/m^3. This result can be attributed both to the use of Radonstop and the introduction of the new screed and new flooring, these interventions that have better isolated the indoor environment from the soil. The resulting decrease in concentration of radon can be estimated about 41%, although this remains above the action level. This is due to the very high initial value of radon concentration in this room. This leads consequently to a significant reduction in the radiation dose due to radon received by workers. Further advantages of the action of remedy are the simplicity of construction, the low cost and the speed of implementation. Despite of the radon concentrations reduction due to Radonstop paint use, it remains above of the action level of Italian legislation, so a more effective remedial action, such as depressurization was suggested.

IV. CONCLUSION

In this paper, the effectiveness of remedial radon in a school on the island of Ischia was tested. Radon concentrations measured in some classrooms and offices, before the action, showed that the concentrations were higher than the action level of 500 Bq/m^3 adopted in Italy for the workplace. The remedial action was conducted in the office that showed the highest concentration of radon and its effect was to reduce it by 41%. This percentage reduction obtained is in agreement with other results [24] that show similar reduction about 50% by applying different types of effective remedial measures, such as depressurization, natural ventilation and sump. It consisted in the construction of a concrete slab under the floor and the use of a paint stop radon applied on the walls and floors of the room. Interestingly, the radon concentration was measured four months after the application of the remedy and it was found to be stable.

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