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Electret ion chamber and environmental gamma radiation background: Preliminary results on the optimization of a radon gas measurement system

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Summary. — A study to evaluate the feasibility of using a system routinely used for measurements of radon gas concentration for measuring the background of gamma radiation was carried out. This approach would reduce the employment of different detectors to a single type, standardizing the methodology adopted and reducing the costs affecting other types of detectors. A 1440 hours long measurement was performed, using an experimental EIC system. The results were compared with measurements provided by a proportional counter and thermoluminescence dosimeters used as a reference. The results suggest the potential of the EIC system for unconventional use for gamma radiation background measurements.

1. – Introduction

Human exposure to ionizing radiation is a continuous and inevitable condition of life on Earth. This environmental radiation consists of natural radiations due to the presence of primordial radionuclides in the ground and high-energy cosmic rays reaching the Earth's atmosphere with a variable contribution depending on altitude [1]. In addition, from the second postwar period onwards, the contribution of nuclear tests and accidents has led to the uncontrolled release of considerable quantities of radioactive materials into the environment, widely dispersed in the atmosphere and deposited everywhere on the Earth's surface [2].

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For natural environmental background radiation, the greatest contribution is from radon gas. The impact on human health is well known [3-7], so monitoring of the radon gas activity concentration in confined environments plays an increasingly important role in the management of radioprotection for both workers and population. Many authors investigated the radioprotection issue through surveys designed on purpose, including our research group which contributed to the characterization of the national territory [8] and of specific regional areas [9-14].

Regarding regulations, to confirm the need for monitoring and surveillance, there has been an ever-increasing interest: from measurements in specific work places [15], up to the directive 59/2013 EURATOM which extends radioprotection to the population and living environments [16], up to the recent implementation of the directive at national level with the Legislative Decree 101/2020 [17].

Considering therefore a consequent and conspicuous increase in the request for measurements, this work arises from the need to optimize the use of a measurement system already used for radon gas measurements, the electret ionization chamber system (EIC) [18].

However, one aspect to consider is the limit of the system: EIC is not selective for radon gas, so the air inside the diffusion chamber is also ionized by gamma radiation and therefore it is necessary to subtract the gamma background using data already available and characteristic of the place [19] or obtained by experimental measures. For the latter, expensive detectors are usually used which can be complex to use or expensive, such as, for example, high-pressure ion chamber (HPIC), thermoluminescent dosimeters (TLDs) proportional counters and so on.

For this preliminary test the proportional counter and the TLDs were used as reference, while the experimental setup was EIC shielded with radon proof material.

Although EIC is a very versatile system for different types of measurements [20-22], its use for environmental gamma radiation is not widespread at all, nor is there a standard procedure [23-27].

2. – Materials and methods

2˙1. *Location of measurements*. – The building selected for the measurement test was the Physics Museum (fig. 1), an area of the Federico II university museums complex (Naples). It is located in "Collegio Massimo dei Gesuiti" complex since 2005, at the level above courtyard, in the former refectory. The building dates back to 1572 and became the first seat of the university in 1767 [28]. In addition to its historical-artistic relevance, the building is attractive from a structural point of view, as it is built in tuff and piperno, materials that are notoriously interesting from the radiological point of view [29-31] and as it has already been studied by our research group [12].

2˙2. *Experimental EIC system*. – The electret ion chamber system manufactured by Rad. Elec. Inc. (Frederick, MD, U.S.A.) in SLT configuration (Short chamber of 210 cm^3 and Long Term electret) was used. The charge loss of the electret was measured using an electrometer (Rad. Elec. Inc. Mod. 6383-01, Frederick, MD, U.S.A.). EIC was hermetically wrapped with a double layer of paper-polyethylene-aluminium with radon proof action and exposed for 1440 hours.

The average dose rate over the exposure period is given by the following equation:

$$\text{Dose Rate [nGy/h]} = 8{,}69 \cdot \{1000 \cdot ((I - F)/(CF \cdot T[\text{h}])) - BG\}, \tag{1}$$

where I is the initial voltage, F is the final voltage, CF is the calibration factor, T [h] is the exposure time expressed in hours, BG is the correction due to the radon in the chamber when the bag is sealed.

CF is calculated according to the formula

$$CF = A + B \cdot \ln((I + F)/2), \tag{2}$$

where A and B are values that vary according to the chamber-electret configuration, in our case A is -0.3921 and B is 0.1587.

2·3. *Portable proportional counter*. – The model used is the Berthold LB 123 D-H10 and it consists of a basic evaluation unit LB 1230 UMo and a probe LB 1236-H10 (Berthold Technology, Germany). The probe has a measurement range of 50 nSv/h–10 mSv/h, energy range of 30 keV–1.3 MeV and calibration factor of 0.214 μSv/h per counts per second (cps).

The proportional counter provides time-integrated measurements, therefore the measurement time should be adequate so that the data obtained is statistically significant. For this study, an exposure time of 60 minutes was chosen in each room of the museum every 15 days.

2·4. *Thermoluminescent dosimeter (TLD)*. – TLD-100 dosimeters, based on lithium fluoride doped with magnesium and titanium (TLD-100LiF:Mg, Ti; Harshaw Chemical Company) were used. High sensitivity to different radiation qualities and wide linear response range (10 μGy–10 Gy), are the reasons why TLDs-100 are frequently chosen to evaluate environmental gamma dose rate [32-34].

Two dosimeters were placed in a polyethylene box $2 \times 1.5 \times 0.4$ cm, containing the identified codes of the devices. For each room a set was installed (fig. 1) and exposed for 1440 h.

A detailed description of the annealing and reading protocol of the TLDs is available in refs. [35, 36].

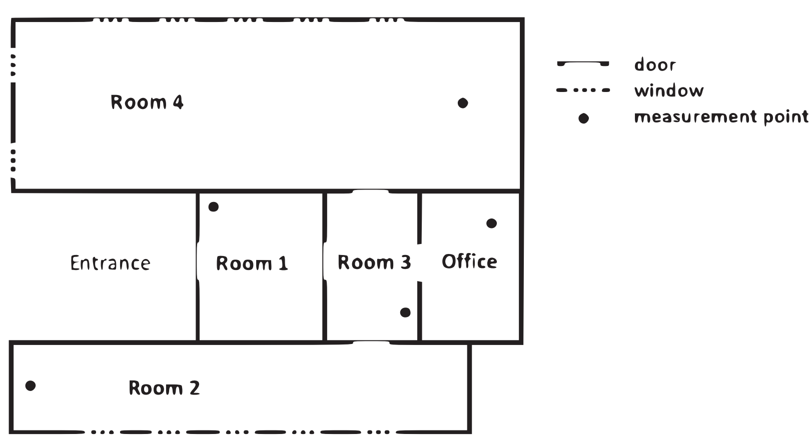


Fig. 1. – Plan of the Physics Museum (not to scale). It shows the arrangement of the rooms marking the localisation of doors, windows and measurement points.

For the reading process a TLD-Reader, Harshaw 3500, was used, connected to a computer equipped with WinREMS (Windows Radiation Evaluation and Management System) software.

In order to obtain the dose value from TLDs reading, it is necessary to provide the calibration factor (CF), usually an average calibration factor representative of the lot of TDL is applied. CF was calculated by exposing the TLDs to a known radiation beam of photons with an average energy of 3 MeV at the LINAC of the "Fondazione Pascale" Cancer Institute in Naples. The TLDs were calibrated in the dose range 0.2–1.2 Gy: for each point dose measurement the thermoluminescence (TL) glow curves were carried out and the main peak areas recorded in order to obtain the TL value of the signal. The calibration coefficient was carried out from the slope of the linear curve with its own statistical error, resulting equal to $4.3 \pm 0.4\,\mathrm{nC} \cdot \mathrm{mGy}^{-1}$ [37].

Since the CF is known for the dosimeters used, the dose can be calculated using the following formula:

$$D = R/CF, \tag{3}$$

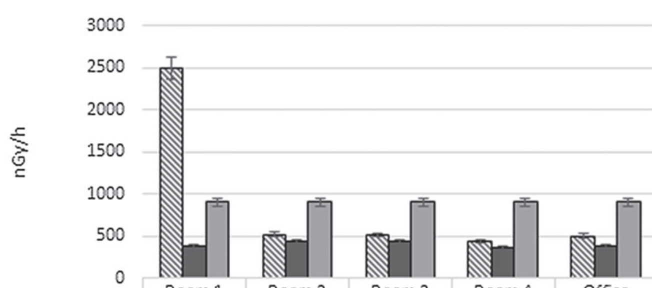
where R is the raw charge data from the photomultiplier tubes (in nC).

3. – Results and discussion

The results of the five measurement points of the three detectors are shown in fig. 2.

The data show a clear inconsistency in the response of the experimental EIC double wrapped system, this is due to an error during the handling of the electret, which has almost completely lost the voltage, so it will be excluded from discussion. On the other hand, the responses of the TLD are quite coherent, which revealed an average dose rate of 908 ± 49 nGy/h. However, these results are not comparable to those obtained with the EIC experimental setup and the proportional counter.

In particular, the doses of the TLDs exceeded the values obtained with both other two detector types resulting on average 2.3 and 1.8 times greater than the measures provided by the proportional counter and the experimental EIC system (excluding the



	Room 1	Room 2	Room 3	Room 4	Office
EIC double wrapped	2491	519	517	438	502
Proportional counter	385	436	439	367	382
TLD-100 LiF:Mg,Ti	908	908	908	908	908

Fig. 2. – Comparison of gamma radiation values in each measurement point for each detector type. The error calculated is equal to 5% of the measurement value.

altered values of room 1), respectively. Since TLDs are much more sensitive than the other two detectors, for this preliminary evaluation we decided to exclude their results from any speculation.

The mean gamma dose rate calculated with the experimental EIC system was $494 \pm 25\,\text{nGy/h}$; while the result obtained with the proportional counter was $406 \pm 20\,\text{nGy/h}$.

In this case, despite having an over-response of EIC of an average value of 1.2, it can be assumed that the system is comparable and usable in place of the proportional counter.

4. – Conclusions

This study concerned the optimization of a system used to measure the concentration of radon gas activity. In the preliminary test, proportional counter and TLD as references and an experimental system with EIC coated with a double layer of radon proof material were used. The exposure of the three detectors was carried out in a building characterized by construction materials of great radiological interest and notoriously emitters of gamma radiation. Preliminary results highlighted the potential compatibility of the EIC experimental system with the proportional counter, while highlighting a greater sensitivity of the electrets. On the other hand, TLDs gave results that were not comparable with the previous ones, however it is interesting to study the possibility of increasing the exposure time of the dosimeters and reconsider the comparison between the three systems.

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