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Indoor radon measurement via Nuclear Track Methodology: A comparative study

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Indoor radon concentration represents an important public health challenge, for simple and inexpensive measurement devices and methods, suitable for large-scale indoors radon measurements, are required. Nuclear Track Methodology, by using a closed-end cup device as a radon chamber is an attractive option for such large-scale indoor radon measurements. A comparative analysis of the detection efficiency of four different (one commercial and 3 specially designed) passive closed-end cup devices for the measurement of indoor radon concentrations is presented. CR-39 (Lantrack®) polycarbonate was the detector material. The four devices were simultaneously exposed to a mean radon concentration of 860 ± 60 Bq m^{-3} inside a closed room for periods of one, two and three months. An AlphaGUARD® radon monitoring system was used to continuously monitor the radon concentration within the room. The chemical etching and reading procedures were carried out following a well-established protocol for indoor radon surveys. The detection efficiency and the exposure-time-response relationship of each of the devices were determined.

1.- Introduction

Radioactive Radon gas is one of the main contributors to the effective dose equivalent in humans (IAEA, 1989). The concentrations of this natural radioactive source have been studied in several countries by a number of international organizations (Amgarou et al., 2003; Bocchichio et al., 2005; Miles, 1998; Moreno et al., 2008; Starnd et al., 1992; WHO, 2009). One of the standing challenges is the choice of the most appropriate measurement device, given the characteristics of the study involved. The Department of Energy (DOE), the Environmental Protection Agency (EPA) and other USA European Community agencies have dedicated significant resources to the measurement of indoor radon levels.

In this paper, a comparative study of the detection efficiency of four different passive closed-end cup devices used for large-scale indoor radon measurements is presented. Three of the devices were developed ad-hoc, while the fourth is commercially available.

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The main goal of this work is to develop an indoor radon measurement system suited to local conditions, to chemical etching and calibration protocols and to our readout system, thus improving the worldwide knowledge database of indoor radon levels in dwellings and other buildings.

2.- Methodology

Nuclear Track Methodology (NTM) is one of the best methodologies for large-scale indoor radon measurements (Espinosa, 1994). Indeed, detector response does not depend on temperature or humidity, the detectors do not need a power supply to operate, the data is highly reproducible and, most importantly, it is significantly cheaper than alternative methods for the measurement of indoor radon levels.

Because of its attractive technical and economic characteristics and the availability of its components, the passive closed-end cup system was chosen as a model for the design of the indoor radon detectors. CR-39 Lantrack® of 500 μm thickness was chosen out of the range of possible alpha detector materials because of its energy response, size, and relatively easy handling.

2.1. Indoor radon measurement devices

The first detector consists of a commercially available plastic cup, the end of which is sealed with a membrane made from a plastic bag. The radiation sensitive material (CR-39) is hung from the center of the cup (Figure 1.a). The volume of this device is 330 ml. The second detector device is similar to the first, but now the cup with the CR-39 chip is not sealed by a membrane but rather placed within a sealed plastic bag (Figure 1.b). The volume of the second device is 380 ml. The third device uses a photographic film case instead of a plastic cup. The CR-39 is placed at the end of the film case, parallel to the sides of the case, and the case is sealed with the same type of membrane as used in the first two detector models (Figure 1.c). This device has a volume of 30 ml. The response of these three devices was compared with that of Landauer® commercial device, which has a volume of 20 ml (Figure 1.d). CR-39 Lantrack® chips (1.9 cm x 0.9 cm) were used in all four detection systems.

Figure 1.- Four devices for indoor radon measurements.
The first three were developed ad-hoc; the fourth is Landauer® commercial device.

2.2. Radon exposure

The four indoor radon devices were placed inside a closed room with a mean radon level of 860±60 Bq m^{-3} as monitored by three dynamic detection systems (AlphaGUARD®, Rad-7® and Sun Nuclear® 1027) (Figure 2). Sixteen detectors (four detectors of each model) were simultaneously exposed for a period of one month. Another sixteen detectors were exposed for two months, and a further sixteen detectors were exposed for three months.

After each exposure period, the detectors were chemically etched following a well-established protocol (Espinosa and Gammage, 1993), and analyzed using a Digital Image Analysis System (DIAS) (Espinosa et al, 1986).

The detectors were chemically etched in a 6.25M KOH solution at a temperature of 60±1°C for 18 hours (Espinosa and Gammage, 1993). The readout method includes the use of an optical microscope, a CCD camera, 100X magnification and the Mocha® software, which allows the development and maintenance of several visual effects and processing, with the advantage of being both cross-platform and compatible with other third party tools, editing software, and compositing suites.

Figure 2.- Diagram (left) and photograph (right) of the exposure chamber.

3.- Results and discussion

It is well known that, when a radioactive particle impinges a nuclear track detector, it produces damages at the molecular level of the polymeric bonding, within fractions of nm around the trajectory of the particle, forming the so-called Latent Track (LT), which is revealed through the chemical etching. The energy required to form the latent track is obviously lost by the particle and it is known as the Restricted Energy Loss (REL), which, for non-relativistic conditions, is basically equal to the total energy loss (E_{max}) in the material.

Accordingly, the REL depends on the molecular structure of the material used as detector, through a number of nuclear and molecular parameters, among which the shell correction term takes into account the possible charge screening to the incoming particle charge by the electrons of the atoms in the medium. This effect is significant when the velocity of the impinging ion is comparable or even smaller than the orbital velocity of the bounded electrons of the target, such as in the case of radon radiation. According to some calculations (Apel et al., 1997), the REL can change up to nearly 3 orders of magnitude from polymeric to metal materials. In the specific case of typical polymeric materials, like CR-39 and Lexan (registered trademark of a commercial polycarbonate resin) for example, the change is of E_{max}=200 eV for CR-39 to E_{max}=350 eV, for Lexan, that is, a ratio of change of 2/3.5. This, on the one hand, provides a clue of why standard polymeric materials, as the ones employed in the present study, show such significant differences. Indeed, most commercially-available polymers contain additives and various types of crosslinking agents, used to improve their thermal and mechanical behavior, and these substances modify the local electron density. On the other hand, the above could allow to set standards for molecularly designing adequate detectors.

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Also, it has been reported that the detection efficiency of LT depends on the impinging angle, that is, the macroscopic geometry of the detector. Therefore, a completely shapeless object, as the plastic bag, would result in a more efficient geometry, as observed experimentally in Figure 3.

Other important technological parameter to assess the suitability of a detecting system is the linearity of its response with respect to the exposure time, to ensure the significance of a long-term measurement. Accordingly, the average response of all the devices, as a function of exposure time, is shown in Figure 3. As observed there, in all cases, a linear dependence on exposure time was found. The slopes of the plots in the Figure equal the average efficiencies of the systems, because if one type registers double amount of tracks in 1 month, it will still register double amount of tracks after 2 months, and it will remain proportional until saturation is reached. Also, it must be noticed that, for the exposure periods studied here, no saturation was observed whatsoever.

Figure 3.- Response of the different devices as function of exposure time.

According to our observations, some geometrical parameters, such as the volume of the exposure chamber and the distance between the case and the CR-39 play an important role, along the lines discussed above. In the particular case we describe in this present article, they have been kept fixed and their influence thus reduced. However, it would be worth while to explore in detail how these factors and others related, such as the orientation of the cup (either standing or laying on its side) could affect the specific efficiency. This could be important not only for scientific reasons, but also from a practical standpoint, since it is difficult, for potential large-scale in-field applications to guarantee that the exact position of the devices would be maintained.

4.- Conclusions

Since radon is a radioactive natural gas, originated from the decay of radioactive uranium in soil, it is extremely difficult to prevent it from entering homes and other buildings, becoming trapped and concentrated in indoor air. According to the EPA, radon gas is the second leading cause of lung cancer, and the number one cause of lung cancer among non-smokers. This stresses the need of reliable, cost-effective detection systems, which can be also quickly and simply interpreted. The commercially available instruments are often costly and require a relatively high level of technical expertise to be able to extract meaningful and usable information.

The approach followed in this present work demonstrates the feasibility of designing and producing low cost, trustable systems for large scale use in developing areas. Even for developed countries, we believe our proposal to represent and attractive possibility of recycling waste materials as NTD systems, both from ecological and educational perspectives.

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Finally, more than attempting to convince the reader on the benefits of the specific systems described herein, we hope to encourage the developing of systems ad-hoc, as well as some research projects along the lines discussed above.

5.- Acknowledgments

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HIGHLIGHTS

- Low cost Nuclear Track detectors systems.
- Reliable indoor radon measurements.
- Long term assessment of home radiation levels.
- Large scale indoor radon measurements.

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FIGURE CAPTION

Figure 1.- Four devices for indoor radon measurements. The first three were developed ad-hoc; the fourth is Landauer® commercial device.

Figure 2.- Diagram (left) and photograph (right) of the exposure chamber.

Figure 3.- Response of the different devices as function of exposure time.

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Model I: Sealed plastic cup.	Model II: Plastic cup inside a sealed plastic bag.	Model III: Photographic film case.	Model IV: Landauer® commercial device.
1.a)	1.b)	1.c)	1.d)

Figure 1.- Four devices for indoor radon measurements. The first three were developed ad-hoc; the fourth is Landauer® commercial device.

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Figure 2.- Diagram (left) and photograph (right) of the exposure chamber.

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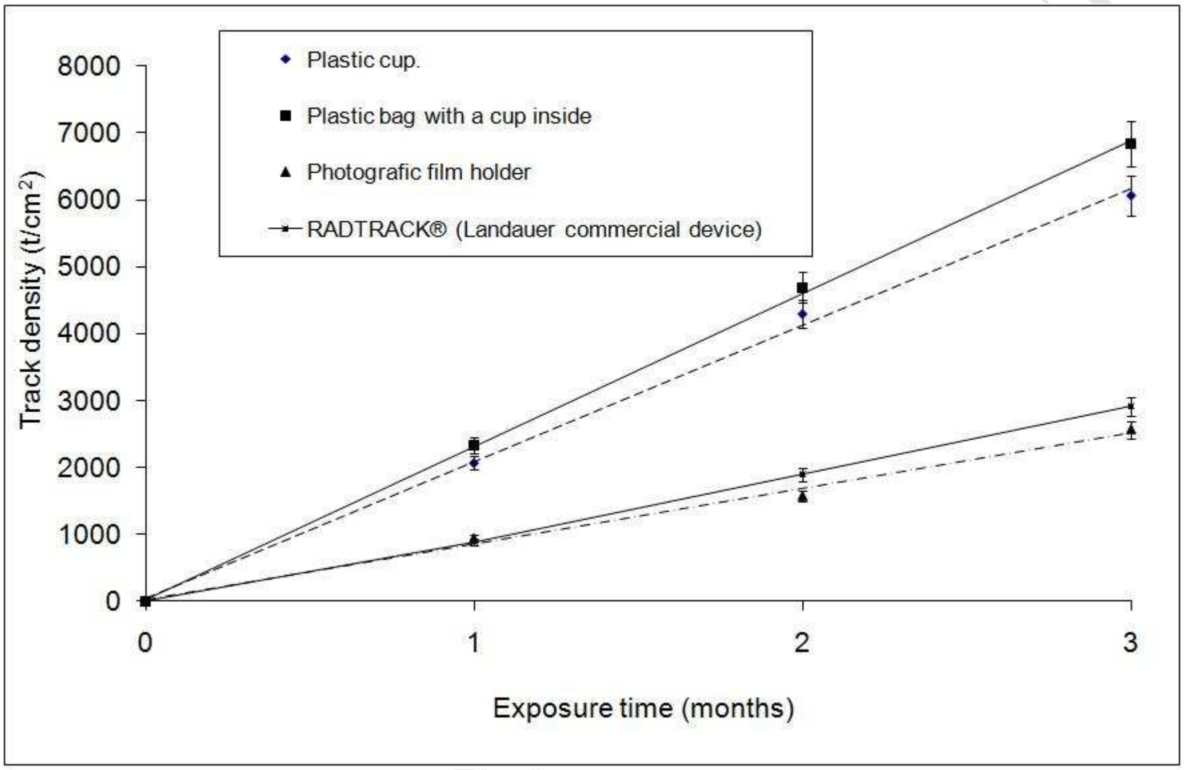

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