

Characterization of LR-115 Type 2 Detectors for Monitoring Indoor Radon 222: Determination of the Calibration Factor

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Abstract The city of Lima, capital of Peru, has about 11 million inhabitants. Lima has no records about the indoor Radon 222 concentration levels in dwellings. Hereby, we are planning to register the indoor radon concentrations in Lima and in other cities of Peru in the next three years. First, we will determine the calibration factor for the detectors which will be used in our measurements. For this purpose, Solid State Nuclear Tracks Detectors of nitrocellulose nitrate (LR-115 type 2) were used. The calibration process using a Radium 226 source was described to obtain the calibration factor. Linear response in tracks number was found in relation with irradiation time and its stability after time at the calibration chamber.

Keywords: Cellulose nitrate, Nuclear tracks, Dosimeter, Alpha detector

1. INTRODUCTION

Radon 222 is the main natural radioactive contaminant [5,13]. Peru, specifically the city of Lima, has no records of this pollutant. The Nuclear Tracks Laboratory at PUCP is making a first mapping project of Radon 222 and their descendants, in the homes of Lima and Callao. This first project will culminate in 2018.

Nuclear tracks detectors are used [2,4] due to the ease of use and good performance in similar studies [8,9]. The Nuclear Traces research group of PUCP (GITHUNU) has already achieved some experience with cellulose nitrate LR 115 type 2, used in previous research work with good results [11,12].

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Pereyra, P.
 López, M.E.
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It is for this reason that one of the first tasks is to develop characterization of dosimeters.

At the same time, the IPEN is conducting parallel monitoring using nuclear tracks detectors CR-39, in Lima and in two other cities: Puno and Arequipa. The aim is that the two entities can compare the results with both types of dosimeters, giving greater strength. CR-39 dosimeters are commercial dosimeters and will be processed in external laboratories; however, the LR-115, prepared locally, will be processed in the PUCP.

Under the agreement between the Pontificia Universidad Católica del Peru (PUCP) and the Peruvian Institute of Nuclear Energy (IPEN), the calibration factor of passive detectors cellulose nitrate (LR-115), the result of this work is obtained as a starting point for monitoring Radon 222.

The nuclear tracks laboratory of IPEN has a Radium 226 source, used to determine the calibration factor for these detectors. This work is the beginning of different joint research between the two institutions, with the main objective to develop a radon map in Lima city and later on in the country.

2. FUNDAMENTALS

Using equations for the secular Radon equilibrium and its progeny, you can reach the expression [1]:

$$t = \frac{\ln \left[\frac{\lambda_{Ra} / (\lambda_{Ra} - \lambda_{Rn})}{\frac{A_{Rn}^0}{A_{Ra}^0} - \frac{\lambda_{Rn}}{\lambda_{Ra} - \lambda_{Ra}}} \right]}{\lambda_{Ra} - \lambda_{Rn}} \quad (1)$$

Where

A_{Rn}^0 : Initial Radon 222 activity

A_{Ra}^0 : Initial Radium 226 activity

λ_{Ra} : Radium 226 decay constant = $0.120333 \times 10^{-6} \text{ days}^{-1}$

λ_{Rn} : Radon 222 decay constant = $0.181286208 \text{ days}^{-1}$

Whereas at $t = 0$ the initial activity of Radon 222 is zero, we can calculate the time to reach the secular equilibrium as 65.77 days. Detectors, after various tests, verified that the time needed to reach secular equilibrium is about 65 days, even with an initial activity of Radon 222.

Radio 226 activity is calculated. This should be the same as Radon 222 when the secular equilibrium is reached.

$$A_{Ra226} = \frac{m_{Ra226} \lambda_{Ra226} N_A}{226 \text{ g/mol}} = 1898.77 \text{ Bq} \quad (2)$$

It must be,

$$A_{Ra226} = A_{Rn226} = 1898.77 \text{ Bq} \quad (3)$$

Now Radon 222 concentration in the chamber is calculated, knowing that its volume is 0.77 m^3 :

$$C_{Rn222} = \frac{A}{V} = 2472.35 \text{ Bq/m}^3 \quad (4)$$

The dilution is evident when considering the effect of the antechamber. Then it is considered for an initial volume with secular equilibrium $V_{initial} = V_{chamber}$ with the concentration of 2472.35 Bq/m^3 and with a final volume $V_{final} = V_{chamber} + \Delta V$, obtaining the concentration of Radon 222;

$$C_{final,Rn222} = \frac{0.768 \text{ m}^3 \times 2472.35 \text{ Bq/m}^3}{0.768 \text{ m}^3 + 0.01 \text{ m}^3} = 2440.58 \text{ Bq/m}^3 \quad (5)$$

Therefore, the concentration of Rn 222 has decreased due to increased total volume. Part of the Radon has passed to the antechamber, thereby decreasing the activity in the main chamber. It is necessary to know the time that Radon activity will be the initial activity again.

In the chamber the activity must be

$$A_{chamber,Rn222} = C_{final,Rn222} V_{chamber} = 1874.37 \text{ Bq} \quad (6)$$

Once again the time for secular equilibrium is calculated using the previous results from Eq. (6) and Eq. (1). The time required obtained for the secular equilibrium is 41.83 days.

Pereyra, P.
López, M.E.
Pérez, B.
Rojas, J.
Martínez, J.
León, K.

3. MATERIALS AND METHODS

The experimental arrangement is shown in **Figure (1)**. The radon chamber (aluminum tank) and the antechambers (glass beakers) are observed. The cellulose nitrate detectors LR 115 are then placed at a known concentration in the antechambers for a prefixed time. The antechambers are necessary to prevent the loss of secular equilibrium to open the chamber. This prevents the decrease in concentration in the time set for the calibration process, improving the system efficiency.

An active system Alpha Guard is also used along with the Alpha Pump, whose function is to recirculate the gas to standardize its concentration in the system. The circulation flow is moderate, for extract them easily. The detectors were placed on a mica base; similarly it will be use in the monitoring, to replicate actual conditions [6]. After subjecting the detectors to different concentrations of Radon exposure for various periods, fluctuating from 7 to 40 days, we proceeded to engraving and reading the detectors, in the laboratory of Nuclear Tracks of PUCP, according to the conditions set for engraving and reading [10]. A thermostated bath and an optical microscope, shown in Figure (2), are used.

Several fields were examined for reading. Uncertainties were calculated using the standard combined uncertainty [7].



Figure 1: Radon chamber and antechamber detectors container.



Figure 2: Lecture equipment and etching equipment.

4. RESULTS AND DISCUSSION

The relationship between the density of traces and the concentration is as follows:

$$C_{Rn222} \left[\frac{Bq}{m^3} \right] = \frac{(\rho_{measurement} - \rho_{background}) \left[\frac{tracks}{mm^2} \right]}{K \left[\frac{tracks}{mm^2} \times \frac{m^3}{Bq \times hours} \right] \times t [hours]} \quad (7)$$

The results obtained show a nearlinear behavior in the detector response when plotting the number of tracks versus exposure time, even for long time exposure **Figure (3)**, allowing thus to calculate the calibration factor for the detectors.

In **Figure (4)** the stability of the obtained calibration factor as a function of time can also be seen. The behavior of the calculated values for the calibration

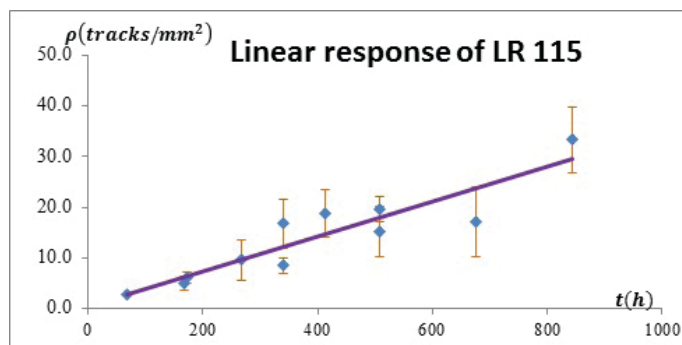


Figure 3: Lineal response of LR-115 to exposure to Radon 222.

Pereyra, P.
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 Pérez, B.
 Rojas, J.
 Martínez, J.
 León, K.

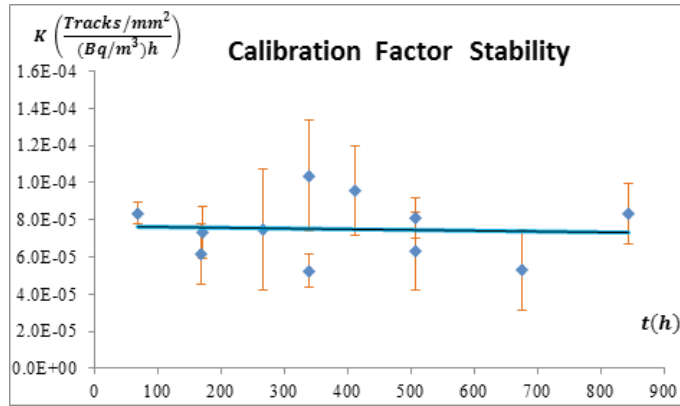


Figure 4: Stability of Calibration Factor.

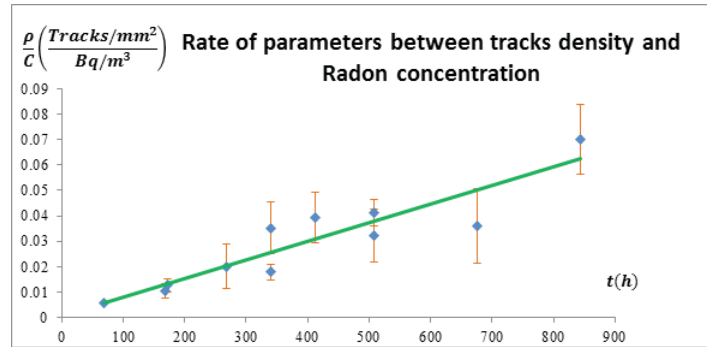


Figure 5: Calibration Factor.

factor for different irradiation times ranging around the determined average value is displayed.

We worked with two groups of detectors; in some cases the two values obtained for the same given time are presented. In such cases, also very similar responses between the two groups are obtained.

We can so calculate the calibration factor. Finally, in **Figure (5)** the corresponding calibration factor is determined.

The value obtained for the calibration factor is:

$$K = 8.402 \times 10^{-5} \left[\frac{\text{tracks} / (\text{hours} \times \text{mm}^2)}{\text{Bq} / \text{m}^3} \right] \quad (8)$$

5. CONCLUSIONS

It could be stated that the cellulose nitrate detectors calibrated have a good linear uniform answer for different irradiation response times. In addition, the calibration factor obtained in Eq. (8) is not affected by the time or tracks density. Additionally no cases of detector saturation, even for the highest concentrations, were presented.

The relevance of this work relies on having determined the calibration factor to be used in the Radon222 monitoring project in Lima, Peru. The calibration factor here obtained is similar to other similar research with this type of detector.

The advantage of using cellulose nitrate detectors LR 115 relies in its ease to prepare detectors, not being as rigid as another.

The main disadvantage of cellulose nitrate detectors is its low resistance to UV radiation or extreme moisture conditions, so outdoor detection use may arise other problems.

6. ACKNOWLEDGMENTS

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