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# Short-term exposures of radon dosimeters

## Project report

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# 1. Introduction

In tunnels, water tanks and other underground facilities, radon concentrations can be very high. Workers who have to regularly monitor these facilities are exposed to these high concentrations for often short periods of time, and up to several times a day. The dose received by people depends on various physiological factors and is difficult to measure with the passive dosimeters usually used, as equilibrium does not have time to be established during a short period of exposure.

The aim of this project is to set up an experimental device to expose dosimeters to a very high concentration of radon for a short time. The objective of the experiment is to study the response of conventional dosimeters to successive short exposures (15 min - 30 min) to radon concentrations comparable to those to which people are exposed (5 kBq/m$^3$ - 10 kBq/m$^3$).

# 2. Method

## 2.1. Generating the reference radon atmosphere

A time constant radon atmosphere is generated in the large measurement chamber (130 litres) by a continuous air flow through a radium-226 source which emanates radon-222. The radon activity concentration depends directly on the air flow rate, as well as the volume of the chamber and the parameters of the radium source and is calculated as follows:

$$C_{\mathrm{Rn-222}} = C_0 + \frac{E}{\lambda_{\mathrm{Rn-222}} \cdot V + Q_V}$$

with $C_0$ being the initial radon activity concentration in the air, $\lambda_{\mathrm{Rn-222}}$ the decay constant of radon, $V$ the measurement chamber volume, $Q_V$ the air flow rate and $E$ the radon emanation rate, which is expressed as $E = A_{\text{Ra-226}} \cdot \lambda_{\text{Rn-222}} \cdot \chi$ where $A_{\text{Ra-226}}$ is the activity of the radium source and $\chi$ the emanation coefficient. The parameters take following values :

$C_0$ is close to zero (< 30 Bq/m$^3$) and is neglected in the case of very high concentrations

$\lambda_{\mathrm{Rn-222}} = \frac{\ln(2)}{T_{1/2Rn-222}}$ with the half-life of radon $T_{1/2Rn-222} = 3.8232$ days

$\lambda_{\mathrm{Ra-226}} = \frac{\ln(2)}{T_{1/2Ra-226}}$ with the half-life of radium $T_{1/2Ra-226} = 584'388$ days

$$A_{\text{Ra-226}} = A_{0\,Ra-226} \cdot e^{\left(-\frac{\ln(2)}{T_{1/2Ra-226}} \cdot (t-t_0)\right)}$$

with $A_{0\,Ra-226} = 199.9$ kBq the activity of the radium source on 04.10.2019

$\chi = 0.998$

$V = 130$ l

$Q_V = 3.9$ l/min to obtain a dosimeter exposure of 5 kBq/m$^3$

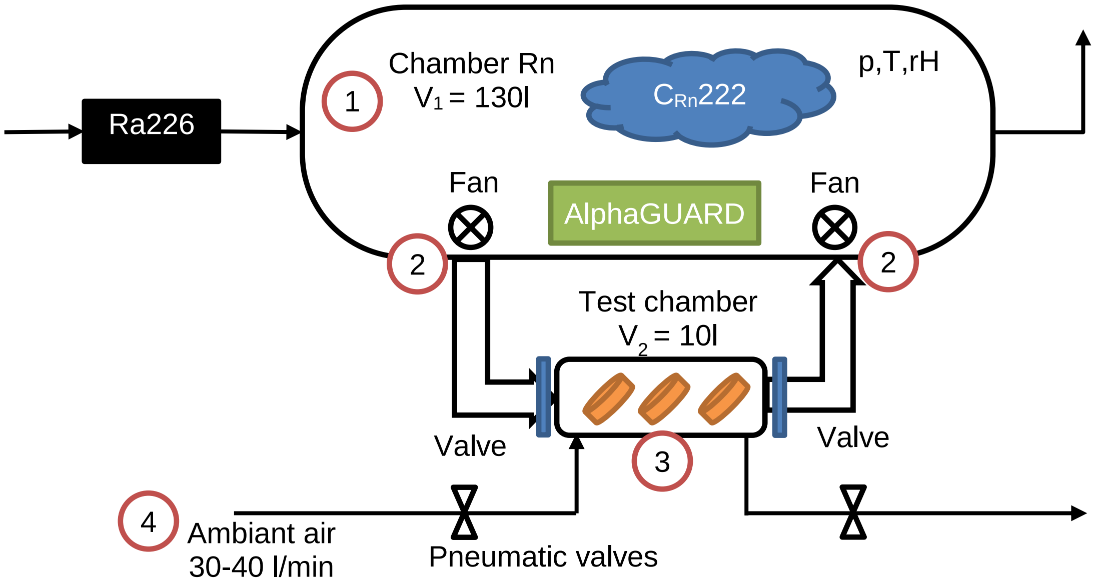
$Q_V = 2.0$ l/min to obtain a dosimeter exposure of 10 kBq/m$^3$

The concentration thus generated is very stable over time and can be calculated accurately and in a traceable manner: the air flow control devices were calibrated at the METAS Flow and Hydrometry Laboratory and the radon emanation source is linked to the primary standard of the CMI (Czech Metrology Institute). The volumes of the measuring chambers were measured at METAS by the Laboratory for Flow and Hydrometry.

An AlphaGUARD PQ2000 (EF2142) instrument measures the radon concentration every 10 minutes in order to monitor its evolution and value.

## 2.2. Short-term exposures

The reference radon atmosphere is generated in the large measurement chamber as described in the paragraph above, to which a smaller 10 litre chamber is connected (see illustration below). The pipes connecting the two chambers can be opened or closed by means of valves. Fans are placed at the inlet of the pipes, allowing the radon-containing air to flow rapidly to the small chamber as the valves are opened (approx. 1000 l/min). In addition, a low-radon ambient air circuit is used to ventilate the small chamber in order to bring the radon concentration down rapidly after exposure (approx. 30-40 l/min). An electronic radon dosimeter (Sarad RadonScout Pro) is placed in the small chamber in order to get an indication of the concentration value every 10 minutes.



| Number | Description |
|---|---|
| 1 | Chamber with known radon reference atmosphere, volume = 130l |
| 2 | Valves and fans to circulate air between the two chambers |
| 3 | Test chamber containing passive dosimeters and an electronic dosimeter, volume = 10l |
| 4 | Ventilation circuit of the test chamber (low radon ambient air) |

## 3. Measurement sequence

### 3.1. Description

A measurement sequence consists of a successive series of the following system states, which are illustrated in figure 1 :

1. **Generation of radon concentration**:
   The valves in the small chamber are closed. In the large chamber, a radon atmosphere of the desired concentration is generated with a constant air flow. This takes some time, until the equilibrium of the radon decay products is reached.
2. **Short-term dosimeter exposure**:
   The constant air flow is stopped. The valves of the small chamber are opened and the fans are switched on: quickly, the dosimeters are exposed to a high concentration of radon in the small chamber.
   During this step, the radon concentration has slightly decreased since the volume of the chamber has been changed from 130 litres to 140 litres.
3. **Aeration of the small chamber**:
   The valves of the small chamber are closed and the two chambers are again disconnected from each other. The ventilation circuit of the test chamber is switched on, in

order to quickly remove the radon from the small chamber. Meanwhile, the radon airflow in the large chamber is reactivated to restore the reference radon concentration.

A LabView program was written to automate the measurement sequence.

Figure 1 shows the evolution of the radon concentration from the beginning of the first measurement sequence. Note that the values returned by the RadonScout are measured with a certain reaction time. Nevertheless, the sum of the values corresponds to the theoretical exposure during the time the valves were open.

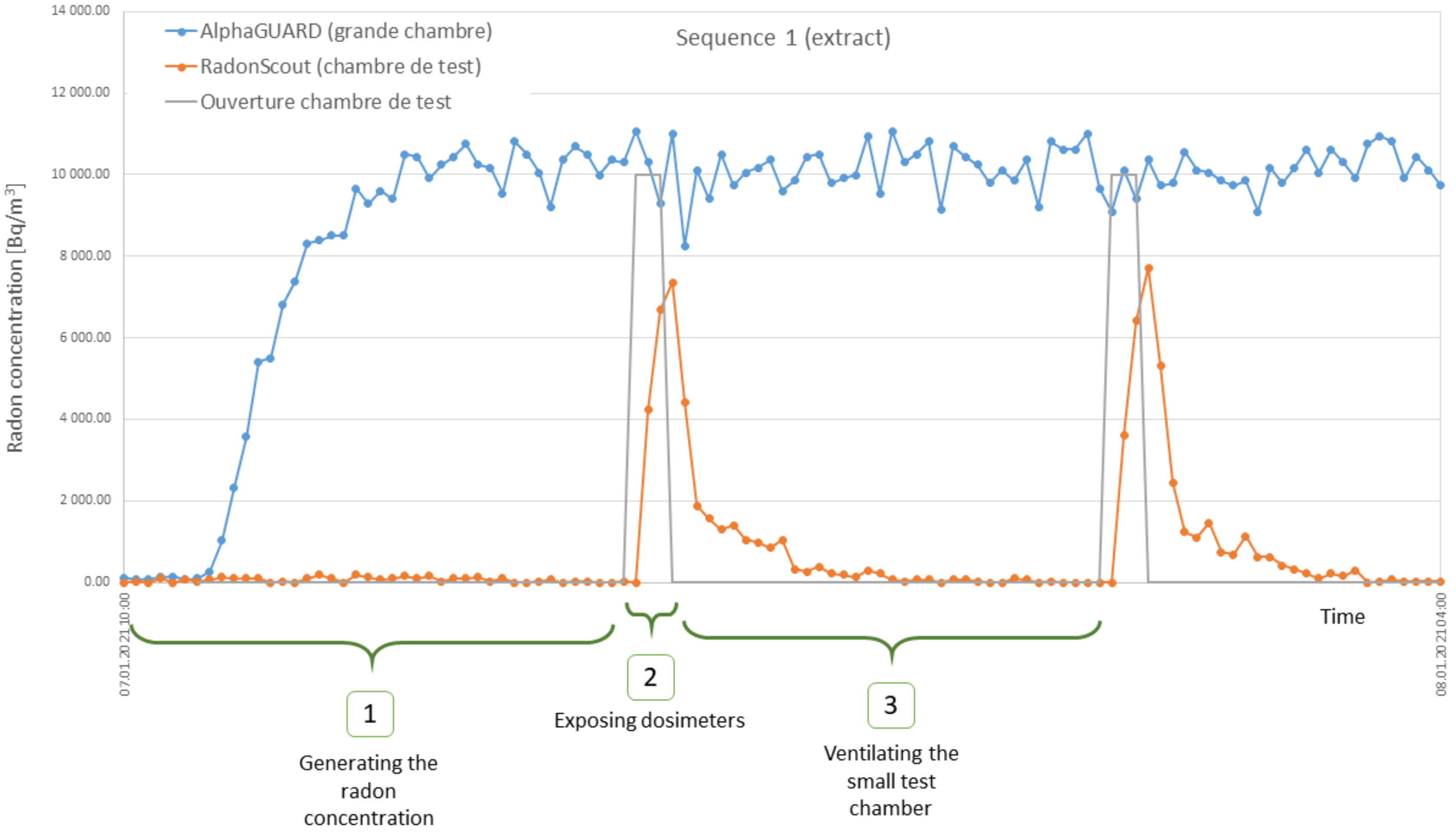


*Figure 1 Plot of radon concentration versus time for the first two exposure periods of measurement sequence 1.*

## 3.2. Parameters used

The table below shows the parameters used for each of the four measurement sequences. Two different reference concentrations were chosen, combined with two different durations of exposure. The number of successive exposures was determined in order to have the same total exposure at each sequence (160 kBq h/m$^3$), except for the first one which was half (80 kBq h/m$^3$). These values were determined in relation to the OIMRI requirement (Annex 9) which sets the minimum radon exposure that should be measurable at 50 kBq h/m$^3$.

| | **Sequence 1** | **Sequence 2** | **Sequence 3** | **Sequence 4** |
|---|---|---|---|---|
| **Reference exposition** | 80 kBq h/m$^3$ | 160 kBq h/m$^3$ | 160 kBq h/m$^3$ | 160 kBq h/m$^3$ |
| **Reference concentration** | 10 kBq/m$^3$ | 5 kBq/m$^3$ | 10 kBq/m$^3$ | 5 kBq/m$^3$ |
| **Duration of an exposure** | 30 min | 30 min | 15 min | 15 min |
| **Number of exposures** | 16 | 64 | 64 | 128 |
| **Total exposure time** | 3.7 days | 8 days | 14 days | 14.7 days |

# 4. Dosimeters tested

Different types of passive radon dosimeters were tested. For each type, 5 dosimeters were placed in the small chamber to be exposed, and 2 so-called "transport" dosimeters were not exposed, in order to measure the background noise during transport. The types of devices are the following:

- Radtrak2®, Radonova, Sweden
- Duotrak®, Radonova, Sweden
- Radout™ with Politrack® from Mi.am Srl, Italy, provided by Institut de radiophysique (IRA), Lausanne, Switzerland
- Radout™, Mi.am Srl, Italy
- Personal Radon Dosimeter 2032, Karlsruher Institut für Technology (KIT), Germany
- Personal Dosimeter Typ PD, Altrac, Germany

# 5. Measurement results

## 5.1. Presentation of results

For each sequence and for each type of dosimeter, the average of the values measured by the 5 dosimeters exposed in the measurement chamber and the average of the 2 transport dosimeters is calculated. The result given is the difference between the two, together with its measurement uncertainty. The deviation of the measured exposure value from the reference value and the standard deviation are also given.

Table 1-Table 2-Table 3-Table 4 show the results for each measurement sequence respectively. Figure 2 and figure 3 show each measurement result as a function of the relative deviation (x-axis) and standard deviation (y-axis). The type of symbol used in the first plot depends on the measurement sequence, while in the second plot the type of symbol depends on the type of dosimeter.

| Sequence 1 | **Chamber [kBqh/m³]** | **Transport [kBqh/m³]** | **Difference [kBqh/m³]** | **Deviation [%]** | **STD [%]** |
|---|---|---|---|---|---|
| **Altrac, Typ PD** | 119.07 | 37.48 | 82 ± 0 | 3% | 3% |
| **Radtrak2®** | 118.20 | 21.00 | 97 ± 14 | 22% | 4% |
| **Politrack®** | 109.34 | 14.15 | 95 ± 12 | 20% | 8% |
| **KIT, 2032** | 199.44 | 111.06 | 88 ± 15 | 11% | 3% |
| **Reference** | | | 79.4 ± 3.7 | 0% | |

*Table 1 : 10 kBq/m³ , 16 pulses of 30 min (expected total exposure = 80 kBqh/m³)*

| Sequence 2 | **Chamber [kBqh/m³]** | **Transport [kBqh/m³]** | **Difference [kBqh/m³]** | **Deviation [%]** | **STD [%]** |
|---|---|---|---|---|---|
| **Altrac, Typ PD** | 223 | 47 | 177 ± 0 | 14% | 2% |
| **Radtrak2®** | 281 | 38 | 243 ± 27 | 58% | 3% |
| **Politrack®** | 230 | 17 | 213 ± 34 | 38% | 10% |
| **KIT, 2032** | 178 | 28 | 150 ± 11 | -3% | 7% |
| **Duotrak®** | 195 | 34 | 195 ± 14 | 26% | 4% |
| **Radout™** | 175 | 23 | 152 ± 23 | -1% | 2% |
| **Reference** | | | 154.2 ± 7.1 | 0% | |

*Table 2 : 5 kBq/m³ , 64 pulses of 30 min (expected total exposure = 160 kBqh/m³)*

| Sequence 3 | **Chamber [kBqh/m³]** | **Transport [kBqh/m³]** | **Difference [kBqh/m³]** | **Deviation [%]** | **STD [%]** |
|---|---|---|---|---|---|
| **Altrac, Typ PD** | 242 | 72 | 170 ± 0 | 12% | 3% |
| **Radtrak2®** | 292 | 43 | 250 ± 45 | 65% | 6% |
| **Politrack®** | 188 | 14 | 174 ± 33 | 15% | 11% |
| **KIT, 2032** | 164 | 52 | 112 ± 11 | -26% | 13% |
| **Duotrak®** | 190 | 0 | 190 ± 18 | 26% | 8% |
| **Radout™** | 270 | 42 | 228 ± 28 | 51% | 5% |
| **Reference** | | | 151.2 ± 7 | 0% | |

*Table 3 : 10 kBq/m³ , 64 pulses of 15 min (expected total exposure = 160 kBqh/m³)*

| Sequence 4 | **Chamber [kBqh/m³]** | **Transport [kBqh/m³]** | **Difference [kBqh/m³]** | **Deviation [%]** | **STD [%]** |
|---|---|---|---|---|---|
| **Radtrak2®** | 316 | 61 | 256 ± 45 | 56% | 5% |
| **Politrack®** | 137 | 23 | 114 ± 32 | -30% | 6% |
| **KIT, 2032** | 182 | 45 | 138 ± 12 | -16% | 11% |
| **Duotrak®** | 248 | 0 | 248 ± 21 | 52% | 4% |
| **Radout™** | 279 | 32 | 248 ± 28 | 51% | 4% |
| **Reference** | | | 163.6 ± 7.5 | 0% | |

*Table 4 : 5 kBq/m³ , 128 pulses of 15 min (expected total exposure = 160 kBqh/m³)*

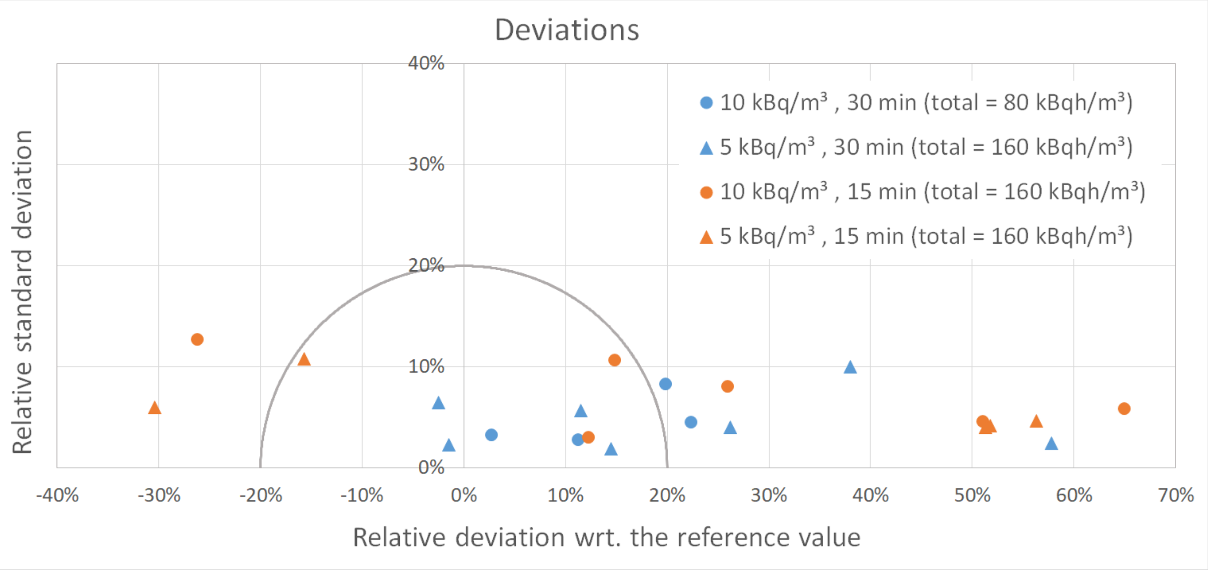


*Figure 2  Representation of the measurement results as a function of the deviation from the reference value (x) and the standard deviation (y). The type of symbol used depends on the measurement sequence.*

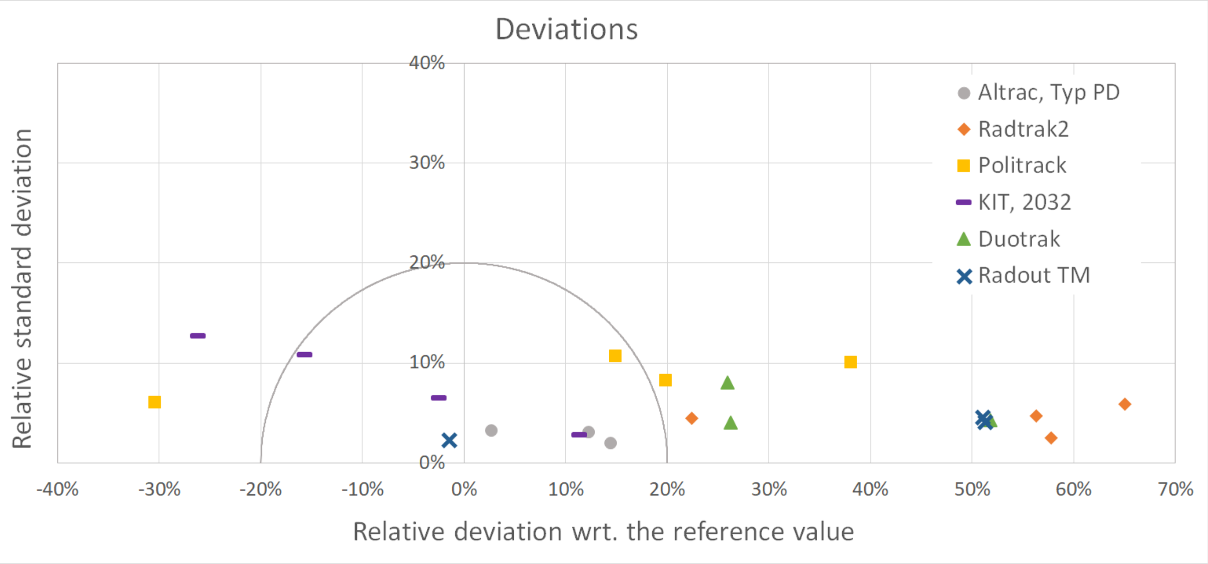


*Figure 3  Representation of the measurement results as a function of the deviation from the reference value (x) and the standard deviation (y). The type of symbol used depends on the type of dosimeter.*

## 5.2. Interpretation of the results

Overall, we observe that the values measured by the dosimeters tend to be higher than the predicted exposure. Furthermore, the deviation between the measured and predicted values becomes larger when the radon concentration is lower and/or when the exposure time interval is shorter.

In the case of 30-minute exposures to 10 kBq/m3 (sequence 1), the results are consistent with the reference value. The deviation of the measured values from the predicted value does not exceed 22%.

For sequences 2, 3 and 4, the dosimeters with the best results are those from KIT (less than 30% deviation), but the mean value is underestimated in all three cases. The PD dosimeters (Altrac) perform well on all sequences (deviation < 14% and always positive). It should be noted that no such dosimeter was used for the last sequence. The Duotrak (BABS) have 26% deviation on sequences 2 and 3, then rise to 52% on the last sequence. The Politrack dosimeters (IRA and Econs) have very variable deviations, between -30% and 50% deviation depending on the sequence. The Radtrak dosimeters (SUVA) have a deviation of more than 50% each time.

In the case of the KIT dosimeters, in the first sequence all dosimeters measured very high values, including the transport dosimeters. However, the difference between the dosimeters exposed in the test chamber and the transport dosimeters is consistent with the predicted value. It is therefore assumed that the dosimeters were exp

osed to an unusually high radon concentration during transport.

The fact that most dosimeters overestimated the exposure is difficult to explain. One hypothesis is that the air flow rate when ventilating the test chamber after exposure is lower than when stirring the air with the large chamber. In addition, the supply of low-radon air to the test chamber is through a thin pipe. It is therefore possible that the flow through the test chamber is not smooth and that the radon takes longer to be removed than in the case of an ideal flow. This could explain a longer exposure than ideally expected.

Another possible explanation is that the plastic holder, in which each dosimeter is packed for return to the laboratory, absorbs the radon, then releases it and exposes the dosimeter again [1].

## 6. Conclusion

This experiment showed that all types of dosimeters tested are able to respond to short exposures to very high concentrations of radon activity. However, the results overall overestimated the total radon exposure. This could be due to a non-ideal airflow when ventilating the test chamber after exposure to the high concentration. Or it could be due to the storage of dosimeters in plastic holders when they are sent to the laboratories. In order to better understand what is going on, one could consider measuring the radon concentration every minute in the test chamber, for example with a RadonMapper and a pump connecting it to the inside of the test chamber, as the latter is too small to hold a RadonMapper or an AlphaGUARD.

## 7. Références

[1] H. Möre and L. M. Hubbard, $^{222}$Rn Absorption In Plastic Holders For Alpha Track Detectors: A Source Of Error, Radiation Protection Dosimetry, Vol. 74, Nos. ½, pp. 85-91 (1997), Nuclear Technology Publishing