Retrospective radon progeny measurements for dwellings based on implanted ^{210}Po activities in glass objects

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Abstract

In the present work, we used the (CR–LR) difference technique for retrospective radon progeny measurements in 17 dwellings based on implanted ^{210}Po activities in glass objects. A total of 48 glass objects were examined, but only 19 objects gave results which were sufficiently reliable due to the sensitivity of the method. From these 19 data, an increase in the surface ^{210}Po activities in the glass objects with the age of the glass objects was noticeable as expected. The surface activities of ^{210}Po in the glass objects were then converted to the potential alpha energy concentration (PAEC) through a calibration curve. It was found that the PAEC for dwelling sites did not change significantly with the building age.

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1. Introduction

Methods for long-term passive radon measurements based on nuclear track detectors have been very well established and widely used. Surveys of existing techniques have been given by Nikolaev and Ilic (1999) and Nikezic and Yu (2004). Although these are classified as long-term measurement methods, the duration of measurements usually range between a few months and one year and are still too short compared to the average lifespan of a person. For risk estimation for a person, the total cumulative exposure is needed (Bochicchio et al., 2003; Nikezic and Yu, 2005). Thus, measurements performed for a few months might not be representative. As a possible solution to this problem, retrospective dosimetry based on measurements of ^{210}Po activity in objects was proposed. Retrospective radon dosimetry for home environments based on measurements of implanted ^{210}Po activities in glass objects have been introduced and practiced for many years (e.g., Lively and Ney, 1987; Samuelsson, 1988; Mahaffey et al., 1993; McLaughlin, 1998; Bochicchio et al., 2003).

The activity of ^{210}Po implanted in the surface of a glass object can be determined by using "(CR–LR) difference technique" (Falk et al., 1996). In this method, two SSNTDs, namely, LR 115 and CR-39 were fixed side by side on the examined glass object. Since LR 115 has an upper energy limit about $< 5\,\mathrm{MeV}$ for nominal removed layers, it will not detect alpha particles directly emitted by ^{210}Po (with an initial alpha energy 5.3 MeV). Therefore, effectively, LR 115 records alpha particles emitted by ^{210}Po only from the bulk glass material (through energy absorption by the glass material), and not those in the surface layer. In contrast to LR 115, the CR-39 detector effectively does not have an upper energy limit concerning the relevant alpha particles and will thus detect all alpha particles emitted by ^{210}Po in the surface layer as well as alpha particles from the bulk glass material. The difference between the two detector responses gives information on the implanted ^{210}Po in the surface layer.

2. Methodology

There were totally 17 dwelling sites selected for the present studies. The ages of the dwellings range from 5 to 30 years. At each site, one to three pieces of different glasses were examined. Those glass objects were present at the sites since the

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Table 1
The track densities registered on the CR-39 and LR 115 detectors in the glass objects

Code[a]	Age (y)	Track density on CR-39 (track cm^{-2})	Track density on LR 115 (track cm^{-2})
1A	22	609 ± 25	211 ± 15
1B	22	580 ± 24	233 ± 15
1C	22	585 ± 24	237 ± 15
1D	22	672 ± 26	254 ± 16
1E	22	692 ± 26	270 ± 16
1F	22	596 ± 24	265 ± 16
2A	12	544 ± 23	134 ± 12
2B	12	487 ± 22	109 ± 10
2C	12	418 ± 20	94 ± 10
3A	11	273 ± 17	71 ± 8
3B	11	340 ± 18	59 ± 8
4A	20	437 ± 21	163 ± 13
4B	20	335 ± 18	140 ± 12
5A	12	396 ± 20	156 ± 12
5B	12	360 ± 19	139 ± 12
5C	12	696 ± 26	232 ± 15
5D	12	1278 ± 36	650 ± 25
5E	12	1211 ± 35	544 ± 23
6A	30	541 ± 23	188 ± 14
6B	30	448 ± 21	250 ± 16
7A	30	754 ± 27	419 ± 20
7B	30	880 ± 30	415 ± 20
7C	30	777 ± 28	246 ± 16
7D	30	716 ± 27	286 ± 17
8A	21	616 ± 25	277 ± 17
8B	21	588 ± 24	274 ± 17
8C	21	638 ± 25	304 ± 17
8D	21	624 ± 25	354 ± 19
9A	6	628 ± 25	245 ± 16
9B	6	564 ± 24	259 ± 16
9C	6	642 ± 25	328 ± 18
9D	6	660 ± 26	333 ± 18
10A	8	596 ± 24	241 ± 16
10B	8	777 ± 28	223 ± 15
11A	10	715 ± 27	295 ± 17
11B	10	802 ± 28	364 ± 19
12A	14	924 ± 30	253 ± 16
12B	14	762 ± 28	232 ± 15
13A	5	424 ± 21	117 ± 11
13B	5	425 ± 21	108 ± 10
14A	5	344 ± 19	96 ± 10
14B	5	596 ± 24	140 ± 12
15A	13	603 ± 25	178 ± 13
15B	13	597 ± 24	164 ± 13
16	9	506 ± 22	120 ± 11
17A	6	499 ± 22	241 ± 16
17B	6	539 ± 23	185 ± 14

[a]Code: the numbers refer to the site numbers.

dwellings were built so they could be used to surrogate the age of the dwelling sites. Therefore, these glass objects are useful for retrospective determination of the radon concentrations of the dwellings.

The SSNTDs used in the present study were LR 115 and CR-39 detectors. For each examined glass object, two pieces of LR 115 detectors and two pieces of CR-39 detectors were attached to the glass surface for a period of time. The size of all the detectors was $3 \times 3 \, cm^2$. In the present study, the period of exposure of the SSNTDs on the glass objects ranged from 14 to 99 d.

The LR 115 detectors were purchased from DOSIRAD, France (LR 115 film, Type 2, non-strippable). The detectors consist of an active layer of red cellulose nitrate on top of a $100 \, \mu m$ clear polyester base substrate. After the desired exposure, the detectors were etched in a 2.5 N aqueous solution of NaOH maintained at $60 \, °C$ in a water bath. The temperature was kept constant with an accuracy of $\pm 1 \, °C$. The detectors were etched using a magnetic stirrer (Model no. SP72220-26, Barnstead/Thermolyne, Iowa, USA) to provide a faster etching (Yip et al., 2003a). After etching for 1 h, the detector was removed from the etchant, rinsed with de-ionized water and dried.
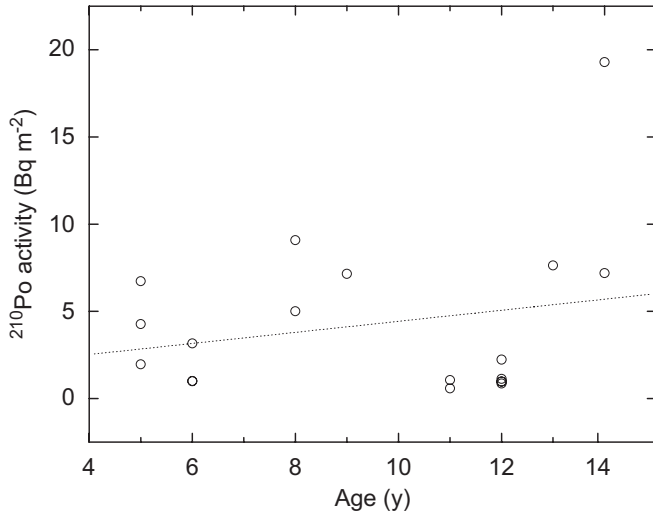
Fig. 1. Dependence of the surface ^{210}Po activities in the glass objects with the age of the glass objects.
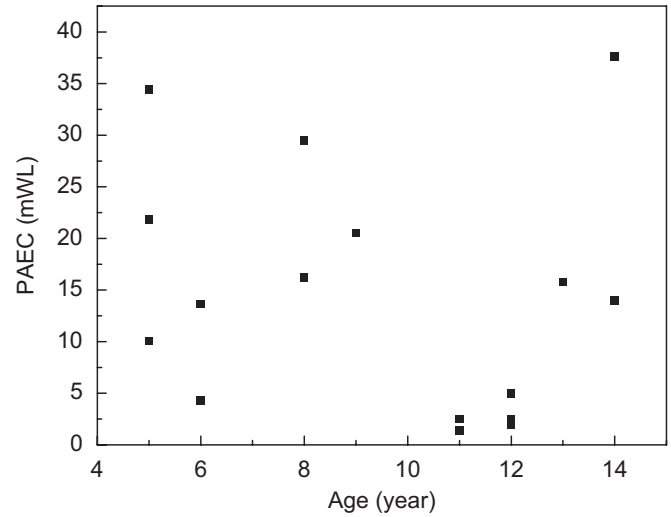

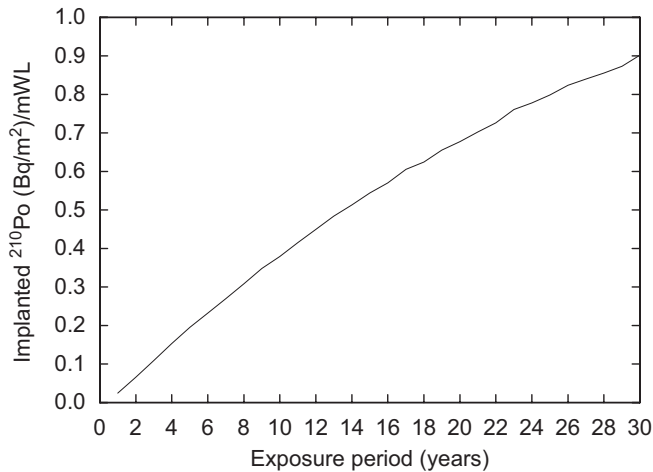Fig. 3. Relationship between the PAEC and the age of the glass objects.

Fig. 2. Calibration curve showing the relationship between the activity of implanted ^{210}Po (in Bq m^{-2}) per unit PAEC (in mWL) as a function of the exposure period of the glass object.

The removed active layer during chemical etching was significantly affected by the presence and amount of the stirring, and thus cannot be controlled easily (Yip et al., 2003a). Therefore, actual monitoring of the active layer thickness is necessary when using the LR 115 detector. In the present study, the thickness of the active layer of the LR 115 detector was obtained from the corresponding infrared transmittance (Ng et al., 2004). Different methods have been proposed to measure the active layer thickness of LR 115 detectors, e.g., energy dispersive X-ray fluorescence (EDXRF) (Yip et al., 2003b) or determination of the optical density using a color commercial document scanner (Yu and Ng, 2004). The infrared absorption method was adopted in the present work.

The infrared transmittance was measured using a Perkin Elmer Fourier transform infrared (FTIR) spectroscopy system (Model 16 PC FT-IR) for 10 cycles. The wave number range employed was between 1700 and 1500 cm^{-1}, with a resolution of 4 cm^{-1}. The scanned diameter was 9 mm so the scanned area was 0.64 cm^2. The infrared transmittance at the wave number at 1598 cm^{-1} (corresponding to the O–NO$_2$ bond) was measured and the relationship from Ng et al. (2004) was used to give the corresponding thickness of the active layer for LR 115 detector.

After chemical etching, the track densities were determined by manually counting the number of tracks on the detectors by using the optical microscope with 200 × magnification. Only the fully perforated tracks were counted. This visibility criterion has been introduced in order to minimize the level of subjectivity. The ratios of track densities were then calculated.

The CR-39 detectors were purchased from Page Mouldings (Pershore) Limited (Worcestershire, England) with the thickness of 1000 μm. After the exposure, The CR-39 detectors were etched in 6.25 N NaOH maintained at 70 °C by a water bath, which is a frequently used etching condition for CR-39 detectors for 6 h. The temperature was kept constant with an accuracy of ±1 °C. The CR-39 detectors were etched with no stirring, and the bulk etch rate was found to be relatively constant as 1.2 μm h^{-1} (Ho et al., 2003). Thus the removed layers of the CR-39 detectors were 7.2 μm.

The activity of ^{210}Po (Bq m^{-2}) is given by McLaughlin (1998) and Falk et al. (1996) as

$$A_{^{210}\text{Po}} = \frac{\text{CR} - B \times \text{LR}}{T \times K} \tag{1}$$

where CR is the net number of tracks per cm^2 on the CR-39 detector, LR the net number of tracks per cm^2 on the LR 115 detector, B the ratio of track densities recorded on a CR-39 detector to that on an LR 115 detector attached to a piece of unexposed glass, K the sensitivity factor for the CR-39 detector to surface ^{210}Po activity (in the unit tracks cm^{-2} per Bq h m^{-2}), and T the period of time (h) for which the CR-39 and LR 115 detectors are mounted on the glass surface.

In our previous work, we have modified the parameters B and K with some detailed considerations (Nikezic et al., 2006).

3. Results and discussion

The track densities on both the CR-39 detector and the LR 115 detector measured for the 48 glass objects in the 17 dwelling sites are listed in Table 1, together with the age of the glass objects.

We then made use of Eq. (1) to calculate the activities of ^{210}Po on the surface of glass objects. However, in some cases, the net values of $(CR - B \times LR)$ were smaller than the uncertainties in the $(CR - B \times LR)$ values. In these cases, the measurements were deemed not sufficiently sensitive to give meaningful data and should therefore be excluded from our data analyses. From the total 48 sets of data collected from the 17 dwelling sites selected for the present studies, only 19 sets of data produced net values of $(CR - B \times LR)$ which were larger than one standard deviation in $(CR - B \times LR)$. These data are shown in Fig. 1. From these 19 data, the best-fit line has a slope of 0.32. Despite the relatively small number of remaining samples and the scattering of the data, the increase of the surface ^{210}Po activities in the glass objects with the age of the glass objects is noticeable. The trend is expected since the surface activities of ^{210}Po in the glass objects should in general increase with the time of exposure of the glass objects.

The surface activities of ^{210}Po in the glass objects were then converted to the potential alpha energy concentration (PAEC) (in mWL) through a calibration curve calculated using the results from Nikezic and Yu (2006), which is shown in Fig. 2. Fig. 3 shows the relationship between the PAEC and the age of objects (which surrogates the age of the buildings). From Fig. 3, we can see that the PAEC for dwelling sites does not have an obvious change with the building age. However, the sample size is relatively small in the present work. A larger-scale survey will be carried out in future. Nevertheless, the present results are among the first results available in the literature obtained using the (CR–LR) difference technique for retrospective radon *progeny* measurements for dwellings based on implanted ^{210}Po activities in glass objects, and have demonstrated the feasibility of the technique.

Acknowledgment

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