METHODS OF RADON MEASUREMENT AND DEVICES

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1 Introduction

Many techniques and instruments are available for the measurement of radon and its decay products, with advantages and disadvantages for different situations. For many purposes we want to know long-term average exposures, but for diagnostic purposes a continuous measurement may be appropriate. We have to decide what technique to use on the basis of the feasibility and cost of the measurement as well as the accuracy and applicability of the technique.

2 The quantity to be measured

Radon is by far the largest contributor to the radiation exposure of populations, and most of that exposure takes place at home. For this reason, the great majority of radon measurements are aimed at assessing human exposures at home. There may also be significant exposures at work for many people. Traditionally occupations such as mining have been regarded as being the only ones in which there is significant radon exposure, but more recently it has been found that above-ground workplaces in high radon areas can have high enough radon levels to deliver radiation doses that exceed international limits.

The risk of lung cancer is related to the long-term exposure of people, so it is important that estimates of radon levels in homes and workplaces should be as close as possible to the long term average. Estimating long-term average is complicated by the fact that radon levels can vary widely from day to day, as shown in Figure 1.

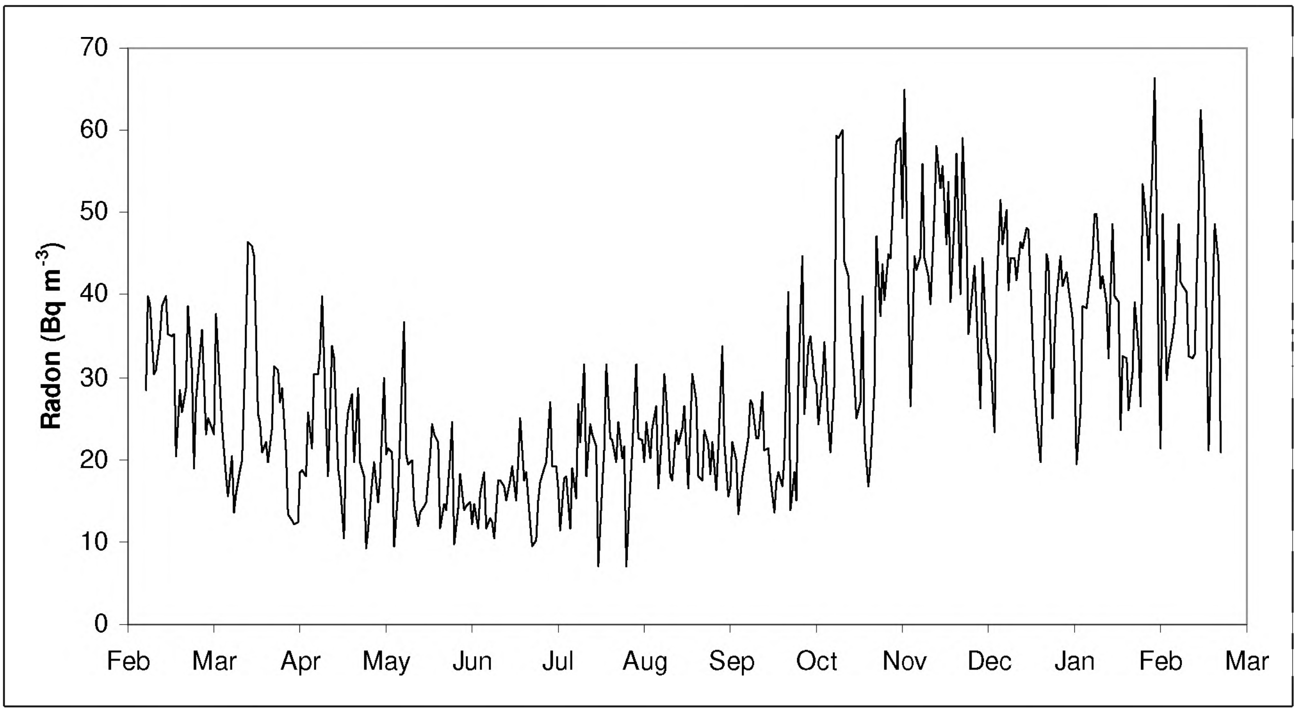

Figure 2. Variation in radon levels in a house in Germany over a year (Miles, 2001).

In some cases the variation can be even more extreme, as shown in Figure 2. It was eventually found that the highest radon levels in this building occurred when the wind blew in one particular direction. It is clear that in such cases measurement of radon over a day or a few days could very seriously underestimate the annual average exposure. For this reason it is generally advised that short-term measurements should not be used as the basis of advice on whether or not a building has a radon problem. On the other hand, after long-term measurements were used to discover that there was a radon problem in the building whose radon results are shown in Figure 2, continuous active measurements were very helpful in identifying the cause of the problem.

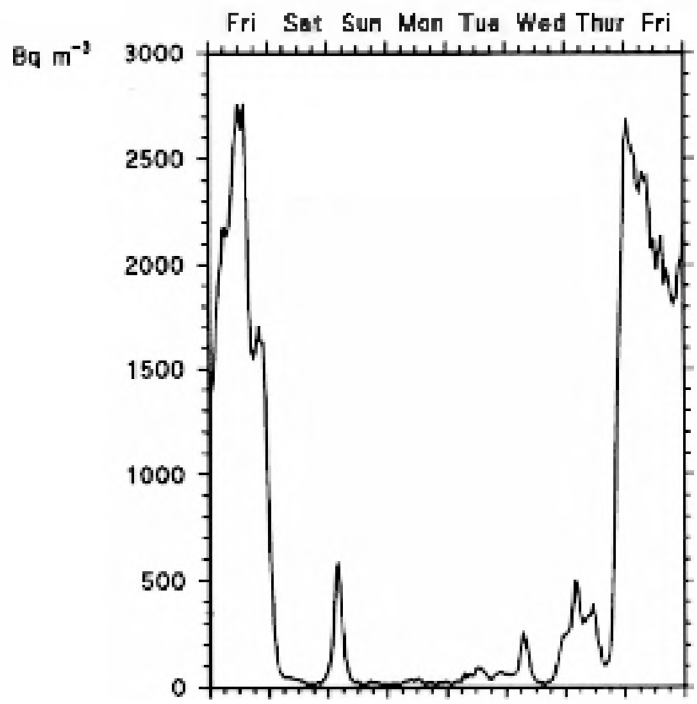

Figure 1. Variation in radon levels in a school classroom. The room has a suspended wooden floor, and ventilation under the floor has been increased in an attempt to reduce the radon level.

The duration of a measurement can vary over a wide range:

- Grab sample - seconds or minutes (for instance scintillation cells)
- Short-term average - days (for instance charcoal)
- Long-term average - weeks or months (for instance etched track, electret)
- Continuous - integration over a period of minutes or hours repeated indefinitely (for instance ionisation chambers)

Further details of measurement systems are given by OECD (1985) and Urban and Schmitz (1993). This paper will concentrate on radon gas measurement methods, with emphasis on etched track detectors.

3 Active measurement methods

3.1 Scintillation cells

Scintillation cells were developed by Lucas (1957). In this method, a hermetically sealed metal container is filled with the air of interest by evacuating and filling through a single vacuum connector, or by flushing with several cell volumes of air through the cell using two connectors.

The cell is a metal cylinder, with one end closed by a transparent window. It is usual to filter the air that enters the cell, thus preventing radon decay products from entering the cell. Once filled, radon decay products will be formed from the radon in the cell and after about three hours the short-lived decay products in the cell will be in secular equilibrium with the parent radon. There will then be three alpha particles emitted within the cell volume for every radon decay, one each from radon-222, polonium-218 and polonium-218. The internal surfaces of the cell are covered in a scintillator, usually ZnS:Ag, and the light pulses resulting from the interaction of alpha particles released in the cell volume and the scintillator are recorded by a photomultiplier tube and associated electronics. In order to make a continuously sampling instrument, air may be pumped through the chamber continuously or it may be allowed to diffuse in through a light-tight barrier.

3.2 Ionisation chambers

In an ionisation chamber an electrical field is established between two or more electrodes. Filtered air is either allowed to diffuse into the chamber, or it is pumped in, and the current caused by ionisation of the gas inside the chamber is detected. The ionisation measured is that caused by the decay of radon and its decay products. Either the total ionisation in the chamber is measured, or the pulses caused by individual alpha particles are counted separately. The latter technique has the advantage that it is possible to distinguish between the pulses caused by different decay products and by radon. If the associated electronics are set to reject counts from polonium-214 (the last of the short-lived decay products, with the highest energy alpha particle at 7.7 MeV), a fast response time can be obtained. The response time of the instrument also depends on the rate of replacement of air in the ionisation chamber.

In recent years commercial ionisation chambers have been widely adopted as secondary standards in radon calibration laboratories.

3.3 Electrostatic collection of decay products

Instruments employing this principle also have a chamber into which air diffuses or is pumped (Wicke and Porstendorfer, 1981). In this case a solid state detector is used to measure alpha particle energies. The detector, or a screen covering it, is raised to a high voltage to collect the charged radon decay products as they are formed. A proportion of the alpha particles emitted by the decay products will enter the solid state detector. As with ionisation chambers, it is possible to discriminate between the different decay products to improve the response time of the instrument. The proportion of decay products collected on the charged screen depends on the humidity of the air, so a desiccant is normally used to remove water vapour.

4 Passive measurement methods

4.1 Charcoal detectors

Activated charcoal has an affinity for many gases including radon. Radon adsorbed on charcoal will decay, and the decay products formed will be retained, allowing the adsorbed radon to be measured by gamma spectrometry of the emissions from lead-214 and bismuth-214 (George, 1984). An alternative to gamma spectrometry is liquid scintillation counting. For this, charcoal which has been exposed to radon is mixed with a liquid scintillation cocktail, in which the radon dissolves readily. The liquid is counted in standard liquid scintillation counting equipment.

The detectors usually comprise a bed of granulated activated charcoal held in position by a metal mesh in a metal canister with a removable lid. Before use the open canister is heated to remove any adsorbed gas and water vapour. The lid is then taped in place and the canister moved to the measurement location where the lid is removed, exposing the charcoal. At the end of the exposure period the lid is replaced and secured and the canister returned to the laboratory for analysis.

Charcoal detectors are not true integrators, as the radon absorbed at the start of an exposure will decay and partially desorb from the charcoal during the exposure. The desorption can be reduced if a diffusion barrier is placed between the surface of the charcoal bed and the atmosphere. Measurements are carried out over a period of 2-7 days, as the 3.82 day half life of radon, and its desorption from charcoal makes longer measurements meaningless. Charcoal detectors can make accurate measurements of radon concentrations. The principal drawback to their use in measuring radon concentrations in buildings is that the concentrations vary over longer time periods than a few days, so the result is not truly representative of the long-term average.

4.2 Electret ion chambers

Electrets are the electrostatic equivalent of permanent magnets, having a permanent surface charge resulting in a surface potential that may be several kV. In a commercial development of this technique (Kotrappa et al, 1992), a teflon electret is placed at the bottom of a conducting plastic chamber, known as an electret ion chamber (EIC). Radon diffuses into the chamber volume and the electret loses charge because of the general air ionisation produced by radon and it decay products in the chamber volume.

This detector acts as a true time-integrator of radon exposure, but has a limited dynamic range. Two electret elements of different thickness, and hence sensitivity, are available, and three different chamber sizes may be used. The devices are sensitive to gamma rays and a compensation for this has to be applied. Where the most precise measurements are called for, a correction for elevation should be made to compensate for the effect of atmospheric pressure variation.

In using these devices, it is essential that the instructions for preparing and reading out the electrets are followed closely. Dust on the charged surface of the electret and dropping the EIC on a hard surface can both partially discharge the electret, leading to an overestimate of radon exposure.

4.3 Etched track detectors

Etched track detectors rely on the use of a plastic material to record the tracks of alpha particles from radon and its decay products. This damage can be revealed later by etching the plastic in a solution of NaOH or KOH, sometimes supplemented with ethanol.

Three materials are generally used for radon measurements: LR-115 (a thin film of coloured cellulose nitrate on an inert backing), polycarbonate, and CR-39 (poly allyl diglycol carbonate, PADC). Polycarbonate detectors require electrochemical etching, in which an alternating voltage is applied across the detector during etching. A study of the performance of different laboratories in international intercomparisons of passive radon detectors (Miles and Sinnaeve, 1986) showed that LR-115, polycarbonate and CR-39 could all be used to make accurate measurements. Differences in accuracy between laboratories were caused by differences in quality control rather than the materials used.

Two types of etched track detector are commonly used, one (known as a closed detector) consisting of a track detector within a container which allows radon-222 to diffuse into it. The other (known as an open detector) consists of naked track-detecting material exposed to the ambient atmosphere. Closed detectors exclude radon decay products which are present in the ambient atmosphere, recording only those alpha particles generated by the radon entering the container and the decay products formed from it. This form of detector therefore provides a result which is related to the true average radon gas concentration during the time of exposure.

Open detectors, however, record alpha particles originating from both radon-222 and radon-220 and their decay products in the ambient atmosphere. Their response to radon and its decay products as a function of equilibrium factor, F, depends on the detector material used. Open detectors made from Kodak LR-115 have a sensitivity as a function of F which is intermediate between that of a true radon gas detector and a true Equilibrium Equivalent Radon (EER) detector, being closer to the true radon gas response. Bare CR-39 detectors have a response which depends strongly on F, and are not recommended.

Etched track detectors are generally used over periods from a month to a year. From the point of view of obtaining representative results from a building the duration should be as long as possible. However, practical considerations often limit the duration of the exposure, and some detector materials lose sensitivity with very long exposure in the air. Etched track detectors are produced and processed in many laboratories (Howarth and Miles, 2003).

5. Detector considerations for large-scale surveys

5.1 'Always on' or 'switchable' detectors?

Some types of etched track detector can have their ability to record radon exposure switched on or off, while others record exposure continuously. The second type can only be 'switched off' by placing it in a radon-free environment, such as sealing in a radon-proof bag.

Open etched track detectors only record when they have an air space in front of the sensitive element, so in effect they are 'switched off' at all other times, such as in transit. In this they are similar to charcoal detectors, which are 'switched on' by unsealing the lid, and to the type of electret that has a plunger to switch it on or off. There is also one type of closed etched track detector, made by Algade, which has a switch on the base which stops and starts its recording of radon exposure. In general, though, closed etched track detectors are 'always on'.

There are advantages and disadvantages to both 'always on' and 'switchable' detectors. Ones that can be switched off do not record exposures received in transit, so avoid that source of uncertainty. They can also be useful when it is necessary to estimate radon exposure during working hours only, as they can be switched off when staff are not present. But these detectors have significant disadvantages as well: they rely on householders and customers to read and obey instructions, and to prevent detectors being switched off when they should be recording. If instructions are not followed, either deliberately or unintentionally, use of such detectors may lead to radon concentrations being significantly underestimated.

'Always on' detectors have the disadvantage that they record exposures during transit unless they are dispatched in radon-proof bags. Using radon-proof bags carries the same disadvantage as switchable detectors: the laboratory relies on the householder to follow the instructions correctly, or radon concentrations may be underestimated. 'Always on' detectors have the advantage that if a householder forgets to open a package of detectors, or does not deploy them as instructed, they still record radon exposure in the location where they are left, which will almost always be in the house.

When detectors are used in postal surveys, the advantage of 'always on' detectors is overriding: transit exposures are generally very small and can be experimentally measured, but errors caused by householders not obeying instructions are almost impossible to estimate.

5.2 Response to radon-220

Open detectors or closed ones with a short diffusion half-time will respond to radon-220 (thoron) as well as radon-222. The Karsruhe KfK A closed detector, for instance, has been shown to be sensitive to radon-220 (Tokonami et al, 2001). Some detectors have been designed with two chambers, to allow both radon-222 and radon-220 to be assessed. In order to avoid uncertainty in what quantity is being measured, it is preferable that a detector should either measure both isotopes separately or measure only radon-222. In most cases a single closed detector is used, with a diffusion half-time of more than 10 minutes, avoiding any response to radon-220.

5.3. Avoidance of electrostatic effects

If detector holders are made of insulating plastic, electrostatic charges can build up on them or on the detecting element itself, attracting the radon decay products formed inside the holder. This can lead to uneven track distributions (see Figure 3), and errors in estimating the radon exposure of the detector.

To avoid these effects, the holder may be made of a conducting plastic, or the holder and the detecting element may be treated with an anti-static solution. An appropriate solution of a household detergent may be used for this purpose.

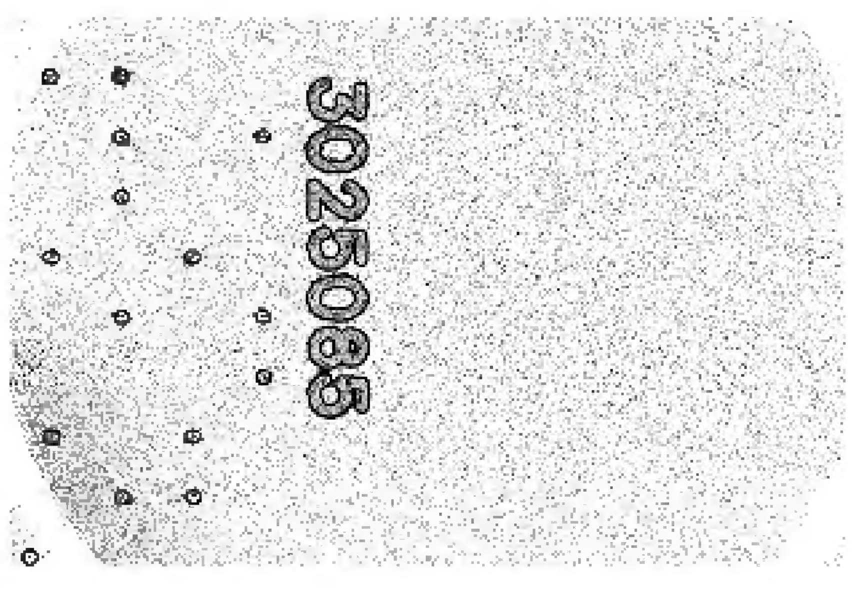

Figure 3. Etched track detector element showing uneven track distribution caused by electrostatic effects.

5.4 Quality assurance for passive radon detectors

The principle of operation of passive radon detectors is very simple, and it might be thought that there is little to go wrong with them. However, international intercomparisons have shown that even experienced laboratories can make errors. The quality measures required to maintain satisfactory standards of performance can be considered under two headings: quality control within the laboratory and external quality assessment such as testing schemes and intercomparisons. Both of these are essential if accurate results are to be obtained.

5.5 Quality control within the laboratory

The background track density and the sensitivity of different sheets of detector material need to be assessed. If the sheets of detector material are produced in batches, and it can be shown that there is no significant variation in sensitivity and background within a batch, it may be sufficient to assess these quantities for batches instead of for each sheet.

Checks on the etching process are essential. The sizes of etched tracks can vary depending on the temperature and concentration of the etchant, as well as the duration of etching. Standard elements should be included in each etch batch, so that checks can assess whether there is significant variation between etch batches.

Counting of etched tracks by automatic counters is necessary if there are large numbers of detectors to be counted. However, factors such as loss of focus or variation in illumination can lead to large errors in the assessment of exposures. Regular re-counting of standard elements, among the elements from detectors exposed in houses, can allow such errors to be detected and corrected.

5.6 External quality assurance

International intercomparisons provide an opportunity to assess the accuracy of passive radon detectors and compare the performance of different laboratories (Howarth and Miles, 2003). It is usually found that the accuracy of detectors is not as high as would be expected from a consideration of the sources of uncertainty such as the numbers of tracks counted, calibration uncertainty, etc.

In some countries there is a testing scheme for passive detectors, to ensure that they meet a specified standard of accuracy (for instance, Miles and Howarth, 2000).

A small proportion of detectors may be removed from the supply, given a standard exposure of radon by someone not involved in the production and processing of the detectors, and returned to be processed alongside detectors exposed in houses. Such blind tests allow the accuracy of the whole detector production and processing system to be assessed routinely.

5.7 Detectors need to be easily deliverable

For large scale surveys of radon in houses, it is important that detectors should be small enough so that they can be delivered by the normal post, and can easily be posted back to the laboratory without the householder having to take a parcel to a post office. For this reason, detectors should have a smallest dimension of no more than 3 cm.

6 Conclusions

The ideal detector for large scale surveys of radon in houses is a small, closed detector in a conducting holder which excludes radon-220, supported by rigorous quality assurance procedures.

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