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Interpreting short and medium exposure etched-track radon measurements to determine whether an action level could be exceeded

A.R. Denman*, R.G.M. Crockett, C.J. Groves-Kirkby, P.S. Phillips

School of Science and Technology, The University of Northampton, St George's Avenue, Northampton, NN2 6JD, UK

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ABSTRACT

Radon gas is naturally occurring, and can concentrate in the built environment. It is radioactive and high concentration levels within buildings, including homes, have been shown to increase the risk of lung cancer in the occupants. As a result, several methods have been developed to measure radon. The long-term average radon level determines the risk to occupants, but there is always pressure to complete measurements more quickly, particularly when buying and selling the home. For many years, the three-month exposure using etched-track detectors has been the de facto standard, but a decade ago, Phillips et al. (2003), in a DEFRA funded project, evaluated the use of 1-week and 1-month measurements. They found that the measurement methods were accurate, but the challenge lay in the wide variation in radon levels - with diurnal, seasonal, and other patterns due to climatic factors and room use. In the report on this work, and in subsequent papers, the group proposed methodologies for 1-week, 1-month and 3-month measurements and their interpretation. Other work, however, has suggested that 2-week exposures were preferable to 1-week ones. In practice, the radon remediation industry uses a range of exposure times, and further guidance is required to help interpret these results. This paper reviews the data from this study and a subsequent 4-year study of 4 houses, re-analysing the results and extending them to other exposures, particularly for 2-week and 2-month exposures, and provides comprehensive guidance for the use of etched-track detectors, the value and use of Seasonal Correction Factors (SCFs), the uncertainties in short and medium term exposures and the interpretation of results.

1. Introduction

Radon is a naturally occurring radioactive gas with a variable geographic distribution. It can migrate from underlying rock, entering and accumulating in buildings. There are several isotopes of radon; the most common is radon-222, with a half-life of 3.8 days. A second isotope, radon-220, often known as thoron, is also found in the environment with a concentration on average one tenth that of radon-222. Thoron has a half-life of 54.5 s, and makes a small contribution to the dose received by occupants. Radon has been shown to be the second most significant risk factor for lung cancer after tobacco smoking (AGIR, 2009), and as a result, many national governments have established Action Levels for both domestic housing and workplaces, above which action should be taken to reduce radon levels. The risk from radon is proportional to the lifetime cumulative exposure to radon (AGIR, 2009), and Action Levels have therefore been established in terms of annual average radon levels. In the United Kingdom (UK), the current Action Levels are 200 Bq m^{-3} for dwellings (O'Riordan, 1990) and 400 Bq m^{-3} for workplaces (IRR, 1999). For domestic housing, the Action Level relates to the annual average radon level, but the UK legislation for workplaces (IRR, 1999) specifies the Action Level as the winter maximum. However, there is a current proposal in the European Union (EU, 2014), based on the latest ICRP guidance (ICRP, 2014), to adopt an Action Level for the annual average radon level of 300 Bq m^{-3} for both houses and the workplace.

Radon levels in buildings are, however, widely variable with a diurnal variation – usually much higher at night – and with other variability related, for example, to the external weather and occupancy patterns. As a result, measurements with short term

* Corresponding author.
E-mail addresses: Tony.Denman@northampton.ac.uk (A.R. Denman), Robin.Crockett@Northampton.ac.uk (R.G.M. Crockett), Chris.Groves-Kirkby@Northampton.ac.uk (C.J. Groves-Kirkby), Paul.Phillips@Northampton.ac.uk (P.S. Phillips).

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exposures may not be a good estimate of the annual average radon level. Traditionally, in the UK and many other countries, etched-track radon dosimeters have been used with three-month exposures, and corresponding appropriate measurement protocols have been established. However, there is a demand for shorter term exposures, particularly for house sales. In a project funded by the UK Department for Environment Food & Rural Affairs (DEFRA), Phillips et al. (2003) evaluated the usefulness of 1-week and 1-month measurements compared to 3-months, and in subsequent work (Groves-Kirkby et al., 2006) suggested when such exposures could be used and proposed measurement protocols for each. Crockett et al. (2006) have subsequently shown that a lunar bi-weekly tidal cycle also influences radon variation, and recommended that a 2-week exposure is preferable to a 1-week one.

One of the most significant patterns of radon level variation in domestic housing is seasonal, with levels higher in winter than summer. Wrixon et al. (1988) therefore proposed the use of Seasonal Correction Factors (SCFs) which they developed from a large series of aggregated measurements in domestic properties, and for many years these have been used in the UK to correct term radon measurements in both domestic housing and the workplace. However, using the data from the original DEFRA study, Denman et al. (2007a) developed SCFs with lower seasonal variation, and commented on the applicability of using seasonal corrections. Recently, Miles et al. (2012, corrected 2014) have recommended the use of revised national SCFs for the UK, which are closely aligned to those of Denman et al. (2007a).

In addition to diurnal and seasonal variations, a number of studies have shown variations in the average radon level year-on-year, with coefficients of variation of 14% or above, as noted by Bochicchio et al. (2009), which are considered to be primarily due to meteorological variations, while some regions may have significantly different seasonal corrections due to underlying geology (Burke and Murphy, 2011).

Etched-track detectors are now used widely by industry for domestic radon level assessments, and, whilst 3-month exposures remain the preferred option, a wide variety of exposure times are used in practice, including 6-weeks, 2-months, and 4-months to suit clients. There is therefore a need for comprehensive guidance over a wider range of exposure periods. This paper reworks the analysis of the original data, and also compares that with the results from the analysis of an extended dataset for 4 houses over 4 years (Crockett et al., 2016), to extend the analysis to other exposure periods, to review and comment on the appropriateness of making seasonal corrections, and to provide appropriate guidance on the interpretation of results and use of seasonal corrections.

2. Methods

The measurement methodology has been described in detail by Phillips et al. (2003), and Groves-Kirkby et al. (2006). 1400 etched-track detectors from two different suppliers, 600 activated-charcoal detectors and 50 reusable electrets were used in a total of 37 dwellings around Northamptonshire, a county in the English Midlands of the UK.

During the year April 2002–March 2003, etched-track detectors were placed in each dwelling for up to four consecutive 3-month exposures and, simultaneously, for twelve consecutive 1-month exposures. In addition, 1-week measurements using simultaneously-exposed etched-track, activated-charcoal and electret detectors were conducted at approximately 1-month intervals. The 1-week exposures were managed to ensure that detector exposure was 168 ± 2 h, with 1-month exposures similarly managed to ensure exposure was 672 ± 2 h. Following this, measurements were continued for a further three years in a subset of 4 of these dwellings using electret detectors exposed for 1-week periods (the extended electret series).

Detectors were placed according to the UK National Radiological Protection Board (NRPB) protocol (Wrixon et al., 1988), which uses two detectors, one placed in the main living room (generally at ground level) and one in the main bedroom (usually on the first-floor). The protocol calculates a weighted average of the two readings, the bedroom being assigned a weighting of 0.55, the living room 0.45. The weights reflect the usual configuration of UK houses which have two floors, with bedrooms on the upper floor, the usual pattern of occupancy with bedrooms occupied at night, and the usual radon variation where levels are higher at night, and are lower in upper storeys. These weightings have been reviewed in occupancy studies by Briggs et al. (2003), and shown to be appropriate as an estimate of radon exposure of occupants.

For this paper, the etched-track data were re-analysed from the raw data upwards for the 32 houses (from the dataset of 37) for which annual radon levels can be calculated from 3-month measurements, to compare 1-week, 1-month, 3-month to annual results. The 1-week, 1-month, 3-month data were either (a) uncorrected or (b) seasonally corrected using the SCFs of Miles et al. (2012, corrected 2014) or (c) seasonally corrected using SCFs calculated from the 1-month etched-track data, using an updated version (Crockett et al., 2016) of the method described in Denman et al. (2007a).

The ratios between the 1-week, 1-month and 3-month values to annual values were calculated for the uncorrected and both seasonally corrected data-sets noted in the previous paragraph. These provide distributions for the ranges of values that would be expected if using track-etch detectors for these periods to estimate the annual concentrations. From these distributions a confidence interval around the Action Level was estimated according to the null hypothesis that the actual measurement is not systematically different to the Action level (i.e. ratio to Action Level is 1).

In this case, it is a straightforward confidence interval on the distribution of ratios with mode equal to 1, but the confidence interval itself is a range of values not significantly distinguishable from the Action Level, at the desired level of confidence. It is the values outside the interval, in the tails of the probability distribution, which give definitive results for practical use in the field:

i) values below the lower confidence limit represent annual radon concentrations below the Action Level (no remediation necessary);
ii) values above the upper confidence limit represent annual radon concentrations above the Action Level (remediation necessary);
iii) values in the equivocal range, i.e., between the confidence limits, have varying degrees of chance of indicating an annual level which is above the Action Level and therefore repeat measurements are indicated.

In this study, the standard 95% confidence interval was selected (i.e. lower and upper limits at cumulative probability 2.5% and 97.5% respectively), as this level is generally used in scientific literature. Table 1 shows this methodology applied to the domestic Action Level of 200 Bq m^{-3} for 1-week, 1-month and 3-month ratios and interpolated to other periods using non-linear least-squares regression.

3. Results

The probability histogram and distribution of the ratio of each one-week measurement to the corresponding annual average (for the same location) is shown in Fig. 1. There were 212 ratios of