Short and Long-Term Radon Measurements in Domestic Premises: Reporting Results in Terms of the HPA Action and Target Levels

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Abstract

In the UK, the Action Level for radon gas in domestic buildings has stood at 200 $Bq.m^{-3}$ for many years. Some years ago, our group made an extensive study of 7-day, 1-month and 3-month measurements in thirty-four un-remediated dwellings in a high-radon area over a full year. It was shown that one-week exposures were less reliable indicators of the long-term radon level, but that this variability was related to the changes in radon level, due to occupancy, weather changes and other influences, rather than measurement accuracy. Our analysis reported the confidence limits for each detection period, and recommended a protocol for reporting. Short-term measurements can be reliable indicators in low-radon areas or for new properties, but in high-radon areas, the use of three-month exposures is indicated.

In 2010 the UK Health Protection Agency (HPA) recommended the introduction of a lower Target Level of 100 $Bq.m^{-3}$, with the intention of encouraging those most at risk from radon to consider remediation of their homes, even if the long-term average is between 100 and 200 $Bq.m^{-3}$. We have reviewed the results of the previous survey in relation to the new Target Level, and report on the limits of confidence established for establishing whether a short-term result is over the target level, and proposes a reporting scheme.

Keywords: Radon, Track-Etch, Electret, Activated Charcoal, Comparative Assessment.

1. Introduction

Radon is a naturally-occurring radioactive noble gas, which has a variable distribution in the geological environment, as it is a decay product of uranium. It is found, in differing degrees, in a wide range of rocks and soils and in building materials incorporating or manufactured from these sources. Of the three naturally occurring isotopes of radon, ^{222}Rn, a direct product of ^{226}Ra in the ^{238}U decay-series, with a half-life of 3.8 days is the most significant. Radon has high mobility, enabling it to move out of underlying rocks and ground-water into caves, mines and the built environment. Although radon dissipates rapidly once in outdoor air, it can concentrate in the built environment. For UK dwellings, the mean radon level is around 20 $Bq{\cdot}m^{-3}$, compared to 4 $Bq{\cdot}m^{-3}$ in outside air (Wrixon *et al.*, 1998) but levels up to 17,000 $Bq{\cdot}m^{-3}$ have been found in residential properties (NRPB, 2004).

Inhalation of radon and its progeny ^{218}Po and ^{214}Po adsorbed onto atmospheric particulates is currently believed (Darby *et al.*, 2005; Krewski *et al.*, 2005) to increase the risk of cancer, and that the annual mortality from exposure to radon in buildings represents 9 % of all deaths from lung cancer, and 2 % of all cancer deaths, in Europe (Darby *et al.*, 2005). UK has established an Action level of 200 $Bq.m^{-3}$ for domestic housing (NRPB, 1990). Recently, Darby et al completed a meta-analysis of European epidemiological radon studies which concluded that the risk was linear at least down to 100 $Bq.m^{-3}$, and that therefore some radon-induced lung cancers appeared in occupants of houses below the current action level (Darby *et al.*, 2007). The total annual mortality from this type of cancer in the UK is between 30,000 and 35,000 (UK Dept. of Health), suggesting that about 1,100 deaths annually are caused by exposure to radon and its progeny (AGIR, 2010).

Indoor radon levels are subject to a number of variations. In addition to the natural daily cycle, other longer temporal and spatial cycles are evident, related to occupancy, weather conditions and seasonal factors, as indoor radon levels are generally higher in winter than summer. As the risk of lung cancer increases with increasing radon exposure – that is a higher average radon level, and length of time exposed at this level - the preferred measure of radon to determine this risk is the annual average radon level. The current UK recommendation to assess the annual radon level is the use of a three-month measurement in conjunction with the application of a Seasonal Correction Factor (HPA, 2011). In some circumstances, however, particularly during the house-sale process or when confirming that safety measures in new homes are

satisfactory, a measurement extending over three months is impractical or inappropriate. The question then arises as to whether short-term measurements, although probably less reliable, have sufficient value to be of use. To establish the value of short-term measurements, we undertook a year-long study of radon levels in homes in the County of Northamptonshire, funded by DEFRA, (Phillips *et al.,* 2004). A range of results from the survey have already been reported (Phillips *et al.,* 2004; Denman *et al.,* 2004a, 2004b; Denman *et al.,* 2005; Gillmore *et al.,* 2005). This included the value and reliability of short-term and long-term testing protocols (Groves-Kirkby *et al.,* 2006).

In view of the finding that some risk exists below 200 $Bq.m^{-3}$, HPA introduced the concept of a Target Level of 100 $Bq.m^{-3}$, with the aim of encouraging householders at greater risk to consider remediating their homes and reducing their radon risk, even if the long-term result fell below the Action Level, but above the target level (HPA, 2010).

This paper reviews data in the year-long DEFRA research project with a view to establishing the confidence limits for detecting this new target level, and establishing a suitable protocol for measurement and reporting.

2. Method

Track-etch detectors are used for 3 month measurements, while track-etch, electret and activated charcoal can be used for short term measurements of around one week. The DEFRA project compared one-week, one-month and three-month measurements in 37 homes to each other, and to the annual average radon level in the same house, over a one year period. The detectors used and the method of measurement was described in Groves-Kirkby *et al.* (2006). The method of analysis in Groves-Kirkby *et al.,* 2006, was extended to consider the Target Level of 100 Bq m^{-3}, in addition to the Action Level of 200 Bq m^{-3}.

3. Results

As indicated in Groves-Kirkby *et al.,* 2006, all measurement systems showed good linearity, and the short-term methods were consistent with each other. However, there was a considerable diurnal variability of radon levels at all measurement sites (see Figure 1); and significant week-on-week variability (see Figure 2).

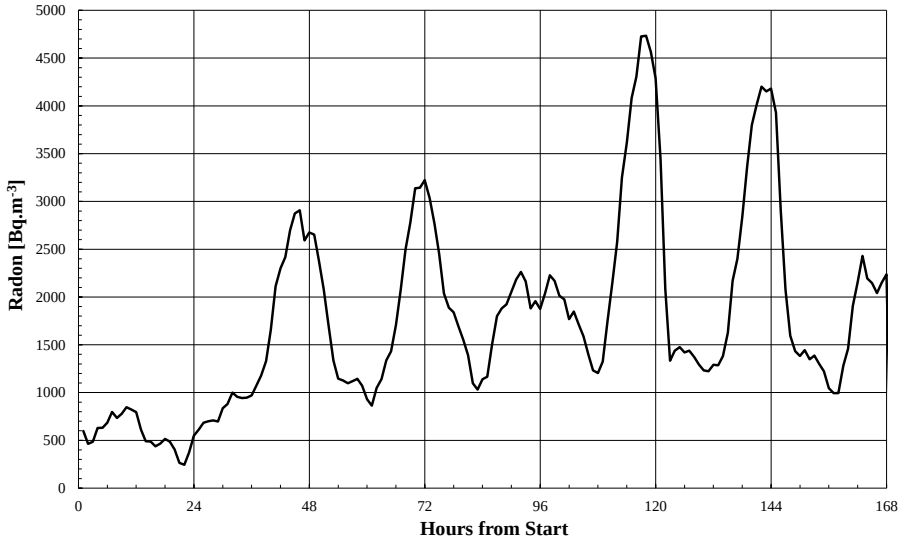

Figure 1 – typical radon levels in a test house, measured hourly by RAD-7

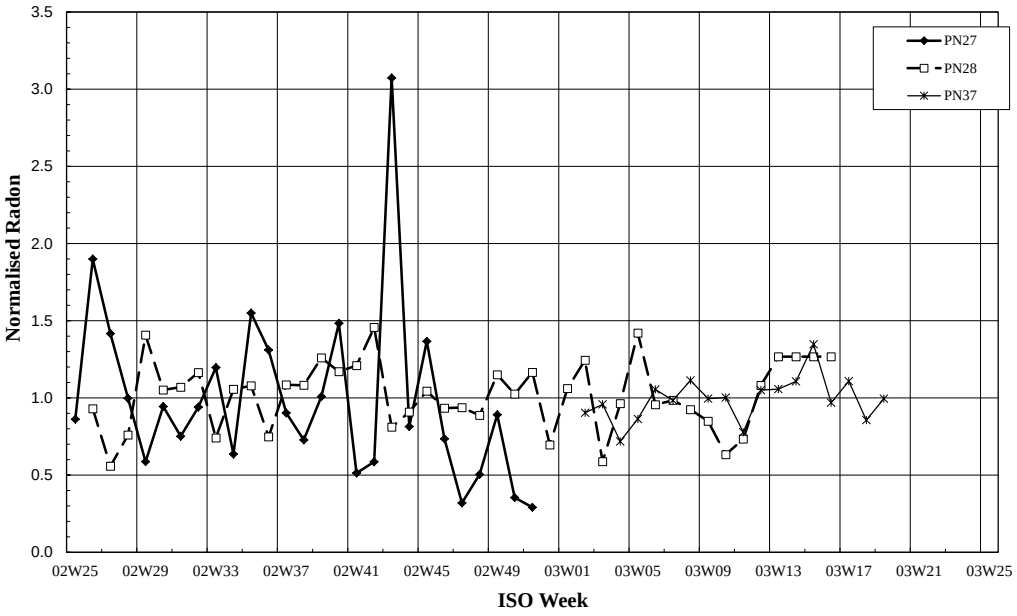

Figure 2 – weekly average radon levels in three test houses

Figure 3 shows the distribution of ratios of activated charcoal and electret one-week results to the corresponding three-month track-etch outcomes, together with log-normal fits to these data. Comparable plots were obtained from the other comparisons.

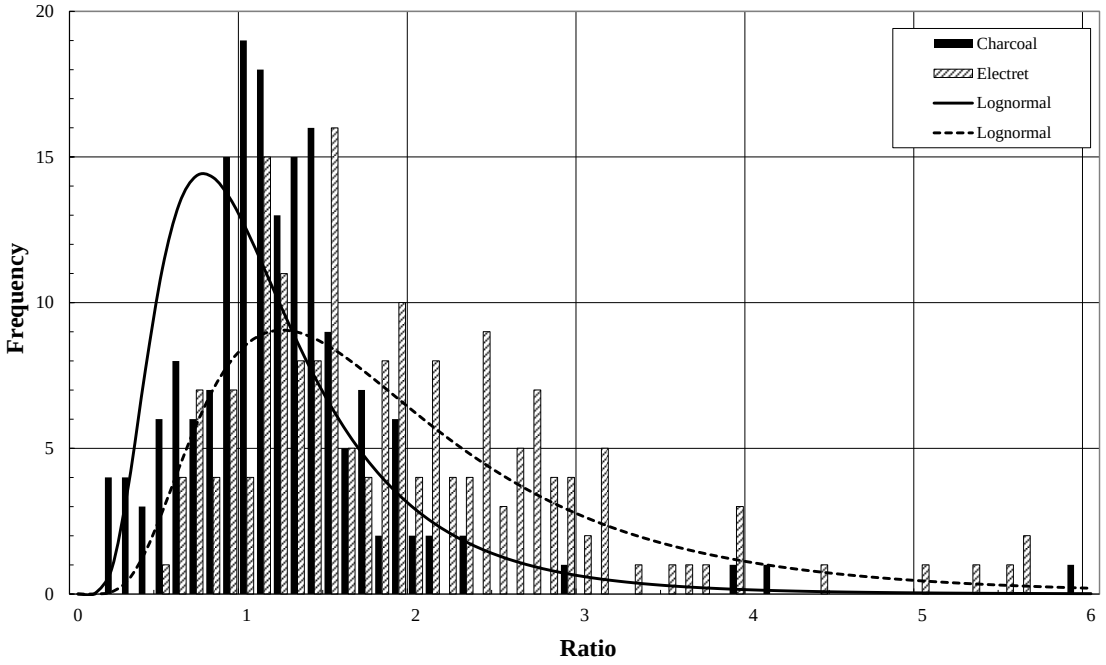

Figure 3 – comparison of one-week results to the three-month measurement in the same test house.

Using mean and standard deviation for each dataset, 95% confidence levels were derived representing the probability that one-week or one-month radon levels were within 5 %, 10 %, or 20 % of the three-month radon level, and the results are summarised in Table 1.

Required Accuracy	**Charcoal** *one-week*	**Electret** *one-week*	**Track-Etch** *one-week*	**Track-Etch** *one-month*
5 %	6.6 %	4.9 %	5.7 %	11.1 %
10 %	13.2 %	9.9 %	11.4 %	22.0 %
20 %	26.5 %	19.9 %	22.8 %	42.1 %

Table 1: Probabilities that 1-week and 1-month outcomes represent 3-month track-etch outcomes

Derived from this analysis, Table 2 indicates the threshold levels above and below which there can be 95 % confidence that the indicated annual level is respectively greater or less than the Action Level of 200 $Bq \cdot m^{-3}$, compared to the advice on the interpretation of results given by the National Radiological Protection Board (NRPB), now the Health Protection Agency (HPA).

95 % Confidence Level	**Charcoal** *one-week*	**Electret** *one-week*	**Track-Etch** *one-week*	**Track-Etch** *one-month*	**NRPB Advice** *three-month*
Lower [$Bq \cdot m^{-3}$]	68	59	75	109	130
Upper [$Bq \cdot m^{-3}$]	522	667	518	478	360

Table 2: 95 % Threshold confidence limits that a result indicates the annual average radon level is above or below the Action Level of 200 $Bq.m^{-3}$

Extending this analysis, Table 3 indicates the threshold levels above and below which there can be 95 % confidence that the indicated annual level is respectively greater or less than the newly introduced Target Level of 100 $Bq \cdot m^{-3}$.

95 % Confidence Level	**Charcoal** *one-week*	**Electret** *one-week*	**Track-Etch** *one-week*	**Track-Etch** *one-month*
Lower [$Bq \cdot m^{-3}$]	34	30	38	55
Upper [$Bq \cdot m^{-3}$]	262	333	260	240

Table 3: 95 % Threshold confidence limits that a result indicates the annual average radon level is above or below the Target Level of 100 $Bq.m^{-3}$

4. Discussion

All detector systems exhibit good linearity with mean radon level during the exposure and all appear intrinsically suitable for use in Domestic and Workplace applications. Short-Term (i.e. one-week) exposures are possible but the results have a reduced accuracy in estimating the annual average radon level (ie larger equivocal range) because of the inherent variability of radon levels in the built environment. Thus a greater proportion of results will be equivocal than if one-month or three-month exposures were used, necessitating more repeat exposures.

The introduction by the HPA of the concept of the Target Level in the UK now gives five potential outcomes of any radon measurement, as shown in Table 4. It should be noted that only the first and last outcome give a definitive result, the middle three outcomes give rise to consideration of the value of re-testing, or possible remediation.

Measurement Outcomes
Below both levels
Below Action Level, but may be above Target Level
May be above Action Level, may be above Target Level
Above Target Level, and may be above Action Level
Above Action Level, (and Target Level)

Table 4: Measurement outcomes from radon tests

Surveys have shown that the annual average radon levels in any locality follow a log-normal distribution, as in Figure 4. The majority of houses will have low radon levels, but some houses can have very high levels. This distribution has a major impact on the value of using short-term measurements to determine whether a house has raised radon levels.

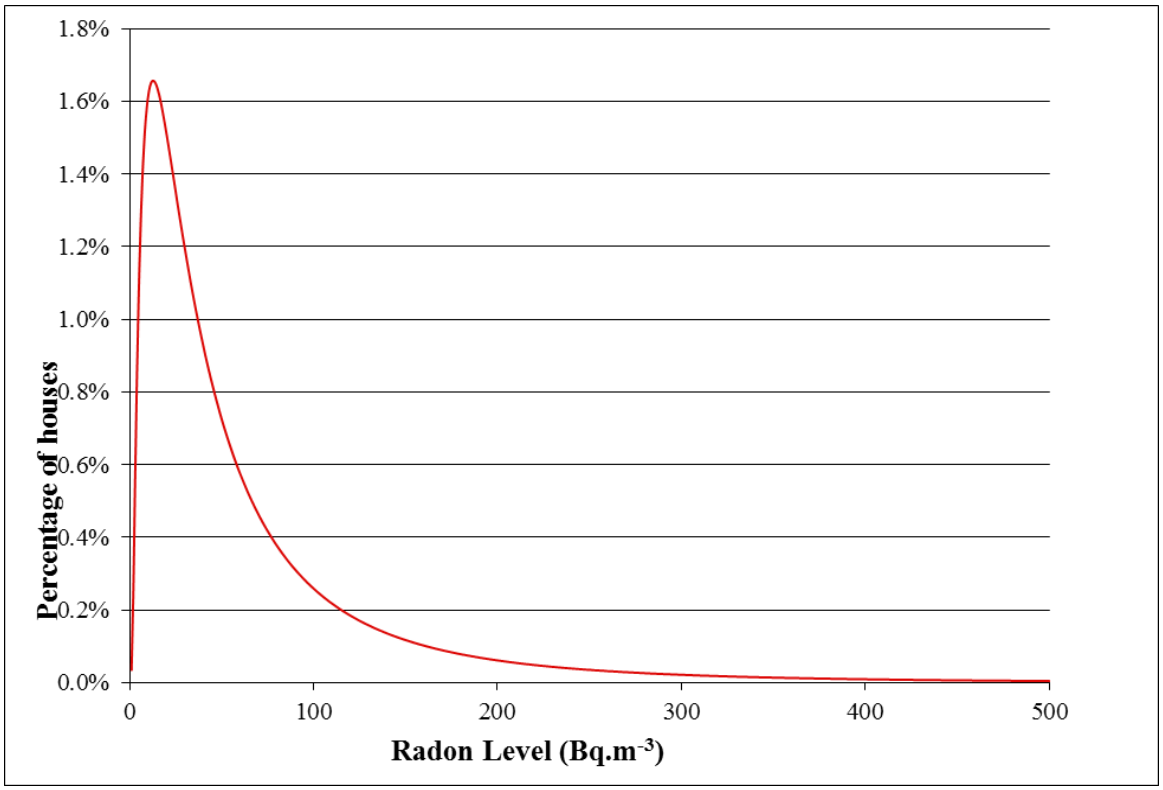

Figure 4 – Distribution of Annual Average Radon Levels - Northamptonshire

Using the known percentage of homes in the counties of Cornwall, Northamptonshire and Buckinghamshire (areas of the UK with high, moderate and low numbers respectively of properties with radon levels above the Action Level (Green *et al.*, 2002)), calculations were made of the proportion of measurements which are likely to fall in each of the categories in Table 4. Results are summarised in Table 5, again using the 95% confidence limit for each level, and shown graphically in Figure 5.

Locality % below Target Level: % between Target and Action Levels: % above Action Level	Measurement Outcome	1-Week Track-Etch	1-Month Track-Etch	3-Month Track-Etch
High - Cornwall	Below both	16.6%	27.8%	28.4%
51.2%: 25.48%: 23.3 %	Below Action, may be above Target	22.7%	26.6%	27.0%
	May be above both	44.6%	29.6%	17.8%
	Above Target, may be above Action	11.6%	10.7%	17.4%
	Above both	4.6%	5.4%	9.5%
Medium - Northamptonshire	Below both	47.2%	60.9%	61.5%
80%: 13%:7%	Below Action, may be above Target	24.2%	20.8%	21.1%
	May be above both	24.3%	13.3%	9.1%
	Above Target, may be above Action	3.4%	3.7%	6.8%
	Above both	0.9%	1.4%	2.8%
Low - Buckinghamshire	Below both	59.9%	75.8%	76.5%
92.4%: 6.4%: 1.2%	Below Action, may be above Target	26.0%	17.7%	17.6%
	May be above both	13.6%	5.8%	4.3%
	Above Target, may be above Action	0.5%	0.5%	1.5%
	Above both	0.03%	0.2%	0.2%

Table 5: Target and Action Level thresholds - statistics in high, medium and low radon areas

From Table 5, it is evident that one-week measurements are noticeably more useful in areas with a low and medium percentage of properties with radon levels in excess of the Action Level, where the majority of results will be reliable indicators that annual average radon levels are below both the Target and Action Levels. In an area, such as Cornwall, with a high proportion of properties with radon concentrations in excess of the Action Level, the majority of one-week results will be in the one of three equivocal outcomes,

with only around 5 % of results being definitely abnormal. The improved accuracy offered by three-month determinations in this situation is a significant benefit, but even so the majority of results will be in the three central equivocal outcomes. One-week exposures would also be suitable for newly-constructed houses with radon precautions where radon levels are expected to be low.

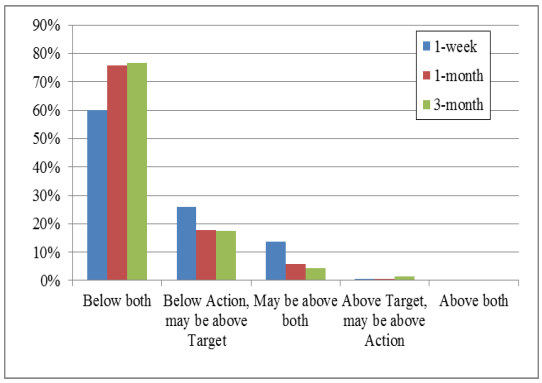

Figure 5(a) – Buckinghamshire (Low radon)

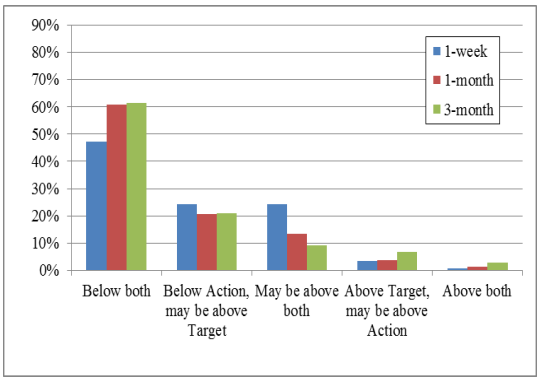

Figure 5(b) – Northamptonshire (Medium Radon)

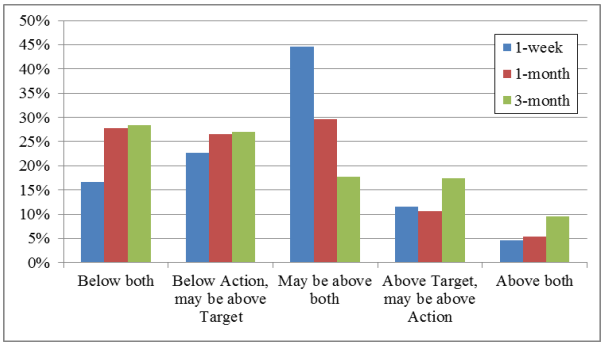

Figure 5(c) – Cornwall (High radon)

5. Conclusions

Although track-etch, charcoal and electret devices are suitable in principle for one-week measurements, natural radon variability causes one-week measurements to have a greater variability as a surrogate for the annual average radon level, which is used to determine the risks to occupants. This variability has been shown to result in a significant percentage of results from one-week, one-month and three-month measurements to be indeterminate, especially now that HPA have introduced the concept of a Target Level, in addition to the Action Level. The general public may find it confusing that such a significant number of tests will not result in a clear-cut result, but will require repeat measurements, or decisions on the significance of an equivocal result.

One-week exposures can be of value to assess radon levels in low radon areas or for new properties, but in high-radon areas, the use of three-month exposures is indicated. This analysis also established confidence limits for radon measurements. We recommend that three-month exposures are required in high radon areas, but in low radon areas, and for new homes, one-week measurements can be used.

6. Acknowledgements

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