

# Reducing the Health Risks from Radon in the UK Overground Workplace

A.R .Denman\*

School of Health, The University of Northampton, Northampton, NN2 7AL, UK.

**Abstract.** In response to the potential health risk from radon in workplaces in the United Kingdom (UK), the Ionising Radiations Regulations 1999 include the protection of workers from excessive radon levels. Under the Management of Health and Safety at Work Regulations 1999, employers are required to make risk assessments for potential hazards in the workplace. This is taken to apply to the risk from radon in premises in areas where over 1% of domestic housing properties have average annual radon levels over the Action Level. Whilst the UK Action Level in domestic housing has been set at  $200 \text{ Bq}\cdot\text{m}^{-3}$ , the workplace limit is  $400 \text{ Bq}\cdot\text{m}^{-3}$ . The Regulations require that this limit be compared to a 24-hour winter maximum, while in domestic properties the annual average radon level is compared to the Action Level. This paper discusses the application of the Regulations in the UK to ensure compliance and reduce risk from radon in the workplace, include use of short-term measurements, and the consideration of seasonal variation. Reduction of radon levels can be achieved by methods similar to those in domestic properties, but, in large buildings, several sump/pump systems may be required. Case studies have shown that the sump/pump system preferentially reduces radon levels at night, when workers are not usually present. Thus to achieve a significant health benefit the average radon level should be reduced below  $325 \text{ Bq}\cdot\text{m}^{-3}$ .

**KEYWORDS:** *Radon, Workplace, Regulations, Seasonal Correction, Remediation*

## 1 Introduction

The health risks from radon gas were first identified in mines [1] and, initially, safety regulations concentrated on ensuring that underground workers were protected against radon. However, over the last 20 years or so, it has been established that the radon levels in United Kingdom (UK) domestic housing are sufficient to be a health risk to occupants [2], an Action Level has been established and radon Affected Areas, where study indicates that over 1% of domestic housing properties have radon levels over the Action Level [3], have been defined. Many studies have shown that radon levels in the over-ground workplace are similar to those in nearby domestic housing [4], and that workers within the buildings can receive significant doses, which can be significantly greater than those received from occupational exposure to other radiation sources, such as the medical uses of X-rays [5,6]. Recent estimates suggest that radon in the workplace is responsible for around 90 to 280 lung cancer deaths in the UK [7].

In a response to the identification of this health risk from radon in United Kingdom (UK) workplaces, the Ionising Radiations Regulations [8] include measures to ensure the protection of workers from excessive radon. As with other UK Health and Safety Regulations, premises are inspected and conformity with the regulations is enforced by the Health and Safety Executive. Under other Health and Safety Regulations [9], employers are required to make risk assessments for any potential hazards in the workplace, and the Health & Safety Executive's interpretation is that this applies to the risk from radon in any workplace premises in all areas that the National Radiological Protection Board (NRPB) (now the Radiation Protection Division of the Health Protection Agency) have declared as Radon Affected Areas. For radon, as well as other uses of radioactivity and ionising radiations, the Regulations require the employer to take the advice of an independent and accredited qualified scientific expert, known as the Radiation Protection Adviser (RPA). In the case of radon in the workplace, the employer may require to use the services of an RPA, where it is difficult to reduce radon levels, or to provide other expert advice.

Whilst the UK Action Level in domestic housing has been set at  $200 \text{ Bq}\cdot\text{m}^{-3}$ , the workplace limit is  $400 \text{ Bq}\cdot\text{m}^{-3}$ . This difference reflects the fact that radon levels are usually higher at night. The

---

\* Presenting Author, E-mail: tony.denman@northampton.ac.uk

application of these limits, however, diverge, since in the home, two measurements are made, one in the living room and one in the bedroom, and a weighted average is taken, while a single measurement in occupied rooms is used in the workplace. More significantly, the Ionising Radiations Regulations state that the workplace limit is averaged over any 24-hour period. As radon levels are normally highest in winter, this is interpreted as the average radon level at the winter maximum, and measurements done at other times of year are corrected, using pre-determined seasonal correction factors, to a winter reading. In contrast, in the domestic situation the measurements are averaged and then corrected to an average for the whole year, which is then compared to the Action Level.

## **2 Measurement Protocols**

In a large building many radon detectors may be required to ensure an adequate survey. Detectors should be placed in alternate occupied rooms on the lowest level. This is because radon levels can be raised in a single room, particularly if it is a small office where the door is kept shut routinely; but in that circumstance adjacent rooms are likely to have moderately elevated radon levels, which would suggest a more detailed survey to find the room where radon entered the building. In general, radon levels are lower in the upper floors of buildings, on average 67% of that on the floor below. For this reason, it is not usually necessary to measure radon levels in upper floors. However, in some buildings, a large stair-well can create a “stack effect” carrying radon directly to the uppermost floor. In one four-storey office building in Northampton, UK, levels of around 400 Bq·m<sup>-3</sup> were found on the top floor, and 2,000 Bq·m<sup>-3</sup> in the cellar, but intervening floors had radon levels around 200 to 300 Bq·m<sup>-3</sup>.

Where possible, measurements should be made in the Autumn, Winter or Spring, as radon levels are generally higher at these times of year. The building should be in normal use, with any heating and ventilation operating normally. A building with no heating will give a false negative result. As noted below, unoccupied school-rooms can give anomalously raised radon results in the summer.

### **2.1 Measurement Period**

Standard UK practice is to measure radon using a Track Etch Detector exposed over a three-month period. This length of exposure is more than sufficient to get an accurate measurement of radon levels, as demonstrated by Phillips et al. [10] who studied the use of charcoal canisters and electrets, as well as track etch detectors, with a minimum exposure period of a week. However, this work also concluded that shorter exposure periods result in wider variations in the result due to the significant changes in radon level due to the prevailing weather conditions.

Charcoal canisters and electrets are specifically designed for short-term exposures of around a week, but it should be noted that Electrets also respond to other ionising radiation, and so are not suitable to workplaces where X-Rays and radioactive isotopes are used. Track-etch detectors are generally used for 3-month and 1-month exposures, but can be accurate down to seven-day exposures.

However, the wide variations in actual radon levels make seven-day measurements only suitable for initial screening measurements in low radon areas, or as a rapid survey of buildings with radon mitigation in place. Whilst three-month measurements may be the UK norm, one-month measurements are a reasonable compromise between the estimation of a long-term average and speed.

As the regulations specify a twenty-four hour period, the use of direct reading radon meters is not indicated for the initial assessment to determine whether a workplace has sufficient radon to be covered by the regulations, but these can be useful in assessing occupants’ doses and for attempting to find the ingress of radon in complicated situations.

As radon levels vary significantly in the short term, and diurnally, any measurement will show some variability from the long-term average. Phillips et al. [10] considered this and published equivocal ranges for domestic exposures [11], which can be used to determine uncertainty in workplace measurements.

## 2.2 Measurement Uncertainty

Phillips et al. [10] provide the most comprehensive assessment of the effect of short-term variations in radon levels on the accuracy of one-week/one-month/three-month measurements. Although the report refers to domestic houses, it is applicable to the workplace, particularly as there is virtually no workplace data available. Due to the short-term variability, there is a range where the uncertainties of the measurement result mean that the actual long-term average could be above the Action Level, and therefore a repeat measurement is indicated. The method of Phillips et al. applies the uncertainties to the uncorrected initial result and converting this method to the workplace using the winter maximum and the workplace limit gives the values in Table 1.

**Table 1:** Level below which an uncorrected result in the workplace definitely indicates that the winter maximum will be below the UK workplace Action Level of  $400 \text{ Bq}\cdot\text{m}^{-3}$

Period of Measurement	Level Below which Result is normal ( $\text{Bq m}^{-3}$ )
1 week	150
1 month	218
3 months	224

However, the specific wording in the regulations implies that should the average radon level ever exceed  $400 \text{ Bq}\cdot\text{m}^{-3}$  then the Ionising Radiations Regulations apply. Therefore in the workplace situation, a reading of above  $400 \text{ Bq}\cdot\text{m}^{-3}$ , whenever measured, must always indicate that the Ionising Radiations Regulations apply and action must be taken.

## 2.3 Seasonal Correction Factors

The Radiological Protection Division of the Health Protection Agency (formerly the NRPB) have published sets of seasonal correction factors for both domestic properties and workplaces. They have, however, confirmed that the base data-sets for these two sets of correction factors are identical, being both determined from the same set of measurements in domestic properties and the correction factors themselves only differ because the domestic factors estimate the annual average, while the workplace factors aim to calculate the winter maximum. There is therefore no published data deriving generalized workplace seasonal correction factors from workplace seasonal radon variations, and only very limited published data on seasonal variation in the workplace. There are certainly significant exceptions where the standard domestic seasonal correction factor does not apply, which are considered below. But there is no inherent reason to think that otherwise the variations in the home and the workplace should be significantly different, although differing occupancy patterns and building size might make subtle changes to seasonal variation.

However, Denman et al. [12] have recently shown that domestic seasonal correction factors vary with radon level and that there is less seasonal variation at lower radon levels. Their set of thirty-seven houses had half the seasonal variation of the NRPB data set and as the average radon levels were grouped around the domestic UK action level of  $200 \text{ Bq}\cdot\text{m}^{-3}$ , this data set is more applicable to the levels around workplace action level where it is critical to establish whether the workplace is or is not above  $400 \text{ Bq m}^{-3}$ . Table 2 gives a list of the seasonal correction factors from this data set to give an annual average and Table 3 gives the factors to give a winter maximum. Where the exposure period is not an integral number of months, the seasonal correction factor for the number of months giving an exposure time closest to the actual exposure should be used.

**Table 2:** Seasonal Correction Factors to give annual average, for a range of exposure periods

Start Month	1 month	2 month	3 month	4 month	5 month	6 month
January	0.79	0.82	0.87	0.93	0.99	1.04
February	0.86	0.92	0.99	1.06	1.12	1.15
March	0.98	1.06	1.14	1.20	1.23	1.22
April	1.15	1.24	1.30	1.32	1.29	1.23
May	1.34	1.38	1.38	1.33	1.25	1.17
June	1.43	1.40	1.32	1.23	1.14	1.06
July	1.37	1.28	1.18	1.09	1.01	0.96
August	1.20	1.10	1.01	0.95	0.91	0.88
September	1.02	0.94	0.89	0.85	0.84	0.84
October	0.88	0.84	0.81	0.81	0.82	0.84
November	0.80	0.78	0.78	0.80	0.83	0.87
December	0.77	0.78	0.80	0.84	0.89	0.94

**Table 3:** Seasonal Correction Factors to give winter maximum, for a range of exposure periods

Start Month	1 month	2 month	3 month	4 month	5 month	6 month
January	1.03	1.07	1.13	1.21	1.29	1.36
February	1.12	1.20	1.28	1.38	1.45	1.50
March	1.28	1.38	1.48	1.56	1.60	1.59
April	1.50	1.61	1.69	1.71	1.68	1.61
May	1.74	1.80	1.79	1.73	1.63	1.52
June	1.87	1.82	1.73	1.60	1.48	1.39
July	1.79	1.66	1.54	1.41	1.32	1.25
August	1.56	1.43	1.32	1.24	1.18	1.15
September	1.32	1.23	1.16	1.11	1.09	1.10
October	1.14	1.09	1.06	1.05	1.06	1.09
November	1.04	1.02	1.02	1.04	1.08	1.14
December	1.00	1.01	1.04	1.09	1.16	1.23

## 2.4 Use of the Seasonal Correction Factors

When a single workplace measurement is undertaken, the factors in Table 3 should be used to estimate the winter maximum in all cases, and the result compared to  $400 \text{ Bq}\cdot\text{m}^{-3}$ . However, the Regulations do not require specific seasonal correction factors to be used, instead permitting accredited Radiation Protection Advisers to interpret a series of radon measurements and to estimate a more appropriate winter maximum value. Thus, if a repeat measurement is inconsistent with the first, additional measurements should be considered to judge the specific seasonal trends for the room. When in doubt, the measurements should be made in the period January/February to get a direct measurement of the winter maximum.

Some types of premises have been shown to have atypical seasonal variations and are listed in Table 4. In the case of school premises, the lack of use of school buildings over the summer period can result in exceedingly high levels in closed rooms, which, in recent cases, have been double the measured winter level. It is therefore recommended that schools are not measured when students are absent.

**Table 4:** Workplaces where standard seasonal variation may not exist

Air-conditioned Buildings
Central Rooms of a large building with no external windows
Upper Floors of a building with a central stairwell and significant radon levels in the basement
Schools

There are also some cases where unusual underlying rock formations can result in high summer levels and low winter levels. However, in this case, the underlying logic of the Ionising Radiations Regulations implies that the maximum radon level whilst the buildings are occupied, should be compared to the limit.

### 3 Dose Estimations

It is not normally necessary to estimate occupants' dose, but it may be necessary in cases where it proves difficult to reduce radon levels, and where the levels are sufficiently high that short-term re-location is being considered. It is also important for workers in radon mitigation companies, and in utility companies with underground pipework. Exposure is calculated by simply multiplying the average radon level by the time of exposure, and converting to an effective dose.

The Ionising Radiations Regulations require that doses, from radon and other radiation sources, are "As low as Reasonably Achievable". A useful initial confirmation of this is the comparison of the calculated dose with the general dose limits in the Ionising Radiations, which are currently 20 mSv per year for classified radiation workers and 1 mSv for the general public. In addition, the annual dose received by unclassified workers should be well below 6 mSv. Denman et al [6] have demonstrated, in the NHS workplace at least, 75 % of occupants working full-time will receive less than 6 mSv annually, if working in an environment with an winter maximum level of 400 Bq m<sup>-3</sup>.

When making projections of dose to occupants over short periods that aim to estimate an annual exposure it is appropriate to use the seasonal correction factors which give the annual average radon level (as in Table 2) as this will yield the annual average radiation dose. However, to estimate actual dose during a fixed period of occupation, uncorrected values should be used.

The above method does ignore any temporal or diurnal variation of radon levels, and so is an approximation to the actual dose received by the occupant. This is not a problem when the estimate is demonstrably well below dose limits. In a few special cases where a significant radon exposure could occur, or the variability of radon levels need to be considered, track-etch detectors can be used as personal dosimeters to measure actual exposure.

### 4 Actions to Reduce Workplace Risk from Radon

The Regulations encourage employers to take action to reduce radon levels. This can be done at a reasonable cost, usually by constructing a sump under the building and adding a fan to draw the radon to the outside. In larger buildings, several sumps may be required. In the UK, the Radon Council has established standards for the mitigation industry, and employers are encouraged to use contractors who are registered with the Council. Once the employer has demonstrated by repeat measurements that the levels are below the Action Level, the Regulations no longer apply. However, the employer is left with the duty of ensuring that the mitigation is still working, by checking regularly that the fan is running, and conducting a repeat radon measurement every 3 to 5 years.

In some cases, it may not be possible, or it may be too costly or impractical to reduce radon levels. In this case the Regulations permit the use of restricted access as a means of reducing risk from radon. This is often invoked for cellars, when they are infrequently occupied. The maximum number of hours that can be spent in the room will be determined by the Radiation Protection Adviser, who will also assess how the employer will restrict access, and prepare written instructions, known as Local Rules,

which describe the system of work that ensures the safe use of the room, and which will ensure that any exposure is “As Low As Reasonably Achievable”. The employer will need to monitor the use of the room, to demonstrate that it is being used within the limits; and liaise with the Radiation Protection Adviser if it is not found possible to comply with the Rules.

In the special case of workers needing to access underground utilities, such as telephone cables, and water pipes, in radon Affected Areas, the system of work may include the requirement to lift the manhole cover, and wait for a specified period as the radon concentrated in the air-space below the cover disperses, before starting work.

## **5 Protection of New Buildings**

UK Building Regulations for domestic properties in radon Affected Areas require protection against radon. In higher radon areas this consists of a radon-proof membrane, and a sump, capable of taking a pump, if radon levels are shown to be high. Therefore similar protection should be installed in new workplaces in the same location, as Denman et al [4] have shown, at least for UK National Health Services workplaces, that there is a similar percentage of rooms in such buildings over the Action Level as there are domestic houses in the same area.

It should be noted that failure of such membranes in domestic houses has been noted by Denman et al. [13], amongst others, with a failure rate of around 50%. It is therefore incumbent on the employer, under the Management of Health and Safety Regulations [9], to test the radon levels in new buildings, once the building is occupied and heating is operating.

## **6 Dose to Occupants of Remediated Workplaces**

As far as the Regulations are concerned, premises which have been remediated so that levels are below the Action Level of  $400 \text{ Bq}\cdot\text{m}^{-3}$  are no longer at risk and are not covered by the Regulations, beyond the employer demonstrating by visual inspection and occasional repeat measurement that the remediation is still working. However, Denman et al. [14] showed in some National Health Service premises in Northamptonshire that the active pump form of remediation preferentially reduced the high night-time radon levels, and have recently confirmed the preferential reduction of high night-time radon levels in a remediated domestic property [15]. In their paper on the Health Service workplace [14] Denman et al. noted that the greatest reduction in radon levels, following remediation, occurred at night, when workplaces were generally unoccupied, and estimated that the health benefits to workers in these workplaces were less than would be indicated by the reduction in average radon levels. They therefore proposed a workplace post-remediation Action Level of  $325 \text{ Bq}\cdot\text{m}^{-3}$  to ensure that there would be tangible benefits to workers, and that radiation doses received were definitely below 6 mSv per year.

## **7 Conclusions**

This paper describes the current methods for ensuring that workers in the UK are adequately protected from radon, and has illustrated some practical issues relating to the methods of measurement and interpretation of results, which are dictated by the short-term and seasonal variations in radon level. In general, the current regulatory situation ensures that workers are adequately protected from radon, but the author suggests that, because active remediation using a pump/sump system preferentially reduces the higher night-time radon levels, it would be appropriate to introduce a lower Action Level for remediated rooms of  $325 \text{ Bq}\cdot\text{m}^{-3}$ .

## **8 References**

- 
- [1] BEIR VI (Committee on Health Risks of Exposure to Radon). Health Effects of Exposure to Radon, National Research Council (Washington, DC: National Academy Press) ISBN 0-309-05645-4 (1999).

- 
- [2] DARBY, S. et al., Residential radon and lung cancer - detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14,208 persons without lung cancer from 13 epidemiologic studies in Europe, *Scandinavian Journal of Work, Environment and Health* 32 Suppt.1 (2006) 1.
- [3] O'RIORDAN, M.C. Human Exposure to radon in homes: recommendations for the practical application of the board's statement, *Docs. NRPB* 1 (1990) 17.
- [4] DENMAN, A.R., LEWIS, G.T.R., BRENNAN, S.E. A study of radon levels in NHS premises in affected areas around the UK, *Journal of Environmental Radioactivity* 63 (2002) 221.
- [5] DENMAN, A.R., PARKINSON, S. Estimates of radiation dose to National Health Service workers in Northamptonshire from raised radon levels, *Brit. J. Radiology* 69 (1996) 72.
- [6] DENMAN, A.R. et al. Do the UK workplace radon action levels reflect the radiation dose received by the occupants? *Journal of Radiological Protection* 19 (1999) 37
- [7] THOMAS, G. National enforcement of radon in the workplace, *Proceedings of the 9<sup>th</sup> European ALARA Network Workshop*, 18-21 October 2005 (2005).
- [8] The Ionising Radiations Regulations 1999, *Statutory Instrument 1999 No. 3232*, London: HMSO (1999).
- [9] The Management of Health and Safety at Work Regulations 1999, *Statutory Instrument 1999, No. 3242*, London: HMSO (1999).
- [10] PHILLIPS, P.S. et al. A comparative analysis of radon measurements of various durations in dwellings (Weekly vs three-monthly radon measurements), *DEFRA Commissioned Research Project EPG 1/4/72; RW 8/17/64*. ISBN 1-900868-44-X; London: DEFRA (2003).
- [11] GROVES-KIRKBY, C.J. et al. Time-integrating radon gas measurements in domestic premises: comparison of short- medium- and long-term exposures, *J. Environ. Radioact.* 86 (2006) 92.
- [12] DENMAN, A.R. et al. The value of seasonal correction factors in assessing the health risk from domestic radon – a case study in Northamptonshire, *Environ. Int.*, 33 (2007) 34.
- [13] DENMAN, A.R. et al. Do radon proof membranes reduce radon levels adequately in new houses? *Proceedings of the 7th SRP International Symposium 'Change and continuity in Radiation Protection'*, Cardiff, 12-17 June 2005, (2005) 441 and CD-Rom.
- [14] DENMAN, A.R. et al. Radon in the workplace : implications of studies of post-remediation monitoring, *Rad. Prot. Dosim.* 111 (2004) 51 (Special Edition for the 1st International Applied Physics Conference, Badajoz, Spain, 13-18 October 2003)
- [15] DENMAN, A.R. et al. A detailed investigation of the individual health benefits arising in a domestic property following radon remediation – a case study in Northamptonshire, UK, *J. Environ. Radioact.*, 99 (2008) 1175.