Workplace radon in Northamptonshire

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Northamptonshire is classified as a radon affected area, with greater than 1 per cent of domestic dwellings being above the UK Action Level of 200Bq m⁻³. Workplace radon is also a health risk in Northamptonshire, with a significant number of premises being predicted to be above this Action Level (400Bq m⁻³). After an extensive survey in National Health Service premises, using track etch detectors and real time monitoring systems, it was found that certain staff were receiving very high doses - up to around 20mSv. The annual collective dose from radon, in the rooms with elevated levels, was 285mSv, an average of 4.45mSv. After remediation of the rooms the average dose fell to 0.5mSv. The average cost of radon remediation in Northamptonshire premises was £3,950 per per cent of homes being above the action level.

Introduction
Radon is a naturally occurring radioactive gas formed in the decay series of uranium. The only isotope of radon normally abundant enough to cause a health problem is ²²²Rn. This isotope is formed by the decay of ²³⁸U. It has a half life of 3.82 days and decays into ²¹⁸Po, which in turn decays into ²¹⁴Po, ²¹⁴Bi and ²¹⁴Po. These four radionuclides are called radon daughters or progeny and can be found attached to aerosol particles in indoor air. The isotopes ²²²Rn, ²¹⁸Po and ²¹⁴Po are all alpha particle emitters; these particles result in very localised energy deposition in living tissue. The ²²²Rn isotope provides the largest contribution (50 per cent) to the total radiation dose received by the general UK population – 2.6 millisieverts (mSv).

The standard unit of activity is the Becquerel (Bq) – one nuclear disintegration per second. Activity concentrations are quoted as becquerels per cubic metre (Bq m⁻³). The unit for dose equivalent is the Sievert (Sv). In studies on low dose radiation it is usual to give doses in millisieverts (mSv).

In this paper we report results from a detailed survey carried out in National Health Service (NHS) premises in Northamptonshire, a county in the Midlands of England, and compare remediation costs with other workplaces.

Radon in buildings
There are a number of sources for radon in buildings. These include: outside air, water supplies, building materials and the ground under the building. Overall, the most significant source is the ground under the building. Radon in outside air in the UK is found in very low levels, with a mean of 4Bq m⁻³ (Wrixon et al., 1988) and it is unlikely to lead to elevated levels of indoor radon.

Radon enters buildings via cracks in concrete floors, through gaps in suspended wooden floors and via service points. The reason for the entry is that the atmospheric pressure is lower indoors than outdoors. Air will flow into a normal UK domestic building at around 1 change per hour and around 1 per cent of that will come from soil gas.

The mean UK radon concentration in dwellings is near to 200Bq m⁻³ (Brown et al., 1981). Although the mean value is low there are a significant number of dwellings over 1,000Bq m⁻³ or more. Radon levels can vary markedly from night to day (Figure 1) and also from season to season. Indeed, seasonal correction factors must be applied to every value determined to give a true representation of an average value over a year.

The building research establishment (BRE) has undertaken a survey of the various means to remedy elevated radon levels in buildings and has published its findings, e.g. BRE (1992).

Radon affected areas
In 1990 the National Radiological Protection Board (NRPB) recommended that the Action Level for radon in existing homes be 200Bq m⁻³, averaged over a year. Parts of the country with a 1 per cent, or greater, probability of homes being above this level are regarded as affected areas. The NRPB advised that Cornwall and Devon should be regarded as such in 1990. In 1992, Derbyshire, Northamptonshire and Somerset (National Radiological Protection Board, 1992) were similarly classified. For a county, which is an affected area, a radon map is produced that shows areas with <1 per cent, 1-3 per cent, 3-10 per cent and >30 per cent of homes being above the action level, this facilitates action by the appropriate authorities, via building regulations. Figure 2 contains information about the percentage of homes in Northamptonshire above the action level.
Radon and geology
Elevated radon levels can be equated with the underlying geology and in particular the concentration of $^{226}$Ra, the precursor of $^{222}$Rn, in rocks and soil. Elevated levels of $^{226}$Ra should lead to high levels of $^{222}$Rn in soil gas. It must also be remembered that soil permeability is another important factor.

Northamptonshire is an area of sedimentary Jurassic rocks. The highest regions of radon production are found on Northampton sand ironstone, upper Lincolnshire limestone, glacial sand and gravel. The ironstone contains phosphorus, which is often associated with uranium.

Radon and workplace legislation
Exposure of workers to radon is governed by the Ionising Radiations Regulations 1985 (Health and Safety Executive, 1985), and the Health and Safety Commission have issued an Approved Code of Practice covering radon (Health and Safety Commission, 1988). Health and Safety executive advice is that employers in affected areas are required by the Management of Health and Safety at Work Regulations 1992 (Health and Safety Executive, 1992) to make a risk assessment about radon by testing their premises.

The NRPB have advised that the action level for domestic premises be 200Bq m$^{-3}$ and 400Bq m$^{-3}$ for workplaces. At levels above 400 in workplaces, the ionising Radiations Regulations are deemed to apply and the Health and Safety Executive must be notified. Rooms with levels over 1,000Bq m$^{-3}$ are Controlled Areas and requires action, under Regulations, to limit dose.

This study uses the best current estimates to relate radon exposure to dose received. It was assumed that 126kBq h$^{-1}$ m$^{-3}$ was equivalent to 1mSv. This factor was derived from factors in the Approved Code of Practice (Health and Safety Commission, 1988).

Figure 1
Variations in indoor radon levels in a NHS room in Northampton

Figure 2
Percentage of homes, in Northamptonshire, above the action level

Radon: a human carcinogen?
Studies with miners exposed to raised levels of workplace radon, and its progeny, have found that exposure increases the risk of lung cancer. The NRPB have reviewed 11 studies that produce overwhelming evidence that radon is a human carcinogen (National Radiological Protection Board, 1993).

Numerous case-controlled studies have been launched to directly assess the lung cancer risk from indoor radon. Some studies report positive or weakly positive findings, others report no increased risk at all.

In an attempt to provide more information a recent meta-analysis of eight case-controlled studies was carried out (Lubin and Boice, 1997). The study concludes that the risk from indoor radon is in line with that which has been proposed on the basis of studies with miners and that it is a carcinogen in the home and the workplace.

Materials and methods
Radon is an alpha emitter, as are two of its short-lived progeny. The method for detection...
for general survey work is a small radon diffusion chamber housing a plastic alpha-track detector (Denman, 1994). This provides a measure of the total radon exposure over the measurement period. It is then possible to calculate the average radon concentration over the measurement period.

To ensure that the response is little affected by diurnal and other time variations in radon, the detectors were left in position for one to three months. Time-averaged values were calculated using NRPB values for seasonal correction factors.

Hourly measurements were made in rooms with elevated radon levels that displayed marked variations (Figure 1). This occurred over a period of one to four weeks using a direct reading RAD seven meter (Denman and Parkinson, 1996). This actively pumps air samples into a measuring chamber. Staff were asked to fill in a questionnaire to indicate how many hours they spent in each room in an attempt to estimate the occupancy factor. The radiation dose to staff could then be calculated, and expressed as an effective radiation dose using the relation that 1mSv is equal to 126kBq m–3 hours.

The accepted protocol for radon measurement in the workplace is to position detectors in a selection of ground floor rooms chosen to reflect the normal occupancy pattern of the building. In small premises, a detector is placed in each of the two most frequently occupied rooms. In large buildings one should be deployed for at least every 100 m2 of occupied rooms. In large buildings one should be deployed for at least every 100 m2 of occupied rooms. In large buildings one should be deployed for at least every 100m2 of floor space. In very large, open buildings one should be used for every 500 m2 of floor area.

### Results

Northamptonshire is an affected area and elevated levels of indoor workplace radon are to be expected. The results for districts and boroughs in Northamptonshire are to be found in Table I. Included in Table I are average radon values in housing in the regions, these surveys are extensive, based on a large number of dwellings, and give an indication of possible levels in the workplace.

The quantity of data is still relatively small and so somewhat limits the confidence that can be placed on it, even so, the range from 9 to 21 per cent, clearly suggests that there is a significant problem in the region. These values are high compared to the approximately 6 per cent of the schools in the county that required remediation for workplace radon. The value for schools is probably representative of the scale of the problem across the county. Schools are evenly spread and they represent workplaces that differ in size from the small, some 60 pupils, to the very large, with hundreds of pupils and large complexes of buildings. The result from schools, however, needs to be treated with some caution as most rooms are quite large, but in buildings with smaller rooms the proportion above the limit may be higher. The percentage for NHS properties, at 8 per cent, may be higher because of the significant number of smaller offices. A more detailed survey is under way in the county, in an attempt to determine a more accurate figure for the proportion above the action level, but this will not report for some time yet.

Radon levels can vary markedly even within relatively small areas. The values for the area covered by Northampton Borough are presented according to postcode in Table II.

Northamptonshire NHS properties are within four NHS trusts, and include two general hospitals, health centres and residential homes, the total number of properties is 82. The total staff number is some 6,693 whole time equivalents. Our survey has to date measured radon levels in 1,038 rooms and this has the usual log-normal distribution which is also reported in a number of surveys of residential premises with 1 per cent over 1,000Bq m–3 and 8 per cent over the workplace action level. Typical readings from a building with raised levels are found in Table III. The results for the distribution of radon over all properties are found in Table IV.

<table>
<thead>
<tr>
<th>District/borough</th>
<th>Number tested</th>
<th>Percentage above action level</th>
<th>Average radon levels in housing (Bq m–3)</th>
<th>Population</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corby</td>
<td>37</td>
<td>11</td>
<td>38</td>
<td>53,000</td>
<td>8,000</td>
</tr>
<tr>
<td>Daventry</td>
<td>228</td>
<td>9</td>
<td>74</td>
<td>63,000</td>
<td>66,600</td>
</tr>
<tr>
<td>East Northants</td>
<td>80</td>
<td>10</td>
<td>63</td>
<td>66,000</td>
<td>51,000</td>
</tr>
<tr>
<td>Kettering</td>
<td>178</td>
<td>16</td>
<td>107</td>
<td>77,000</td>
<td>23,400</td>
</tr>
<tr>
<td>Northampton</td>
<td>184</td>
<td>21</td>
<td>55</td>
<td>181,000</td>
<td>8,100</td>
</tr>
<tr>
<td>South Northants</td>
<td>52</td>
<td>10</td>
<td>61</td>
<td>71,000</td>
<td>63,500</td>
</tr>
<tr>
<td>Wellingborough</td>
<td>95</td>
<td>14</td>
<td>66</td>
<td>68,000</td>
<td>16,300</td>
</tr>
</tbody>
</table>

### Table II

Variation in radon levels in commercial premises within a borough council (Northampton), by postcode

<table>
<thead>
<tr>
<th>Radon (Bq m–3)</th>
<th>Percentage of properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td>33.6 33.3 56.3 75.0 50.0</td>
</tr>
<tr>
<td>0.10-0.199</td>
<td>23.5 20.0 18.8 4.1 23.0</td>
</tr>
<tr>
<td>0.20-0.399</td>
<td>14.3 0 15.6 8.3 6.2</td>
</tr>
<tr>
<td>&gt;0.400</td>
<td>28.6 26.7 9.3 12.8 17.0</td>
</tr>
</tbody>
</table>
Several rooms are very small store rooms that are rarely entered, these have been discounted and will not be remediated. A total of 21 workplace locations were found to be over the limit and needing remediation. In all, 11 have been successfully remediated and two require further work. The costs for the remediation for locations is found in Table V, which also contains data on other types of workplace locations in Northamptonshire.

Locations with levels in excess of 550Bq m$^{-3}$ were fitted with one or more sumps and extractor fans. The total cost for these eight locations was £39,300. The lowest cost for these locations was £640, here a single sump, with fan, was installed to successfully remediate one small room.

In another case, where the level was 430Bq m$^{-3}$, the void below the building was fitted with an improved form of passive ventilation as well as additional fans to actively expel air from the underfloor void to the external environment. This was considered suitable to bring the level below that required by legislation. The cost for this was £2,000.

A further two locations, where radon levels were just above the limit, were fitted with extractor fans only in the underfloor void, sumps were not deemed necessary. The cost for these was £2,150.

As soon as a problem was detected a Health and Safety adviser was consulted. An action plan was devised and tenders were invited from companies who were on the UK Radon Council’s list of approved contractors. Remedial work was then carried out, mostly within a period of around three months. Only in one case, that of an office with levels of 2,870Bq m$^{-3}$, was it necessary to evacuate and prevent staff entering.

The annual dose from radon in the NHS workplace has been estimated for 64 staff who work in the identified hot-spots. The distribution is shown in Figure 3. The annual total collective dose for these staff from radon was 285mSv, an average of 4.45mSv. After remediation the average dose fell to 0.5mSv.

### Table III
Detailed survey of an NHS building with raised radon levels

<table>
<thead>
<tr>
<th>Location</th>
<th>Direct reading (Bq m$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reception</td>
<td>800</td>
</tr>
<tr>
<td>Interview room</td>
<td>1,800</td>
</tr>
<tr>
<td>Consulting room</td>
<td>3,200</td>
</tr>
<tr>
<td>Treatment room</td>
<td>1,900</td>
</tr>
<tr>
<td>Corridor</td>
<td>700</td>
</tr>
<tr>
<td>Staff toilets</td>
<td>50</td>
</tr>
<tr>
<td>Rest room</td>
<td>300</td>
</tr>
</tbody>
</table>

### Table IV
Distribution of radon levels in sites in NHS properties in Northamptonshire

<table>
<thead>
<tr>
<th>Average radon level (Bq m$^{-3}$)</th>
<th>Hospital A (Northampton Sand)</th>
<th>Hospital B (Upper Lias Clay)</th>
<th>Total of all sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;100</td>
<td>207</td>
<td>130</td>
<td>655</td>
</tr>
<tr>
<td>101–200</td>
<td>37</td>
<td>44</td>
<td>184</td>
</tr>
<tr>
<td>201–300</td>
<td>13</td>
<td>19</td>
<td>64</td>
</tr>
<tr>
<td>301–400</td>
<td>8</td>
<td>7</td>
<td>39</td>
</tr>
<tr>
<td>&gt;400</td>
<td>16</td>
<td>5</td>
<td>81</td>
</tr>
</tbody>
</table>

**Discussion**

Simple estimates of dose to workers, based on average radon levels, can be misleading. Radon levels can vary markedly during a 24 hour period (Figure 1) with the highest levels appearing outside of standard working hours. As occupancy, on the whole, decreases there is a reduction in ventilation with an increase in radon concentration. As some organisations may employ a number of shift workers at night time, who operate in a sedentary manner, there may be considerably greater doses received by these than others who work during the day. The NHS employs a considerable number of night workers and these may be at extra risk. However, it is essential to know the variations in radon levels throughout a 24 hour period as well as the time-averaged levels, over prolonged periods, to design a comprehensive remediation package.

The NRPB indicate that continuous exposure for 80 per cent occupancy at 100Bq m$^{-3}$ gives an effective dose of around 5mSv per year. In the management of high radon levels it is essential to reduce levels as quickly and effectively as possible to the workplace action level. Increasing ventilation alone can result in some clear advantages. In one room, with a value of 710Bq m$^{-3}$ during working hours, merely opening windows caused the dose to staff to drop from 5.0mSv to 1.1mSv per year. Immediate action must be taken when a location is identified with very elevated levels. In some cases it is necessary to temporarily seal off the room, or severely limit access, until remediation. In extreme cases, for say very small store rooms, it may be more cost effective to seal off the room permanently as the cost of long term remediation may be greater than the value of the space.

In some cases, before remediation, NHS staff were receiving doses well above 5mSv per year. These doses are in excess of those received by hospital workers working with radiation, such as radiographers, radiologists, physicists and radiotherapists. We have calculated that our programme costs around £180,000 to achieve an annual...
Man-Sievert reduction. It is interesting to compare this value with that proposed for domestic properties in Sweden (Snihs, 1992). Snihs suggests that costs in Sweden are around £30,000 per Man-Sievert saved annually, at an action level of 400 Bq m$^{-3}$. Exposure in the workplace is not directly comparable with the home, as residents are exposed to radon in the home when levels are the highest, while many workers are exposed to the lowest radon levels if working 9 a.m. to 5 p.m. The volume of a room is also a critical factor; very large areas have a reduced stack effect and very little underpressure. It is difficult to directly compare both situations but it can be said that remediation in commercial premises tends to be significantly higher in cost than domestic dwellings as there are often multiple foci of radon entry which complicates radon reduction.

The costs for a radon programme are always greater than the mere costs of remediation. We quote a value of £43,450 for remediation work but this neglects the costs of detectors as well as staff time. We estimate that on completion the total cost will be around £98,000 for all 21 locations. For our study, remediation costs are 76.5 per cent of total costs, the others are: staff time (9.2 per cent) and detectors (14.3 per cent).

The data that are available for remediation costs are informative. Those for remediation in schools are particularly useful to compare with those from the NHS. The costs come from remediation in 21 schools out of the approximately 360 tested throughout the county. The costs are higher in the NHS properties because of a small number of situations that proved particularly difficult to deal with, because of multi-focal entry points. The costs for the schools appear to be more representative of “the average situation” found throughout the county for small to medium enterprises (up to 250 employees), especially those with larger rooms.

The arithmetic mean of £1,953 for schools compares to a figure of around £1,110 that can be derived from data provided by the NRPB for remediation of domestic properties, with sumps (Kendall et al., 1994). Our data for schools span the period 1993 to 1996 and the data from the NRPB are up until mid-1994. During that time remediation costs have hardly risen, so the figure quoted by the NRPB will still stand, to a good approximation, today.

Within Northamptonshire there are approximately 19,000 enterprises, that fall into the following categories:

- 15,000 1–10 employees;
- 4,000 11–199 employees;
- 100 > 200 employees;

Workplaces in the first category should have remediation costs associated more closely with domestic and those in the second with schools and so it is possible to suggest an approximate figure for a likely cost to the county to remediate in these types of business, assuming that 6 per cent require remediation. The figure is in the region of £1,460,000. The full costs should consider staff time for monitoring, installing remediation and the costs of the detectors. It is then likely that this figure will increase by 20-30 per cent. It is problematic to suggest an overall value for larger companies as details are needed about the nature of the site(s). A further study is planned to take place in this area. The final cost will of course depend on the number above the action level. Initial work by some authorities suggest that this may be as high as 14 per cent (Dixon et al., 1996). The possible range of costs is quite wide with our value being a conservative one.

**Table V**

<table>
<thead>
<tr>
<th>Costs, so far, for remediation in some Northamptonshire workplaces</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NHS</strong></td>
</tr>
<tr>
<td>Number of locations</td>
</tr>
<tr>
<td>Total cost (£)</td>
</tr>
<tr>
<td>Average cost per location (£)</td>
</tr>
<tr>
<td>Range (£)</td>
</tr>
</tbody>
</table>

**Figure 3**

Estimated doses for 64 staff in locations with raised radon levels

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**Conclusions**

From our studies with NHS properties in an affected area we conclude:

1. There are no raised levels in ward areas. This may in part be due to the relatively large volume of these rooms.
2 Raised radon levels are very localised. Sometimes only one of an adjacent pair of rooms is affected.

3 Radon gives more dose to more staff than use of X-rays and isotopes for therapy and diagnosis.

4 The dose received by staff from radon (20-24.9mSv – Figure 3) is far higher than expected and swift remedial action was essential.

5 For the total NHS staff, current risk estimates suggest that radon in the workplace gives rise to 0.13 lung cancers per annum (of which 13 per cent would occur in staff working in areas of high radon and so could be avoided), compared with a natural incidence of six lung cancers.

6 Once remediated, it is essential that no structural changes take place in buildings until an impact assessment on the remediation systems takes place.

7 Periodic testing should occur to ensure that the remediation system is still effective (Naismith, 1997).

References


