THE COST EFFECTIVENESS OF RADON REMEDIATION PROGRAMMES IN HOSPITALS, SCHOOLS AND HOMES IN RADON AFFECTED AREAS IN THE UK

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Radon gas is now considered to be a health hazard when found in excessive amounts in the built environment. The levels of radon vary greatly, with some geographical areas having very high levels. In the United Kingdom, Northamptonshire was declared an Affected Area in 1992, and it was at this stage that our group first started studying radon levels and the steps taken to reduce them.

The radon levels both before and after remediation were studied, together with the number of occupants of affected rooms, and their pattern of occupation. The totals costs of the programme were recorded, including the survey using etched track detectors to find the affected room, and work done to reduce radon levels. This analysis provided a total cost of the remediation programme per dose saved.

This analysis was carried out, first for Health Service properties in Northamptonshire, and then for schools and domestic properties. Comparison of the three programmes showed that the programme in schools was the most cost effective, but that a completed programme in domestic properties would be almost as effective. However, in the UK, only 10% of those who discover raised radon levels have so far organised remedial work, greatly reducing the cost effectiveness of the domestic remediation programme. It was found that it was four times more expensive to remediate Health Service properties compared to a completed programme in domestic properties. The results were close to theoretical predictions made for domestic properties in other countries.

All the programmes could be justified when compared to the National Radiological Protection Board (NRPB) initiative to reduce patient dose from dental X-Rays. However, if the uptake of householders was less than 10%, a domestic remediation programme was excessively expensive.

The analysis has now been extended to series of houses in North Oxfordshire, and Somerset, which has allowed a comparison of cost effectiveness for areas with different percentages of houses above the domestic Action Level of 200 Bq m\(^{-3}\).

As expected, it is more cost effective to target areas with higher percentages of houses above the Action Level. More importantly, the percentage of householders who find raised radon levels and then organise remediation is critical. Programmes to reduce domestic radon levels in areas where 2% or less of houses are above the Action Level are difficult to justify financially unless a high householder response is achieved.

Key Words :- Affected Areas, Radon, Remediation, Cost Effectiveness, Hospitals, Schools

INTRODUCTION

Radon has been shown in a number of studies to cause lung cancer. It has a variable distribution in houses and workplaces, and comparison with studies in miners suggests that a significant number of cancers will be induced where levels are high. Recent studies by Lubin and Boice (1997) and Darby et al (1998) have supported this assessment.
In the UK, the National Radiological Protection Board has designated a number of Affected Areas where 1% or more of the homes are above the Action Level of 200 Bq m$^{-3}$ (NRPB 1990). These include Northamptonshire, Somerset (NRPB 1992), and North Oxfordshire (NRPB 1996). A number of studies have considered the theoretical costs of widespread programmes to locate and remediate domestic properties in various countries, including Colgan and Gutiérrez (1995, 1996) in Spain. These studies conclude that such programmes in affected areas are cost-effective.

Since 1993, a comprehensive radon remediation programme in National Health Service properties in Northamptonshire has been undertaken, and Denman et al (1997) have studied the costs and dose saving, and reported on the cost effectiveness. This method has been extended to domestic properties in Northamptonshire (Denman and Phillips 1998a), and then schools (Denman and Phillips 1998b). This paper reviews this work, and provides an updated comparison of the three studies.

The analysis has now been extended to domestic remediation programmes in North Oxfordshire and Somerset, as well as subsets of the Northamptonshire data. The areas studied are shown in Figure 1. This paper presents these results, and in particular considers the variation in costs with the percentage of houses found to be over the Action Level, and then considers the implications for radon remediation programmes in other locations.

METHODS

The comprehensive radon remediation programme in National Health Service properties in Northamptonshire included two major hospitals, 26 health centres and 14 clinics. Using over 1000 etched track detectors, some 21 locations with radon levels above the workplace Action Level of 400 Bq m$^{-3}$ were found. Using direct reading radon gas meters, which recorded the radon level each hour, in each affected room, and occupancy factors determined by asking staff to complete questionnaires recording their movements, the dose received by occupants was estimated. A similar assessment was made after successful remediation, and the collective dose saving was calculated. Denman et al (1997) reported that a total of 135 staff worked in the affected rooms, out of a total of 11,100 staff, and that the collective dose saved annually was estimated to be 0.533 man-sievert.

Denman and Phillips (1998b) applied the same analysis to the Northamptonshire County Council remediation programme for 348 schools, where 20 schools were affected. Although in the same geographical area, there was half the number of rooms with raised radon levels that would have been predicted from the NHS data, which may be due to the number and size of large classrooms and greater air mixing due to the high occupancy.

Both series showed the typical log-normal distribution of initial radon levels which has been noted in previous studies.

Denman and Phillips (1998a) reported a similar analysis of 48 domestic homes in Northamptonshire where remediation had been carried out. This series has now been extended to 65 houses. The total number of occupants is 156; an average of 2.40 per house. From the average radon levels before and after remediation, assuming an average occupancy of 12 hours each day, the collective dose saving was estimated to be 2.22 man-sieverts.
The distribution of initial radon levels in the series of 65 houses is shown in Figure 2, and this has the same pattern as reported by Denman and Phillips (1998a). Compared to the log-normal distribution this suggests that almost half of those with radon levels between 200 and 300 Bq m\(^{-3}\) decided that the expense of remediation was unacceptable - although 1 occupant decided it was worth remediating with a result of 190 Bq m\(^{-3}\).

In the UK, free radon testing was offered in Affected Areas; and in Northamptonshire this was available from 1992 to 1997. The householder was, however, expected to pay any remediation costs. Bradley (1996) reported a postal questionnaire in Devon and Cornwall in 1994, that suggested that only 10% of those finding a raised level organised the remediation work. If a reduced number of occupants proceeding to remediation is taken into account, and considering the total cost of providing the initial tests and undertaking remediation, the cost effectiveness drastically worsens.

The same analysis was applied to smaller series of domestic houses where remediation had been carried out in North Oxfordshire and Shepton Mallet, Somerset. In addition the Northamptonshire data was split into three separate series depending on the location of the houses, making use of the post-codes for each house. For each of these areas, Bradley et al (1997) state the percentage of houses found to be above the Action Level, and these values range from 2.9% to 15.9%. In each series the range of initial radon levels followed a similar pattern to that in Figure 2; that is the different geographical locations did not have any impact on the decisions of those finding radon levels just above the Action Level. Table 1 summarises the data for these series.

RESULTS AND DISCUSSION

The total cost of the NHS programme, including the initial etched track detector survey, remedial work, and subsequent testing was £98,000, giving a total cost per man-sievert annually saved of £184,000. Despite the lower percentage of rooms above the Action Level, the dose reduction achieved in schools was significant, and the cost effectiveness was better at £19,400 per man-sievert.

For the domestic series, Bradley et al (1997) report that 6.25% of houses in Northamptonshire are above the domestic Action Level. Applying this figure the cost effectiveness of a radon remediation programme would be £38,140 per man-sievert if 100% of houses found to be over the Action Level were remediated. This is a higher figure than reported in Denman and Phillips (1998a). This is in part due to the fact that the original analysis ignored local Value Added Tax (17.5%) which was payable by the householder on the remediation work. However, the main factor was that the original analysis assumed that the percentage of homes above the Action Level would be similar to the percentage of rooms over the Action Level in NHS properties, which Denman et al (1997) found to be around 9%. As can be seen, this is higher than found by Bradley et al (1997). This is due to the fact that the NHS results are dominated by measurements at the two district general hospitals, and the underlying geology for most of each site is Northampton Sand, which is the geology implicated in raised radon levels in Northamptonshire (Marley et al, 1997).

If a reduced percentage of householders organising remediation is taken into account, and considering all the initial testing that would be required to find these households, the cost effectiveness becomes much worse. The total costs per man-sievert saved annually are shown for all
these series in Figure 3. It can be seen that for the domestic programmes if less than 10 % of householders organise remediation the programme becomes less cost-effective than programmes in the workplace.

Denman et al (1997) compared the remediation programme in NHS properties with the NRPB initiative to reduce patient dose from dental X-Rays. Converted to 1997 prices, the NRPB programme had total costs of £327,000 per man-sievert saved annually. The NRPB (1994) considered that the programme was justified but approaching the financial estimate of the general health detriment of X-Ray dose which would be saved.

In Northamptonshire, Bradley et al (1997) record that a total of 4171 houses had been found to be over the Action Level in Northamptonshire by January 1997. Extrapolating from the our series, and using the latest NRPB risk estimate (NRPB 1993), then for the 10 % which were remediated, the domestic remediation programme in Northamptonshire to date will avoid 0.43 lung cancers per year. This result, together with similar estimates for the programmes in NHS properties and schools, are shown in Table 2, where the results are also compared to the potential lung cancers avoided if all houses in Northamptonshire with raised radon levels were remediated, and the natural incidence of lung cancer, which is dominated by the risks of smoking. The estimates show that it would not be possible to statistically demonstrate the success of a local radon remediation programme, because the reduction in lung cancers would be masked by the higher natural incidence. Although the remediation programme in schools is the most cost-effective, the domestic remediation programme has the potential for the greatest reduction in lung cancers.

The results of the analysis for North Oxfordshire, Somerset and the three areas of Northamptonshire are shown in Figure 4 where the total cost per man-sievert saved annually has been plotted against the percentage of houses above the Action Level. The cost effectiveness improves as the percentage of houses above the Action Level increases, and the figure clearly shows that costs escalate if there is both a low percentage of houses above the Action Level, and a low percentage of householders organising remediation.

As noted above, Colgan and Gutiérrez (1995.1996) have made theoretical estimates of a national domestic remediation programme in Spain. They assumed that they would find around 8.7 % of houses above 200 Bq m$^{-3}$. Figure 5 shows their estimate of total cost per man-sievert saved if all houses above this level were remediated, compared to the results of our series assuming that all houses are remediated. It can be seen that the costs found in our series, which represent the only published data from actual remediation programmes, are close to theoretical estimates.

**CONCLUSIONS**

A review of cost effectiveness of actual remediation programmes of domestic properties in the UK, have shown that results are similar to theoretical estimates.

Comparisons between the costs and dose saving of remediation programmes in schools, hospitals and domestic properties, show that it is most cost effective to conduct radon remediation in schools in a radon Affected Area. It is almost as cost effective to remediate domestic properties in the same areas and a greater reduction in lung cancers can be achieved, but only if all householders can be encouraged to undertake any necessary remediation. In the UK at present, only 10 % of households...
finding levels over the Action Level have so far organised remediation, so a review of current strategy is indicated.

In contrast, programmes to reduce domestic radon levels in areas where only 2% or less of houses are above the Action Level and only a low householder response is expected cannot be financially justified.

It may be appropriate to consider a graduated approach to radon mitigation, with schools being remediated over a wider area than either domestic properties or the over-ground workplace. Once a mechanism for ensuring that a high percentage of affected domestic properties are remediated has been found, this could be extended to other areas with a lower percentage of domestic properties above the Action Level.

REFERENCES


Documents of the NRPB 1994; 5(3). Chilton, NRPB.

Table 1: Affected Areas Studied

<table>
<thead>
<tr>
<th>Area</th>
<th>Postcode</th>
<th>Number of Remediated Houses in Series</th>
<th>Percentage above Action Level</th>
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<tr>
<td>Northamptonshire</td>
<td>All NN and PE8</td>
<td>65</td>
<td>6.3</td>
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<tr>
<td>- Area 1</td>
<td>NN1 to NN4</td>
<td>20</td>
<td>4.9</td>
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<tr>
<td>- Area 2</td>
<td>NN6</td>
<td>18</td>
<td>14.7</td>
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<tr>
<td>- Area 3</td>
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<td>25</td>
<td>8.4</td>
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<tr>
<td>North Oxfordshire</td>
<td>OX15-17</td>
<td>17</td>
<td>15.8</td>
</tr>
<tr>
<td>Shepton Mallet</td>
<td>BA5</td>
<td>16</td>
<td>2.9</td>
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Table 2: Lung Cancers Averted Annually by Remediation Programmes in Northamptonshire

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<tbody>
<tr>
<td>NHS Workplace</td>
<td>0.017</td>
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<tr>
<td>Schools (Staff and Pupils)</td>
<td>0.14</td>
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<tr>
<td>Domestic Programme to date</td>
<td>0.43</td>
</tr>
<tr>
<td>Potential Saving if Domestic Programme complete</td>
<td>16</td>
</tr>
<tr>
<td><strong>Natural Incidence</strong></td>
<td><strong>320</strong></td>
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Figure 1: Map of England showing Percentage of Houses over Radon Action Level, and study areas

Areas of Study

Northamptonshire
North Oxfordshire
Shepton Mallet

From an Original Map by NRPB

Figure 1: Map of England showing Percentage of Houses over Radon Action Level, and study areas
Figure 2: Distribution of Initial Radon Levels
Figure 3: Comparison of Radon Remediation Programmes in Northamptonshire
Figure 4: Costs of Remediation
Figure 5: Comparison of Estimates