Cost Effectiveness and Health Benefits of Domestic Radon Remediation Programmes – An Update

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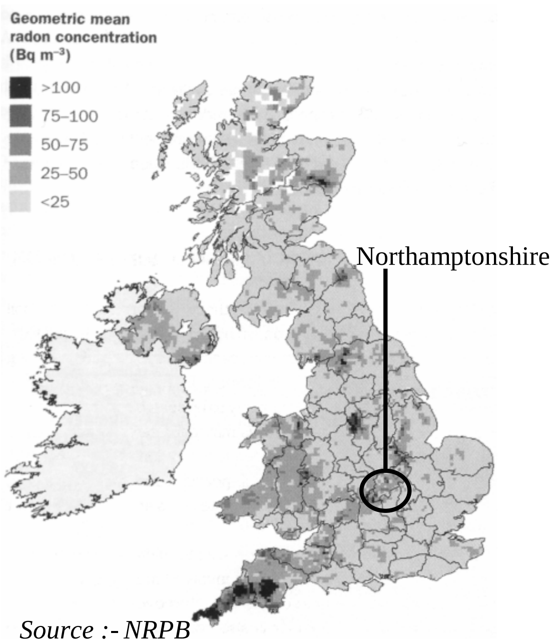
Abstract. The costs of remedial work and the radon level reduction achieved in a series of domestic properties in Northamptonshire has been the subject of study by our group for some years, as Northamptonshire was declared as a Radon Affected Area in 1992. Previous analysis, which relied on estimations of the total number of affected houses extrapolated from the National Radiological Protection Board (NRPB) test data, suggested that a testing and remediation programme in Northamptonshire could be justified. The NRPB has continued to initiate and collate radon testing, and published further results in 2003. These results include predictions of the total affected houses which are lower than those assumed before. Recently, the ECRS computer software programme has permitted calculation of individual risk, rather than a population average. These predictions have profound effects on our previous analysis - particularly since only limited numbers of householders test their homes, and even fewer remediate if they discover raised levels.

1. Introduction

Radon gas has been shown to cause lung cancers in Uranium miners. It has a variable occurrence in the built environment, including domestic properties, and extrapolation from the miners' data has suggested that many members of the public are at increased risk from lung cancer [1]. A meta-analysis of eight national epidemiological studies by Lubin and Boice [2], and a case-control study in the South West of England [3] support this view.

FIG. 1 Radon Map of UK



In the UK, the National Radiological Protection Board (NRPB) has established an Action Level of 200 Bq m^{-3} for domestic properties. The NRPB has also declared a number of Radon Affected Areas, where their work had indicated that over 1 % of the housing stock would have radon levels over the Action Level. Campaigns have been initiated and supported to encourage occupiers in these areas to test their homes; Northamptonshire, shown in FIG. 1, is such an area [4].

Our group has extensively studied the radon problem in Northamptonshire, in hospitals [5,6], the workplace [7], schools [8] and domestic properties [9,10,11,12,13]. The underlying theme was the assessment of health benefits and the costs of comprehensive radon remediation programmes, and whether such programmes could be justified. This work compared actual results to theoretical estimates by several authors [14,15,16,17,18] who considered a range of strategies for such programmes in several countries, and judged them to be justified. Recently, Stigum *et al.* [19] published a similar study for Norway, showing that even allowing for current uncertainties in lung cancer risk, a radon remediation programme in Norway could be justified.

Our work culminated in the publication of a comparative study of all the remediation programmes studied by our group [20].

Since then the European Community Radon Software (ECRS) development [21] has permitted the individual dose assessment from radon exposure. Application of this software to our domestic series suggested that those most at risk from radon were not carrying out remediation [22].

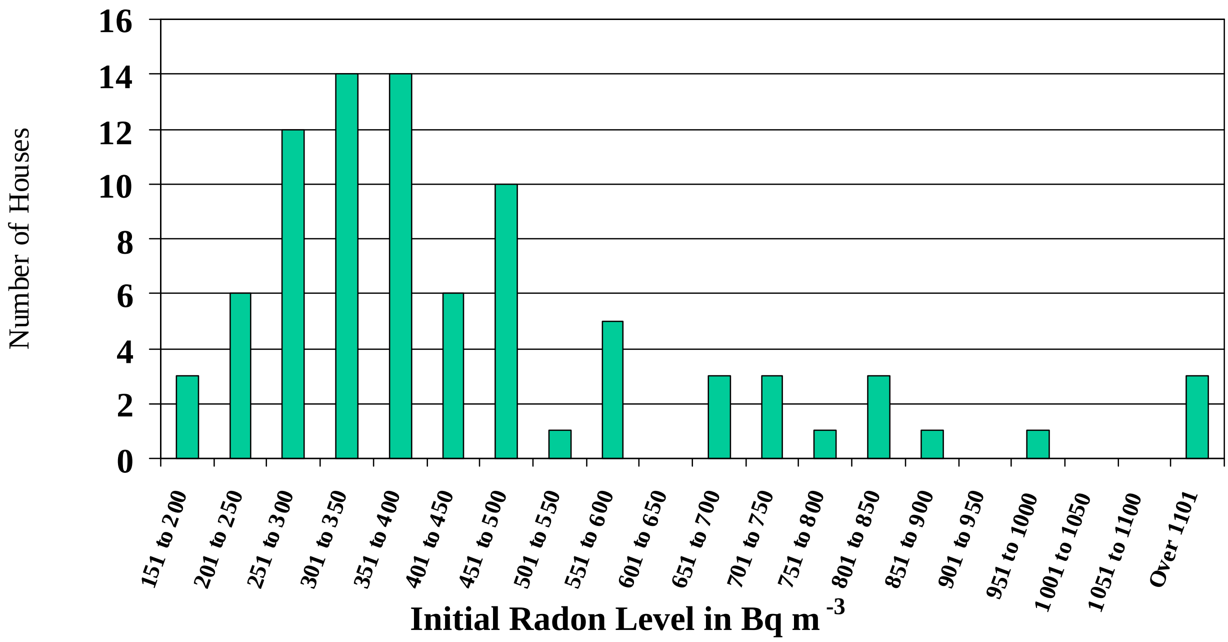
The NRPB has recently published an update on their comprehensive survey of radon levels in UK houses [23], which includes an estimate that fewer houses in Northamptonshire than previously estimated will be found with radon levels above the Action Level.

This paper considers these recent significant developments, their effect on the interpretation of the value of radon remediation programmes in domestic properties in Northamptonshire, and the implications for the public health policies of local authorities and Primary Care Trusts (PCTs) in Radon Affected Areas.

2. Method

The data series presented are domestic properties in Northamptonshire in which remediation work was carried out by a single company, following UK Radon Council Protocols [24], and where radon gas measurements had been made both before and after the remedial work using the NRPB protocol. Under this protocol, two track etch detectors are placed in the home for three months, one in the master bedroom and one in the living room. The results are then seasonally corrected, and a weighted average for the house found by adding 55 % of the bedroom value and 45 % of the living room value. The occupants agreed that their results could be used for this analysis, and gave details of the number of occupants in their property. A subsequent postal questionnaire gave additional details of occupants, including smoking habits, occupation and gender.

FIG. 2. Initial Radon Levels in Remediated Homes



Results for houses outside Northamptonshire, or where initial remediation was unsuccessful and further remediation was planned but not yet completed, were excluded. The resultant series consisted of 86 locations with a total of 212 occupants, an average occupancy of 2.47. Initial radon levels were in the range 168-1500 Bq·m^{-3}, with a distribution as shown in FIG. 2. The distribution is similar to previously reported results. In order to estimate the total number of homes that would have been tested to yield this number of homes above 300 Bq·m^{-3}, the series was compared statistically to a standard log-normal distribution. As noted before [9], higher numbers were predicted for the range 201 to 300 $Bq \cdot m^{-3}$. Such a pattern would correspond to a disproportionate number of householders with results in this range testing for radon levels but then not implementing the necessary remediation work. A plausible explanation for this result could be that householders with test results in this range might assume that the risks from exposure are sufficiently low to obviate the need to remediate. Indeed, we provide evidence later in this paper that suggests that this explanation is the case.

One essential input to the model is the knowledge of the total number of houses that are above the Action Level in the study area. The NRPB has been conducting measurements throughout the UK, and correlating results for many years. Bradley *et al.* [25] published a summary of the results up to 1997, which indicated that 6.3 % of houses tested in Northamptonshire were above the Action Level. This value was used to estimate the total number of houses in the county, which would be found over the Action Level, using linear extrapolation, as in the previous studies [9,10,11,12,13]. However, the NRPB has recently published an update [23], which includes predictions of the expected numbers of houses above the Action Level based on an analysis of test results within 1 km squares in South West UK, and within 5 km grid squares for the rest of England and Wales, including Northamptonshire. The NPRB has given two estimates - one considered *minimum*, and the other *top end* - at District Council and County level. The NRPB state that the range reflects the inherent uncertainties in the estimates; the minima are calculated using the lower range value and the maxima the actual calculated probability. They further note that the shape of the log-normal distribution and the known biases in the responses of householders to offers of measurements both suggest that using the top range value would lead to a significant overestimate. The predicted numbers of houses for Northamptonshire by the various methods are shown in Table I.

Table I. NRPB Estimates of the number of Houses in Northamptonshire over the Action Level

Source	**Number of Houses**	**Percentage of total Housing Stock**
1997 Review	16196	6.3 %
2003 Review - Minimum	7700	2.9 %
2003 Review - Maximum	11300	4.2 %

The total cost of the remediation programme was calculated by summing the costs of the track etch radon measurements for the total number of houses and the costs of remediation and re-testing in the series. The costs were corrected to 2001 costs using the UK official Retail Price Index figures for Repairs and Maintenance [26].

In initial reports of this series, it had been assumed that each occupant was in the house for an average of 12 hours each day, and moved between rooms in such a manner that the NRPB weighted average radon level was valid. Recently, results of a survey of occupancy patterns in Northamptonshire have been published [27], and found an average occupancy of 17 hours 17 minutes (72 %), which is used in this paper. The dose saving was calculated as an effective radiation dose using the relation that 1 milliSievert is equal to 126 $kBq \cdot m^{-3} \cdot hrs$ [9], and the lung cancers averted by the reduction in dose was calculated using the NRPB estimate that 3.5×10^{-4} lung cancers are induced per Working Level Month [28].

Individual risk estimates are now possible using the ECRS. The ECRS programme required additional information from our study cohort – namely the age, sex and smoking habits of each occupant. To obtain this information, postal questionnaires were sent to all of the households in the study cohort. Respondents were also asked to estimate the number of hours spent at the home on a recent weekday and weekend. The use of the programme has been described elsewhere [29]. 45 households (52% return) returned questionnaires. Analysis showed that those who remediated were older, had fewer children and smoked less than the general population. As a result, the health benefits to the study population were 38.8 % of those expected for an average population [29]. This was primarily due to the fact that only 14.6 % of the group smoked, compared to the national average of 28 %, and the fact that smoking and radon are now considered multiplicative risks [30].

3. Results

Table II gives the results for our series showing the final radon level together with the costs of remediation, and the calculated annual dose saving, which totalled 4.41 Man-Sieverts for the 86 homes.

Table II - Details of Study Cohort

	Initial Radon Level [Bq·m^{-3}]	**Final Radon Level [Bq·m^{-3}]**	**Remediation Cost (corrected to 2001) inc. VAT**	**Annual Dose Saving [mSv] - for an Individual in each property**	**Annual Dose Saving [mSv] - for total occupants in each property**
Average	470	66	£830	20	51
Minimum	170	8	£350	2.5	5
Maximum	1500	200	£1750	75	300
Total			£71000	1730	4410

The total number of homes that needed to be measured to provide the sample cohort was predicted by statistical comparison depending on the number expected to eventually be found over the Action Level. For the *top end*, 2870 houses would have been measured, for the *minimum* 4390. These numbers represent the expected number of houses tested if all those over 300 Bq·m^{-3} are remediated. These are higher numbers than predicted from 1997 review, which was 1760. This has an impact on the total cost of the programme, which would be *top-end* £174500, *minimu*m £227500 (1997 £135700). The costs vary purely because of the differing numbers of houses to be tested. The total costs per Man-Sievert saved annually for each prediction is shown in Table III, together with the total cost per annual lung cancer avoided.

Table III - Cost Effectiveness of Completed Domestic Remediation Programme in Northamptonshire

	Total Cost per Man-Sievert Saved in £1000s	**Total Cost per Lung Cancer Averted in £1000s**	**Annualized Cost per Lung Cancer Averted in £1000s**
1997 Review	30.8	963	53
2003 Review - Minimum	51.5	1616	82
2003 Review - Maximum	39.6	1239	65

It is also possible to calculate an average annual cost, known as Annualized Cost, which spreads costs over the project period, corrects for inflation during the project period, takes into account the mean lifetime of buildings, and includes running and maintenance costs. This technique has been described by Colgan and Gutiérrez [14], who used it to study proposals for a national programme of radon remediation in domestic dwellings in Spain. Current Northamptonshire estimates indicate the running costs of a fan to be £35 per annum, and that the fan itself would need replacing, on average, every 10 years at a current cost of £125. Every house in our series required a single fan to achieve the necessary reduction in radon level. We also assumed a 40-year accounting period. The calculation of Annualized

Costs also requires the use of a discount rate, based on the annual rate of inflation. At the time of the first paper, the UK government recommended the use of 10 %, matching the assumptions of Colgan and Gutiérrez [14], but this value has steadily dropped, and now the recommended values are 3.5 % for projects lasting 30 years or less, and 3 % for longer projects [31]. The latter value is used in this analysis. Using these assumptions, we estimate that the Annualized Cost of this programme would be as shown in Table III.

4. Discussion

The NHS Workplace study [8] reported a Collective Dose Reduction of 0.533 Man-Sievert per year for 135 affected staff working in 19 locations with raised radon levels, while this study reports a Collective Dose Reduction of 4.41 Man-Sievert per year for 212 occupants in 86 locations. In part this is due to a greater occupancy at home than at work, but also because radon levels are generally lower during the day. Therefore, the domestic radon remediation programme reviewed in this paper is more effective in achieving dose saving than the workplace remediation programme, which was carried out in the same locality.

In the UK, during the period when the householders in this series would have organised their initial tests, such measurements were provided free in Northamptonshire. Despite considerable publicity over many years, only 30 % of householders have organised such tests of their homes [23]. Further, only 5% of those householders finding results over the 200 $Bq{\cdot}m^{-3}$ Action Level had organised remediation by 1993 [32,33]. Lee and MacDonald [33], in their work, questioned householders about why they did not organise remediation, and one reason cited was that the discovery of a moderate level of radon was not considered worth taking action about. Our series confirms that this is the case in practice in a significant number of cases.

In 1996, Bradley [34] reported results of a postal questionnaire to 10500 householders with initial radon test levels over the Action Level. Of the 5000 questionnaires returned, 20 % had organised remediation. Assuming that those not returning the questionnaire had not organised remediation, Bradley suggested an overall uptake of 10 %. The reasons given by respondents for not carrying out remediation were evenly split between cost considerations and because they did not consider radon to be a hazard. It should be noted that, in Sweden where there is legislation requiring householders to remediation, the percentage of householders proceeding to remediation was higher, but still only 40 % [17].

Further, Denman *et al.* [29] have shown that those who remediate are not representative of the general population. The study cohort is less at risk, primarily because fewer of its members smoke, but also because they are older and have fewer children. This reduces cost effectiveness to 38.8 % of that calculated from straight extrapolation. This figure should thus be applied to the calculation of cost effectiveness of the current programme. Table IV summarises the impact on cost effectiveness of the current status of the remediation programme. It should be noted that the UK Department of Environment, Food and Rural Affairs (DEFRA) recently initiated a series of local roll-out programmes to raise awareness and increase the number of homes remediated. There are no studies yet to indicate whether these programmes have reached those most at risk, or just encourage more like-minded people to remediate.

Table IV- Cost Effectiveness of Domestic Remediation Programme in Northamptonshire to date assuming 10 % remediation, and risk profile as Denman *et al.* 2003

	Total Cost per Man-Sievert Saved in £1000s	**Total Cost per Lung Cancer Averted in £1000s**	**Annualized Cost per Lung Cancer Averted in £1000s**
1997 Review	156	12 600	577
2003 Review - Minimum	364	29 400	1304
2003 Review – Maximum	245	19 700	884

The current position in Northamptonshire, with around 10 % remediation and a population profile as found by Denman *et al.* [29], gives a range of Annualized Costs per annual lung cancer saved in our series from £884,000 for the NRPB estimate of the *top-end* number of houses to be found, to £1,304,000 for the *minimum*, as shown in Table IV. These figures are in excess as the value for the remediation programme in the NHS workplace [8], despite the fact that the Annualized Costs of the completed domestic programme are significantly below that in the Workplace. The Annualized Cost for the NHS workplace (2001 prices), with a 3 % discount rate is £388,000.

The lower risk of those who have remediated will reduce the estimate of the number of lung cancers averted by the domestic radon remediation programmer to date. Further, the reduction in the expected percentage of houses that will be found to be over the Action Level impacts on the estimated number of lung cancers that will eventually be averted once remediation programme is complete. Estimates of the lung cancers averted are given in Table V. It should be noted that such a reduction would be difficult to demonstrate at a county level, because of the impact of smoking prevalence on the lung cancer statistics. Further, any change will not become apparent for at least 15 years because of the latency period of lung cancer induction. This makes it impossible for even a successful public promotion and radon remediation programme to achieve the reduction in lung cancers expected of it in the NHS Cancer Plan 35.

Table V– Estimates of Lung Cancers related to Radon in Northamptonshire: assuming 10 % remediation, and risk profile as Denman *et al.* 2003

	Annual Lung Cancers averted when programme complete	**Residual Lung Cancers due to radon that cannot be averted (at current Action Level)**	**Lung Cancers averted by domestic radon remediation to date**	**Lung Cancers averted by new building programme**
1997 Review	23	42	0.22	1
2003 Review - Minimum	9	17	0.09	0.4
2003 Review – Maximum	14	26	0.14	0.6

Kennedy *et al.* [10] took the results from the initial analysis and extended them to estimate the cost per life year gained, based on the finding that, in Northamptonshire, lung cancer contributes, on average, to 13.51 life years lost. These estimates were updated in Coskeran *et al.* 38] using a larger data set. In both studies, the cost-effectiveness of remediation programmes in domestic properties in Northamptonshire was judged against other forms of health intervention designed to reduce the threat of lung cancer. Coskeran *et al.* [38] also assessed the remediation programmes in terms of whether or not they represented a cost-effective intervention for health improvement. To do this, they employed a criterion suggested by Gerber and Phelp [36] that health programmes can be considered cost-effective if the cost per life-year gained is less than double average income.

The cost-effectiveness threshold for Northamptonshire established using the Gerber-Phelps criterion (£29,218 in 2001 prices) is similar to the £30000 threshold associated with the National Institute for Clinical Excellence (NICE) in the UK. NICE do not have a formally published threshold for cost-effectiveness and their judgements on which technologies to recommend are not based on costs alone. But retrospective analysis of adjudications in their first three years of operation by Towse and Pritchard [37] suggested that NICE is unlikely to recommend NHS funding for projects with a cost per life-year gained above £30,000.

Kennedy *et al.* [10] showed that the radon remediation programme for domestic properties would be cost-effective on both criteria for Northamptonshire. Their estimate of cost per life-year gained was £17,155 (2001 prices). Coskeran *et al.* [38] divided the domestic properties into postcode classifications. They found that the remediation programme was cost-effective on the Gerber-Phelps criterion throughout the county apart from in the town of Northampton, where the estimated cost per life-year gained was £51,246 (2001 prices), well in excess of both threshold levels. It should be noted that in both studies a discount rate of 6 % was used. If a rate of 3.5 % had been applied in these studies, it would have reduced the cost per life-year gained.

The revised cost effectiveness estimates add further to the arguments of Coskeran *et al.* [38], who call into question whether it is cost effective to conduct domestic radon remediation programmes in areas with less than 5 % of housing above the Action Level, if a high response rate cannot be guaranteed. Until a reliable method of engaging public attention, and action, is found, the efforts in radon remediation should be concentrated in areas where high percentages of houses are over the Action Level.

UK policy has gone some way to observe this, as the Press Release for the current stage of the UK Radon Programme noted that the measurement programme offered free testing to every home with greater than a 5 % probability of being over the Action Level, and the new Roll-Out initiative is aimed at local authorities where there are areas with over 5 % of houses above the Action Level [39].

A critical issue is that remediation programmes must be designed to target those most at risk; something which the UK programme to date has not achieved.

The updated NRPB results also means that Affected Areas need no longer be defined on the County or District scale, but can be defined as areas as small as 5 km square. It is therefore possible to advise a householder whether their house is likely to be affected by reference to radon maps. This service has been launched by the NRPB and the British Geological Survey (BGS), and householders can obtain such advice, before deciding whether to test. The drawback to this information is that it will give statistical probability based on either the geology or existing domestic results. Neither of these will allay the concerns to the individual about the radon levels to which they are exposing themselves and their families. With proven accurate and economic testing available, testing would seem to be the more straightforward approach. If this were undertaken at the conveyancing stage of house sales, then the whole housing stock would be tested in due course.

5. Conclusions

An updated analysis of a series of radon remediation in domestic properties in Northamptonshire suggests that the dose-reduction is significant, and that completed programmes in Affected Areas where a high number of houses are remediated are significantly more cost-effective than workplace programmes in the same locality. However, the impact of the reduced estimates of the number of houses that will eventually be found over the Action Level is to lower the estimated cost-effectiveness compared to previous published studies. Although NRPB has designated radon Affected Areas with only 1 % of housing over the Action Level, it is only cost effective to target areas with 5 % over the Action Level.

Domestic programmes where few householders proceed with remediation may be cost effective, but are much more costly than programmes that achieve 100 % remediation of at-risk properties - partly because of the larger number of houses tested to achieve a remediation, but also because those who have remediated to date are among the least at risk from radon.

These findings support the need to carefully target radon remediation programmes, and develop schemes that are likely to engage a large percentage of the local population.

It is crucial that local authorities and Primary Care Trusts (PCTs) take into account these findings, and establish a realistic way forward in encouraging the public to measure and then remediate their homes in high radon areas.

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