A Cost-effectiveness Analysis of Domestic Radon Remediation in Four Primary Care Trusts located in Northamptonshire, UK

Thomas Coskeran
School of Accounting, Finance and Economics
Liverpool John Moores University
John Foster Building
98 Mount Pleasant
Liverpool
L3 5UZ
UK
Tel: +44 (0)151 231 3371
email: T.Coskeran@livjm.ac.uk

Antony Denman
Medical Physics Department
Northampton General Hospital
Cliftonville
Northampton
NN1 5BD
UK
Tel.: +44(0)1604 545450
Fax.: +44(0)1604 544612
e-mail: tony.denman@ngh.nhs.uk

Paul Phillips
SITA Centre
School of Environmental Science
University College Northampton
Boughton Green Road
Northampton
NN2 7AL
UK
Tel.: +44(0)1604 735500
e-mail: paul.phillips@northampton.ac.uk

Roger Tornberg
Radon Centres Ltd.
Moulton
Northampton
NN3 7UF
UK
Tel: +44 (0)1604 494118
email: rt@radon.co.uk

1. Introduction

Radon, a radioactive gas, is a threat to human health when found in even moderate concentrations in domestic buildings. Those living in such conditions face an increased risk of lung cancer brought about by elevated levels of exposure to radiation in the respiratory tract caused by the gas. Lubin and Boice (1997), Darby et al (1998), Kreienbrock et al (2001), and Darby et al (2002) all demonstrate this link between radon and lung cancer. National Research Council (1999) and Darby et al (2002) have also emphasised that the risk from radon is a linear one and that there is no threshold below which exposure to the gas is safe. As a result, [ ] estimates that in the UK some 2000 deaths a year result from exposure to radon. Where radon gas is found, therefore, a public health issue of concern to both health professionals and policy makers arises.

The existence of radon in the built environment is associated with certain geological formations and, as a result, tends to be concentrated in particular geographical areas. Green et al (2002) identify the location of raised radon levels in England and Wales. The UK's National Radiological Protection Board (NRPB) has designated those areas where more than one per cent of domestic properties have radiation levels over 200 Becquerels per cubic metre (Bq m^{-3}) as "Affected Areas". The county of Northamptonshire, UK, has been included amongst these since 1992.

In the case of Northamptonshire, the prevalence of radon reflects the underlying geology of sedimentary rocks from the Lower and Middle Jurassic periods. Radon levels are especially high where Northampton Sand Ironstone, Upper Lincolnshire Limestone, Marlstone Rock Bed and glacial sand and gravel are found. Phillips et al (2000) have moreover shown that high levels of permeability in the rocks found within the county lead to higher levels of radon exposure in the county's buildings than would otherwise be expected.

The NRPB has also defined 200 Bq m^{-3} as the UK Action Level for domestic properties. Where exposure is above this level, householders are advised to take steps to remediate against radon. An increasing literature exists, however, which shows that householders either do not wish or do not consider it necessary to remediate. Bradley et al (1997), Ryan and Kelleher (1999), Phillips et al (2000), and Eunkyung Park et al (2001) all identify such tendencies.

In addition to the inertia of householders, some authors have been sceptical of the benefits to be derived from remediating against radon. Abelson (1991), Peterson (1996) and Cohen (1997) have all cast doubt on the efficacy of remediation measures. In Northamptonshire, Coskeran et al (2002) question the cost-effectiveness of radon remediation within certain parts of the county. And Denman et al (2003) have suggested that it is actually householders least at risk from the effects of exposure to radon who remediate the most, a result which would indicate that remediation efforts are not always properly targeted.

Taken together, these issues place policy-makers in a dilemma. On the one hand they face a demonstrable threat to public health from the existence of radon gas. But on the other the inaction of householders suggests that measures to deflect the threat will be hard to implement. Against such a background, this paper attempts to address aspects of the current policy predicament in two ways.

First, it links the conduct of remediation programmes to a key set of local public policy-making bodies within the county, namely the primary care trusts (PCTs). As relatively new organisations, the PCTs have not yet developed full intelligence on the nature of the radon problem they face. The results obtained in this study will, therefore, be valuable for the development of public health policy within the relevant areas. Second, applying cost-effectiveness analysis allows comparison of costs involved in radon remediation with those of other interventions that can reduce the risk of contracting lung cancers. By considering approaches with a common outcome, in this case life-years gained from averting or treating lung cancers, it is possible to consider how radon remediation compares with the cost-effectiveness of other forms of health interventions. Policy-makers can then determine the appropriate use of resources to obtain the best outcome for their client populations.

In the next section, the nature of the PCTs within Northamptonshire and their role within the public health policy-making process is discussed. Section 3 considers the methods and data used to estimate cost-effectiveness within PCTs in Northamptonshire. In Section 4, the results obtained from this study are reported and Section 5 discusses the significance of these results for policy makers. Section 6 concludes with recommendations for action in PCTs.

2. Primary Care Trusts in Northamptonshire

The UK government set up PCTs across England and Wales in the period after 1999. Since 2002, they have had the prime responsibility for planning health services within their local communities and framing policy on public health matters. PCTs are, consequently, relatively new organisations with developing agendas to meet the health needs of their local populations.

In total, five PCTs serve the county of Northamptonshire. No data were available for this study on properties located in South Peterborough PCT, whose area of responsibility covers a small part of the north-east of the county. The discussion in this paper is, therefore, restricted to consideration of the four other PCTs that operate within Northamptonshire either solely or, as in the case of Cherwell Vale PCT, in part. These four PCTs do, however, account for 95% of the county's population.

Details on the population and budgets for the four PCTs, which are the subject of the discussion in this paper, are given in Table 1. Figure 1 shows the geographical location of the PCTs in relation to the radon map of the county.

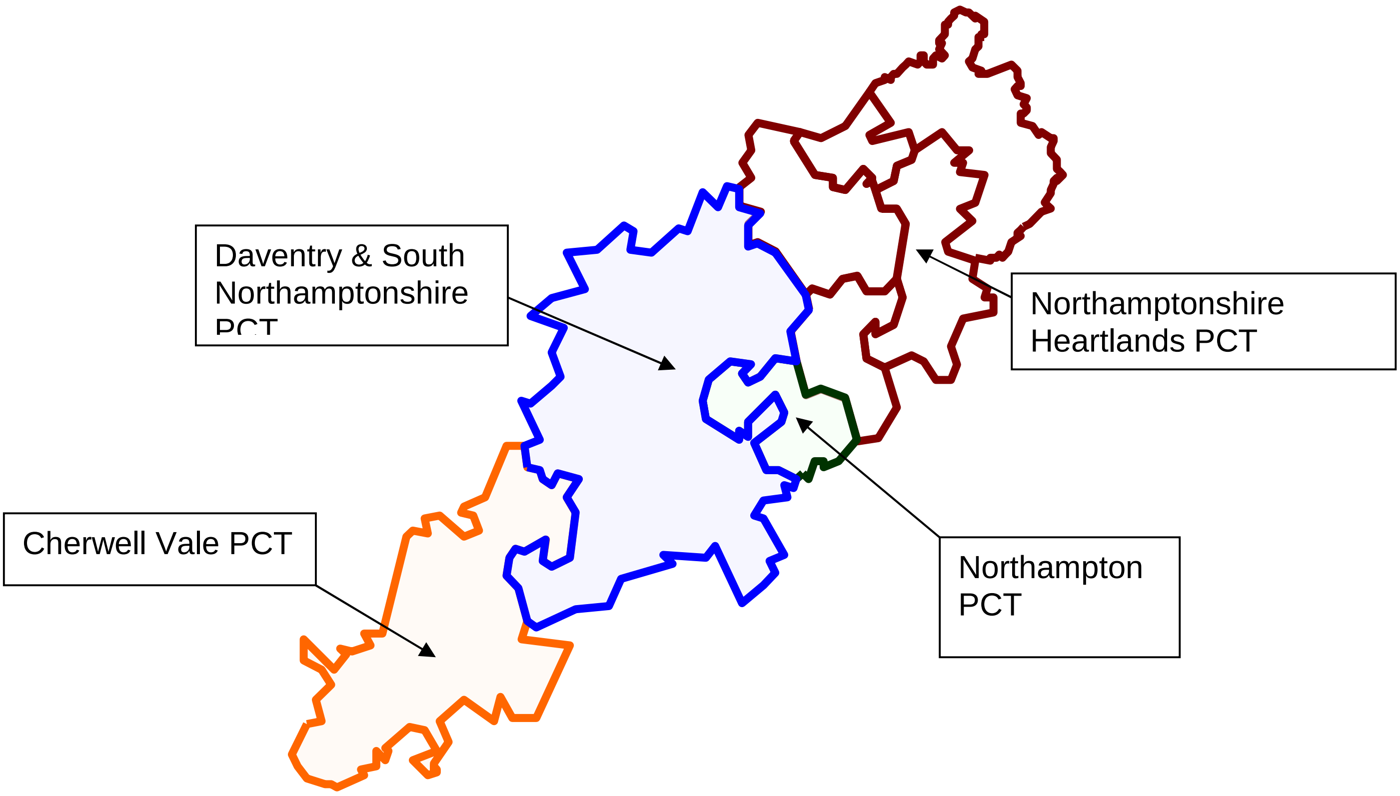
Table 1

PCTs in Northamptonshire

PCT	*Population*	*Budget (£million)*
Cherwell Vale[a]	122 009	79.6
Daventry & South Northamptonshire	101 006	71.7
Northampton	208 645	172.6
Northamptonshire Heartlands	283 758	222.2

Notes: [a] Cherwell Vale PCT covers only part of Northamptonshire. The population figures are the total for the PCT, which also operates within North Oxfordshire.

Figure 1: Northamptonshire PCTs and Radon Map



As Table 1 shows, these PCTs are substantial organisations in the local context. Despite this, they have not figured greatly in the development of policy towards radon remediation. Emphasis has, instead, been on local authorities taking initiatives at the district council level. Phillips et al (2000), for example, point to the importance of building regulations, which are under local authority control, in implementing radon remediation. This has been a significant factor in strengthening the role of local authorities. The UK's Department for the Environment, Food and Rural Affairs (2000) also emphasises their role and makes only passing reference to the place of health professionals in encouraging remediation efforts.

The situation, in part, reflects the relative newness of PCTs as organisations, but an imbalance in the relative roles of local institutions exists. This paper seeks to redress that balance by providing results for each PCT so that primary care health professionals can make informed choices about the public health benefits of radon remediation within their areas of local responsibility that will complement the existing activities of local authorities.

3. Method

The paper uses a significantly expanded version of a data series employed in Coskeran et al (2002). In that earlier paper, properties in Northamptonshire where householders had carried out remediation were analysed by postcode areas, the postcode of a property being a six- or seven-character representation of its location. In this paper, properties have now been classified by the PCT in which they are located. The classification was done using the postcode data on each property in combination with the *NHS User Postcode Directory*, which maps individual postcodes within England and Wales to PCTs. In total, the data series comprises details of 91 properties. This makes it one of the largest data sets in the UK with actual remediation data for domestic properties. Table 2 gives the numbers of properties in the data set by PCT as well as the percentage of all properties above the Action Level in each PCT.

Table 2: Remediated homes in Northamptonshire's PCTs

PCT	*Number of properties Remediated*	*Percentage of properties above Action Level*
Cherwell Vale	20	9.00
Daventry & South Northamptonshire	28	5.60
Northampton	30	5.10
Northamptonshire Heartlands	33	7.76
Total	91	

The percentage of properties above the Action Level for each of the PCTs was estimated from data in Green et al (2002). The latter give the percentage of properties above the Action Level for most postcodes to four characters within the Affected Areas of England and Wales. The estimate used here is a weighted average of the percentage of properties above the Action Level for all postcodes found within each PCT.[1]

The data in this study covers remediation programmes conducted between July 1993 and February 2003. The same contractor carried out all remediation works in line with the Radon Council's Code of Practice (1995). This work involves installation of sumps fitted with a fan, which extracts radon rich air and expels it into the atmosphere. Radon measurements before and after

[1] Where the percentage above the Action Level for a postcode to four characters was not available the percentage for the postcode to three characters was used instead.

remediation were taken in each property using the NRPB protocol[2]. Only properties with a validated result were used in the samples for each PCT. Radon levels were corrected by the contractor for seasonal variation using NRPB correction factors, again according to the Radon Council's Code of Practice (1995).

Exposure of residents to radiation was estimated using the average occupancy for Northamptonshire residents reported in Briggs et al (2003). They suggest a figure of 72 per cent of the day or 17 hours and 17 minutes per day. Residents were also assumed to have moved between rooms in a manner consistent with the NRPB weighted average radon level.

The total cost of the radon remediation programme in each PCT was estimated as the sum of:

- the imputed initial costs of radon measurement for properties in the PCT;
- the costs of remediation work on the properties;
- the cost of retesting properties after the remediation work;
- the cost of maintaining the remediation system (that is, the cost of operating the fans); and
- the cost of fan replacement every ten years.

The series only includes properties that have been remediated. These, however, are only a percentage of those above the Action Level, as not all householders with readings above this level choose to remediate. In addition, as Green et al (2002) show, only a proportion of properties even in Affected Areas will have readings above the Action Level. This implies that to obtain the number of properties that have remediated in each PCT and for which

[2] The protocol involves the use of two track etch detectors placed in the property for three months to obtain radon levels. One detector is placed in the main bedroom and the other in the living room. A weighted average of the two readings is found by taking 55% of the bedroom value and 45% of the living room. The detectors record the total radon exposure, but results reported for each household are expressed as a weighted corrected average radon level in Bq m^{-3} as the length of time of exposure is known.

data are available, the number of tests that needed to be carried out is given by the expression:

$$n/ar$$

where n is the number of properties in the sample for which remediation costs are available;

a is the proportion of properties in the PCT above the Action Level as estimated from Green et al (2002); and

r is the proportion of those above the Action Level who remediate.

The proportion of householders above the Action Level who remediate (r) is in this paper assumed to be 10 per cent. This is in line with results reported by Bradley (1996). The sensitivity of the results to changes in this assumption is, however, also examined.

To remove the effect of inflation on the values reported, all costs quoted are given in 2001 UK pounds. Values were converted into 2001 UK pounds using the price index series for housing repairs and maintenance charges given in the *Monthly Digest of Statistics*. Values throughout are given to the nearest pound. All cost figures are quoted excluding Value Added Tax, as cost-effectiveness should depend on the actual costs incurred in testing and remediation and not the rate at which the government levies this indirect tax.

The reduction in exposure to radiation that resulted from the remediation work was calculated using a method suggested by the UK Health and Safety Commission. This involves using, as Denman and Phillips (1998) show, an Equilibrium Factor of 0.5 and the relationship derived by the NRPB from epidemiological studies of the risk of radon that one milliSievert equals 126 000 Bq m^{-3} per hour. In turn, the number of estimated lung cancers averted due to the reduction in annual dose was calculated using the estimate given in NRPB (1993) that 3.5×10^{-4} lung cancers are induced per Working Level Month.

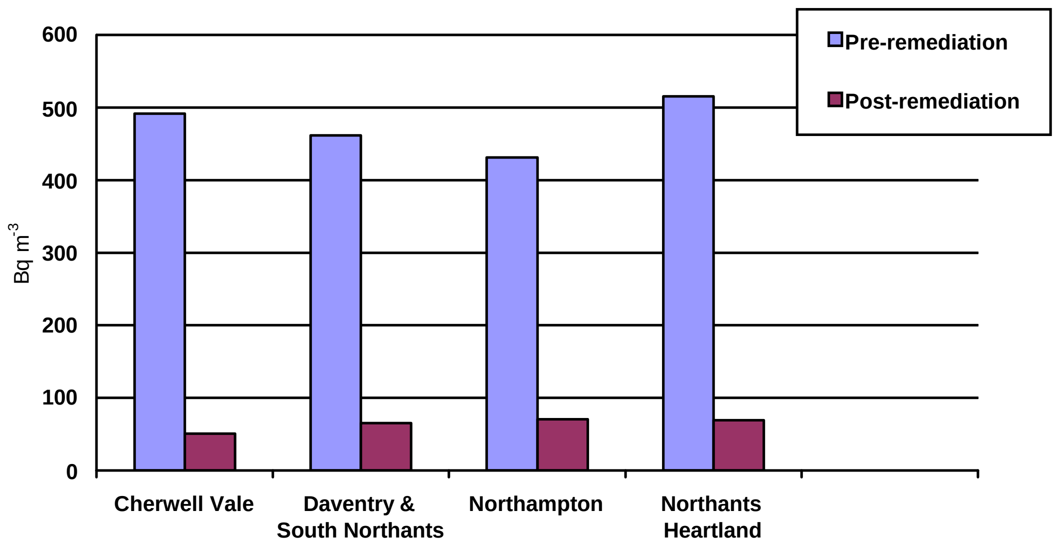
Averting lung cancers yields the benefit of additional life years to residents. Kennedy et al (1999) suggest that in Northamptonshire every lung cancer averted produces 13.51 additional life years. As the cost of obtaining these additional life-years is that of remediation, it is then a simple matter to determine the cost per life-year gained. The final figure obtained allows for comparison with the cost-effectiveness of other forms of intervention that can avert lung cancer.

In carrying out all calculations, both costs and life-years gained were discounted at a rate of 6 per cent. This does not correspond with the advice offered in HM Treasury (2003), which recommends a discount rate of 3 per cent for projects that last beyond thirty years, as is assumed to be the case in this paper. The decision not to use the advised rate was made to allow for comparison with other studies. The effect of using the lower rate would be to reduce the cost per life-year gained and, therefore, enhance the cost-effectiveness of the radon remediation programmes.

4. Results

Figure 2 shows the reduction in average levels of radon exposure in the four

Figure 2: Pre- and Post-Remediation Levels by PCT



Northamptonshire PCTs for which data were available. All four cases experienced reductions in average radon readings per household of more than 80%. As the data indicate, remediation of properties by a contractor following best practice will lead to average radiation levels after remediation that are well below the NRPB's Action Level. In addition, none of the properties in the series had final readings above the Action Level once remediation had taken place.

Further details on the impact of the remediation programmes on exposure to radiation are given in Table 3 for each PCT.

Table 3: Outcomes of the remediation programmes by PCT

PCT	*Number of properties*	*Average number of occupants*	*Average reduction in radon per household (Bq m^{-3})*	*Average reduction in annual dose (milliSivert)*	
				Per person	*Per household*
Cherwell Vale	20	2.00	440.80	22.00	43.83
Daventry & South Northamptonshire	28	2.46	396.46	19.79	50.73
Northampton	30	2.37	360.77	18.01	42.38
Northamptonshire Heartlands	33	2.64	446.00	22.26	60.70

As Table 3 demonstrates, each of the PCTs experienced different levels of reduction in average radon exposure. This was primarily due to differences in the initial values for exposure, as post-remediation results were broadly similar. The largest average reduction was in Cherwell Vale PCT, where the remediation programme brought about an average reduction of 89.6% in exposure to radiation. This is in line with figures for the rest of the UK discussed in Naismith et al (1998). The reductions in radon levels, Table 3 also shows, result in significant reductions in radiation doses for individuals.

Table 4 gives the costs of the remediation programmes in the different PCTs. The estimate of testing costs reflects the assumption that 10 per cent of householders above the Action Level will remediate, that is, r in the expression above equals 0.1. The percentage of properties above the Action Level for each PCT (a in the earlier expression) is taken from Table 2.

Table 4 illustrates the considerable variation in remediation costs between PCTs. For example, average remediation costs in the most expensive PCT, Northamptonshire Heartlands, are, at £724 per property, 30 per cent higher than in the cheapest, Northampton, where the comparable figure is £558.

Table 4

Costs of the remediation programmes by PCT

	PCT Costs (£)[a]			
Cost Headings	*Cherwell Vale*	*Daventry & South Northamptonshire*	*Northampton*	*Northamptonshire Heartlands*
Imputed Initial Testing Costs	76 756	148 832	175 170	126 647
Remediation programme	12 515	16 525	16 726	23 883
Testing after remediation	596	834	893	983
Operation of Fan [b]	15 046	21 065	22 569	24 826
Fan Replacements [b]	2 297	3 216	3 446	3 791
TOTAL COST[c]	**107 210**	**190 473**	**218 806**	**180 130**
Average Remediation Cost	626	590	558	724
Average Total Cost	5 360	6 803	7 294	5 458

Notes: [a] At constant 2001 prices. [b] Present value discounted at 6 per cent. [c] Totals may not add due to rounding error

Once the costs of pre- and post-remediation testing, and those of maintaining and operating fans are included, however, the relative standing of the various PCTs changes. Northampton becomes the most expensive and Cherwell Vale the least. Again, the variation in costs is large with Northampton's costs being 36% higher than those for Cherwell Vale.

Incurring these costs yields benefits in the form of reduced lung cancers and additional life years for residents who undertake remediation. The outcomes for each of the PCTs on these measures are shown in Table 5.

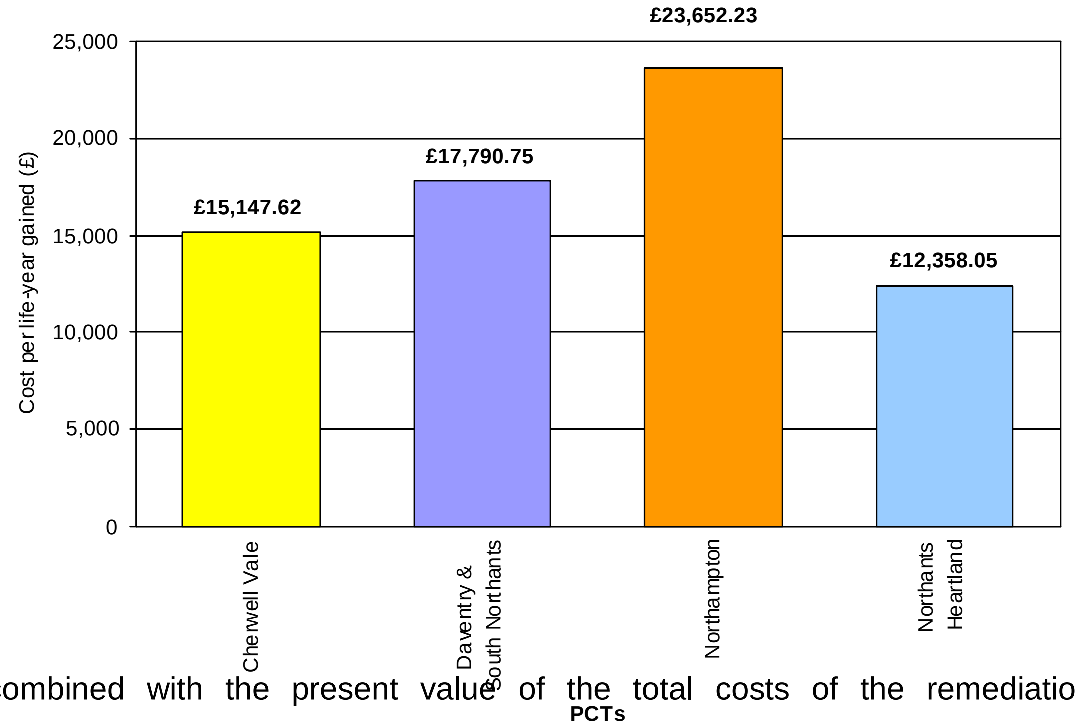
Table 5: Dose reduction, lung cancers averted and life years gained by PCT[a]

PCT	*Total man-Sv saved*	*Total Lung cancers averted*	*Total Life Years Gained*	*Present Value Life Years Gained* [b]
Cherwell Vale	35.064	1.184	15.998	6.379
Daventry and South Northamptonshire	58.852	1.988	26.851	10.706
Northampton	50.853	1.717	23.201	9.251
Northamptonshire Heartlands	80.124	2.706	36.556	14.576

Notes: [a] All values in the table are given for savings over a period of forty years. [b] A discount rate of 6 per cent is used for estimating the present value.

The calculation of the number of lung cancers averted is based on the assumption that the remediation undertaken will reduce exposure to radon over a forty-year period. When the reduction in lung cancers is translated into life-years gained, the resulting figure can be discounted to present values and

Figure 3: Cost per Life-Year Gained by Remediation in four PCTs



combined with the present value of the total costs of the remediation programme shown in Table 4. This gives the cost per life-year gained for each PCT's remediation programme. The results by PCT on this measure are shown in Figure 3. As the figure confirms, the cost per life-year gained varies considerably between the four PCTs. Northampton at the highest cost is almost double that of the lowest cost PCT, Northamptonshire Heartlands.

5. Discussion

The results above indicate how cost-effectiveness can vary between geographically proximate PCTs when faced with a similar policy problem. In terms of cost-effectiveness, tackling radon remediation would, on the average, be more appropriate in Northamptonshire Heartlands PCT than in Northampton PCT. Even in Northampton, however, there is a case for seeing radon remediation as cost-effective, as is discussed below.

Variations in cost-effectiveness can reflect differences in the percentage of properties within each PCT above the NRPB's Action Level. In general, cost-effectiveness in an area will, other things being equal, improve as the percentage of properties above the Action Level increases. This occurs because fewer properties need to be tested in areas with higher percentages to find those properties that require remediation. Testing costs are, as a result, lower. In Coskeran et al (2002) there was a significant relationship between the percentage of properties above the Action Level and cost-effectiveness when properties in Northamptonshire were considered by postcode. In this paper, however, the link is not strong. Cherwell Vale PCT, for example, has the highest percentage of properties above the Action Level but is not the most cost-effective. Also, Northampton PCT has a similar percentage of properties above the Action Level to Daventry and South Northamptonshire PCT, but has a cost per life-year gained that is 33% higher.

These results would suggest that benefits gained from remediation programmes are playing a more significant role in determining cost-effectiveness when the analysis of properties is carried out by PCT rather than by postcode. This can be explained by the geological homogeneity of areas where properties have the same postcode. Average reductions in radiation per property in that case are similar and, consequently, not as important in determining differences in cost-effectiveness. In the case of analysing by PCT, where average reductions in radiation per property are different, the reduction in radiation has a bigger impact on determining cost-effectiveness than does the percentage of properties above the Action Level.

The remediation programmes can also be assessed in terms of whether or not they represent a cost-effective intervention for health improvement. Gerber and Phelps (1997) have suggested that health programmes can be considered cost-effective for such purposes if the cost per life-year gained is less than double average income. The latest available figure in Office for National Statistics (2002) for Northamptonshire's GDP per head is from 1998 and was £13 369 at current prices. On a conservative assumption of three per cent growth per annum in nominal GDP per head between 1998 and 2001, this would give a figure of £14 609 for Northamptonshire GDP per head in 2001. The associated Gerber-Phelps threshold in that year would then be £29

218. In all four PCTs, the cost per life-year gained, Figure 2 shows, is less than this threshold figure when it is assumed that ten per cent of householders above the Action Level remediate.

The figure for the Gerber-Phelps threshold is, it should be noted, similar to the £30 000 cut-off point recommended by the National Institute for Clinical Excellence (NICE) in the UK. As Raftery (2001) suggests, NICE is unlikely to recommend NHS funding for projects that have a cost per life-year gained higher than this figure. On both criteria, therefore, the remediation programmes in all four PCTs are cost-effective for policy purposes.

Cost-effectiveness can also be improved, however, if the percentage of households above the Action Level that remediate could be increased above the ten per cent level assumed in this study. By improving this proportion, a reduction in the costs shown in Table 4 would follow from the reduced number of initial tests that would be needed to bring about a given number of remediations and the associated gain in life-years.

Thomas and Hobson (2000) looked at how improvements in this remediation rate could be achieved in Cherwell District Council, which covers some of the area serviced by Cherwell Vale PCT, and two other local authorities. They suggest that properly conceived programmes of support for those testing above the Action Level could raise percentages remediating by between twelve and fourteen percentage points. This makes it feasible that twenty five per cent or more of all householders with elevated radon test results above the Action Level could then remediate.

To test for the effect of such changes, Table 6 provides indicative results for the four PCTs in situations where 15, 20 and 25 per cent of householders remediate. For completeness, a figure for 5 per cent of householders remediating is also included. The results in Table 6 confirm that if initiatives were pursued to raise the percentage of householders remediating then cost-effectiveness would be further enhanced for all the PCTs.

Table 6: Cost per life-year gained for varying percentages of householders who remediate

	Percentage of Householders above the Action Level who remediate				
PCT	*5*	*10*	*15*	*20*	*25*
Cherwell Vale	£25 521	£15 148	£11 690	£9 961	£8 924
Daventry & South Northamptonshire	£31 692[a]	£17 791	£13 157	£10 840	£9 450
Northampton	£42 588[a]	£23 652	£17 340	£14 185	£12 291
Northamptonshire Heartlands	£21 047	£12 358	£9 462	£8 014	£7 145

Note: [a] Values that would not be cost-effective under the Gerber-Phelps criterion.

The figures in Table 6 do not take account of the cost of the programmes that would be needed to encourage increased remediation. These costs would, therefore, have to be included in any final assessment of cost-effectiveness. There may also, as Eunkyung Park et al (2001) suggest, be resistance to information programmes promoting remediation if they are not properly constructed. Such difficulties may add to the costs of the programmes. But as the programmes in all the PCTs would appear to be cost-effective by some margin if ten or more per cent of householders remediate, they would only cease to be so if the costs of programmes to encourage remediation reached relatively high levels. In the case of Northampton PCT, for example, if 15 per cent of households were to remediate, the remediation programme remains cost-effective on the Gerber-Phelps criterion provided the costs of promoting remediation are less than £109 880. This, it should be noted, is the lowest available budget for a putative remediation programme.

Table 6 also suggests that even if remediation levels among householders fell to five per cent in Cherwell Vale and Northamptonshire Heartlands PCTs, they would remain cost-effective. This suggests a robust case for PCTs in these two areas to be engaged with encouraging remediation.

It is also possible, using the Gerber-Phelps criterion, to determine the percentage of properties above the Action Level that must be found in the PCT for the remediation programme to remain cost-effective. The calculation assumes the proportion of householders remediating remains at ten per cent and that all other factors are constant. Results are given in Table 7.

Table 7: Percentage of properties above the Action Level necessary to ensure cost-effectiveness

PCT	*Percentage*
Cherwell Vale	3.82
Daventry & South Northamptonshire	3.08
Northampton	3.94
Northamptonshire Heartlands	2.64

These results suggest that where the percentage of properties above the Action Level is less than the figure for the PCT given in Table 7, remediation would not be cost-effective. They call into question the NRPB's notion of identifying radon Affected Areas as those with more than one per cent of properties above the Action Level. If areas have between one and three per cent of properties above the Action Level they will not, at least in the case of

Northamptonshire PCTs, be cost-effective targets for remediation programmes. This point was first raised in Coskeran et al (2002) where a figure of five per cent was suggested as a possible indicator of action. Using these latest figures, a threshold figure of between three and four per cent seems more appropriate for identifying an Action Level when the cost-effectiveness of remediation work is taken into account. This remains, though, an issue into which further investigation is required.

The cost-effectiveness of the programmes can also be compared with other means of saving life years through reducing the number of cases of lung cancer. NICE, for example, have suggested that the cost per life-year gained from providing advice on giving up smoking is of the order of £2 000. Clegg et al (2001), in assessing the overall effectiveness of certain new drugs - vinorelbine, gemcitabine, paclitaxel and docetaxel – that can be used to treat non-small-cell lung cancer report a cost per life-year gained of between £2 194 for vinorelbine and £17 546 for docetaxel. Wake et al (2002) estimate that continuous hyperfractionated accelerated radiotherapy as a treatment for lung cancer had a cost per life-year gained of £11 227.[3] And Coyle and Drummond (1997) suggest a figure of £36 950 per life-year gained for hyperfractionated radiotherapy alone. The costs per life-year gained quoted in this paper, therefore, sit in the middle of a range of possible interventions that can reduce lung cancer treatments.

6. Conclusions

The study of the four Northamptonshire PCTs suggests that the pursuit of radon remediation programmes within these PCTs is likely to be cost-effective provided sufficient householders remediate. The cost-effectiveness of the programmes is demonstrated by reference to standard criteria for determining cost-effectiveness for policy purposes in health care settings. Comparison

[3] The studies do not identify in which year's prices these money values are denominated. But this should not make a significant difference to the actual figures quoted or the conclusions arrived at here.

with other forms of intervention for treating and averting lung cancer confirm the relative cost-effectiveness of these programmes. Cost-effectiveness will also be improved in those PCTs where a higher percentage of properties above the NRPB's Action Level of 200 Bq m^{-3} is found and where a greater percentage of householders remediate. These conclusions would suggest two courses of action for PCTs wishing to address the public health issues raised by the incidence of radon in their areas.

First, PCTs should consider how they might contribute to the encouragement of remediation among householders. In the past, this has been left to local authorities, and yet primary care practitioners, as Baldwin et al (1998) have noted, are in a key position to be able to transmit messages about the health hazards caused by radon. General practitioners, for example, could be expected to discuss radon with patients in the same way that they are encouraged to raise the issue of smoking. Indeed, there may even be, as Lee et al (1999) propose, synergistic benefits to be had from linking the discussion of these two health hazards. In the instance of smoking, GPs advising interventions has been estimated by Buck et al (1997) to have a cost per life-year gained of between £94 and £545 depending on the extent of the advice offered. If comparable figures were to those for radon remediation quoted in this paper, it would still mean that radon remediation in these fours PCTs would be a cost-effective approach to reducing lung cancers.

The second course of action open to PCTs is to identify within their own localities those areas where the proportion of properties above the Action Level is high. Even within relatively small geographical locations, there can be, as Green et al (2002) demonstrate, considerable variation in the percentage of properties above the Action Level. By identifying those areas at the level of postcode, or, perhaps, electoral ward, it would be possible to focus the PCT's effort to encourage remediation on those general practices whose patients fall within these boundaries. As Thomas and Hobson (2000) point out, an emphasis on local delivery of the health benefits of remediation is crucial in bringing about improved remediation rates.

These two courses of action should then be concentrated within those parts of a PCT where the percentage of properties above the Action Level is high but the current rate of remediation is low. The pay-offs from pursuing such a policy are likely to be best in these areas. Denman et al (2003), for example, suggest that there is considerable scope for identifying householders who have not yet remediated but for whom remediation would be a highly desirable course of action. Identifying these groups should become a priority for the PCTs. This approach may involve some initial work identifying these elements in the PCTs' local population, but the results of this paper suggest that significant health benefits delivered in a cost-effective manner would follow.

In addition to their own initiatives, PCTs can also draw upon the experience and expertise of local authorities in their locality. In the case of Northamptonshire's PCTs, the geographical boundaries of local district councils are not entirely consistent with their own boundaries, but the case for accessing the knowledge and expertise of these organisations is self-evident. By taking such actions, PCTs in Northamptonshire and elsewhere will be drawing on the evidential base provided in this paper. They will also be introducing the role of health professionals into an area where it has been lacking in the past.

References

Abelson P (1991), Radon today: the role of flimflam in public policy, *Regulation*, 14(4): 95-100

Baldwin G, E Frank and B Fielding (1998), US women physicians' residential radon testing practices, *American Journal of Preventive Medicine*, 15 (1): 49-53

Bradley E J (1996), Responses to radon remediation advice *Proc. 9th Int. Congress International Radiation Protection Association* 4-798 - 4-800

Bradley E J, Lomas P R, Green B M R and Smithard J, (1997) Radon in dwellings in England: 1997 Review *National Radiological Protection Board Report R293* (Didcot, Oxfordshire., UK)

Briggs D J, A R Denman, J Gulliver, R F Marley, CA Kennedy, PS Phillips, K Field and R M Crockett (2003), Time-activity modelling of domestic exposures to radon, *Journal of Environmental Management*, Vol 67, No 2, p107-120

Buck D, Godfrey C, Parrott S, and Raw M (1997), *Cost effectiveness of smoking cessation interventions,* Health Education Authority, London

Clegg A, DA Scott, M Sidhu, P Hewitson, and N Waugh (2001), A rapid and systematic review of the clinical effectiveness and cost-effectiveness of paclitaxel, docetaxel, gemcitabine and vinorelbine in non-small-cell lung cancer, *Health Technology Assessment 2001*; 5 (32)

Cohen B (1997), Problems in the radon vs. lung cancer test of the linear no-threshold theory and a procedure for resolving them, *Health Physics*, 68(2): 157-174

Coskeran T, A Denman, P Phillips and G Gillmore (2002), A critical comparison of the cost-effectiveness of domestic radon remediation programmes in three counties of England, *Journal of Environmental Radioactivity* 62 (2002): 129-194

Coyle D and Drummond M (1997), Costs of conventional radical radiotherapy versus continuous hyperfractionated accelerated radiotherapy (CHART) in the treatment of patients with head and neck cancer or carcinoma of the Bronchus, *Clinical Oncology,* 9:313-321.

Darby S, Whitley E, Silcocks P, Thakrar B, Green M, Lomas P, Miles J C H, Reeves G, Fearn T and Doll R (1998) Risk of lung lancer associated with residential radon exposure in South-West England: a case-control study *Brit. J. Cancer* 78 394-408

Darby S, Hill R and Doll R (2002), Radon: a likely carcinogen at all exposures *Ann. Oncol.* 12 1341-1451

Denman A (2003) et al

Denman A R and Phillips P S (1998), A review of the cost effectiveness of radon mitigation in domestic properties in Northamptonshire, *J. Radiol. Prot.*18 119-124

Department for Environment, Food and Rural Affairs (2000), *Radon Good Practice Guide* PB 7933

Eunkyung Park, C Scherer and C J Glynn (2001), Community involvement and risk perception at personal and societal levels, *Health, Risk and Society*, 3 (3): 281-292

Gerber A and C Phelps (1997), Economic foundations of cost-effectiveness analysis, *Journal of Health Economics*, 16: 1-31

Green, B M R, Miles, J C H, Bradley, E J, and Rees, D M, (2002) *Radon Atlas of England and Wales*, Chilton, NRPB-W26

HM Treasury (2003), *The Green Book: Appraisal and Evaluation in Central Government*, London, The Stationery Office

Kennedy C A, Gray A M, Denman A R and Phillips P S (1999), A cost effectiveness analysis of a residential radon remediation programme in the United Kingdom, *Brit. J. Cancer* 81 243-247

Kreienbrock L (2001), Kreuzer M, Gerken M, Dingerkus G, Wellmann J, Keller G and Wichmann H E, Case-control study on lung-cancer and residential radon in Western Germany *Am. J. Epidemiol.,* 153 42-52

Lee M, E Lichtenstein, J A Andrews, R E Glasgow and S E Hampson (1999), Radon-Smoking Synergy: A Population-Based Behavioral Risk Reduction Approach, *Preventive Medicine*, 29: 222-227

Lubin J and J D Boice (1997), Lung cancer risk from residential radon: a meta-analysis of eight epidemiological studies, *Journal of the National Cancer Institute*, 89(1): 49-57

Naismith S, J C H Miles and C R Scivyer (1998), The influence of house characteristics on the effectiveness of radon remedial measures, *Health Physics*, 75 (4): 410-416

NRPB (1993), Estimates of late radiation risks to the UK population, Documents of the NRPB, 4(4), Chilton, UK

National Research Council (1999) *Health Effects of Exposure to Radon BEIR VI* Washington DC: National Academy Press

Office for National Statistics (2002), *Regional Trends*, 37 London UK: Office for National Statistics, The Stationery Office

Peterson M (1996), Two models for assessing environmental health policy: the case of radon in U.S.homes, *Management Science*, 42:1476-1492

Phillips P S, J D Fraser and A R Denman (2000), Effectiveness of secondary radon protection in Northamptonshire houses, *Environmental Management and Health*, 11(4): 337-352

Radon Council The, Ltd (1995), *The Radon Manual: a guide to the requirements for the detection and measurement of natural radon levels associated with remedial measures and subsequent monitoring of results* (London, UK)

Raftery J (2001), NICE: faster access to modern treatments? Analysis of guidance on health technologies, *[British Medical Journal]* 323:1300-1303

Ryan D and C C Kelleher (1999), A survey of householders' mitigation strategy, *European Journal of Public Health*, 9(1): 62-64

Thomas A and Hobson J (2000), Review and evaluation of the radon remediation pilot programme, *Department of the Environment, Transport and the Regions Report* No. DETR/RAS/00.004 (London, UK)

Wake B.L., Taylor, R.S., Sandercock, J. (2002), *Hyperfractionated/ accelerated radiotherapy regimens for the treatment of non-small cell lung cancer. A systematic review of clinical and cost-effectiveness.* Birmingham: University of Birmingham, Department of Public Health and Epidemiology, January 2002.