The Impact of improved Radon Mapping on the Cost Effectiveness of UK Domestic Radon Remediation Initiatives for Existing Housing

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ABSTRACT

In the UK, excessive levels of radon gas have been detected in the built environment, including domestic housing. Areas where 1% of existing homes were found to be over the Action Level of 200 Bq m^{-3} were declared to be Radon Affected Areas. Initially these areas followed administrative boundaries, known as counties. However, with increasing number of measurements of radon levels in domestic homes recorded in the national database, these areas have been successively refined into smaller. This, together with improved geological mapping, has led to more precise definition of radon-affected areas.

One result is the identification of small areas with raised radon levels within counties where previous analysis had not shown a problem. In addition, some parts of areas that were considered Radon Affected are now considered low or no risk. Our analysis suggests that the net result of improved mapping is to increase the number of houses which should be tested.

The changes should ensure that more affected houses are identified, but this depends on the public response to publicity of the new affected areas, which, despite various publicity campaigns, only around 40% of house-holders in affected areas have measured radon levels, and only 15% of those finding raised radon levels have remediated their homes.

Our group has assessed the actual and potential cost-effectiveness of the latest remediation campaigns. It is noted that the additional step will add only a marginal cost. Moreover, cost-effectiveness remains strongly dependent on the percentage of houses over the action level in an area, and on the percentage of householders who carry out remediation once they have found high levels. At current response rates, our research suggests that remediation programmes are not currently justifiable in areas where less than 5% of houses are affected.

KEYWORDS: Radon, Remediation, Radon Affected Areas, Domestic Houses, Radon Mapping, Cost Effectiveness

1. INTRODUCTION

The naturally-occurring radioactive gas, radon (Rn-222), is the second most significant risk for lung cancer after tobacco smoking. High levels of radon were first identified in uranium mines, but more recently, it has been established that significant levels are found in the built environment, including domestic housing, and case control studies have shown an associated increase in lung cancer, which has a linear relation to radon level (BEIR VI, 1999; Darby *et al.*, 2005).

In the UK, sections of the country where 1% of existing homes were found to be over the Action Level of 200 Bq m^{-3} were declared to be Radon Affected Areas (RAAs) (NRPB, 1990). The UK has a number of geographical areas with raised radon levels, of which the county of Northamptonshire is one, with 7.1% of homes measured as having radon levels over the UK domestic Action Level of 200 Bq m^{-3} (Rees *et al.*, 2011). The current UK methodology to reduce radon risk in the home has two elements. Firstly, new homes in RAAs are required to be fitted with radon protection – basic protection if the area has over 3% and less than 10% of existing houses over the Action Level, and full protection if over 10%. Secondly, for existing homes, the methodology is to encourage householders in RAAs to test their homes for radon, identifying homes with raised levels, and then encouraging their householders to take remedial action. Remediation is provided by a number of commercial companies, and standards of work are determined by Radon Council Guidelines. There have been a number of local campaigns in high radon areas where free testing has been provided, a few cases where a means tested grant for remediation work has been provided, and a new local initiative in Cornwall where some costs and guidance are provided where radon levels are over 10,000 Bq m^{-3}, but generally the householder is required to pay the costs.

Radon levels in homes can be tested simply and at low cost (£49.80 including all taxes, 2012 prices, http://www.ukradon.org), and, if raised radon levels are found, remediation work, usually involving the introduction of a sump and attached pump to extract radon to outside and costing around £850, will reduce radon levels nearly always well below the Action Level. Over the last 15 years, campaigns in UK RAAs to measure and reduce radon in the home have been implemented through the local councils' environmental health departments.

Initially RAAs followed administrative boundaries, known as counties (Bradley *et al.*, 1997). However, with increasing numbers of measurements of radon levels in domestic homes recorded in the national database, these areas have been successively refined into smaller units – down to 1 km grid squares in 2007 (BRE, 2007). This, together with improved geological mapping, has led to more precise definition of RAAs.

One aspect of these changes is to identify small areas with raised radon levels in regions where the older analysis had not shown a problem, while some locations that were considered RAAs, with more precise mapping, are now in areas of lower radon potential, or none.

This paper discusses the implications of the improved mapping and its impact on the future development of radon remediation programmes in the UK.

2. THE DEVELOPMENT OF RADON MAPPING

2.1 Radon Measurements and Mapping

The initial phase of radon measurements in the UK conducted by the National Radiological Protection Board (NRPB) led to the identification of RAAs which followed administrative boundaries, known as counties, with areas of over 500 km^2. Northamptonshire, for example, in the centre of England, was declared a RAA by the NRPB in 1992 (NRPB, 1992). Guidance for protective measures in new homes in specific identified areas was published by the Building Research Establishment (BRE) and became enforceable in law from 1993 (BRE, 1992). For existing homes there are no legal requirements, but, as noted above, householders in RAAs are encouraged to test for radon, and remediate, if appropriate.

The NRPB continued to make and collate measurements in existing homes across the UK, including parts of England where measurements were limited, Scotland, Wales and Northern Ireland. This has led to a continuing series of ever more detailed reports (Bradley *et al.*, 1997, Green *et al.*, 1992; 1999; 2002; 2008; 2009, Kendall *et al.*, 1994, Lomas *et al.*, 1996; 1998, Miles *et al.*, 2007, NRPB, 1993a; 1993b; 1996a; 1996b; 1998; 1999) – a process that has continued since NRPB was absorbed into the HPA (Health Protection Agency). By 2009, HPA had recorded more than 480,000 measurements of radon levels in homes in England (Rees *et al*., 2011). Rees *et al*, (2011) note that most measurements have been targeted on houses in high radon areas, and that only one fully representative UK survey has been carried out, reported by Wrixon *et al*., (1988).

2.2 Geological Mapping

In parallel with the radon measurement and mapping programme, the British Geological Survey has been grouping radon measurements by geological boundaries in England. By 1999 this mapping was sufficient to produce 1:50,000 maps of radon potential of different rock types. The development of radon potential mapping has been described in a sequence of papers (e.g. Appleton, 2004, Appleton and Miles, 2010, Miles, 1998, Miles and Ball, 1996) which stress that due to the multiplicity of factors which can influence radon levels, such mapping can only indicate geographical variation in the probability that buildings in a given area may exceed the radon Action Level; assessment of individual cases requires site-specific measurements.

During the 1990s, the resolution and indeed coverage of radon potential maps was constrained by paucity of data in some parts of the UK and by the need to digitise geological maps in many areas (Miles, 1998, Miles and Ball, 1996, Green *et al*., 2008). Nonetheless, significant advances were made in mapping for England and Wales by combining approaches of mapping of household radon data by geological unit (at 1:50,000 scale) and 5km grid squares (Miles, 1998). By 2004, the British Geological Survey and NRPB were collaborating in the production of maps of the most radon-prone areas in England and Wales at a resolution of 1km grid squares (Appleton, 2004).

The approach taken in Scotland has been somewhat different, with relatively small samples of household radon measurements in the 1980s indicating average radon concentrations for Scotland being below the UK average, but with four areas of elevated concentrations around Dalbeattie, Ballachulish, Helmsdale and Aberdeen and the Dee Valley (Green *et al.,* 2008). A concerted mapping programme since 2000, has provided a fuller picture, based on 5km grid maps, which have revealed additional at risk areas in the Scottish Border, Great Glen and Orkney Mainland (Green *et al.,* 2008).

Given the complexity of factors which can influence radon potential within individual buildings, it is important that the reliability of the mapping described above be assessed. Recent work (Appleton and Miles, 2010), has reported statistical analyses which have tested the widely reported assumption that geology is a major control on the variation of indoor radon potential. Previous work indicated that at broad scales, geological factors only account for relatively modest proportions of explanation of indoor radon variation. However, at the scales described above and with the inclusion of superficial as well as bedrock geology, geological factors can be shown to contribute 34-40% of explanation of this variation (Appleton and Miles, 2010).

3. THE IMPLICATIONS OF IMPROVED RADON MAPPING

Improved radon mapping, together with improved geological mapping, has led to more precise definition of RAAs, and revisions to the BRE guidance. The 1999 revision of BR211 (BRE, 1999) contained both radon and geological maps using a 5 km grid, with the value of radon potential determined by each map graded in three levels. The implications for a specific location could be interpreted by using a matrix square (Miles, 2000). In the 2007 revision, these two maps had been replaced by a single hybrid map using a 1 km grid (BRE, 2007). The HPA Indicative Atlas (Miles *et al*., 2007) on which the 2007 revision is based is also a hybrid map. Whilst previous reports gave the average radon potential in a unit grid, the Indicative Atlas gives the highest radon potential within a 1 km grid where there are sufficient results to consider areas smaller than the unit grid.

While the legislation for new homes is linked to the BRE Guidance, which contains maps and was last revised in 2007, the advice for existing homes is based on the NRPB (and subsequently HPA) reports. The latest HPA Atlas (Miles *et al*., 2007) has also been reproduced as an electronic map which utilises the highest resolution of the current radon dataset, and is regularly updated. The electronic map can be interrogated by inputting either post-code or ordnance survey map reference (ukradon website, 2012). This system is now available to householders who can pay a modest amount to obtain an estimate of the radon potential of their home, and receive advice as to whether a radon measurement is advisable.

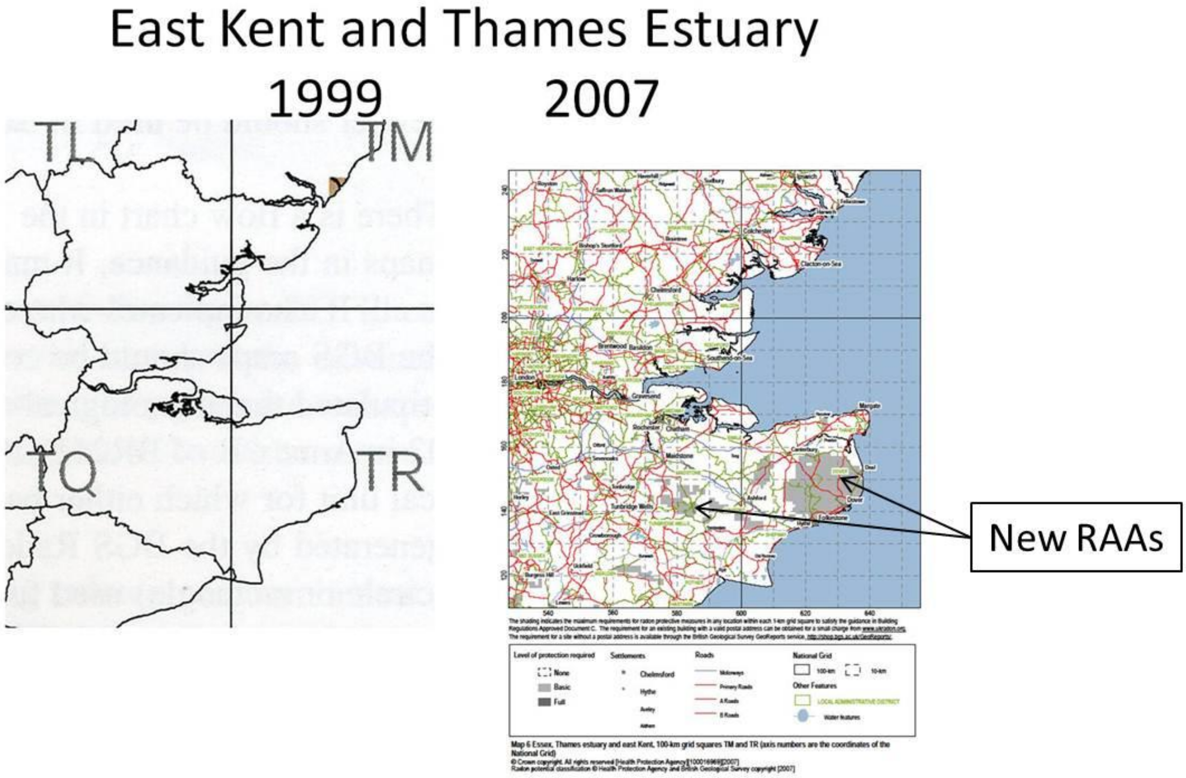

Figure 1: **Radon Affected Areas in Kent; comparison of 1999 and 2007 maps.**

One aspect of these changes is to identify small areas with raised radon levels in regions throughout England and Wales where previous analyses had not shown a problem – for example parts of the South Downs in Sussex, and between Canterbury and the Channel ports in Kent (see Figure 1), both associated with Cretaceous Chalk strata. Killip (2005) had earlier demonstrated through detailed local mapping that elevated radon levels in Sussex are associated with the Lower Campanian Tarrant Member of the Culver Chalk (cf. Mortimore, 2011) and also more particularly with Tertiary and Quaternary deposits overlying this Chalk. Killip noted the similarity between post-Cretaceous deposits in the South Downs and northern France, with the latter being derived from erosion of Maastrichtian Chalk and possibly containing high levels of uranium due to the occurrence of phosphate-rich material. Jarvis (2006) confirmed the widespread occurrence of granular phosphates in Chalks of Santonian-Campanian age in southern England. Radon levels in dwellings would then be strongly related to gas migration in response to permeability and fissuring of geological substrate. It is possible that similar mechanisms have affected the Upper Chalk of the North Downs. The latest maps must place emphasis on the geology, since the declaration of the RAA near Canterbury is based on only 993 dwellings tested in the whole of Kent, with 9 found to be above the action level.

In addition, some parts of areas that were considered Radon Affected Areas are now considered low or no risk. The change in the number of potentially affected houses has been estimated by visual comparison of the 1999 and 2007 maps to identify the areas, towns and cities where designation has changed, and finding the numbers of houses from local and national statistics. The major conurbations of London, Manchester, Birmingham and Leeds remain low radon areas. Our analysis suggested that the net result of the improved mapping increased the number of houses which should be tested, as indicated in Table 1, although there are also a significant number of houses within areas which could not be categorised by this method.

%age of Affected Houses in Area	Number of Houses
>3% but <10% in 2007; not affected in 1999	920,985
>3% with some >10% in 2007; not affected in 1999	167,101
>10% in 2007; not affected in 1999	297,984
Total Houses in newly identified RAAs	*1,386,070*
Unclassifiable by method used	6,616,007
In Radon Affected Areas in 1999	1,068,844
Not in Radon Affected Areas, 1999 and 2007	13,493,322
Total Housing Stock	***22,564,243***

Table 1 – Classification of Existing Housing Stock in England and Wales 2008/9 into Radon Affected Areas in BR211, 1999 and 2007 editions

Table 1 suggests that around 1.4 million additional houses require testing for radon levels, compared to the 1999 guidance (BRE, 1999), as a result of more detailed mapping. However, the move to mapping by the maximum rather than average radon level in each grid square will result in identifying a lower percentage, than this maximum which will need remediation measures. As radon levels in a group of houses follows a log-normal distribution, the percentage requiring remediation will be skewed to less than half of the maximum.

3.1. Public Response Rates

Alongside the developments in radon measurement and mapping in UK, public health campaigns have been run in RAAs to encourage householders to measure and then if appropriate, to reduce radon in their homes. Historically, these initiatives have been implemented through the local councils' environmental health departments. Initial response rates for house testing in 1991-2 were around 12%, rising through a series of repeat initiatives in the late 1990s to 34 %. Pilot studies demonstrated that localised publicity, involving the local councils and health agencies, improved response (Stopps, 2008). Despite quite extensive publicity, only around 40% of householders in RAAs have tested radon levels in their home, and of those who discover raised levels, only 15% remediate their homes (Zhang *et al*., 2010).

Our group has studied the characteristics of those who remediate their homes, and has shown that they are older, have fewer children, and include fewer smokers than the general population (Denman *et al*., 2004). The risks from radon and smoking are considered to be sub-multiplicative (BEIR VI, 1999), and so smokers, who are most at risk from radon, are not being targeted by current radon remediation campaigns. This impacts on the cost-effectiveness of radon remediation programmes, and Denman *et al*., (2004) concluded that the radon remediation programme they studied was four times less effective than would be expected from looking at population-average risks.

More significantly for this analysis, Poortinga and colleagues at Cardiff University presented preliminary results of a study of public perception in a number of RAAs (Poortinga, 2010), and demonstrated that awareness of radon hazards was much lower in recently declared RAAs, compared to areas, such as Cornwall, which were the first to be so designated. It is likely therefore that initially householder awareness and participation is likely to be low in areas, such as the one in Kent, which have been newly designated, and are some distance from previously designated RAAs. To date 38 % of homes in Cornwall have been tested, but only 0.2% of homes in Kent (Rees *et al*., 2011)

3.2. Cost Effectiveness

The benefits of remediating houses can be quantified from knowledge of the average radon levels before and after remediation and the current risk estimates for lung cancers induced by radon. The costs of remediation are those of installing the sump and pump, together with running costs for the pump, but for a programme to locate affected houses in a given area, this must also include the initial testing of each house, including those subsequently found to be below the Action Level, currently £49.80 including all taxes (http://www.ukradon.org, 2012). Denman and his co-workers have done extensive studies of cost-effectiveness of such programmes, and in a review (Denman *et al.*, 2008) have shown that cost effectiveness is critically affected by the percentage of houses over the Action Level in the area, the percentage of householders who remediate their homes once they have found raised radon levels, and the percentage of householders who smoke, and the updated results for actual remediation programmes in existing houses updated to December 2011 prices, and the current UK average occupancy of 2.32 (Office of National Statistics) is shown in Figure 2.

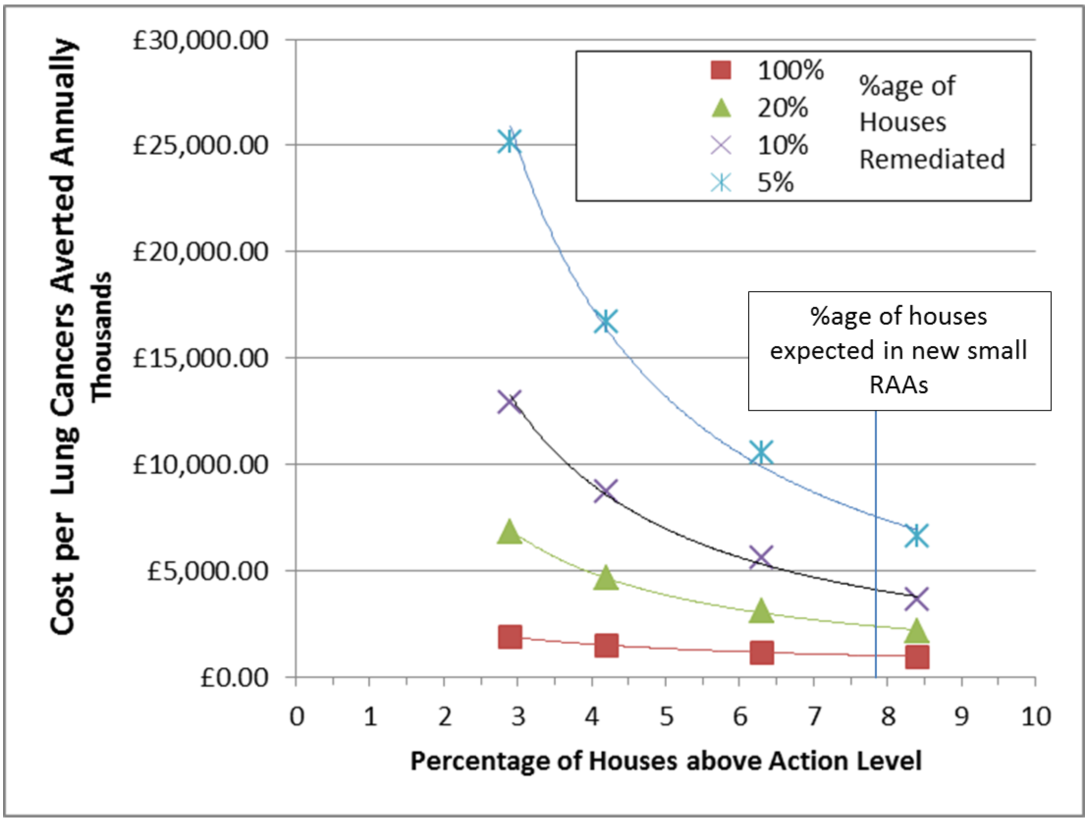

Figure 2: Cost per Lung Cancer Averted Annually, for areas with different percentages of existing houses over the Action Level, showing the impact of householders not proceeding to remediate, once a raised result is found.

The primary impacts of improved radon mapping, once testing and remediation is complete in the newly defined RAAs, would be to increase the total cost, because more affected houses are found, but also to increase the number of lung cancers averted. A theoretical estimate, using the average radon level reduction found in the remediation programmes studied by Denman *et al.*, (2008), suggests that for the house numbers in Table 1, the costs in the newly defined RAAs would be £156,350,000, and 160 lung cancers would be averted annually, giving a cost-effectiveness of £980,000 per lung cancer averted annually if all householders carried out remediation. The introduction of the step of paying for an online radon potential report for each house, at £3.60, only affects the cost and cost effectiveness marginally to £1,013,000.

Figure 2 shows that, although the cost of testing each house is small, the impact of testing a large number of houses to find a few that have high radon levels is significant, and thus cost-effectiveness considerations dictate that testing should be targeted, and that the improvement in defining radon affected areas is significant. Indeed, the theoretical calculation suggests that testing the whole housing stock of the England and Wales (22 million), when the average percentage of houses over the Action Level is 0.5%, is £6,485,000 per lung cancer averted; assuming that 32% of the housing stock are blocks of flats, with an average of four storeys and four flats per storey.

When judging the cost-effectiveness of a healthcare intervention, it is appropriate to consider the cost-effectiveness in terms of the cost per QALY (Quality-adjusted Life Year). Using the methodology of Coskeran *et al.*, (2009), who assumed that a lung cancer sufferer lost an average of 13.51 years of life, and, after diagnosis, had a reduced quality of life, the cost per QALY for the newly defined RAAs including a radon potential report is £4,110, using a discount rate of 3.5%. The National Institute for Health and Clinical Excellence (NICE) in the UK, http://www.nice.org.uk/, provides guidance on the value of healthcare interventions, and generally considers that an intervention with a cost per QALY over £30,000 is inappropriate. This shows that a completed radon remediation programme for existing houses in the newly defined RAAs is justified.

However, the percentage of house-holders who remediate their houses after discovering raised radon levels in their homes is still only around 15% in the established RAAs, despite years of publicity. If this level of remediation is achieved in the new RAAs the cost per QALY would be £18,400, assuming a population-average risk. Moreover, the evaluation of those who have remediated by Denman et al (2004) would suggest that the cost per QALY is likely to be four times higher, unless more smokers can be encouraged to remediate.

4. DISCUSSION

Improved radon mapping, together with geological mapping has resulted in the identification of more and smaller radon affected areas, with the potential to find more affected housing stock. The limited number of measurements which have so far been made in low radon areas suggests that there is potential to refine maps further, although the interpolation provided by geological mapping goes someway to cover this. The cost-effectiveness analysis given above indicates that it would be cost-effective to find and remediate existing houses in the newly defined Radon Affected Areas.

The identification of such small areas introduces complexities for local and national agencies trying to increase radon awareness. More significantly, the new maps raise the question of both public awareness and public perception, particularly since there has only been a modest uptake by householders to first test their homes, and then to reduce radon levels if high levels are found in the known radon affected areas.

In addition, the most at risk, smokers, have been shown to be less likely to participate. This has a significant effect on the estimated benefits of radon remediation programmes, and therefore the cost-effectiveness. Comparison with other healthcare interventions suggest that the ability to encourage smokers to remediation is critical. Developing public health initiatives to target smokers is therefore important as a means of targeting those most at risk, and justifying the value of radon remediation.

5. CONCLUSIONS

Improved radon mapping provides the capability to more closely target houses that may be affected by radon, and will identify more houses than previously. The analysis in this paper suggests that further refinement is possible. However, such mapping introduces complexity into local interpretation of building regulations, and, more particularly, requires both local public awareness and public participation, both of which have been shown to be modest.

At current response rates, our research suggests that remediation programmes are not currently justifiable in areas where less than 5% of houses are affected. Public awareness campaigns in the newly defined RAAs are essential to get the most benefit from improved radon mapping. However, other public health initiatives to target specific groups who are more at risk from radon, such as smokers, are likely to be more significant.

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