Cost Effectiveness of Radon Protection in new homes in the newly defined small radon affected areas

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ABSTRACT

In the UK, excessive levels of radon gas have been detected in 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. Building Regulations have been introduced that require that new homes built in areas where between 3 and 10 % of existing houses are above the Action Level should be built with basic radon protection using a membrane, and houses in areas over 10 % should be built with full radon protection.

Initially these affected 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 units – 5 km grid squares in 1999, down to 1 km grid squares in 2007.

One result is the identification of small areas with raised radon levels within regions where previously no problem had been identified. 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 affected houses. Further, the process is more complex for local builders, and inspectors, who need to work out whether radon protection in new homes is appropriate.

Our group has assessed the cost-effectiveness of radon remediation programmes, and has applied this analysis to consider the cost-effectiveness of providing radon protection in new homes, both in the newly defined areas, and countrywide. This includes modelling the potential failure rate of membranes, and whether testing radon levels in new homes is appropriate.The analysis concludes that it is more cost effective to provide targeted radon protection in high radon areas, although this introduces more complexity.

KEYWORDS: Radon Remediation, Radon Affected Areas, Radon Mapping, Cost Effectiveness, New Houses.

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 have been required since 1992 to be fitted with radon protection through the Building Regulations (eg Building Regulations 2010). Secondly, for existing homes, the methodology is to encourage householders to reduce radon risk by testing in their homes in RAAs to measure radon levels, identifying those with raised levels, and then encouraging the householders to take remedial action.

In new homes, the Building Regulations require 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%. Basic protection of new homes is in the form of a radon-proof membrane fitted across the floor area of the house to a BRE standard to prevent any ingress of radon gas as the house or building is built (BRE, 2007). Full protection adds a sump in the foundations under the house, so that an electric extract pump can be fitted quickly and cheaply in the event of high radon levels being detected, once the building is complete.

At present, however, the legislation does not require radon testing on building completion. This is despite reports by Denman et al, and others, that there is an inherent and significant failure rate of radon-proof membranes (Denman *et al.*, 2007a; Coskeran *et al.*, 2007). Radon levels in homes can be tested simply and at low cost (around £49.80 including all taxes, 2012 prices, http://www.ukradon.org), and, if raised radon levels are found, remediation work, will reduce radon levels nearly always well below the Action Level. In new houses with basic protection, remediation will usually involve the introduction of a sump and attached pump costing around £850, while in a house with full protection, where the sump is already in place, the pump alone will cost around £85.

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 new housing 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 enforceable in law from 1993 (BRE, 1992). For existing homes there are no legal requirements.

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 in all cases 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 radon reference levels; 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, as shown in Figure 1. 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.

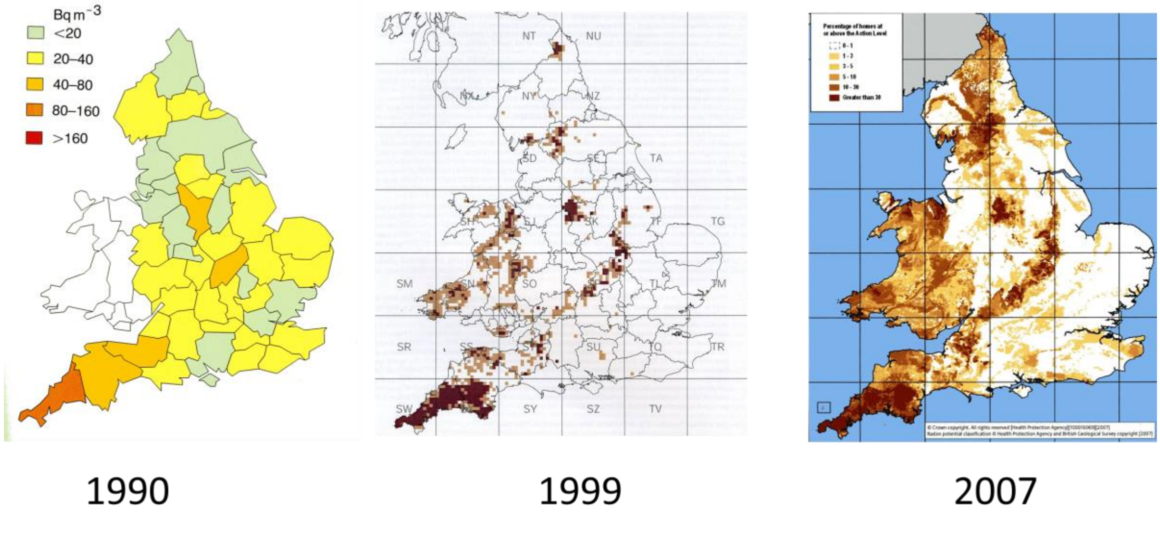

Figure 1 – Radon Maps of England and Wales, 1990, 1999 and 2007

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 then 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, 2011). This system is now available to householders who can pay to obtain an estimate of the radon potential of their home, and receive advice as to whether a radon measurement is advisable.

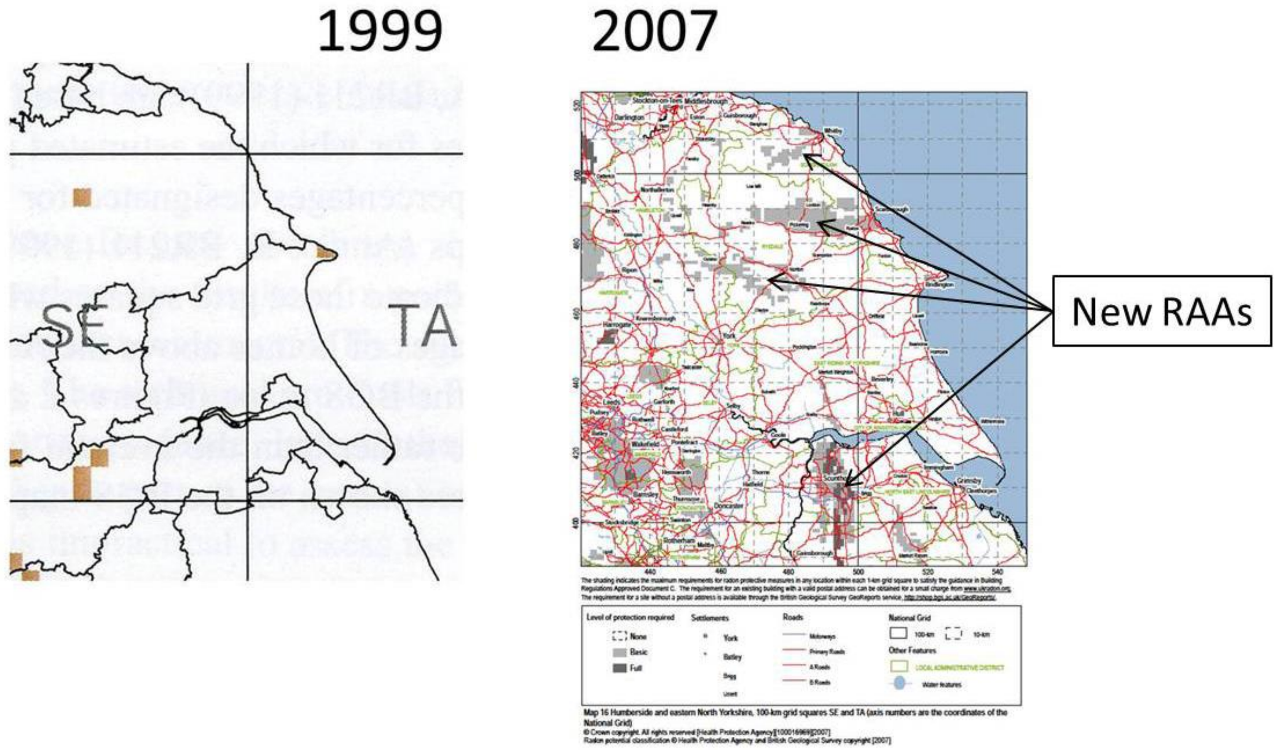

Figure 2: **Radon Affected Areas in Lincolnshire and Yorkshire; comparison of 1999 and 2007 maps.**

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 – examples include parts of the South Downs in Sussex, and between Canterbury and the Channel ports in Kent, and also an area inland from Scarborough, and the linear feature of the Lincolnshire Edge/Lincoln Cliff, which are both shown in Figure 2.

Given the experience of the authors' of radon in dwellings in Northamptonshire, the recent highlighting of raised radon levels on the Lincolnshire Edge by the 2007 map is unsurprising; this feature is underlain by Middle Jurassic rock of Aalenian to Lower Bathonian age, many of which are lateral correlatives of the radon-bearing lithologies in Northamptonshire, including the Northampton Sand Formation (cf. Cox and Sumbler, 2002) and the Upper Lincolnshire Limestone, both of which have been noted as being conspicuously radon-rich by a number of authors, including Denman *et al*. (2006).

Some parts of areas that were considered radon affected 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. The 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 existing 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.

The UK Office of National Statistics (http://www.ons.gov.uk/) online publications include details of the number of new houses built in England and Wales, which was used to calculate the number of new homes expected in radon affected areas.

3.1. Public Awareness

Alongside the developments in radon measurement and mapping, awareness campaigns to draw the attention of local councils, builders, inspectors and regulators to radon and the Building Regulations, together with public health campaigns have been run in UK RAAs to encourage existing householders to measure and then if appropriate, to reduce radon in their homes.

For existing housing, initial response rates 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 have tested radon levels in their home in RAAs, and of those who discover raised levels, only 15% remediate their homes (Zhang *et al*., 2010). Poortinga (2010) demonstrated that awareness of radon hazards was much lower in recently declared RAAs. To date 38 % of existing homes in Cornwall have been tested, but only 0.2% of homes in Kent (Rees *et al*., 2011).

Whilst there are no similar statistics for builders and legislators, it is likely that their knowledge and awareness is similarly low in the newly designated areas.

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 remediating existing houses are those of installing the sump, 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. 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.

For new houses, the primary cost is that of the installation of the radon-proof membrane (currently estimated to be around £250, 2011 prices), and, in higher radon areas, the cost of providing a sump (additional £85). Currently, around 32% of new homes are blocks of flats with an average of 4 floors, and 4 flats per floor. Pro rata the cost of a membrane for an average block of flats will be £700, and for sumps £240, as several, with higher power, would be required. Using Denman et al's methodology, it is possible to estimate the impact of providing radon protection in new homes in the newly defined Radon Affected Areas, taking UK government figures which suggest around 150,000 new homes are being built annually throughout England and Wales, and assuming that these new homes are uniformly spread, with around 10,000 in the newly declared areas. A further assumption is that there is an average reduction of radon levels of 0.67 per storey (Denman *et al.*, 2007b).

The primary impacts of improved radon mapping for new homes in the newly defined RAAs, would be to increase the total building cost by around £2,050,000, but also to increase the number of lung cancers averted by around 1.11 a year, at the current average occupancy per house of 2.32. This equates to a cost-effectiveness of £1,840,000 per lung cancer averted.

The above estimates assume a percentage reduction in radon levels that allows for the known failure rate of radon-proof membranes (Denman *et al.*, 2007a), as there is no requirement to test radon levels in new homes. If a post-occupation radon testing regime, together with remediation when required, was introduced, the number of lung cancers averted would rise to 1.90 per year, and the total costs to £2,890,000, so, although costs increase, this would save more lives, and be more cost-effective at £1,525,200 per lung cancer averted.

It should be noted, however, in the UK, that there is a general trend in reducing occupancy per house, which will lower cost effectiveness. In addition, the UK government campaign to reduce smoking reduces risk, with a 1% drop in smoking prevalence reducing the lung cancers averted in the study areas by 0.04, because the risks from radon and smoking are considered to be sub-multiplicative (BEIR VI, 1999), and so smokers are most at risk from radon.

The Health Protection Agency have argued that it is appropriate to provide basic protection to all new housing in order to avert a greater number of lung cancers, and this would also simplify and standardise the building requirements (AGIR, 2009). The cancers averted would rise to 4.7 per year. However, the costs of such a programme, without post-occupation testing would be £27,600,000, and would therefore be far less cost effective at £5,923,600 per lung cancer averted, primarily because of the many houses with inherently low radon levels. This reduces to £5,017,600 per lung cancer averted if the houses are tested, and remediated, if required.

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 is £7,460, using a discount rate of 3.5%, improving to £6,180 if post-occupation testing and remediation of affected properties is included. 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 £20,000 to £30,000 is inappropriate. This shows that a completed radon remediation programme for existing houses in the newly defined RAAs is justified.

Using the same analysis, the basic protection of all new houses has a cost per QALY of £24,000, dropping to £20,330 with testing and remediation. Under NICE guidance this places these initiatives as of borderline value.

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 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.

If new houses were only given protection in RAAs, then the identification of such small areas would introduce complexities for local agencies trying to increase radon awareness. For simplification there will always be pressure to provide a standard solution for a larger area, but this will be more costly, and therefore less cost effective.

The HPA have only recommended a post-occupation testing programme for high radon affected areas (over 10%) (AGIR, 2009). However, our analysis suggests that a post-occupation testing programme in all Radon Affected Areas would be cost-effective.

The new maps also raise the question of both public awareness and public perception, particularly since there has only been a modest uptake by householders in existing homes in known radon affected areas. For new buildings, the target groups would be building contractors and surveyors.

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, with the benefit of averting more lung cancers. However, the trend to lower numbers of people in each building, and the impact of government smoking targets both reduce cost effectiveness.

Such mapping introduces more detailed, localised evidence-based decision-making. However, it also introduces complexity into the local interpretation of building regulations with a range of different planning requirements across a single local authority. More particularly, it also requires both local public awareness and professional participation, both of which have been shown to be modest. However, this analysis has shown that a single unified building requirement for radon protection in all new homes in England and Wales has a far higher cost, and is much less cost effective.

A requirement for radon testing of all new homes, once occupied, would be cost-effective, provided that house-holders carried out the necessary remediation, if a raised level was found.

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