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Development of maps of radon-prone areas using radon measurements in houses

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Abstract

Radon is a radioactive gas arising from the uranium decay chain, and can enter houses from the ground. High radon exposures have been shown to cause lung cancer. Many governments and international bodies have therefore recommended that radon exposures in houses should be limited. Radon levels in houses vary widely from area to area depending on local geology. However, the relationship with geology is complex and varies between rock types, within single rock types and is affected by superficial cover. Even on a single geology, radon levels vary widely depending on house characteristics and the living habits of the occupants. In order to identify houses with high radon levels, it is necessary to map the problem. In the UK, this has been carried out using lognormal modelling of results of measurements of radon levels in houses around the country. Such maps have been the basis of advice from NRPB to the government on limiting radon exposures. Methods of deriving maps at 5 km and 1 km grid square resolution are discussed with examples.

Keywords: Radon; Mapping; Indoor; Houses; Lognormal; Lung cancer

1. Introduction

Radon is a natural radioactive gas which enters buildings from the ground and gives radiation doses to the occupants. It is formed in the earth from the decay of uranium-238 via radium-226. There are small quantities of uranium and radium in all earth and masonry materials, so radon is created continuously under buildings and within buildings.

The supply of radon from walls and floors is limited, but the inflow of radon from the ground is often substantial. Rock and soil, brick and concrete are all porous, so radon can move through them to the surface. If it emerges out of doors, it is readily dispersed

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in the air and concentrations are low. When it enters buildings, however, concentrations can become appreciable. Atmospheric pressure is usually lower indoors than outdoors owing to the warm indoor air rising. This creates a gentle suction that draws soil air into buildings, bringing radon with it. The air comes in through holes and gaps such as those between floorboards or around service entry points.

Radon decays to solid radioactive decay products with short half-lives. When these are inhaled, they can become deposited on the lining of the lungs. Alpha particles emitted by the decay products cause heavy ionisation in the sensitive cells of the lining of the lung which damages the cells and may eventually lead to lung cancer. Radon concentrations in uranium and some other non-coal mines some decades ago were generally high because of poor ventilation; health studies of miners consistently show that increased exposure to radon is associated with increased risk of lung cancer.

Supporting evidence is available from animal experiments and epidemiological studies of people exposed to radon in homes.

Over the past few years, there has been a growing recognition worldwide that radon is by far the largest and most variable contributor to radiation exposure of the public. On average, the radiation doses and risks to the public from radon are more than a thousand times greater than those from the nuclear industry. Many countries have now carried out large-scale surveys and are introducing guidelines to prevent excessive exposures. Maps of radon-prone areas are essential to government strategies to prevent high exposures. Such maps are used to target publicity and measurement campaigns in the affected areas and to define areas for preventive measures in new buildings.

2. Mapping methods

There are two main approaches to producing maps of radon-prone areas: use of house radon data and use of geological information. Since radon in houses largely comes from the rocks in the ground, and geological maps give information on what rocks underlie houses, it seems very attractive at first to use geological indicators such as uranium content and permeability of rocks to map radon-prone areas. As geology has already been mapped in detail in many areas, this method can give maps of radon-prone areas with a high resolution, and so give an impression of accuracy. However, Hulka et al. [1] showed that maps based on geology were not reliable indicators of radon levels in houses. It is likely that this is due to the fact that the relationship between geological indicators and indoor radon levels varies between rock types. This is considered in more detail elsewhere [2]. Miles and Ball [3] showed that lateral variations in geological formations mean that conclusions drawn for one area cannot necessarily be extrapolated to the same geological formations in adjoining areas, and that superficial deposits can greatly alter the radon potential of the ground.

If sufficient results of radon measurements in houses are available, then these can be used to map radon-prone areas directly. Geostatistical analysis by kriging has not been widely used for radon mapping, because of its assumption that the rate of spatial variation is uniform across the area to be mapped. Radon potential may be unvarying or slowly varying over some rock types, with a sharp discontinuity at the boundary between rock types. The method normally used to map radon potential is to group the results by area, and to use the data to estimate mean radon levels in houses or the proportion of them exceeding a threshold in each area.

However small an area is chosen, a wide range of indoor radon levels is found. This is because there is a long chain of factors that influence the radon level found in a building, such as radium content and permeability of the ground below it, and construction details of the building. Variations in these factors between buildings produce the wide range of radon levels measured. The distribution of radon levels in buildings is usually found to be lognormal, whether the whole of a country or a small area is considered. The reasons for radon concentrations following this distribution can be understood from statistical considerations [4].

The choice of the type of area over which to group data is difficult, each possibility having advantages and disadvantages. Administrative areas such as municipalities or postal delivery areas are sometimes used, as it is easy to determine in which area a house falls. Unfortunately, such areas vary widely in size, and their boundaries do not correspond to boundaries between areas with different radon potential. Hence ,maps based on data grouped this way may obscure the underlying pattern of variation in radon potential.

Alternatively, data may be grouped in square blocks of a convenient size, such as 10 or 5 km. This has the disadvantage that a square may cover two or more geological units with different radon potential. It has the advantages that all areas are treated equally, and if data are missing, it is simple to interpolate from surrounding squares [4]. It provides a robust picture of the pattern of variation of radon potential based on measurements in local houses, even if fine detail is missing. For these reasons, the UK National Radiological Protection Board (NRPB) has designated radon Affected Areas on the basis of house radon data grouped by 5 km grid squares [5] (see Fig. 1).

A third method is to group house radon data by geological unit [3]. This is the most logical way of grouping data, as radon potential clearly differs between geological units. This, too has its drawbacks, however. Geological maps at a coarse scale group together rock types which may have very different radon potentials, so obscuring the differences between them. Miles and Ball [3] showed that UK geological maps at 1:50 000 scale were fine enough to distinguish rock types with different radon potentials which were not distinguished on 1:250 000 scale maps. Even at the finer scale, significant variation was observed within the mapped rock types due to lateral variations in the rocks and to superficial cover.

A combination of the second and third methods of grouping data is being explored by the British Geological Survey and the National Radiological Protection Board. In this method, data are grouped both by the 5-km grid square they fall in and the geological unit at 1:50 000 scale. The lateral variation within a rock type and the variation in depth of superficial cover are both likely to be much smaller within a 5-km grid square than over the full area of a geological unit. This method, while probably producing the most accurate estimates of radon potential, suffers from two disadvantages. The first is that very high measurement densities are required to apply it, and the second is that the great majority of UK geological maps at this resolution have not yet been digitised, making the method laborious to apply and resulting in lists of radon potential against rock type and grid square rather than maps.

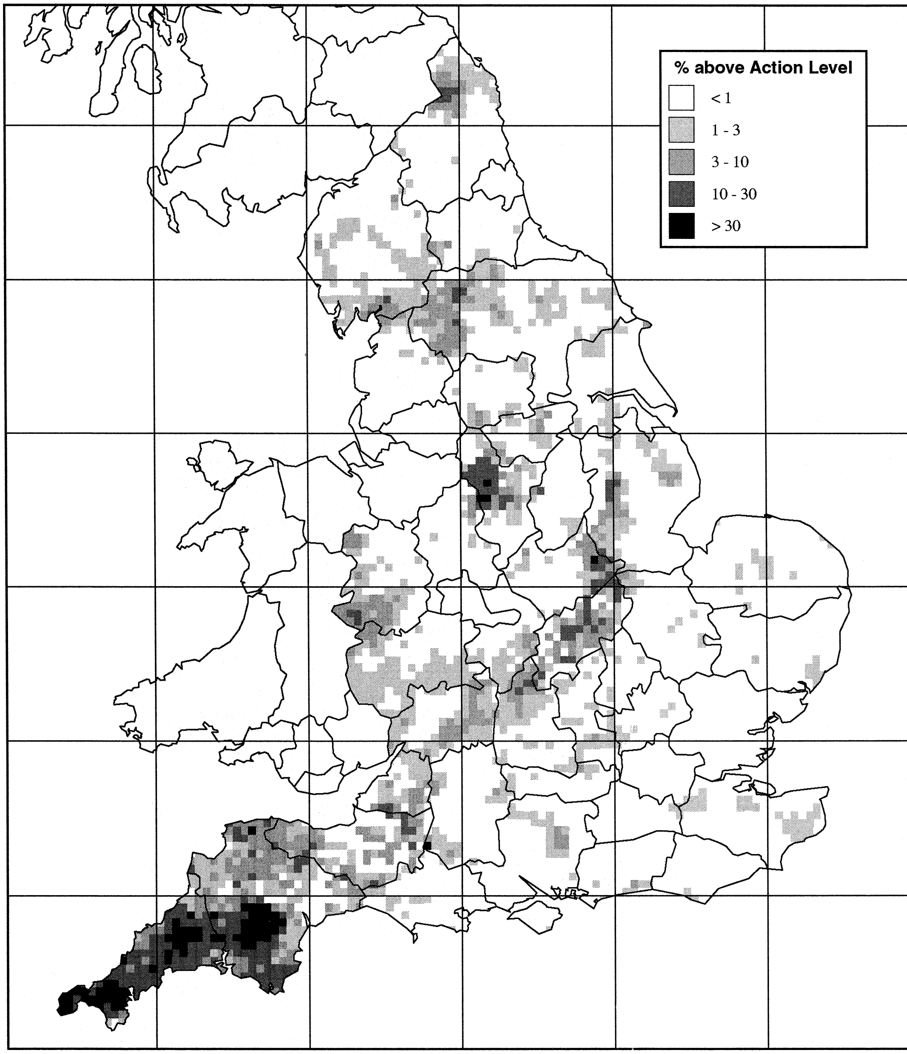

Fig. 1. Estimated percentage of homes above the UK radon Action Level of 200 Bq m^{-3}, mapped by 5 km grid square.

To overcome the requirement above for very high measurement densities, two methods have been considered. One is to use Bayesian statistics to correct the observed geometric means. Price et al. [6] have used this method in the USA to minimise the effects of small sample sizes and to take account of data on estimated uranium in the ground from aerial gamma-ray spectrometry. Data from aerial surveys does not exist for most of the UK, but possibly data on spatial correlations could be used instead. For instance, initial estimates for geological units could be taken from method 3 above, then refined within individual combinations of grid square and geological unit using whatever house radon results were available.

The second method is to use kriging on data grouped by geology. This would plot spatial variations in radon potential within geological units, whatever the cause. The method is more appropriate after the data are grouped in this way, as discontinuities in the radon potential are much less likely.

None of the methods above which rely on grouping data by geological unit can be applied across the UK at present because geological maps at 1:50 000 resolution have not yet been digitised, although tests within limited areas have been promising. A new method has been developed to make use of high measurement densities where they are available, without attempting to plot detailed variations in areas where data are sparse.

The method is based on mapping at 1 km grid square resolution. Some 1 km grid squares in the UK have sufficient house radon results to estimate radon potential directly, but the great majority of squares have no results at all. The mapping procedure is as follows.

(1) Allocate all radon results (after normalisation for the effects of individual house characteristics [4]) to the 1 km grid squares in which they were made.

(2) Taking each grid square in turn, gradually expand a circle around it until the circle encompasses at least n results, where n is a number found experimentally or on statistical grounds to be sufficient for an accurate estimate of radon potential.

(3) Take a weighted geometric mean (GM) or median of the results. A weighted mean has the advantage that it is simple to apply a distance weighting as well as a number weighting. The median has the advantage that it is not affected by deviations from lognormality in the tails of the distribution.

(4) If required, the GM or median obtained above can be used (with an appropriate figure for geometric standard deviation) to estimate the proportion of the distribution above a threshold.

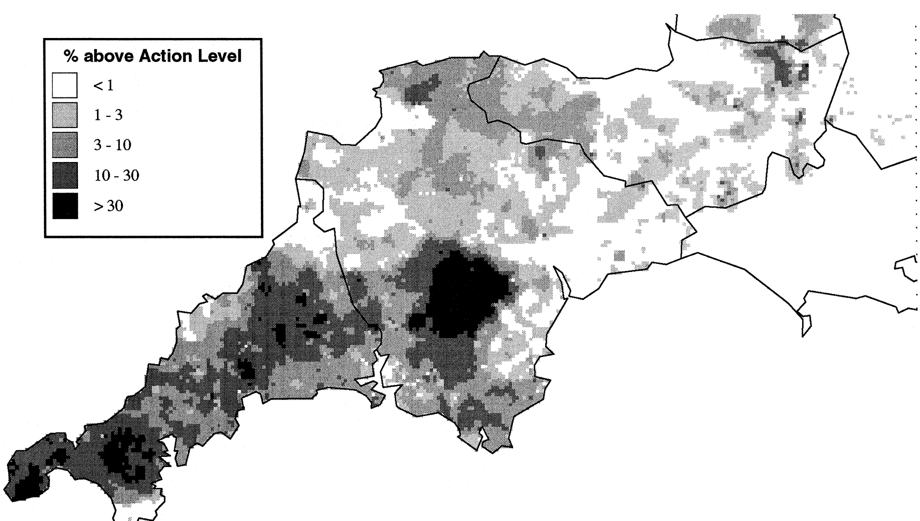

Fig. 2. Estimated percentage of homes above the UK radon Action Level of 200 Bq m^{-3} in southwest England, mapped by 1 km grid square.

Trials using simulated data have suggested that 30 is an appropriate minimum number for n. A potential problem with this method is that in some high radon areas, intensive surveys have been carried out, while nearby low areas have been sparsely sampled. The high density of high radon results tends to raise the estimated level in nearby areas. To prevent this effect, a limit has been placed on the number of contributions to n that can be accepted from any single grid square apart from the central square. The limit decreases rapidly away from the central square, taking a value of 1 for all squares more than 3 km from the central square.

The effect of using this technique is to give a high resolution map where there are many results, and a smoothed map where data are sparse. Fig. 2 shows a map of southwest England calculated in this way. Over most of this map there is a high measurement density because it was known that there were radon problems in the area. The counties to the east of the map have been found to have lower radon levels, and the measurement density here is about 5 results per 5 km grid square. The pattern of high radon levels on the map correlates well with identifiable geological features. Fig. 2 is only an example of the method: several issues remain to be resolved, such as the most appropriate distance weighting to apply. However, it is already clear that maps of this type can allow measurement campaigns in high radon areas to be targeted much more accurately than the 5 km grid square map of Fig. 1 allows.

3. Conclusions

Maps of radon-prone areas are essential to programmes designed to reduce or prevent high exposures to radon. Several methods of mapping have been developed, most now taking radon measurements in houses as their starting point. The results of aerial gamma-ray spectrometry and geological information (where it is available in a suitable form at sufficient resolution) can help to refine and organise these data. Where such information is not available, the house radon data alone can be used to map radon prone-areas directly.

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