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Variation with socioeconomic status of indoor radon levels in Great Britain: The less affluent have less radon

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ABSTRACT

We demonstrate a strong correlation between domestic radon levels and socio-economic status (SES) in Great Britain, so that radon levels in homes of people with lower SES are, on average, only about two thirds of those of the more affluent. This trend is apparent using small area measures of SES and also using individual social classes. The reasons for these differences are not known with certainty, but may be connected with greater underpressure in warmer and better-sealed dwellings. There is also a variation of indoor radon levels with the design of the house (detached, terraced, etc.). In part this is probably an effect of SES, but it appears to have other causes as well. Data from other countries are also reviewed, and broadly similar effects seen in the United States for SES, and in other European countries for detached vs other types of housing. Because of correlations with smoking, this tendency for the lower SES groups to experience lower radon levels may underlie the negative association between radon levels and lung cancer rates in a well-known ecological study based on US Counties. Those conducting epidemiological studies of radon should be alert for this effect and control adequately for SES.

1. Introduction

The short-lived decay products of the naturally occurring radioactive gas radon (so-called radon progeny) are a known cause of lung cancer. Many epidemiological studies have been undertaken to explore this association in the context of domestic exposures, e.g. (Darby et al., 2005; Krewski et al., 2005; Lubin et al., 2004). Tobacco smoking is the main cause of lung cancer and it is important that proper account is taken of this factor in such investigations. The most informative studies have been of case-control design and included detailed information on smoking for the individual study subjects. However, a well-known ecological study reported a negative association between radon and lung cancer in US Counties (Cohen, 1995). Puskin (2003) found a similar inverse trend of cancer mortality with radon level in US Counties for other smoking-related cancers, but not for cancers unrelated to smoking. This strongly suggests that Cohen's observation was a result of confounding by smoking. Nevertheless, Cohen's paper (Cohen, 1995) is still cited, e.g. (Fornalski et al., 2015; O'Connor and Calabrese, 2015), as evidence of relevance to radon risk.

Associations between childhood cancers and radon have also been investigated. Raaschou-Nielsen reviewed studies of indoor radon (Raaschou-Nielsen, 2008) and childhood leukemia and since that time other reports have been published, e.g. by Hauri et al. (2013) and by Kendall et al. (2013b). However many such studies appear underpowered and no clear picture has yet emerged. There have also been reports associating radon with a variety of other cancers: brain (Bräuner et al., 2013); gastro-intestinal tract (Kjellberg and Wiseman, 1995); central nervous system (Del Risco Kollerud et al., 2014); oesophagus (Ruano-Ravina et al., 2014); prostate (Eatough and Henshaw, 1990) and skin (Wheeler et al.,

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2012). Further investigations are required to confirm or otherwise these associations before any firm conclusions can be drawn.

A recent paper reported a striking variation with socioeconomic status (SES) of indoor radon levels in Great Britain (GB: England, Wales and Scotland) (Kendall et al., 2015). Since the study was record-based and did not involve direct contact with study subjects, response bias could not be a factor in this finding. Correlations of SES with indoor gamma-ray dose-rates were also investigated, but there were few effects (Kendall et al., 2015). Correlations between indoor radon concentrations and affluence have been reported in the past, in particular the UKCCS investigation of radon (UK Childhood Cancer Study Investigators, 2002), but have attracted little attention or discussion. It is the purpose of this paper to review these observations and to discuss the implications of, and possible reasons for, such variation.

As Galobardes et al. (2006a, b) point out, there is no single indicator of SES suitable for all study aims and applicable at all time points in all settings. Ideally, a number of separate parameters should be employed and recorded at successive points in the life-course of the study subjects. We discuss the parameters used in the present study in the following section, but in some of the work that we cite other indicators such as income or education are used. However, as Galobardes et al. (2006a) point out most of the indicators proposed are strongly correlated.

2. Materials and methods

2.1. Sources of information

Our main data source (Kendall et al., 2015) is an expanded dataset for a large record-based case-control study of naturally occurring radiation and childhood cancer in GB (Kendall et al., 2013b). This expanded dataset includes about 125 000 study subjects. Radon levels were estimated using over 400 000 measurements grouped according to geological boundaries (Miles and Appleton, 2005). We will refer to this study as the record-based case-control study or just case-control study where this is unambiguous.

The United Kingdom Childhood Cancer Study (UKCCS) (UK Childhood Cancer Study Investigators, 2000, 2002) was a large interview-based case-control study of childhood cancer which studied, amongst other possible aetiological factors, radon gas. We will refer to this study as the UKCCS. Radon measurements were completed in 2226 case and 3773 control homes. The UKCCS investigators reported details of the variation of radon concentrations with SES for their controls which we re-analyse below.

We have also made use of the National Survey of exposure to natural radiation in UK dwellings (Wrixon et al., 1988). This was smaller than the two epidemiological studies outlined above, covering 2093 UK homes, 2048 of which were in GB (the UK is GB plus Northern Ireland). However, the National Survey included information about the dwellings in question that was not available for the other datasets (see Section 2.4).

Table 1 summarizes the data on variation of mean indoor radon concentration with SES from the expanded record-based case-control study (Kendall et al., 2015) and from the UKCCS (UK Childhood Cancer Study Investigators, 2002). We use two types of SES measure: those based on the characteristics of small geographical areas ("areal measures") and those based on the social class of a parent, derived from occupation. In order to simplify comparisons, we reanalyzed areal results for the record-based case-control study in seven categories (heptile 1 being the most affluent) to match the UKCCS data, and results for the two data sources are juxtaposed. Note that the SES categories are similar but not identical in detail.

2.2. Measures of socioeconomic status

The areal SES data used by the record-based case-control study were Carstairs Scores (Carstairs and Morris 1989, 1991) evaluated for electoral wards. Carstairs scores are based on:

1) non-car ownership;
2) overcrowding in private households (more than one person per room;
3) male unemployment rates;
4) the proportion of households in which the head of the household is in social class 4 or 5.

These four variables are measured against the national average and re-scaled so that they have the same degree of variation across the country. The resulting transformed variables are given equal weight and combined to form an overall index of deprivation with higher levels indicating a higher level of disadvantage.

The areal SES data used by the UKCCS (UK Childhood Cancer Study Investigators, 2000) used an index developed by Draper et al. (1991) which predates the Carstairs index. In a broadly similar way to the Carstairs score it uses three measures of deprivation based on the 1991 census:

1. households without a car
2. overcrowded households (more than one person per room)
3. persons unemployed.

The two measures are thus similar, but not identical.

For both the record-based case-control study and the UKCCS the social class index used was derived from the occupation of a parent. Social classes run from 1 (likely to be most affluent) to 5 (likely to be least affluent). Social class 3 is divided into non-manual (3N) and manual (3M) workers; additional background on the meaning of this parameter is given by Rose et al. (2005). For the case-control study the occupation of the father was taken; for the UKCCS the occupations of the parents resident with the child at the time of diagnosis were compared, the adult with the higher class taking priority. For the UKCCS occupation was determined at interview but for the case-control study it was derived from data on the birth record. The latter is self-reported without professional guidance and the data are incomplete (see Section 4.1).

For the case-control study no social class could be assigned for 10 341 (8.3%) of fathers. The mean radon concentration for these individuals was 19.1 Bq m^{-3} compared to 22.0 Bq m^{-3} for those for whom a social class could be assigned. For the UKCCS no social class could be assigned for 584 (15.4%) of fathers; 21 (0.6%) of these were in the Armed Forces. (For the case-control study if it was known that an individual was an officer they were assigned to social class 2 and other ranks to class 3N.) The mean radon concentration for those individuals for whom no social class was assigned in the UKCCS was 19.2 Bq m^{-3} compared to 24.2 Bq m^{-3} for those for whom a social class could be assigned.

For the data of the case-control study the investigators reported that the correlation coefficient between Carstair quintile and occupational social class (6 categories) was 0.28 ($p < 0.001$) based on 57 594 study subjects (Kendall et al., 2013a).

2.3. Estimates of indoor radon concentrations

For both areal SES and individual social class analyses, the radon estimates of the record-based case-control study are from a predictive radon map based on 400 000 radon measurements grouped by geological and grid square boundaries (Miles and Appleton, 2005). The UKCCS radon estimates came from direct