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SURVEYS OF NATURAL RADIATION EXPOSURE IN UK DWELLINGS WITH PASSIVE AND ACTIVE MEASUREMENT TECHNIQUES

B.M.R. Green, L. Brown, K.D. Cliff, C.M.H. Driscoll, J.C.H. Miles and A.D. Wrixon

National Radiological Protection Board, Chilton, Didcot, Oxon, OX11 0RQ, (United Kingdom).

ABSTRACT

A representative sample of over 2,000 UK dwellings was monitored for a year using thermoluminescent and etchable plastic dosemeters to measure gamma-ray dose rates and radon concentrations. The survey was carried out by post. Each householder completed a questionnaire on the type of dwelling and its characteristics. These data will be used in the assessment of the factors affecting indoor exposure. The mean gamma-ray dose rates were 0.062 and 0.057 $\mu Gy\ h^{-1}$ in air and the mean radon concentrations were 25 and 18 $Bq\ m^{-3}$ for living areas and bedrooms respectively. Other results of the preliminary data analysis are given.

More detailed surveys were conducted in areas where the local geology indicated that elevated exposures to natural radiation might occur. Over 800 dwellings were visited and measurements made of several parameters. The mean gamma-ray dose rates varied from 0.05 to 0.10 $\mu Gy\ h^{-1}$ in air. The mean radon concentrations varied from 14 $Bq\ m^{-3}$ to 520 $Bq\ m^{-3}$. Other findings related to equilibrium factors and regional differences are discussed.

INTRODUCTION

The main contribution, about 87%, to the total radiation exposure of the UK population is due to natural radiation (1). The two largest sources of exposure to natural radiation are radon decay products and terrestrial gamma rays in dwellings. The magnitude of indoor exposures varies considerably, especially for radon decay products (2, 3).

Two main types of survey have been carried out and are discussed here: a national survey of a representative sample of all UK dwellings; regional surveys in areas where above-average levels of exposure might be expected from geological considerations (4). The specific objectives of the surveys were to obtain an improved estimate for the means and ranges of the indoor exposures and to correlate variations in the gamma-ray and radon decay product exposures with such factors as geographical location, type of dwelling, building material and the living habits of the occupants.

The survey programme commenced in 1982. Previous publications have had detailed descriptions of the surveys and contained early results (5, 6). The data collection phase was completed early this year and work on data analysis has now intensified. The present paper updates the results and gives some of the findings of the initial data analysis. Only survey data are presented here: dose distributions for the UK population as a whole or to the population of selected areas are not developed. A further paper in this seminar will deal with this aspect of the work (7).

SURVEY TECHNIQUES

The national survey was carried out entirely by post on a representative sample of all UK dwellings. Gamma-ray dose rates and radon gas concentrations were measured in over 2,000 dwellings with lithium fluoride TLD-100 and diethylene glycol bis(allyl carbonate) polymer (CR-39) etched-track dosemeters respectively. The gamma rays were measured for six months and the radon for two consecutive six-month periods (8). Both types of passive dosemeter were extensively calibrated and tested before use (9, 10). Additional information relating to type of dwelling and living habits of the occupants was obtained from a questionnaire, which participants were asked to complete at the end of the survey period.

In contrast, the regional surveys involved a visit to each dwelling during which measurements were made of gamma-ray dose rates, radon concentration, radon and thoron decay product concentrations and ventilation rate (5). Passive radon detectors were left at the time of the visit and replaced after six months so that the average levels of radon over a full year could be determined. Details of type of dwelling and living habits were also recorded.

SAMPLE SIZE AND OVERALL RESULTS

A total of 2,519 householders agreed to participate in the national survey. This figure represents a positive response from just over half the householders approached. The percentage of participants failing to complete the year-long survey period because of moving house, illness, or other reasons was 12%.

As of 1 March 1985 the results from over 1,900 households are available. The relevant values of the parameters of interest are given in Table 1. The means and the ratios between the living areas and bedrooms are similar to the early results previously reported (5). The living area to bedroom ratios are about 1.1 and 1.4 for gamma-ray dose rate and radon concentration respectively.

TABLE 1

Up-to-date results from the national survey

Parameter	Gamma-ray dose rate ($\mu Gy\ h^{-1}$ in air)		Radon concentration ($Bq\ m^{-3}$)	
	Living area	Bedroom	Living area	Bedroom
Arithmetic mean	0.062	0.057	25	18
Geometric mean	0.058	0.053	15	11
Geometric standard deviation	1.5	1.5	2.6	2.5
Number of dwellings in sample	1,984	1,953	1,962	1,954

Over 800 dwellings have been visited in the course of the regional surveys. The specific areas covered were in south-west England (parts of Cornwall and Devon), South Wales (Swansea), central English uplands (parts of Derbyshire and Yorkshire), and south-west and northern Scotland (parts of Dumfries and Galloway, Grampian and Highland regions). The areas surveyed were identified from geological data as being likely to have above-average concentrations of natural radionuclides in the ground because of the presence of, for example, igneous rocks or uraniferous limestone. The samples of dwellings are therefore not representative of the whole regions. The results are shown in Table 2.

TABLE 2

Living area results from active surveys in selected areas

Areas of	Number of dwellings	Vent. rate (ACH)	Gamma-ray dose rate ($\mu Gy\ h^{-1}$ in air)	Radon conc. ($Bq\ m^{-3}$)	Radon decay product conc. (mWL)*	Thoron decay product conc. (mWL)*
Cornwall	329	2.0	0.10	390	17	NM
Devon	150	1.8	0.10	210	11	3.6
Swansea	7	1.2	0.06	14	0.8	0.7
Central uplands	150	1.9	0.05	180	7.8	1.1
Scotland	170	1.8	0.08	42	2.9	1.9

*At the prevailing ventilation rate
NM = not measured

REPRESENTATIVENESS OF NATIONAL SAMPLE

The sample of dwellings for the national survey can readily be inspected to see whether it is truly representative of the housing stock of the UK or whether it is biased because of some self-selection mechanism among participants. There are two readily-available checks, one by house type and the other by date of construction, with data from the General Household Survey for the UK as the reference distribution (11). The checks do show some bias towards detached and semi-detached dwellings at the expense of terraced houses and dwellings in multi-occupancy buildings (see Table 3). The small bias according to date of construction is to be expected from the bias by house type. Terraced houses are predominantly older (63% built pre 1944, 40% pre 1919) and detached houses predominantly newer (60% built post 1945, 37% post 1965). The results will be assessed to see if these biases are likely to distort the final outcome of the survey, and any distortion will be corrected during the final analysis.

TABLE 3

Representativeness of national sample

By type of dwelling Sample size 2,199			By age of dwelling Sample size 1,892		
Type	Reference %	Sample %	Built	Reference %	Sample %
Detached house	17	24	Pre 1919	25	22
Semi-detached house	31	39	1919-1944	25	24
Terraced house	32	24	1945-1964	26	26
Purpose-built flat	14	9	Post 1965	24	28
Converted flats	5	3			
Others	1	1			

REGIONAL VARIATIONS

In a previous paper (5) the available data were examined for differences between the four countries that make up the UK, and the conclusion was drawn that there were no substantial radiological differences between them. The increased number of results make it possible to repeat the exercise for this seminar and to consider much smaller geographical regions. Included this time were the capital cities of each country, two contrasting geological regions (in south-west England the counties of Cornwall and Devon; in eastern England the counties of Norfolk and Suffolk) and Aberdeen city. The latter is of particular interest since it is often called the radioactive city, being predominantly built of granite (2). The results are shown in Table 4 in terms of the arithmetic means.

TABLE 4

Mean gamma-ray dose rates and radon concentrations by region

Region	Number of dwellings	Gamma-ray dose rate (μGy h^{-1} in air)		Number of dwellings	Radon concentration (Bq m^{-3})	
		Living area	Bedroom		Living area	Bedroom
London	122	0.050	0.047	123	12	10
Edinburgh	6	0.069	0.069	7	15	12
Cardiff	10	0.064	0.066	10	32	18
Belfast	3	0.069	0.042	3	11	8
South-west England*	50	0.069	0.061	47	73	57
Eastern England+	95	0.051	0.046	100	24	16
Aberdeen	9	0.087	0.072	8	16	9

*Cornwall and Devon
+Norfolk and Suffolk

In some cases the sample size is still quite small and this limits the precision of the estimates of the means. Nevertheless there are obvious differences in both gamma-ray dose rates and radon concentrations. The gamma-ray dose rate is generally lower in London than in the cities of Edinburgh, Cardiff and Belfast. London is built mainly with brick from the underlying clay: the other cities are built mainly with the new red sandstone or mudstone which underlie them (12). The highest value is for Aberdeen city. The two county regions show differences in gamma-ray dose rates: the predominantly chalk and clay soils of eastern England are reflected in lower values than those found over the predominately granite and old red sandstone rocks of south-west England.

The much wider and more skew distributions for radon concentrations make comparison between the towns with only small samples difficult. All that can be said about the radon concentrations in Edinburgh, Cardiff and Belfast is that they do not differ much from the national values. Radon concentrations in London are about half the national values, in eastern England about equal to them, and nearly three times greater in south-west England. The reasons for this pattern are the combination of the radionuclide content of the ground and its permeability. London clay is fairly low in radionuclides and impermeable; the chalks and glacial deposits of eastern England, though low in radionuclides, are fairly porous; the granites and, to a lesser degree, the old red sandstones of south-west England are both fairly high in radionuclides (13) and extensively fractured and weathered.

The results for Aberdeen city, although few in number, are interesting. Active surveys in 9 different dwellings gave similar results to the passive survey: in living areas, the mean gamma-ray dose rate was 0.074 μGy h^{-1} in air and the radon concentration was 21 Bq m^{-3}. The reason for the above-average gamma-ray dose rate is of course the use of granite as a building material. The reason why the radon concentrations are not also higher than average is not completely clear, but several reasons can be suggested: the relative impermeability of the Aberdeen granite; higher levels of thorium rather than uranium; different construction techniques resulting in greater underfloor ventilation.

EFFECT OF HEATING AND OTHER FACTORS

As an example of the type of detailed information which will be available from a full analysis of the questionnaire, Table 5 gives a breakdown of the types of heating used in the living area of 1,975 dwellings during the winter months. Such information will be considered with the measured radiation values to test for the existence of correlations. In the same dwellings during the same period, 1,542 (78%) had some form of heating in the bedrooms. The type of heating has a marked effect on the ventilation rate and hence on the concentrations of radon and the equilibrium between radon and its short-lived decay products. Other parameters to be analysed from the questionnaire include the type of building materials, the window and internal door-opening habits, the heating patterns, and the use of secondary glazing.

TABLE 5

Living area heating during the winter months

Type of heating	Percentage[1]
Open fire	16
Closed coal or wood fire	6
Gas fire (normal flue)[2]	30
Gas fire (balanced flue)[2]	8
Electric or portable	11
Central heating	55
None	0.3

[1]The sum exceeds 100% as some dwellings have more than one type.
[2]A normal flue draws air from inside the room and increases the ventilation rate: a balanced flue draws air from outside the house and does not affect the ventilation rate.

ACTIVE SURVEYS

The data from the active surveys in the regions are more detailed than those from the national survey and a full analysis will significantly facilitate an understanding of the factors influencing exposure in dwellings, and also provide the information necessary to quantify various relationships.

One of the more important pieces of information needed to interpret fully the results of passive radon detectors is the equilibrium factor between radon and its short-lived decay products. Preliminary analysis of the active survey data has allowed an average equilibrium factor of about 0.35 to be estimated for UK dwellings at the average ventilation rate of about 1.9 air changes per hour prevailing at the time of measurement. This confirms the suggestion made elsewhere that at higher ventilation rates there is little plateout (14), the equilibrium factor of 0.35 being close to the theoretical maximum (15).

SUMMER AND WINTER VALUES

The use of two sets of passive radon dosemeters to monitor dwellings in the regions for a complete year allows seasonal variations to be determined. During the heating season, taken as the months of October to March inclusive, one expects the ventilation rate to be appreciably lower than during the non-heating season. This expectation should be reflected in the radon concentrations, and an analysis of the results for some dwellings in a granite area of south-west England, with above-average indoor concentrations of radon, does indeed show such a pattern: the arithmetic mean radon concentrations in winter are nearly twice the summer concentrations (see Table 6). This is a higher ratio than that found in predominantly clay and peat regions of another country (16). It will be instructive to see the ratios in UK areas with different geology.

TABLE 6

Mean radon concentrations in dwellings* in winter and summer (Bq m^{-3})

Room	Summer	Winter	Summer/Winter Ratio
Living area	280	545	0.51
Bedroom	171	320	0.53

*For 40 dwellings in south-west England

YEARLY RADON CONCENTRATIONS

The use of passive radon dosemeters for a complete year in the regional surveys also facilitates the estimation of the annual arithmetic mean. During surveys, the window of the room being studied is opened to the first position (the smallest fixed opening) so as to ensure that ventilation is predominantly with the outside air and not with air from elsewhere within the dwelling. This means that the radon concentrations measured at the time of the surveys underestimate the concentrations normally experienced by the occupants during the winter months when windows will normally be shut. An examination of the data for a granite region shows this to be the case: the mean radon concentration at the time of sampling was 390 Bq m^{-3}, whereas the annual mean for the same dwellings measured with passive dosemeters for the whole year was 520 Bq m^{-3}. It is anticipated that similar differences will be seen in the results of active and passive measurements from other regions.

CONCLUSION

The full analysis of the data, which is currently in progress, will increase knowledge and understanding of radiation exposure in dwellings. It will enable better estimates to be made of the means and ranges of exposure of the population to radiation of natural origin. It will show the percentage of dwellings that might exceed any future guidelines on indoor exposure to natural radiation in UK dwellings and indicate those regions of the country where remedial and preventive actions might be required.

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