APPENDIX D

Gamma-ray Dose-rates to Human Tissues from Natural External Sources in Great Britain*

The information on environmental gamma radiation given in the last report (Spiers, 1956) was limited by the small amount of experimental data then available. Considerably more information has been accumulated since then and a summary has been published in the Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (1958). The data reported from Austria, France, Sweden and the U.S.A. show that in general dose-rates out-of-doors range from about 50 mrads per year over sedimentary rocks to about 200 mrads per year in granite districts. In houses a similar range of dose-rates is indicated, the rates in individual houses depending upon the nature of the building materials. In some parts of the world, however, very much higher dose-rates have been observed. On the extensive area of monazite sand in the Kerala State of India dose-rates of up to 4,000 mrads per year have been recorded and the mean dose-rate for 10 villages with a total population of 52,000 has been estimated to be 1,270 mrads per year. Mean dose-rates of 500 and 1,600 mrads per year have also been reported from two localities in Brazil.

GAMMA-RAY DOSE-RATES AT SOME LOCALITIES IN BRITAIN

Observations of gamma-ray dose-rates at many localities in Britain have been reported since 1956. The list of observations given in Table 1D is not exhaustive but is intended to indicate the levels and range of dose-rates which might be regarded as representative of this country.

Generally the dose-rates are low in chalk and limestone districts and in houses built of sedimentary rocks; they are higher in brick houses and highest in granite houses in granite districts. In some districts in Cornwall, where spoil from former uranium mines is sometimes incorporated in streets and pavements, very high dose-rates are found. The variation in dose-rate from point to point in these districts can be so great, however, that no quantitative conclusion can be drawn from these data about the mean dose to the population.

It is difficult in any case to estimate a mean dose-rate to a population from a few scattered observations and an attempt has therefore been made to determine the representative mean dose-rates to populations in a few well-defined areas.

MEAN DOSE-RATES TO THE POPULATION IN FOUR DISTRICTS IN SCOTLAND

Surveys of four areas in Scotland have been completed† and the results give a sufficiently representative distribution of dose-rates in each area for

* Figs. 1D-4D and sections of the text are reproduced by permission from the *British Medical Journal*, 1960, i, 1753-59.

† The surveys were carried out by Mr. M. J. McHugh of the Medical Research Council's Environmental Radiation Research Group in the Department of Medical Physics, The University of Leeds. Organization of the surveys was made with the assistance of the Medical Officers of Health, the Hospitals, Universities and Civil Defence Organizations in the areas concerned, to all of whom grateful acknowledgment is made. A detailed account of the investigation will be reported elsewhere.

mean dose-rates to the respective populations to be derived. The surveys covered two predominantly granite districts, Aberdeen City and Aberdeen County, and two districts of sedimentary rocks, Edinburgh and Dundee. In all four areas most of the houses and buildings are made of local stone so that a sufficient homogeneity exists to give significance to a mean population dose-rate.

TABLE 1D

Gamma-ray dose-rates at some localities in Britain

Locality	Rock or soil	Site and material	Dose-rates (mrads/year)		Observer*
			Indoors	Outdoors	
London ...	London clay	2 brick houses ...	26, 32	24, 29	1
Sutton ...	Chalk ...	Brick house ...	47	31	
		Brick hospital ...	50–70	21–30	1
Leeds ...	Sedimentary	Brick house ...	77	48	2
Filey ...	Boulder clay	Brick house ...	72	61	2
Evesham ...	Alluvial ...	Brick house ...	69	43	2
Broadway...	Limestone...	Stone house ...	40	21	2
Bristol ...	Limestone...	Stone houses (2) ...	39		2
Swansea ...	Limestone...	House nr. slag tip	60	40	2
		On slag tip ...		160	2
		Path nr. slag wall...		250	2
Exeter ...	Sedimentary	Hotel	60–80	37	2
Tavistock ...	Sedimentary	Roads		18	2
Liskeard ...	Sedimentary	Roads		26	2
Wadebridge	Sedimentary	Streets		25–45	3
Looe and Mevagissey	Sedimentary	Town and harbours		50	3
Falmouth ...	Sedimentary			50	3
Moreton-hampstead	Granite ...	Roads		67	2
Postbridge	Granite ...	Roads		77	2
Princetown	Granite ...	Roads		82	2
St. Ives ...	Granite ...	Granite house ...	120	80–118	2
		Concrete house ...	53	46–203	2
		Concrete bungalow	107	73	2
		Heap of mine spoil near bungalow		1,000–2,000	2, 3
		School playground		300–420	2, 3
		Streets—35 observations		50–300	2, 3
		Granite laboratory	145		3
Penzance ...	Granite ...	Streets		135	3
Bodmin ...	Granite ...	Streets		135–155	3
Cambourn-Redruth	Granite ...	Streets		130	3
Carbis Bay		Small area in lane		515–600	3

* Observers:—

(1) Vennart, J. (1957).

(2) Spiers, F. W. (1956 and unpublished observations, 1957).

(3) Willey, E. J. B. (1958).

Organization of the surveys

Measurements of gamma-ray dose-rate were made out-of-doors and in houses. The houses, found by private enquiry, numbered 155 in Edinburgh, 103 in Aberdeen and 71 in Dundee. They were distributed in reasonably representative patterns over the built-up areas of the cities and included the various types of building material in proportions closely following the statistics provided by the city surveyors. Approximately the same numbers of measurements were made on roads and pavements.

In Aberdeenshire the distribution of the 172 houses in which measurements were made was arranged to take into account the variations in population density and local geology. The survey included all parishes or boroughs with populations of 3,000 or more and measurements were made in a proportion of the remainder, chosen by a procedure of random selection with some stratification as to size and region. In all groups the numbers of houses selected lay between 10 and 14 per 1,000 inhabitants. Distribution of the out-door measurements followed that of the houses.

The measurements were made with a portable high-pressure ionization chamber, having the required sensitivity and long term stability (Spiers, 1959); a single observation, with an ion-collection time of about 3 minutes, carried a standard error of $\pm$ 1·5 per cent. At each out-of-door site two measurements were made and in houses two measurements were made at each of 3 selected points—the living room, kitchen and one upstairs bedroom. The mean of the six indoor measurements was taken as typical of the house dose-rates. In single-floor flats only two rooms were measured. The cosmic-ray response of the instrument, corrected to allow for overhead shielding, was subtracted from the reading at each site before applying an appropriate gamma-ray calibration factor to derive the local gamma-ray dose-rate.

Results of the surveys

Dose-rates measured in air

For each of the four areas, the average dose-rate out-of-doors was taken as the arithmetic mean of all the outdoor observations in the area. A mean dose-rate in the houses of each city was derived by weighting according to the proportions of houses of different types. For the population of Aberdeenshire a mean indoor and a mean out-of-doors dose-rate was obtained by weighting the mean dose-rate for each of the selected parishes, boroughs and groups of small parishes by the proportion of the total population represented. The mean dose-rates out-of-doors and in houses for the four areas are given in the first section of Table 2D.

The dose-rates out-of-doors in Edinburgh, Dundee and Aberdeen are shown in Fig. 1D; mean dose-rates are indicated by arrows. The mean dose-rate of 104 mrads per year in Aberdeen is more than twice the mean of 48·5 mrads per year in Edinburgh. Fig. 2D shows that the dose-rates in the stone houses

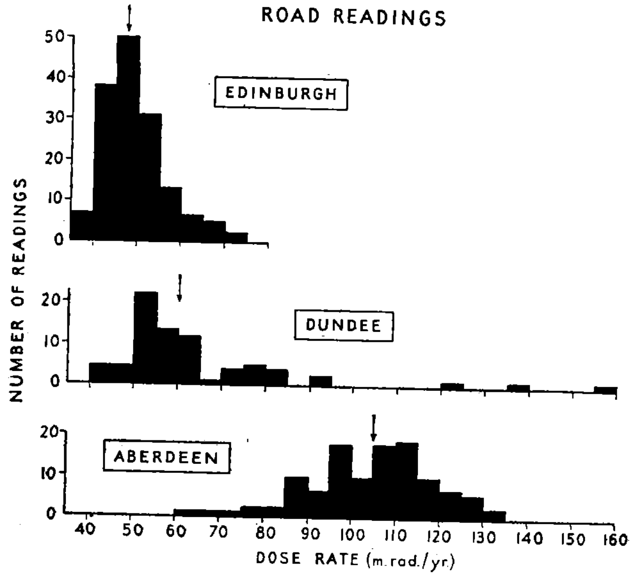

FIG. 1D.—Background radiation out-of-doors in Aberdeen, Dundee and Edinburgh.

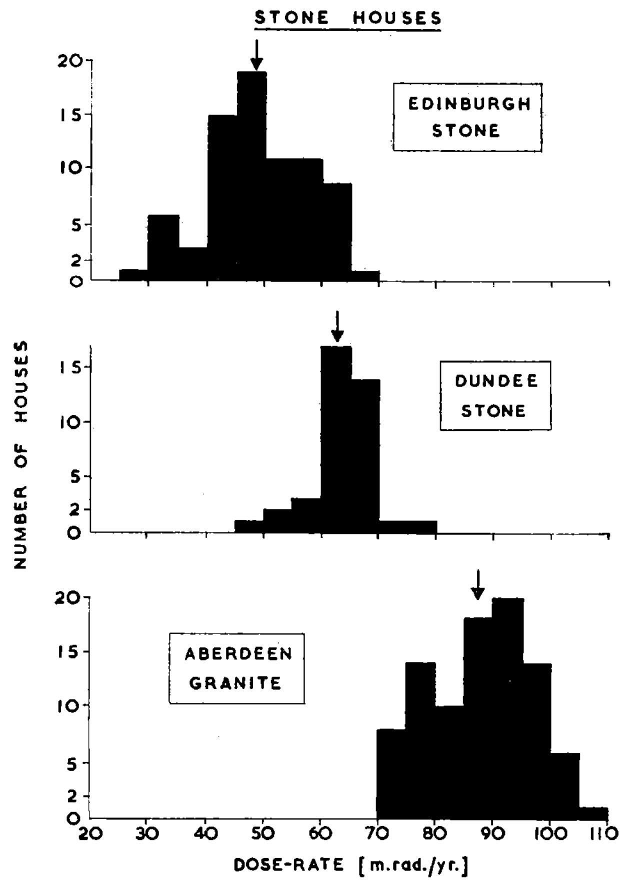

FIG. 2D.—Background radiation inside stone houses in Aberdeen, Dundee and Edinburgh.

in the three cities are also different, the mean dose-rate in the Aberdeen granite houses being 87 mrads per year compared with 48·5 mrads per year in sandstone houses in Edinburgh. Although no exact analysis has been made, the difference in dose-rate between the Dundee (Old Red) and the Edinburgh (Lower Carboniferous) sandstone houses is in keeping with the higher potash content of the Dundee stone (Davidson, 1959).

The results of the out-door measurements in Aberdeen show the interesting feature that the mean dose-rates over half-mile annular zones increase steadily from 75 mrads per year in the peripheral zone (2·5 to 3 miles radius) to 115 mrads per year in the central zone.

The dose-rates measured in the survey of the county of Aberdeen are shown in Figs. 3D and 4D. Each histogram shows a greater spread of dose-rates than is seen in the results for the cities because considerably greater variation exists in surface geology and in the materials used for constructing roads and houses.

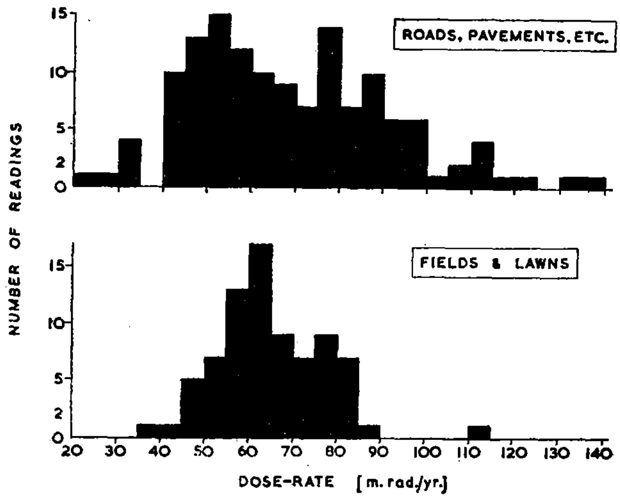

FIG. 3D.—Background radiation out-of-doors in Aberdeenshire (excluding Aberdeen City).

Mean dose-rates to the gonads and to bone marrow

The 24-hour average dose-rates given in the first section of Table 2D are based on an assumed period of 6 hours spent out-of-doors per day.

The average gonad attenuation factor for both sexes has been taken to be 0·63 as measured for background radiation (Spiers, 1956). The attenuation factor for bone marrow has been derived from measurements in a water-filled model irradiated by a nearly omni-directional array of radioactive sources. These measurements were made at several points on the surface and within the model and covered a range of gamma-ray energies (Spiers and Overton, 1960). Using data on the distribution of red marrow in the body (Ellis, 1958) a mean attenuation factor for bone marrow was derived at a gamma-ray energy approximating to that of background radiation.

The value of 0·64 for this mean attenuation factor is very close to that for the gonads and corresponds to a mean marrow depth of about 4 cm from the body surface.

TABLE 2D

Mean gonad and bone-marrow dose-rates from background and internal radiation in four parts of Scotland

Type of radiation	Mean dose-rate (mrads/yr)			
	Edinburgh	Dundee	Aberdeenshire	Aberdeen
Local gamma radiation (measured in air)				
Out-of-doors	48·5	63·0	69·5	104
In houses	60·0	67·2	81·5	85·3
24-hour average	57·1	66·3	78·5	90·0
Total radiation to gonads				
Local gamma radiation	36	42	50	57
Other background and internal sources	49	49	49	49
Total	85	91	99	106
Total radiation to bone marrow				
Local gamma radiation	37	43	50·5	58
Other background and internal sources	43	43	43	43
Total	80	86	93·5	101

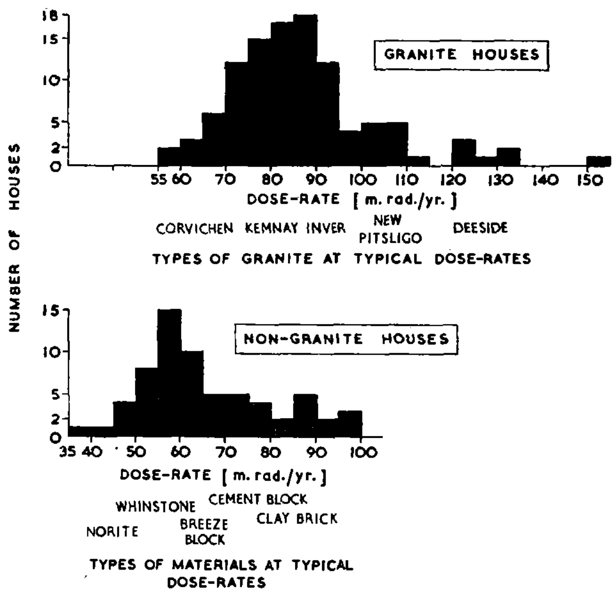

FIG. 4D.—Background radiation indoors in Aberdeenshire (excluding Aberdeen City).

Cosmic rays and potassium 40 contribute most of the dose-rate from natural sources, additional to the local gamma radiation. The cosmic-ray dose-rate averaged for time spent indoors and out-of-doors amounts to approximately 24 mrads per year to both gonads and bone marrow. The gonad dose from potassium 40 is 21 mrads per year, assuming a soft tissue potassium content of 0·2 per cent by weight. In trabecular bone the potassium content may be expected to lie between a value of 0·05 per cent for mineral bone and a value near to 0·2 per cent for bone marrow; a mean dose-rate of 15 mrads per year may be taken as sufficiently representative. Small additional dose-rates from C-14 and radon bring the total internal dose-rates to 49 mrems per year for the gonads and 43 mrems per year for bone marrow.

The remaining entries in Table 2D give the contributions and total doses to gonads and to bone marrow for populations in the four areas investigated. The mean dose-rates for the four areas have standard errors of approximately 1 per cent and in particular the difference in the mean gonad or bone-marrow dose-rates to the populations of Aberdeen and Edinburgh is 21 ± 0·6 mrads per year. If a shorter period of 3 hours is assumed to be spent out-of-doors per day the difference in the population dose-rates in Aberdeen and Edinburgh would be 18·5 mrads per year.

It is evident from these considerations that there is established a difference of 20 ± 1 mrads per year between the mean dose-rates to the gonads and bone marrow of the populations in Edinburgh and Aberdeen. This difference is therefore a known measure with which other low dose-rates can be compared. It is not necessarily legitimate, however, to compare with it small annual doses delivered fractionally at high dose-rates.

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