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MEASUREMENT OF ENVIRONMENTAL GAMMA RADIATION IN NORWEGIAN HOUSES

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Abstract—Results of measurements of the environmental radiation inside Norwegian houses are reported. Three types of measuring equipment were used, i.e. a scintillation rate meter specially designed for low intensity measurements, a Geiger counter with a rate meter, and an ionisation chamber. The average dose rate in air due to environmental radiation was found to be 87 mrad/year inside houses with outer walls of wood, 115 mrad/year for buildings with outer walls of concrete and 129 mrad/year for buildings with outer walls of brick. The average of all the 2026 measurements inside Norwegian houses is 83 mrad/year for the dose rate due to gamma rays, when 25 mrad/year due to cosmic rays is subtracted.

INTRODUCTION

THE rapid increase in the use of all kinds of ionising radiation, besides the small overall increase in environmental radiation due to fallout from nuclear bomb tests, has stimulated research on the hazards to man of small exposure doses. For a study of genetic effects, some information may be gained from a comparison between people living in areas of varying amounts of environmental radiation. Thus, an investigation by KRATCHMAN and GRAHN[1] in the United States seems to indicate that mortality from congenital malformation is higher in those geological areas that contain major uranium deposits, uraniferous water or helium concentrations. Lack of exact mapping of environmental radiation is the main hindrance to the study of many similar and interesting possible effects of small exposure doses.

A world-wide mapping of the naturally occurring radiation is of interest for the solution of many problems also in other fields, for instance in the fields of geology and meteorology. The present article may in this respect supplement similar measurements performed in other countries. Articles containing good reference lists have been published by HULTQVIST[2] and ATEN *et al.*[3]

THE COMPONENTS OF THE BACKGROUND RADIATION

The main sources of environmental radiation are radioactive elements in the earth and in the building materials of houses, mainly the members of the radium and thorium series together with the naturally occurring radioactive nuclide ^{40}K. These three sources are on the average of equal importance. ^{87}Rb, ^{147}Sm, ^{14}C, the actinium series and other natural radioactive nuclides can be ignored either because of the character of their emission or because of insufficient abundance.

An important radiation is cosmic rays. The cosmic ray intensity increases with the height above sea level, and for large multistorey buildings the intensity decreases with the weight of absorbing material above the counter. For our measurements inside buildings no large error is made when assuming a constant value, because most of the measurements are taken at a height less than a few hundred meters above sea level, and the Norwegian houses are relatively small. In the present article we give, therefore, the figures for the measured total ionisation in air, with the cosmic ray intensity included.

In Table 3 where the ionisation in air due to cosmic rays is subtracted, the value of 1.9 ion pairs/cm^3 given by HULTQVIST[2] is adopted.

This corresponds to a dose rate in air of 25 mrad/year, which is about 23 per cent of the measured average total dose rate.

Some radiation also originates within the human body itself. Figures quoted in a United Nations report[4] for the dose rates from the potassium content of the body range from 15 to 20 mrem/year. The corresponding figures for carbon are from 1 to 2 mrem/year. For radium the dose rates to the gonads are about 4 mrem/year, and to the bone up to 20 mrem/year.

A comparison between the various components of the radiation shows that the external gamma radiation is the main contributor to the exposure dose. As people, on the average, spend the main part of their lives inside buildings, the indoor gamma-ray intensity is of primary interest. The present article will be restricted to this component only.

APPARATUS

It is almost impossible to construct a measuring device which will fulfil all the necessary requirements for a reliable investigation of the environmental radiation. The main difficulties met with are:

(1) the low intensity of the various components;
(2) there exists no radiation-free room where the counters could be calibrated;
(3) the counter should be air equivalent or tissue equivalent;
(4) the counter must be made easily transportable.

To overcome these difficulties and make the measurements more reliable, three different devices were constructed and compared. The three devices were a Geiger counter, an ionisation chamber and a scintillation rate meter. The Geiger counter was chosen because it was considered to be the most handy apparatus when many measurements were to be taken at various places. The ionisation chamber was built because it was supposed to give a more reliable result when the absolute intensity is to be expressed in terms of the number of ion pairs produced in air. Lastly, an attempt was made to construct a tissue-equivalent dose meter for intensities in the actual region by use of the scintillation method. The three apparatuses were constructed as follows.

The electronic device built for the Geiger counter was a battery-driven, transistorised rate meter. The Geiger tubes used were geological survey tubes, type G.24 H manufactured by 20th Century Electronics Ltd. They are 25-cm-long glass tubes with an inner metal cathode of 18 mm diameter. To increase the output pulse rate and also to decrease the relative efficiency for counting cosmic rays, two tubes were coupled in parallel, one mounted above the other.

The ionisation chamber consisted of a 2-l. iron bottle with 2.7 g/cm^2 wall thickness, filled with argon at 30 atm pressure. The central collecting electrode was insulated from the bottle by means of a metal to glass seal, a guard ring at earth potential and a ring of teflon. The voltage drop on the central electrode, caused by the ionisation current, was measured by an electrometer circuit built by standard compensation methods. The sensitive components of the circuit were a VX41 Victoreen electrometer tube and a well-damped 2 μA galvanometer as zero instrument. The whole apparatus was mounted in a suitcase for easy transport.

Neither the ionisation chamber nor the Geiger counter are tissue-equivalent dose meters. A nearly tissue-equivalent instrument, therefore, was made with a liquid scintillator, a photomultiplier tube and a current-recording system. For high gamma-ray intensities, this is a well-known method. When the intensity to be measured is comparable with the natural background, considerable difficulties arise. The larger part of the output current is then dark current in the photomultiplier itself, and it is essential to be able to read the dark current before and after each measurement.

To solve this problem a kind of shutter between the scintillator and the photomultiplier is obviously necessary. After various attempts a final solution using a liquid scintillator was adopted. Instead of a mechanical shutter, the effect of liquid surface reflection was adopted. Only about four-fifths of the scintillator-tank volume was filled with the liquid, and with the photomultiplier attached to the top of the tank, the light transport between the liquid and the photomultiplier became very poor because of surface reflections. Almost all the current measured in this position was due to dark current in the tube. When the device was turned to the opposite position, the scintillator liquid attained direct contact with the covering glass of the photomultiplier cathode. Thus, a great increase in the light transport was obtained, and the difference in output current in the two positions is directly proportional to the intensity of the radiation to which the scintillator is exposed. As the effective atomic number of the liquid scintillator is very near the mean value for the human body, the equipment is assumed to be very near tissue-equivalent.

To get scintillating probes good enough for an environmental gamma-ray survey, photomultiplier tubes with very low dark current had to be picked. Two of the probes made were found satisfactory. The first had an EMI 6097 F photomultiplier tube with 200 g of NE 211 scintillator liquid in the tank. The second had a 54 AVP photomultiplier and 1000 g of NE 211 in the tank. The output current from the photomultiplier was measured by standard compensation methods, the sensitive component of the circuit being a VX41 Victoreen electrometer tube. The whole instrument was battery driven and built for easy transport. The actual measurements of the natural background radiation had to be taken with care because the difference in output current for the two positions of the probe was only about 20 per cent of the total.

CALIBRATION AND DISCUSSION OF ERRORS

The calibration of the counters is the most intricate problem when measuring environmental radiation. It is easy to point out various uncertainties for all the measuring methods mentioned above, and it will take too much space to discuss all these problems in detail. Some of the difficulties encountered are mentioned in the following.

The energy distribution of environmental gamma rays is unknown and varies with the relative abundances of potassium, thorium and uranium in the building materials. There will be Compton-scattered gamma rays with energies smaller than those of the primaries, but the relative number of energetic rays will also increase owing to the fact that they can penetrate from deeper layers. As a result, it is assumed that a calibration with primary gamma rays from radium will give a fairly good result. For the calibration, standard radium sources were used, and the ionisation in air, expressed in ion pairs/cm^3, was found by using the value of 8.26 R/hr at a distance of 1 cm from a 1 mg radium source filtered through 0.5 mm of platinum.[5]

The most intense component of the cosmic rays are mesons. A calculation shows that the counting rate from the Geiger probe used will be three times higher for energetic mesons than for 1-MeV gamma rays, when the intensities of the two components are chosen so as to give the same ionisation density in air. For other components with heavy ionisation along their tracks, such as protons of energy less than 100 MeV, this factor is less than 1. Owing to the cathode being thin, the same factor is also less than one for gamma rays of energy exceeding 5 MeV. The relative biological effectiveness of cosmic rays is higher than for gamma rays, and for this reason a relatively high counting efficiency for mesons may be preferable. It is assumed, however, that the variation of the ionisation in air is of more interest, and the relative efficiency for energetic particles having a vertical direction was reduced by a factor of 2 by using two tubes, one mounted close above the other. After this refinement, the Geiger probe is assumed to be fairly air equivalent for cosmic rays as compared to 1-MeV gamma rays. For the ionisation chamber and the scintillation counter no special precautions were taken to improve the air equivalence.

Ideally electronic devices should be built so as to give a calibration curve with a linear output vs. gamma-ray intensity. As this is not always the case, the calibration should be done at a place where the background is very low. A place with exceptional low background was found on a wooden bridge above deep water. To avoid errors due to scattering, both the standard radium source and the detector were placed at a height of 80 cm above the bridge. The calibration curves were found by varying the distance between the source and the detectors. For the Geiger counter the linearity of the electronic equipment could be checked by replacing the two Geiger tubes by a very small one. When exposed to the natural background, this small tube gave almost zero output when compared with that of the larger ones. The shape of the calibration curve could thus be found for the whole scale from zero to maximum deflection by using a strong source at various distances.

The efficiency of the detector probes depends on the angle between the gamma-ray direction and the probe axis. This angular dependence was measured by placing a source at a great constant distance, but at varying direction to the probe axis. The correction was found to be about 10 per cent for the Geiger counter, but almost zero for the scintillation probe and the ionisation chamber, if the calibration source was placed in the direction of maximum efficiency and assuming the natural background to be uniformly distributed in angle.

Both the gamma-ray sensitive probes and the electronic equipment are temperature dependent. The Geiger counter showed the highest temperature effect, namely an increase of 5 per cent from 10°C to 25°C. The error due to the temperature effect is smaller than 3 per cent in actual measurements.

Owing to the low intensity, an actual measurement of the environmental radiation has to be extended over a rather long time to get a reasonable statistical accuracy. Thus, for the Geiger counter a minimum of ten separate readings with a time constant of 10 sec was necessary to get a statistical accuracy of about 5 per cent. The Geiger counter was shockproof and unaffected when moved. Therefore, 5 min was sufficient for a single measurement. To get a reliable measurement with the ionisation chamber or with the scintillation rate meter, the whole apparatus had to stand still for a rather long time in the measuring position after the equipment had been moved. Therefore, to avoid inaccurate results, about ½ hr was the minimum time required.

One source of error to be considered is the effect of radioactive elements in the components of the detectors. Among these are alpha emission from the walls of the ionisation chamber and beta and gamma emission from the glass and other components of the photomultiplier and the Geiger tubes. Most suspicious in this respect is the glass. Therefore, a Geiger tube was broken and the pieces were used as a radiation source in a low-level beta counting anticoincidence combination. A sheet of zone-refined aluminium used as backing for the source was in this measurement assumed to be free from radioactivity. In this way the emission rate from the glass surface was found to be (0.062 ± 0.012) beta particles per cm^2/min, and from the metal cathode surface $(.038 \pm 0.006)$ beta particles per cm^2/min. From these values the counting rate from one Geiger tube due to the radioactive impurity was found to be (6.2 ± 1.5) counts/min. After the calibration it could be shown that the counting rate of 6.2 counts/min, which must be subtracted, corresponds to a correction of 0.46 ion pairs/cm^3 in the final result for the ionisation in air when measuring environmental radiation. The correction for radioactive impurities in the Geiger tube is, therefore, around 6 per cent. For the ionisation chamber and the scintillation probe the corresponding emission was found to be of less importance and was not corrected for.

The gamma-ray intensity varied from place to place in each apartment, but the variation was rather haphazard. However, measurements in sixty-five apartments in Oslo, picked at random, gave an average ionisation intensity of 9.8 ion pairs/cm^3 in the drawingrooms, while the corresponding value in the kitchens was 8.7 ion pairs/cm^3. This difference of about 12 per cent can, at least partly, be explained by the presence of various items of metal furniture in the kitchen. Even within the same room there could in some cases be a substantial variation. Therefore, for each measurement some care had to be taken in choosing a place for observation which seemed to be representative for the apartment under observation. For instance, a far too high value would result if the detector was placed near to a wall or chimney of brick, in a house otherwise made of wood.

The gamma radiation in the open air was found to vary with rainfall and nuclear bomb test activities. Similar variation inside houses was looked for by taking measurements regularly inside a wooden house in the Oslo region. Because no such variation could be detected, the variation is assumed to be less than 5 per cent in actual measurements.

The considerations above show that some of the uncertainties met with are difficult to estimate. Other investigators, HULTQVIST[2] and ATEN *et al.*,[3] estimate their results to be correct to within 20 per cent. Because the results obtained by means of the three different detectors were in good agreement, it is assumed that the error is less than 20 per cent.

RESULTS

The measurements were performed in the years 1958–1963, mostly during the summer seasons. The location of the houses selected for measurements was scattered over almost all the country as far north as Narvik. Because the ionisation intensity can vary considerably from house to house, most of the measurements were taken in towns and villages where it was possible to get values for houses of various types, and thus to get a representative average for the district. In valleys with long distances between houses, a few representative houses had to be picked. The figures given below should give fairly good average values for the exposure doses for people living in southern Norway.

The houses are divided into three main groups, (1) houses with outer walls of wood, (2) houses with outer walls of concrete and (3) houses with outer walls of red brick as shown in Fig. 1. In the first group there are mainly two types, the old type with timber walls only, and the modern type where different kinds of insulating materials are used. No attempt was made to separate these two types, since it was soon borne out by our measurements that, on the average, the difference is very small. In the second group, concrete, the building material is mostly ordinary concrete, but a few houses are also made of various types of prefabricated lightweight concrete blocks. The third group, red-brick buildings, often have floors and some inner walls of wood, especially houses built more than 50 years ago.

When comparing individual houses, there is a substantial variation of the gamma-ray intensity even for houses belonging to the same group. More important, for instance for the study of genetic effects, is to find any systematic difference between easily distinguishable groups of houses, as well as differences between various parts of the country. To get reliable figures for such a comparison, a rather large number of houses must be measured within each district because the individual variation within a relatively small district is often larger than the variation of the average from district to district. Figure 2 shows a map of Norway where the accepted division of the country into different districts is indicated. The results of the measurements within each of these districts are shown in Table 1.

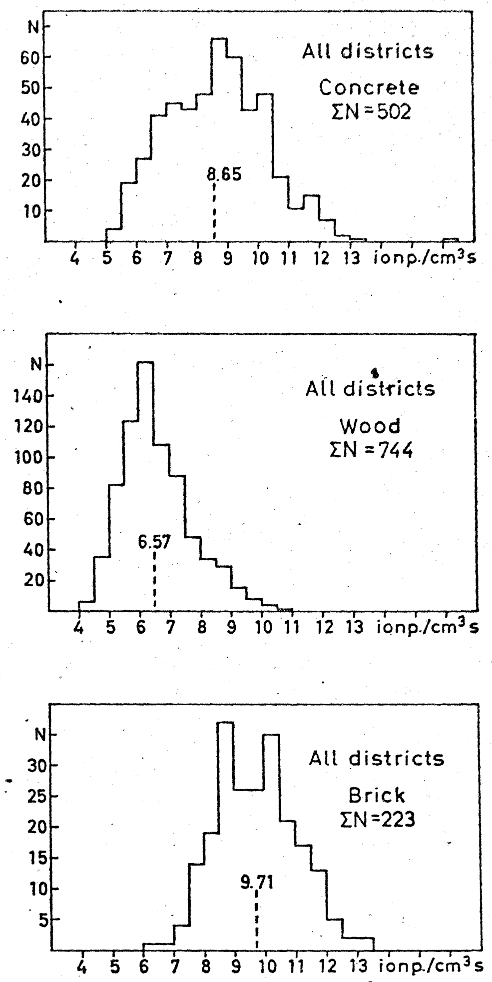

FIG. 1. The curves show the number N of houses measured vs. the total ionisation in air. For each of the groups plotted, the average value for the ionisation in air measured in ion pairs/cm^3 is indicated by the appropriate number and a broken line. ΣN is the total number of houses plotted for each of the curves. Included in Fig. 1 are houses from almost all over the country where a differentiation between the groups brick and concrete has been made.

Table 1. The table shows the ionisation intensity measured inside houses of different types of building materials. The location of the districts is marked in Fig. 2. Five per cent of the measurements had a lower value than the minimum figure shown in the table, and 5 per cent had a higher value than the corresponding maximum figure. ΔI is the standard deviation

District	Building material	Number of houses	Ionisation intensity (ion pairs/cm³s) Min.	Mean	Max.	ΔI
I	Wood	79	4.6	6.2	8.4	1.1
	Concrete	81	6.3	9.2	11.8	1.6
	Brick	15	7.8	10.6	13.0	1.6
II	Wood	147	5.2	7.1	9.2	1.2
	Concrete	68	6.2	8.6	11.3	1.5
	Brick	33	7.6	9.7	12.7	1.5
III	Wood	61	5.2	7.0	8.9	1.1
	Concrete and brick	92	7.8	9.8	11.5	1.1
IV	Wood	58	5.0	7.1	9.1	1.4
	Concrete and brick	285	8.0	10.3	12.6	1.5
V	Wood	45	5.7	7.7	10.2	1.3
	Concrete	29	7.2	9.3	11.3	1.2
	Brick	14	8.6	10.3	11.8	1.3
VI	Wood	45	5.6	7.5	10.0	1.3
	Concrete	38	7.4	9.5	12.1	1.3
	Brick	9	9.1	10.3	11.8	1.1
VII	Wood	37	5.6	6.0	9.6	1.2
	Concrete	41	7.6	9.5	12.0	1.3
	Brick	35	8.2	10.2	11.9	1.0
VIII	Wood	86	5.1	6.1	7.2	0.7
	Concrete	57	6.4	7.8	10.0	1.1
	Brick	12	8.6	9.3	10.7	0.8
IX	Wood	63	4.6	5.6	6.5	0.6
	Concrete	71	5.6	6.9	9.4	1.2
	Brick	43	7.2	8.6	11.0	1.0
X	Wood	6	5.7	6.6	7.2	0.6
	Concrete and brick	28	6.1	8.7	11.8	1.9
XI	Wood	83	4.9	6.1	7.3	0.7
	Concrete	66	6.1	8.0	9.9	1.1
	Brick	10	7.7	8.7	9.4	0.6
XII	Wood	75	4.4	6.1	7.6	0.9
	Concrete and brick	134	6.8	8.6	10.5	1.2
XIII	Wood	38	5.4	6.6	8.5	1.2
	Concrete and brick	42	8.0	10.9	13.5	1.7

A comparison between Fig. 2 and Table 1 shows that the percentage of wooden houses is greater in those districts where there are relatively few towns and villages. For instance, in district I with a great proportion of towns and villages along the seashore, 45 per cent of the houses measured have outer walls of wood, while in district II with only two small towns, the corresponding figure is 60 per cent.

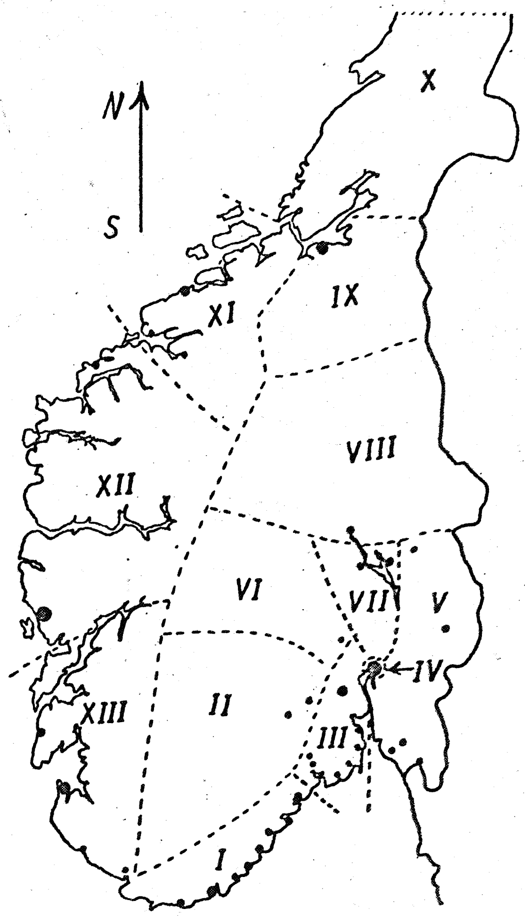

FIG. 2. A map of Southern Norway where the accepted division of the country into different districts is indicated. The main towns are indicated by dots.

In fifty-eight houses with outer walls of wood the ratio R of the ionisation on the ground floor to the ionisation on the first floor was on the average found to be $R = 1.08$. The variation of this ratio was, however, rather large, the minimum value being $R_{min} = 0.90$ and the maximum value $R_{max} = 1.27$, with a standard deviation of $\Delta R = 0.09$. For the other types of building materials, no systematic variation with the height above ground was observed.

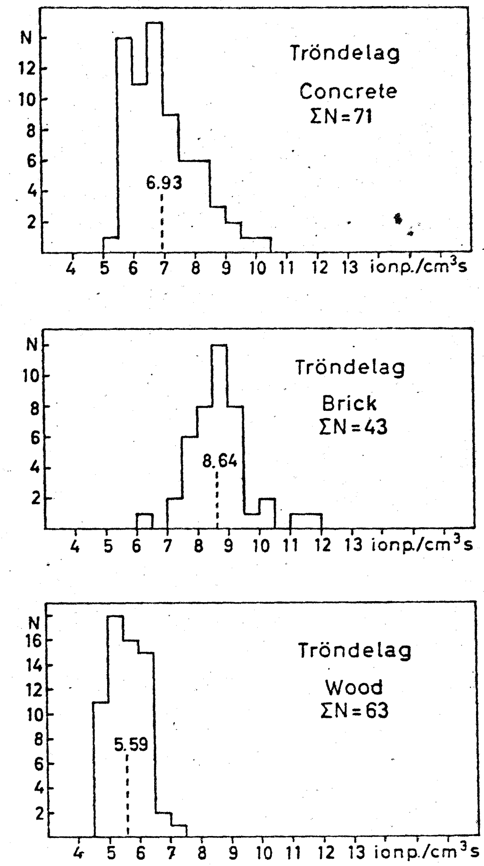

FIG. 3. The number N of houses vs. the ionisation intensity in air for a single district (district Tröndelag, including the town Trondheim, marked IX in Fig. 2).

No significant difference was found between the ordinary heavy concrete and the prefabricated light-weight concrete blocks. The ionisation intensity in houses made of light-weight concrete blocks was found to be on the average slightly smaller than the corresponding value in houses made of heavy concrete. In Sweden[2] a certain type of light-weight concrete containing alum shale was found to be far more radioactive than other building materials.

CONCLUSIONS

Table 1 shows that the actual differences between the various districts are not very great. The variation of the average value from district to district is smaller for the red-brick type and wooden houses than for the concrete type, but followed almost always the same pattern. The most important difference is that for all the districts measured, the average ionisation intensity is higher for the red-brick type houses than for the concrete type, and that the wooden houses show corresponding figures which are substantially lower. Table 2 shows a comparison between the three types of building materials for the whole country.

Table 2. The average value of the ionisation intensity in air inside houses of various types of building materials

Building material	Number of houses	Mean ionisation intensity in air (ion pairs/cm³)	Dose rate in air (mrad/year)
Wood	823	6.6	87
Concrete	594	8.7	115
Brick	245	9.8	129
Brick or concrete	364	9.7	128
All types	2026	8.1	108

The variation between the districts chosen is too small to be of any value for the study of genetic effects. More important variations can, however, be pointed out. One can, for instance, compare the cities of Oslo (from district IV) and Trondheim (from district IX) which have average values for the ionisation intensity in all the houses measured of 9.73 ion pairs/cm^3 and 7.30 ion pairs/cm^3, respectively. In the same way one can compare the towns Stavanger (from district XIII) and Kristiansund (from district XI), where the average values were found to be 9.74 ion pairs/cm^3 and 6.82 ion pairs/cm^3, respectively. In these and similar cases a comparison can be made between groups of people each living under the same conditions. A detailed comparison, especially between areas of different geological conditions, is of more value after the open-air measurements are included. Such measurements are almost completed, and the results will be reported elsewhere.

In the country and small towns and villages, most of the people are living in wooden houses and working in the open-air, where the ionisation intensity is relatively low. In the cities and large towns the inhabitants are mostly living and working in houses made of concrete or brick. Therefore, people living in cities and large towns are, on the average, more exposed to radiation than the rest of the population.

The present measurements may be of interest in the wide-world study of the naturally occurring ionising radiation. Therefore, in Table 3 we have compared our values with data reported from neighbouring countries.[2,3,6]

Table 3. Gamma-dose rates in air inside buildings in various countries. The figures given are, respectively the measured minimum, mean and maximum values after subtraction of the dose rate due to cosmic rays. The maximum and minimum values chosen are defined in the heading of Table 1

Country	Type of building material	Gamma-dose rate in air (mrad/year)		
		Min.	Mean	Max.
Norway	Wood	41	62	93
	Concrete	56	92	127
	Brick	76	104	133
Sweden	Wood	37	45	60
	Brick	57	94	118
	Light-weight concrete	93	155	215
Netherlands	Wood	18	22	26
	Concrete	28	46	63
	Brick	46	58	82
England	Various	73	88	107

For Norway the average dose rate is found to be 83 mrad/year when all the houses are included. For Sweden the corresponding value is 103 mrad/year. In both cases 25 mrad/year for cosmic rays is subtracted. For the observations in the Netherlands, where only one Geiger tube was used in the probe, a value of 30 mrad/year for cosmic rays was chosen. For Norway and Sweden the total number of measurements is 2026 and 986, respectively. In the Netherlands and in England the number of houses measured is only six and seven, respectively. Although there was more than one measurement taken in each house, the total number of houses is too small to give reliable averages for the last two countries. However, Table 3 indicates that there is no extreme low or high ionisation intensity in Norwegian houses when compared with that found in neighbouring countries.

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