INDOOR EXPOSURE TO NATURAL RADIATION IN DENMARK

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INTRODUCTION

A survey on natural radiation in a representative sample of Danish dwellings (1) was carried out by measuring the radon concentration and the absorbed dose rate in air from external radiation in about 500 dwellings. The householders of a total of 926 dwellings were invited to participate in the survey by postal contact. The dwellings were selected randomly from a central register of all Danish buildings. The measurements were carried out with one half in the summer period from April to September 1985 and the other half in the winter period from October 1985 to March 1986. The radon concentration and the external radiation were measured by passive closed dosemeters (2). The sensitive elements were nuclear track detectors (Cr-39) for the measurement of radon and thermoluminescence detectors (LiF TLD-700) for the measurement of external radiation. In each dwelling the radon concentration was measured in the living-room and in a bedroom. The external radiation was measured only in the living-room. When returning the dosemeters the occupants of the dwellings were asked to fill in a questionnaire giving information pertinent to the conditions that may influence the radon concentration in a dwelling: type and age of the dwelling, building materials, ventilation conditions etc.

RESULTS AND DISCUSSION

Measurements of the radon concentration were obtained for 496 dwellings. The arithmetic mean values for different subgroups of the measured dwelling are shown in table 1.

Table 1. Arithmetic mean values of the radon concentration for different subgroups of dwellings.

	Single-family houses		Multi-family houses	
	Arithmetic mean Bq/m^3	Number of dwellings	Arithmetic mean Bq/m^3	Number of dwellings
Living-room, summer	58	168	17	78
Living-room, winter	93	180	24	70
Bedroom, summer	49	168	17	78
Bedroom, winter	73	180	21	70

The arithmetic mean values of the radon concentration for the single-family houses are seen to be higher than the corresponding mean values for multi-family houses. This indicates that the subsoil is the main radon source for single-family houses. For the single-family houses the mean radon concentration is higher for the living-room than for the bedroom and higher during the winter than during the summer. In multi-family houses all the mean values are close to 20 Bq/m^3. For each dwelling an annual average radon concentration has been calculated by multiplying the mean value of the measured semi-annual radon concentration in the living-room and in the bedroom by a correction factor. The correction factor was estimated for different subgroups from the arithmetic mean values for the summer and winter period. The distributions of these annual mean radon concentrations in single-family houses and in multi-family houses have been combined in figure 1. This distribution is expected to be representative of the annual mean radon concentration in Danish dwellings. The corresponding cumulative distribution is shown in figure 2. The mean value of the annual radon concentration was found to be 47 Bq/m^3. The representative cumulative distribution shows that the annual average radon concentration exceeds 200 Bq/m^3 in less than 2% of the Danish dwellings, and that the average radon concentration exceeds 800 Bq/m^3 in only a very limited number of Danish dwellings. By weighting with the distribution of the Danish population (69% of the population are living in single-family houses and 31% in multi-family houses) the population-averaged radon concentration was found to be 53 Bq/m^3.

The most important parameter for the single-family houses was found to be the character of the subsoil under the house. Single-family houses placed on primarily moraine clay was found to have a significantly ($P > 99\%$) higher mean radon concentration (geometric mean 68 Bq/m^3) than houses placed on the other types of subsoil (geometric mean 39 Bq/m^3). This is in good agreement with measurements of the radon emanation from samples of Danish soils (3). No significant differences were found between other types of subsoil, which generally may be characterized as "sand and gravel". The analysis further shows a significant difference within the moraine clay group between the results from the summer period (geometric mean 54 Bq/m^3) and the winter period (geometric mean 85 Bq/m^3). No similar significant difference was found within the sand and gravel group. After the character of the subsoil, the analysis has shown that the type of foundation of the single-family houses is dominant. The highest mean radon concentration was found for houses without basement or with a basement under only a part of the house (geometric mean 65 Bq/m^3). A lower mean radon concentration was found in houses with a crawl space (geometric mean 46 Bq/m^3) and the lowest values were found in houses with a full basement (geometric mean 34 Bq/m^3). These findings reflect different possibilities of entry of radon from the underlying soil through the different types of foundation into the living-rooms and bedrooms.

Measurements of the external radiation were obtained for 489 dwellings. The results are normally distributed. The arithmetic mean values of the absorbed dose rates in air were found to be 83 nGy/h and 90 nGy/h for single-family houses and multi-family houses, respectively. The mean value was found to be higher in buil-

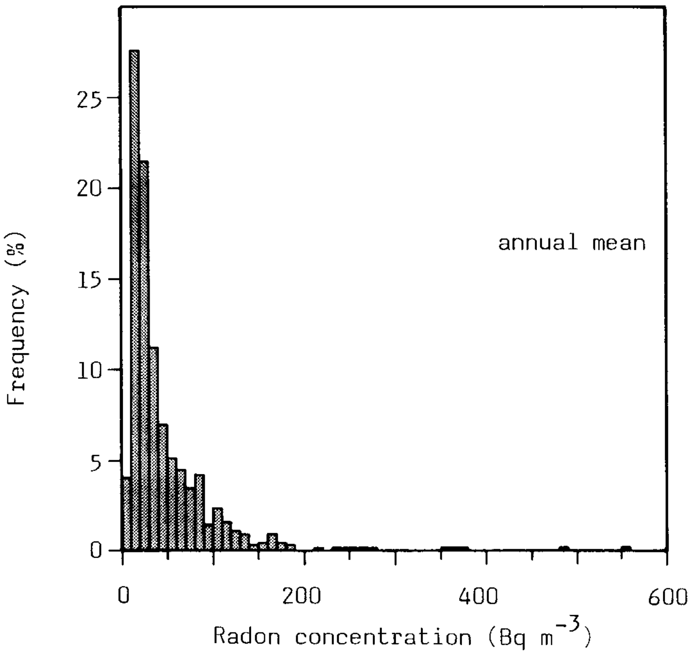

Fig. 1 Frequency distribution of the annual average radon concentration in Danish dwellings based on the 496 investigated dwellings.

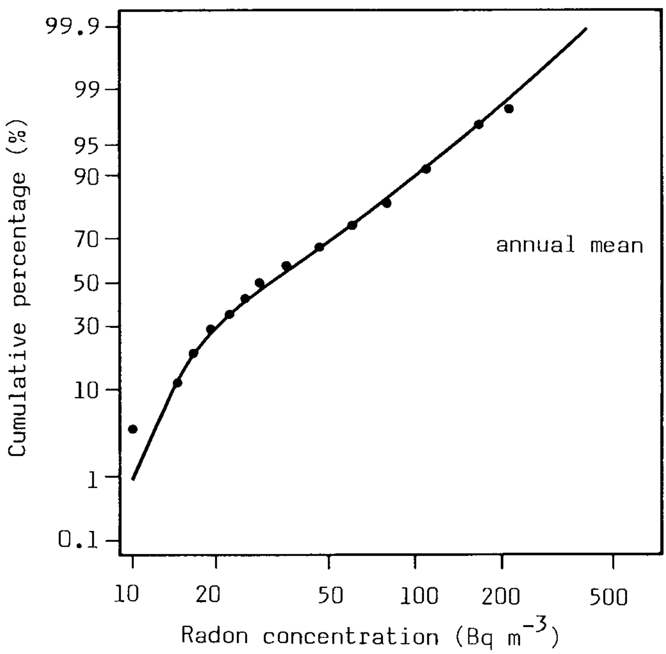

Fig. 2 Cumulative distribution of the annual average radon concentration based on the 496 investigated dwellings. The solid line represents the weighted sum of the two log-normal distributions for the single-family houses and multi-family houses.

dings constructed of clay bricks (single-family houses: 84 nGy/h, multi-family houses: 95 nGy/h) than in buildings constructed of concrete (single-family houses: 74 nGy/h, multi-family houses: 76 nGy/h). This is in good agreement with earlier measurements of natural radioactivity in Danish building materials (4). Furthermore the external radiation was found to be higher in buildings constructed before 1960 (single-family houses: 87 nGy/h, multi-family houses: 98 nGy/h) than in buildings constructed after 1960 (single-family houses: 77 nGy/h, multi-family houses: 77 nGy/h). This is due to a more frequent and more substantial use of clay bricks before 1960.

DOSE TO THE DANISH POPULATION

Assuming residence probabilities of 0.7, 0.2 and 0.1 for staying indoors at home, indoors elsewhere and outdoors, respectively, and assuming the mean value of the annual radon concentration to be 47 Bq/m^3 indoors and 8 Bq/m^3 outdoors, the total annual radon exposure in $Bq \cdot y/m^3$, E, may be expressed as (5): $E = 0.7 \cdot C_{Rn} + 10$, where C_{Rn} is the annual average radon concentration in the home. With an equilirium factor of 0.5 and a conversion factor to effective dose equivalent of 0.076 mSv per $Bq \cdot y/m^3$ EER (6) the population averaged radon concentration of 53 Bq/m^3 in Danish dwellings corresponds to a mean effective dose equivalent to the Danish population of 1.8 mSv in a year from radon daughters. The mean effective dose equivalent to the Danish population from terrestrial gamma rays has been calculated to be 0.32 mSv in a year. A contribution of 31 nGy/h from cosmic radiation has been subtracted from the mean absorbed dose rate in air indoors in Denmark of 85 nGy/h to give a mean indoor gamma ray dose rate of 54 nGy/h. The mean outdoor gamma ray dose rate in Denmark is 35 nGy/h (7).

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