APPLICATION OF OUTDOOR OCCUPANCY FACTOR TO THE EFFECTIVE DOSE CALCULATION IN SOME RURAL COMMUNITIES IN NIGERIA

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Abstract - In situ gamma spectroscopy has been employed to characterize natural radiation in the soil at thirty-two locations in rural communities of Nigeria. In the estimation of the outdoor effective dose to the public, the outdoor occupancy factor has been an important parameter. The factor varies, depending on the prevailing environmental condition in a particular location. This factor has been estimated for the rural areas in Nigeria using an appropriate occupancy factor model that suites the above environmental condition. An outdoor occupancy factor of 0.3 has been estimated for rural areas as against the UNSCEAR factor of 0.2 recommended for the world. The rural outdoor effective dose is 50% above the value obtained when the UNSCEAR factor of 0.2 is employed. The average outdoor effective dose to the rural communities has been estimated to be 48 μSv y^{-1}.

INTRODUCTION

In calculating doses arising from radionuclides deposited in body tissues, a number of quantities to relate the deposition of energy to the observed biological effect in the whole body have been developed by the ICRP [1]. The principal quantities are absorbed dose in tissues, equivalent dose and effective dose. The effective dose, which assesses the overall radiation detriment to the whole body from radiation doses in different organs and tissues, is derived from the absorbed dose rates and the average time spent either outdoor or indoor. In the survey of terrestrial gamma radiation levels of an environment, the knowledge of the outdoor and indoor occupancy factors remain one of the important requirements for calculating the doses to the population [2,3]. In most publications in the area of environmental gamma radiation studies, authors have been employing the occupancy factors recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3]. This assumption, however, may not adequately represent the actual situation in the studied environment. The development of these factors might have been based on the statistics obtained from time budget suiting the working and environmental conditions in the urban and temperate region of the globe, where most activities are carried out indoors. It has been noted that the factor depends, however, on peoples' habits, occupational structure and the prevailing weather conditions, which makes it a location specific parameter [4]. In the rural and tropical environment for example, the use of the UNSCEAR factor has been found to underestimate the outdoor effective dose by 50% [4]. In most African countries, over 60% of the total populations reside in the rural areas. In Nigeria, over 66% of the total populations are rural dwellers [5]. The possible effects of exposure to ionizing radiation due to naturally occurring radionuclides on man have been a cause of growing concern. It has been reported that natural radionuclides are widely distributed in the earth crust and contribute about 85% of environmental radiation level, which are strongly influenced by local geology [6] The natural environment is made up of indoor exposure to radon [7 -9] and outdoor exposure to gamma radiation of both terrestrial and cosmic origin [10-11]

Most of the works so far carried out are in major cities in Nigeria without a particular focus on rural areas where over 66% of Nigerians reside and where such data exit, the UNSCEAR factor has been widely employed. The present work has been conducted in the rural communities of Niger Delta region where extensive oil exploration and mining activities involving the use of radioactive materials take place on daily basis. A new occupancy factor based on a well designed questionnaire results collected from rural areas in the tropical environment has been applied to the calculation of the effective dose in these communities, which then form the basis of comparison between it and the earlier one obtained from the UNSCEAR factor.

GEOLOGY OF THE AREA

Three major depositional (sedimentary) environments (marine, mixed and continental) are observable. Based on the sedimentary environmental classification, the three rocks formations used in describing the subsurface sedimentary sequences are the Benin, Agbada and Akata formations (12). These formations form the bulk of the deltaic (Tertiary) sediments underlining the basement complex of the studied areas. They consist mainly of alternations of sands, sandstones and siltstones. The sandy part constitutes the main hydrocarbon reservoirs, which grain size increases upwards and that the gamma radiation from natural radionuclides in the upper layer of the formation is often higher than in the underlying marine clays. The sandstones or sands are very coarse to very fine grain. The sands are often poorly sorted except where sand grades into shale. Lignite streaks and limonite are common but limonite coated sand grains and feldspars are rare.

MATERIALS AND METHODS

Occupancy factor model

In order to calculate the outdoor/indoor occupancy factors for both the rural and urban areas in Nigeria, a model relating the time budget for various activities of the day to the outdoor/indoor parameters has been developed. The time budget used in the model was evaluated from a priori information obtained from various groups of people in both the rural and urban areas. This involved the use of questionnaires particularly developed to retrieve information from all categories of people in the rural communities with the assumption that time budget and the fraction of the time budget for each activity are considered as parameters, each activity has a component of indoor and outdoor, every member of the various groups is in a place at a given time and the activities are classified as academic/occupation, sleep/rest, leisure and others (miscellaneous). The results collated from the questionnaires have been presented as shown in Table 1.

The time spent either outdoors or indoor was considered as a fraction of the time slot for the various activities outlined above.

The time spent outdoors by a population sub-group during an activity i is x_i given by:

$$x_i = \alpha_i t_i \qquad 1$$

where α_i is a fraction, which is an outdoors weighting parameter, and t_i is the time budget for the activity i.

The time spent indoor by a population sub-group i during an activity i is y_i given by:

$$y_i = \beta_i t_i \qquad 2$$

where β_i is an indoor weighting parameter.

The total time T_{out} spent outdoor is given as:

$$T_{out} = \frac{1}{n}\sum_{i}^{n} x_i \qquad 3$$

and the total time T_{in} spent indoor is given as:

$$T_{in} = \frac{1}{n}\sum_{i}^{n} y_i \qquad 4$$

where n is the total number of the population sub-group.

Site selection and Measurement technique

The present studies were conducted in the month of March, which is the peak of the dry season in the area when most parts could be accessed with minimal difficulty. In all, 175 sites in 32 communities were surveyed and the distribution was such that all communities having one oil operational facility or the other in the area that were accessible were covered. A few communities where oil activities are not known to be taking place were also chosen. Table 1 gives the list of communities surveyed with their serial numbers shown in Fig. 1. The method employed in this work has been reported elsewhere (14), but a brief description of the method will be done. The rapid in – situ method of gamma spectroscopy was employed using a 7.6 cm x 7.6 cm NaI(Tl) detector placed at a height of 1 m above the ground surface. The detector has a resolution of about 8% at at 0.662 MeV line of ^{137}Cs. As shown in a typical spectrum in the field, this resolution is sufficient to resolve the 1.460 MeV, 1.760 MeV and 2.614 MeV gamma peaks that were used to measure ^{40}K, ^{238}U and ^{232}Th, respectively. The detector was coupled to a Canberra series 10 plus Multichannel Analyzer (MCA) (Model No 1104) through a preamplifier base. The output signals from the NaI(Tl) detector were passed to the MCA through co-axial cables of about 5 m. The same length of cable carries high voltage necessary to bias the PMT of the detector from the MCA. The MCA operates on a rechargeable Cd-cell battery, which can last for about 8 hours when fully charged. A standby 12V car battery was used whenever the in-built batteries run down in the field. Counting was done for a preset time of 1000 s at five locations within each of the 32 communities and the counts per second (N_f) for each of the three peaks of interest were obtained for each spectrum. The count per second for each radionuclide at each location was computed using the algorithm in the memory of the MCA.

Calibration procedure

The relevant quantity for the assessment of radiological health effect is the absorbed dose rate and not the soil activity concentration. A conversion from activity concentration to dose rate in air (i.e. $\frac{D}{A}$) is therefore necessary in order to evaluate the health impact. In order to do this, a uniform distribution of the radionuclides was assumed, and also all daughters including gaseous ^{222}Rn and ^{220}Rn from ^{238}U and ^{232}Th series were considered to be in equilibrium with their parents and as such, the effects of the gaseous components were not taken into account. Under this condition, the important factors in in-situ gamma spectrometry reduce to $\frac{N_f}{A}$ and $\frac{N_f}{D}$, which relate N_f to the absorbed dose rate (D) and soil activity concentration (A) of each radionuclide, respectively. The conversion factors obtained by Zombori et al [15]. The quantity D/A is independent of the detector type and had been derived by Beck et al [16] for different detector types as:

$$D = 0.042A_k + 0.429A_u + 0.666A_{th} \qquad (1)$$

Where D (nGyh^{-1}) is the total air absorbed dose rate due to the activity concentrations A_k, A_u, and A_{th} of ^{40}K, ^{238}U and ^{232}Th in Bq.kg^{-1} respectively.

RESULTS AND DISCUSSION

In estimating the outdoors effective dose in any environment, the two factors of importance are the conversion factor from Gy h^{-1} to Sv h^{-1} and the occupancy factor. The former gives the equivalent human dose in Sv y^{-1} from the absorbed dose rate in air (Gy h^{-1}) while the latter gives the fraction of the time that an individual is exposed to the outdoor radiation. The first factor has been recommended by UNSCEAR [3] as 0.7 Sv Gy^{-1} and the second factor as 0.2, which suggests that an average individual stays about 4.8 hours outside daily. This second factor has been employed by many researchers [17 - 24] without constraint and hence, no regard to the pattern of life in the studied areas. In the present effort, the living pattern in the rural areas has been considered using the occupancy factor model presented earlier. The model suggests that the average time spent by rural dwellers is 7.2 hours outdoor representing 30% occupancy factors. The outdoor occupancy factor of 0.3 for the average person in the rural areas is 50% higher than the UNSCEAR factor, which is significant. The increase can be attributed to the differences in the occupational and lifestyle habits, which is a function of the prevailing weather conditions. In the rural areas, majority of the people are peasant farmers, most of whom leave home as early as 6.00 a.m. and return around 5.00 p.m. and 6.00 p.m. each day except religious and festive days. Adult leisure periods are spent under shade of trees and shield made with palm leafs. School pupils also find their way to the farm immediately after school hours and leisure periods are spent playing football either at school during break or at home. Household shores are often carried out in an open yard. Business transactions of goods and services take place in open markets.

The present factor, alongside the absorbed dose calculated from the activity concentration of ^{40}K, ^{238}U and ^{232}Th presented in Table 2 were used to calculate the effective dose presented in the last column of Table 3. The effective dose calculated using the UNSCEAR factor was given in the second column of the same Table. The average effective dose values as presented in the table shows that the estimated outdoor effective dose to member of the public in similar situation in Nigeria and indeed Africa must have been underestimated by about 50% for rural settings. In recognition of the present occupancy factor, the annual effective dose (31.6 μSv y^{-1}) reported for the Delta region of Nigeria [25] using the UNSCEAR factor might have been underestimated by 50%. The oil producing areas in the country best described a rural dwelling pattern; the UNSCEAR factor was employed because the essential data needed to estimate the factor were not available at that moment. Using the present outdoor occupancy factor, the average effective dose to the public in the area has been estimated to be 48 μSv y^{-1}. Figure 2 show the comparison between the effective doses obtained using the present outdoor factor for rural dwellers and the UNSCEAR factor. The indoor effective doses were not evaluated because the essential data on average build-up of radon gas in the indoor atmosphere were not available.

CONCLUSION

The outdoor occupancy factor for the rural dwellers in Nigeria has been estimated. The factors suggested that the effective dose due to the terrestrial gamma radiations to the rural public in Nigeria and similar environment in the continent Africa would either be underestimated by 50% for outdoor or overestimated by 12.5% for indoor in rural areas when the world average values by UNSCEAR is employed. The increase in the outdoor factors over the UNSCEAR value have been attributed to the differences in lifestyle of the people in tropical Africa and those in the temperate region of the globe, which the estimation of the UNSCEAR value might have been based. Apart from this, the differences in occupational practices between the developed and the developing countries could be a major contribution. In the estimation of the outdoor effective dose from terrestrial gamma radiation to the rural areas surveyed in these communities in Nigeria using the occupancy factor of 0.3, the mean outdoor annual effective dose is 48 μSv y^{-1}, which is 68% of the world average value of 70 μSv y^{-1} [3].

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Table 1: Time budget for various activities in the population sub-groups identified in the rural areas [13].

Groups	Activities											
	Leisure			Occupation			Rest			Others		
	α_1	β_1	T_1(hr)	α_2	β_2	T_2 (hr)	α_3	β_3	T_3 (hr)	α_4	β_4	T_4 (hr)
Student	0.6	0.4	4.0±0.6	0.2	0.8	8.0±0.4	0.3	0.7	8.0±0.5	0.6	0.4	4.0±0.6
Farmer	0.7	0.3	1.0±0.7	0.8	0.2	10.0±0.2	0.2	0.8	8.0±0.4	0.4	0.6	5.0±0.6
Trading	0.6	0.4	3.0±0.4	0.7	0.3	9.0±0.3	0.2	0.8	8.0±0.3	0.4	0.6	4.0±0.4
Health Care	0.4	0.6	3.0±0.4	0.3	0.7	10.0±0.1	0.1	0.9	8.0±0.4	0.4	0.6	3.0±0.5
Exten. service	0.4	0.6	4.0±0.6	0.6	0.4	8.0±0.4	0.1	0.9	8.0±0.5	0.4	0.6	4.0±0.6

Table 2: The mean specific activities of ^{40}K, ^{238}U and ^{232}Th for the rural communities

Location		^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
No	Communities	Mean	Mean	Mean
1	Okitipupa	19.5 ± 6.3	17.2 ± 4.3	13.9 ± 3.8
2	Igbokoda	13.4 ± 0.7	10.8 ± 0.7	17.2 ± 2.0
3	Mahin	16.4 ± 5.2	12.1 ± 1.0	18.0 ± 1.8
4	Warri River Flow Station	44.3 ± 3.2	24.4 ± 4.3	22.8 ± 1.6
5	Ovu-kokori	28.5 ± 2.6	11.6 ± 2.0	11.0 ± 2.2
6	Otorugu	53.2 ± 8.0	22.1 ± 3.4	28.2 ± 4.5
7	Otujeremi	57.5 ± 7.1	26.7 ± 1.5	29.0 ± 3.3
8	Evwreni	39.7 ± 7.5	18.4 ± 1.6	23.1 ± 3.1
9	Oroni	41.7 ± 6.5	18.0 ± 1.4	25.9 ± 2.9
10	Uzede West	25.1 ± 3.4	13.1 ± 4.0	19.9 ± 1.8
11	Uzede East	27.5 ± 3.6	11.7 ± 2.1	18.3 ± 1.9
12	Opukushi	43.7 ± 3.4	15.7 ± 3.9	27.4 ± 2.8
13	Sagbama	49.4 ± 4.4	14.7 ± 4.7	25.5 ± 3.9
14	Okoso-logan	22.8 ± 13.0	13.7 ± 5.6	21.6 ± 4.1
15	Oloibiri	48.8 ± 4.4	18.0 ± 1.4	27.7 ± 2.9
16	Soku	36.3 ± 5.2	15.5 ± 2.8	26.7 ± 1.8
17	Ekulama	42.5 ± 2.9	14.8 ± 2.6	30.5 ± 1.9
18	Krakama	36.3 ± 6.0	13.9 ± 6.3	29.7 ± 0.9
19	Abonnema Wharf	36.1 ± 3.0	15.7 ± 2.1	26.5 ± 2.5
20	Elelenwo	28.1 ± 2.6	14.2 ± 3.9	29.0 ± 2.9
21	Obigbo	32.7 ± 8.5	16.2 ± 2.8	26.0 ± 3.0
22	Imo River Flow Station	18.8 ± 2.2	10.8 ± 2.0	28.0 ± 1.8
23	Obunku	24.9 ± 7.4	12.5 ± 3.9	27.2 ± 1.9
24	Afam	26.0 ± 5.0	13.4 ± 4.0	26.4 ± 2.6
25	Ibibio	36.5 ± 4.8	17.9 ± 3.2	28.0 ± 2.3
26	Ibeno	24.6 ± 4.3	21.1 ± 2.5	23.9 ± 2.8
27	Qua Ibo River Flow Station	21.2 ± 1.5	18.3 ± 2.7	29.8 ± 3.1
28	QIT (Mobil Platf.)	26.0 ± 3.9	21.2 ± 4.0	24.4 ± 1.9
29	Ifiayong	22.7 ± 4.5	15.2 ± 2.5	23.6 ± 2.1
30	Eket	20.9 ± 7.3	15.6 ± 3.9	24.1 ± 2.1
31	Uyo	21.9 ± 6.7	16.2 ± 4.0	22.4 ± 3.4
32	Calabar	127.8 ± 0.8	19.1 ± 6.4	25.1 ± 10.5
Mean ± Sd		34.8 ± 20.4	16.2 ± 3.7	24.4 ± 4.7

Table 3: The mean Effective dose for the rural communities

Location	Effective dose ($\mu Sv\ y^{-1}$)	
No	UNSCEAR factor	Present factor
1	22.4	33.6
2	21.4	32.1
3	22.9	34.4
4	34.1	51.2
5	17.3	26.0
6	39.0	58.5
7	42.4	63.6
8	30.1	45.2
9	34.1	51.2
10	25.6	38.4
11	23.4	35.1
12	34.1	51.2
13	32.5	48.8
14	27.2	40.8
15	35.9	53.9
16	33.1	49.7
17	35.9	53.9
18	34.9	52.4
19	33.0	49.5
20	34.0	51.0
21	32.7	49.1
22	30.7	46.1
23	31.3	47.0
24	31.2	46.8
25	35.5	53.3
26	33.2	49.8
27	36.6	54.9
28	38.9	58.4
29	29.7	44.6
30	30.2	45.3
31	29.1	43.7
32	38.6	57.9
Mean ± SD	31.6 ± 3.1	47.4 ± 8.5

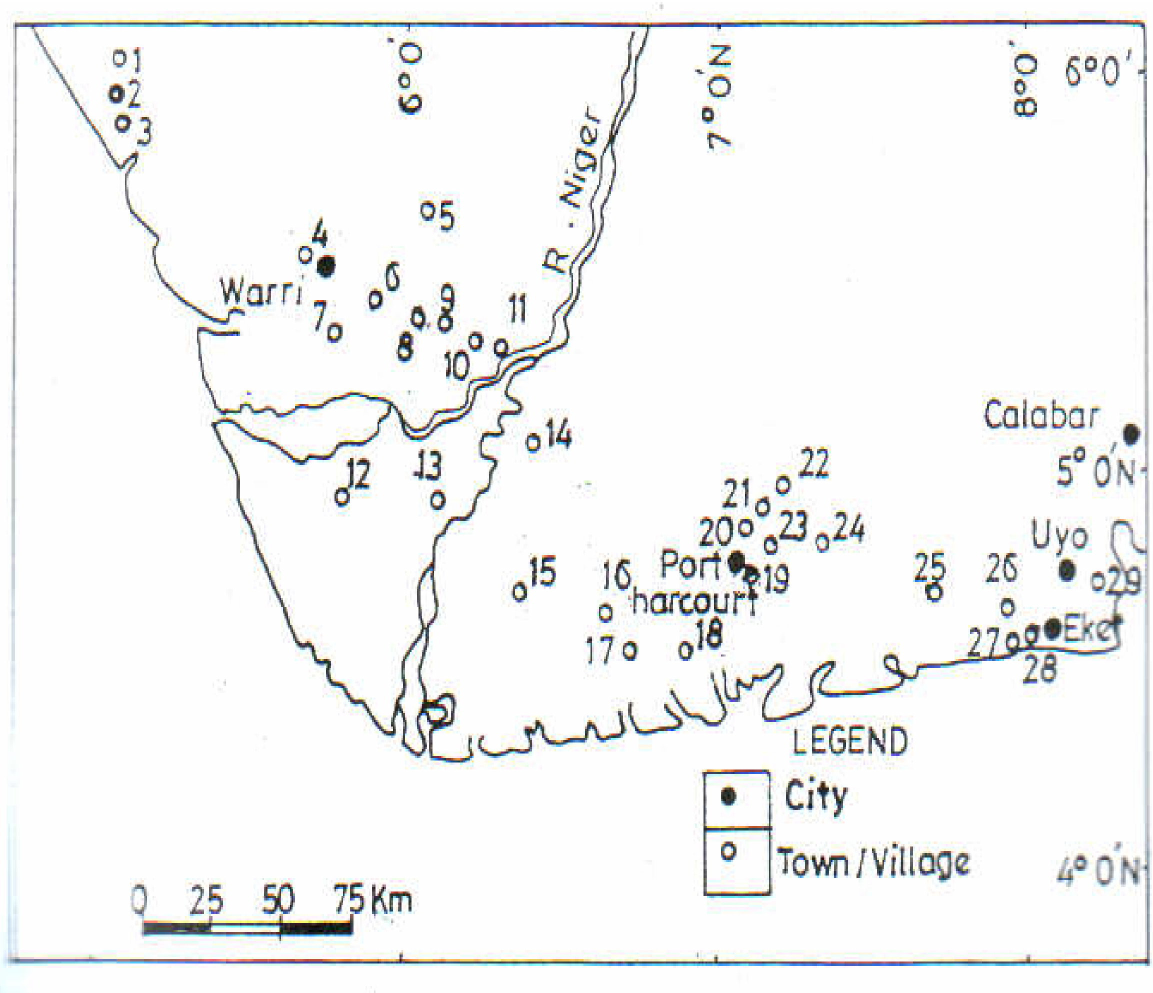

Fig. 1: Map showing the rural communities where measurements were made

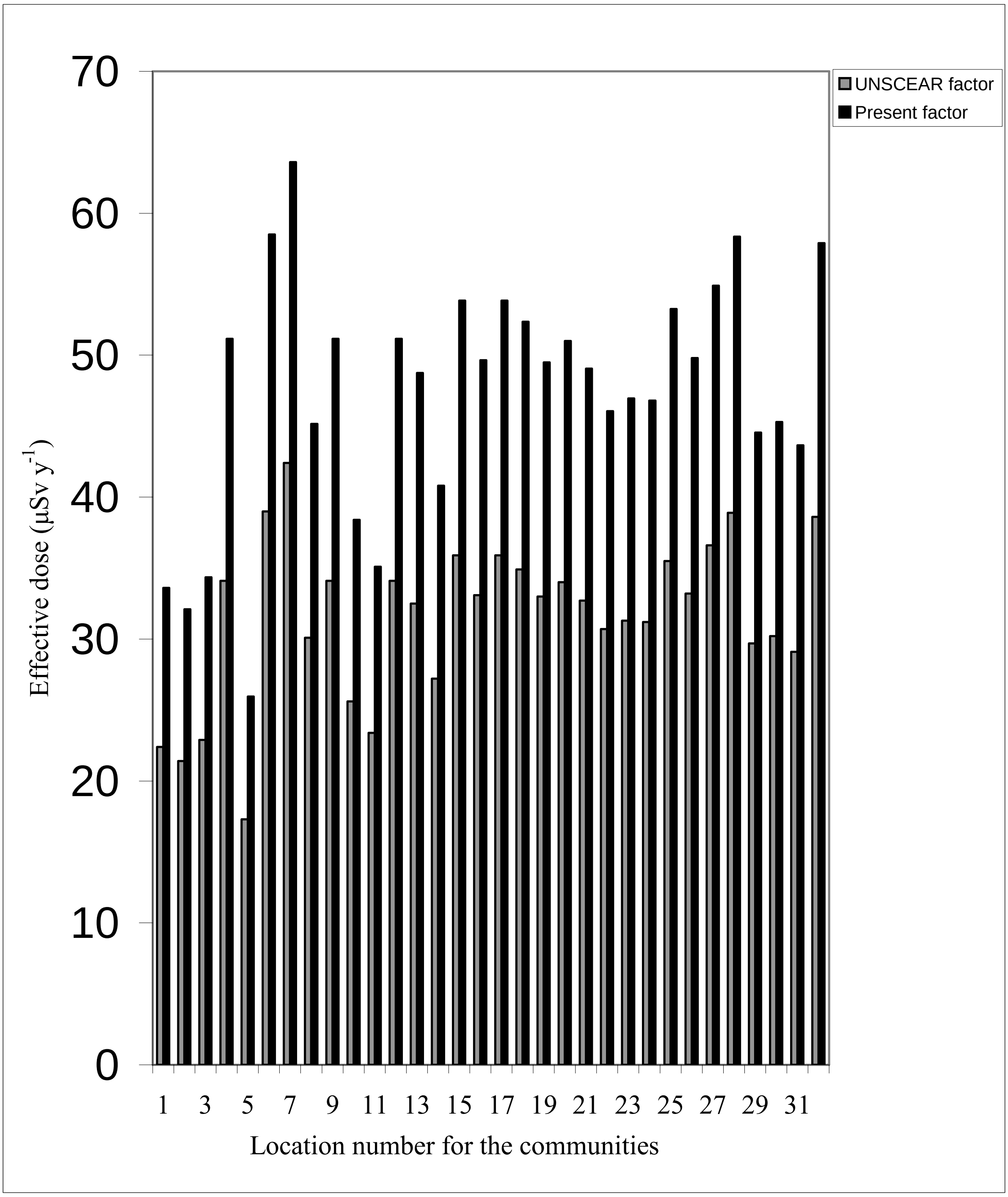

Fig. 2: Comparison between the effective doses calculated using the UNSCEAR occupancy factor and the present occupancy model