A STUDY OF INDOOR RADON LEVELS AND RADON EFFECTIVE DOSE IN DWELLINGS OF SOME CITIES OF GEZIRA STATE IN SUDAN

by

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Exposure to natural sources of radiation, especially ^{222}Rn and its short-lived daughter products has become an important issue throughout the world because sustained exposure of humans to indoor radon may cause lung cancer. The indoor radon concentration level and radon effective dose rate were carried out in the dwellings of Medani, El Hosh, Elmanagil, Haj Abd Allah, and Wad Almahi cities, Gezira State – Central Sudan, in 393 measurements, using passive integrated solid-state nuclear track devices containing allyl diglycol carbonate plastic detectors. The radon concentration in the corresponding dwellings was found to vary from (57 8) Bq/m^3 in Medani to 41 9 Bq/m^3 in Wad Almahi, with an average of 49 10 Bq/m^3. Assuming an indoor occupancy factor of 0.8 and 0.4 for the equilibrium factor of radon indoors, we found that the annual effective dose rate from ^{222}Rn in the studied dwellings ranges from 1.05 to 1.43 mSv per year and the relative lung cancer risk for radon exposure was 1.044%. In this research, we also correlated the relationship of radon concentration and building age. From our study, it is clear that the annual effective dose rate is larger than the "normal" background level as quoted by UNSCEAR, lower than the recommended action level of ICRP, and less than the maximum permissible dose defined by the International Atomic Energy Agency.

Key words: indoor radon, effective dose, CR-39, relative risk, lung cancer

INTRODUCTION

The radon isotope, ^{222}Rn, is a noble and radioactive gas with a half-life of 3.82 days, produced by the decay of the natural radioactive elements from the uranium series. The contribution to the mean effective dose equivalent from inhalation of ^{222}Rn and its short-lived decay products (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po) has been estimated to be about 50% of the total effective dose equivalent from all natural radiation sources [1]. The radon concentration in indoor air varies significantly from season to season and from house to house with respect to the surrounding environment [2-4]. The main natural sources of indoor radon are soil [5], building materials (sand, rocks, cement, *etc.*) [6], water sources [7], natural energy sources like (gas, coal, *etc.*) [8], all of which contain traces of U-238.

In the United States of America, reports recorded for radon alone to be responsible for approximately 15.000-20.000-lung cancer deaths per year [9]. The risk is reported to be proportional to the radon level down to the Environmental Protection Agency (EPA) action level of 0.148 Bq/m^3 and probably even below this level [9, 10]. The International Commission on Radiological Protection (ICRP) recommended a radon concentration from 200 Bq/m^3 to 600 Bq/m^3 for dwellings [11].

Solid-state nuclear track detectors have been widely used for passive measurements of indoor radon and their alpha emitting decay products. The use of the CR-39 plastic track detector in air volume of cups has become the most reliable procedure for time-integrated, long measurements of radon and their daughter activity concentrations under different environmental conditions [12-14]. Using this procedure, measurements of indoor radon levels in Sudan have been done at a certain number of locations [2, 3, 15-17]. This work is the continuation of our other surveys conducted in Sudan aimed at establishing the base-line data on indoor, soil gas, building materials, and water radon concentrations in Sudan [2, 3, 5-7, 15-17]. The aim of this survey is to present and discuss the data obtained from radon measurements carried out in towns from the Gezira State situated in the central part of Sudan.

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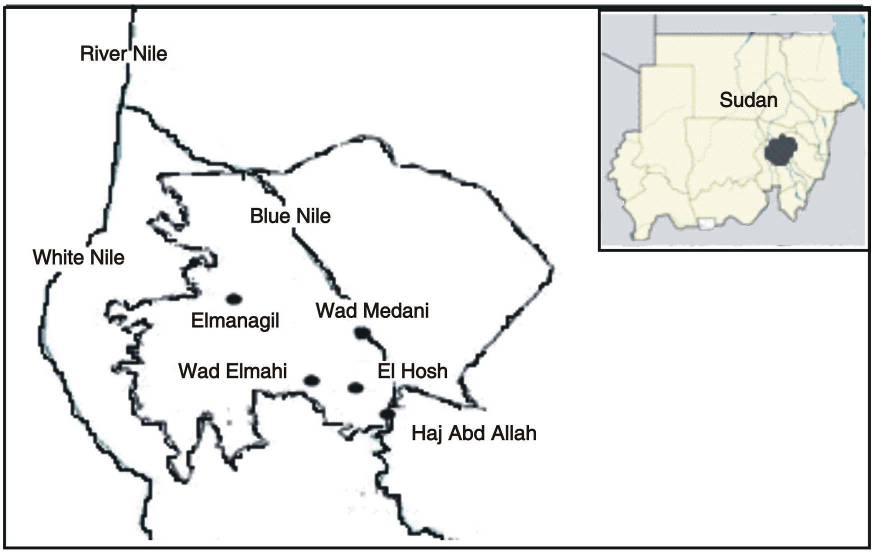

Figure 1. The map showing the studied areas belonging to the Gezira State in the central part of Sudan

MATERIALS AND METHODS

The study area

Indoor radon measurements in buildings were performed in five towns of the Gezira state: Medani, ElHosh, Haj AbdAlla, Elmanagil, and Wad Almahi (fig. 1). The Gezira state is the most agriculturally productive state in Sudan lying between the Blue Nile and the White Nile rivers, bounded by the Khartoum state in the North, Gadarif state in the East, White Nile state in the West and Sennar state in the South. It lies between latitude 13-15.2°N and longitude 32.5-34°E.

The type of construction materials of houses in the study area

The construction materials of most of the houses in the studied areas are mud, red brick and concrete materials. Some houses were built by using a concrete mixture which usually consisted of cement, sand bricks, dolomite, and concrete as the construction materials. Some of the old houses were constructed from clay material. In most of the houses the roofs are made of wood or concrete and are at a height of about 2.5-3.75 m above ground. Each house has rooms with common non-decorated walls where the inhabitants spend most of the daytime and ventilation mechanisms are seldom used. All that was important in determining the indoor occupancy factor (see eq. 2).

Radioactivity measurements

A correct calibration procedure is paramount for good accuracy of results. Hence, precalibrated passive dosimeters containing solid-state nuclear track detectors using allyl diglycol carbonate of super grade quality (CR-39 SSNTD, Pershore Moulding, Ltd., UK) were used to study radon-222 concentrations. These passive dosimeters used here are similar to those we have used in previous studies [2, 3].

We distributed a total of 393 dosimeters at the selected sampling positions. After three months, the dosimeters were collected and chemically etched for nine hours using a 30% solution of KOH at a temperature of 70.0 0.1 °C. An optical microscope was used to count the number of tracks per cm^2 recorded on each detector used. The track density was determined and converted into activity concentration C_{Rn} [Bqm^{-3}] using the following equation [6, 18]

$$C_{Rn} \quad \frac{\rho_{Rn}}{K_{Rn} t} \qquad (1)$$

where ρ_{Rn} is the track density (tracks per cm^2), K_{Rn} – the calibration constant, and t – the exposure time.

Determination of the calibration constant K_{Rn} for dosimeters

Ten dosimeters were prepared for the calibration process and four for the background. The dosimeters were placed in a chamber with the standard radon concentration (170 kBq/m^3). Two detectors were removed from the chamber after 0.25, 0.5, 1, 2, 4, 8, and 16 hours. These irradiated detectors were chemically etched using the same conditions as described. The track density was measured and plotted against the exposure time (fig. 2). The obtained value of the calibration constant was K_{Rn} = 4.824 10^{-3}, tracks per cm^{2}h per Bqm^{-3}.

Dose estimation

To estimate the radon effective dose rate (ED) expected to be received by the inhabitants of these towns due to indoor radon, the conversion coefficient

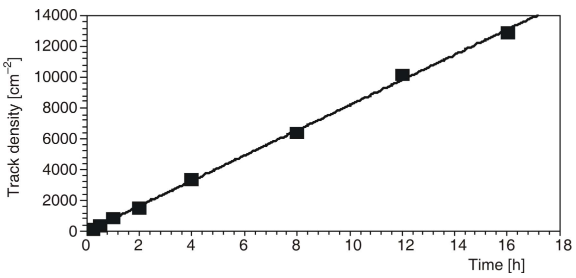

Figure 2. Calibration curve for dosimeters used in studying Rn in buildings

from the absorbed dose and the indoor occupancy factor has to be taken into account. In the UNSCEAR-2000 report [1], the committee recommended the use of 9.0 nSv/h per Bq/m^3 for the conversion factor (D_f) (an effective dose received by adults per unit ^{222}Rn activity per unit of air volume), 0.4 for the equilibrium factor of radon indoors (E_f) and 0.8 for the indoor occupancy factor (O_f). We used the following formula to calculate the effective dose (ED) [1]

$$ED\ [\mathrm{mSv}] = C_{\mathrm{Rn}} D_{\mathrm{f}} O_{\mathrm{f}} E_{\mathrm{f}} \times 24 \times 365 \times 10^{-6} \qquad (2)$$

The relative risk of lung cancer ($RRLC$) due to indoor exposure to radon was calculated using the following equation [2, 3, 19]

$$RRLC = \mathrm{e}^{0.00087352\, C_{\mathrm{Rn}}} \qquad (3)$$

RESULTS AND DISCUSSION

In this study we present results of the average radon concentrations, ED and $RRLC$ in dwellings at five residential areas in the Gezira State. Table 1 shows the radon concentration for the residential areas. The highest values were recorded in Medani 56 ± 9 Bq/m^3 and in Haj Abdallah 54 ± 10 Bq/m^3 while the minimum concentration value of 41 ± 9 Bq/m^3 was recorded in the Wad Almahi area. This may be attributed to the fact that Medani is the capital of the Gezira state where most houses are built from cement, concrete, and bricks (some from mud material) and the dwellings are close to each other. The ventilation mechanisms are air conditioners, fans and little uses of natural ventilation. Also, during its flooding period, the Blue Nile river carries large amounts of suspended material which re-sediments as silt clay, sandy clay, and sand and gravel [20] and some inhabitants use this soil in constructing their houses either directly or produce bricks from it. All of that may contribute to the above average indoor radon concentration in these cities. On the other hand, Wad Almahi and Elmanagil are open small areas situated inside the Gezira state and far away from the riverbanks. Houses are far apart and the construction materials are mainly red brick and straw materials; these materials usually contain lower amounts of naturally occurring radioactive isotopes when compared to cement and concrete materials [6]. Taken together with relatively good natural ventilation, these facts can explain why the values of Rn concentration in buildings of these cities are below the average for the entire study area.

The recorded values of indoor radon concentration in our study (tab. 1) are much lower than the radon action level 200-600 Bq/m^3 as recommended by ICRP-1993 [11], lower than the new reference level (100 Bq/m^3) set by WHO [21] and below the action level (148 Bq/m^3) recommended by the Environmental Protection Agency (EPA) [22]. The mean value is slightly higher than the average world-wide value (population weighted) since the average radon of 40 Bq/m^3 has been reported by UNSCEAR [1] but is well within the values reported for various locations in Sudan and worldwide (tab. 2). Interestingly, Rn concentration values found in this area are considerably lower than in other areas of Sudan, except Khartoum.

The US-EPA recommendations [22] are that no intervention is required if the radon level in buildings is below 74 B/qm^3, indicating that this level is safe for occupancy. Figure 3 displays the frequency distribution of the indoor radon concentration in surveyed cities showing that only a small percentage of houses are slightly above the level requiring intervention, *i. e.* only 1.5% of measurements exhibited concentrations in the high range of 80-100 Bq/m^3. In all probability,

Table 1. Summary statistics of indoor radon concentration measurements, effective dose and radon relative lung cancer risk in cities in the Gezira State

Residential area	No.	Radon concentration [Bqm^{-3}]			ED [mSv]	$RRLC$ [%]
		Min	Max	(Mean ± s. d.)		
Medani	92	27.65	74.15	57 ± 9	1.4 ± 0.2	1.051
El Hosh	86	30.06	94.34	50 ± 10	1.3 ± 0.2	1.045
Elmanagil	68	37.69	70.03	45 ± 9	1.2 ± 0.2	1.040
Haj Abd Allah	74	38.21	81.6	54 ± 11	1.4 ± 0.3	1.049
Wad Elmahi	73	18.96	78.98	41 ± 9	1.1 ± 0.2	1.037
Overall	393	18.96	94.34	49 ± 10	1.3 ± 0.2	1.044

Table 2. Comparison of results with other results in various locations in the world

Country	Mean concentration [Bqm^{-3}]	*DE* [mSv]	*RRLC* [%]	Reference
USA	46	–	–	[24]
Demark	53	–	–	[25]
Brazil	82	–	–	[26]
Italy	52	–	–	[27]
Jordan	32.4	0.46	–	[4]
Saudi Arabia	36.2	0.61	–	[23]
Iraq	75.1	1.3	–	[28]
India	30.3	0.46	–	[29]
Pakistan	138	3.49	–	[30]
Sudan (Kordufan)	109.43	4.16	–	[15]
Sudan (Aroma)	91.5	2.29	1.08	[3]
Sudan (Halfa Aljadida)	94.2	2.36	1.09	[3]
Sudan (Khashm Algirba)	64.1	1.60	1.06	[3]
Sudan (Kassala)	92.38	2.14	1.08	[2]
Sudan (Khartoum)	44.3	1.2	–	[16]
Sudan (Medani)	56.59	1.43	1.051	Present study
Sudan (El Hosh)	50.08	1.26	1.045	Present study
Sudan (Elmanagil)	44.64	1.13	1.040	Present study
Sudan (Haj Abd Allah)	54.22	1.37	1.049	Present study
Sudan (Wad Almahi)	41.52	1.05	1.037	Present study

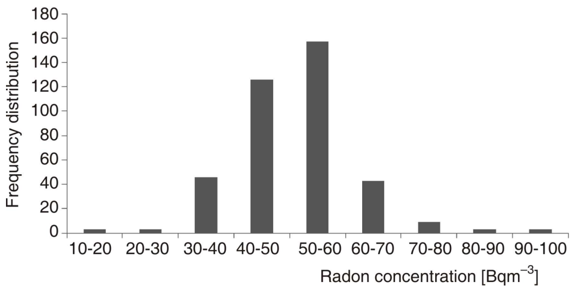

Figure 3. Frequency distribution vs. indoor radon concentration in the cities in the Gezira state

the only intervention needed is to improve ventilation; since it is well known that an increased ventilation rate is an important factor in reducing the indoor radon level [23]. We also found that the indoor radon concentrations in moderately ventilated houses were higher when compared to those in well-ventilated houses.

The range of the radon effective dose rate varied from 1.05 mSv per year to 1.43 mSv per year. The average radon effective dose rate was calculated as 1.25 mSv per year. The effective dose is slightly larger than the "normal" background level of 1.1 mSv per year; as quoted by UNSCEAR-2000 [1], but way below even the lower limit of the recommended action level (3-10 mSv per year) as reported by the ICRP-1993 [11]. The RRLC ranging from (1.037 to 1.051) with an average of 1.044 is almost negligible [19], which is consistent with other findings shown in tab. 1.

The Rn concentration levels were also analyzed in relation to the age of construction of buildings (tab. 3). The surveyed dwellings ranged from new dwellings to dwellings more than 70 years old. The age of a house determines the construction features of the house, technologies, and materials. Cracks and lack of continuity appear together with age in construction material and the building age with the type of construction materials were noticed to be a strong factor in increasing radon flow inside the buildings. As expected [18], the newer buildings with the use of fresh construction materials had generally lower ^{222}Rn levels, since the newer buildings are spacious and well ventilated. The statistically different values were obtained for buildings with age <10 years and older buildings and there is a continuing increase of radon concentration with the building age, with the peak concentration recorded for buildings aged 50-59 years. For buildings aged 60-69 years and older than 70 years, it appears that the inhabitants added some

Table 3. Radon concentration *vs.* the age of the building

Age	Number of dwellings	Radon concentration [Bqm^{-3}]
<10	21	38.01 2.1
10-19	32	43.9 3.7
20-29	42	45.2 4.8
30-39	68	49.5 7.5
40-49	63	46.6 6.0
50-59	51	56.3 8.1
60-69	36	44.3 7.3
>70	23	50.1 6.2

features and improved maintenance to renew their buildings hence the concentration values are lower than the peak value.

CONCLUSION

The mean value of indoor radon concentration measured at five residential areas of the Gezira State - Central Sudan was below the action level recommended by ICRP. The ventilation rate in the residential areas plays a very important role in controlling the indoor radon concentration. Furthermore, the calculated effective dose is lower than the average value given by UNSCEAR and below the ICRP action level. Consequently, the relative lung cancer risk from radon exposure is low in these buildings and they can be considered safe when the hazardous health effects of radon are concerned.

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ИСТРАЖИВАЊЕ КОНЦЕНТРАЦИЈЕ РАДОНА И ЕФЕКТИВНЕ ДОЗЕ УНУТАР ЗГРАДА У НЕКОЛИКО ГРАДОВА ДРЖАВЕ ГЕЗИРА У СУДАНУ

Изложеност природним изворима радијације, посебно ^{222}Rn и његовим потомцима кратког века постало је важно питање широм света јер стална изложеност људи радону у затвореном простору може изазвати рак плућа. Нивои концентрације унутрашњег радона и ефективна доза радона спроведене су у насељима Медани, Ел Хош, Елманагил, Хаџ Абд Алах и Вад Алмахи градовима, држава Гезира – Централни Судан, у 393 мерења, користећи пасивне интегрисане нуклеарне детекторе трагова у чврстом стању који садрже алил дигликол карбонатну пластику. Утврђено је да концентрација радона у односним насељима варира од 57 8 Bq/m^3 у Меданију до 41 9 Bq/m^3 у Вад Алмахију, са просеком од 49 10 Bq/m^3. Примењујући фактор присутности у затвореним просторијама од 0,8 и 0,4 за фактор равнотеже радона у затвореном простору, утврдили смо да је годишња доза ефективне стопе од ^{222}Rn у проучаваним насељима између 1,05 и 1,43 mSv и релативни ризик од рака плућа за излагање радоном 1,044%. У овом истраживању, такође смо направили корелацију између концентрације радона и старости зграде. Из наше студије, јасно је да је годишња стопла ефективне дозе већа од "нормалног" позадинског нивоа како је навео UNSCEAR, нижа од препорученог акционог нивоа ICRP, и мања од максималне дозвољене дозе дефинисане од стране Међународне агенције за атомску енергију.

Кључне речи: радон, ефективна доза, CR-39, релативни ризик, рак грла