DETERMINATION OF SOIL GAS RADON CONCENTRATION FROM SOME LOCATIONS OF GEDARIF TOWN, SUDAN, BY USING CR-39

by

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This work presents the results of the study of radon concentration in soil gas for 187 measurements of soil samples collected from different locations of Gedarif town in Sudan using the can technique, containing CR-39. From in this work, the soil gas radon concentrations were ranged from 4.20 0.61 kBqm^{-3} to 15.15 1.62 kBqm^{-3} with an average of (9.10 1.31) kBqm^{-3}. The annual effective dose was calculated that ranged from 18.71 2.73 mSv to 67.53 7.22 mSv, with an average value of 40.57 5.86 mSv. A good correlation was observed between the radon concentration and soil depth. It was found that soil radon gas concentration increased with depth. The radon concentrations in the soil samples were found to be larger than the allowed limit from the World Health Organization. The results of this work were compared with national and worldwide results.

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

INTRODUCTION

Radon is a radioactive noble gas that does not chemically react with other elements. It is produced from the decay of U-238, which is the main source (approximately 55 %) of the internal radiation exposure of human life. According to UNSCEAR, radon constitutes the major contribution to the dose to which people are exposed. It is well known that exposure of the population to high concentrations of radon and its daughters for long periods leads to pathological effects like the respiratory functional changes such as interaction with biological tissue in the lungs leading to DNA damage and the occurrence of lung cancer. Being aware of the hazardous effects of radon on human health, it was necessary to conduct measurements of radon concentration in the soil.

Radon (^{222}Rn) and its progeny contribute to more than half of the human exposure from natural sources. Radon concentrations in soil gas within a few meters below the surface of the ground are clearly important in determining radon rates of entry into pore spaces and subsequently into the atmosphere and this depends on the radium concentration in the bedrock and on the permeability of the soil [1, 2].

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Radon is generated in rocks and soil by alpha decay of ^{226}Ra and for this reason it is present in the entire Earth's crust, although in varying quantities depending on the geology. After emission from the soil, radon can penetrate through cracks in walls and foundations inside homes where it can accumulate to harmful levels. Radon gas from soil, considered the most important source, enters the house mainly through cracks in the building structure. It is known that the soil underneath the building is the major source of indoor radon.

Radon is a chemically inert gas from the decay of ^{226}Ra, it has half-life of 3.82 days emitting alpha particles whose energy is about 5.49 MeV. Thus, the ionized radiation emitted by soil depends on its content of uranium, and radium elements, since the levels of radon depend mostly on the concentration of radium.

It is possible to be the first basic contribution to establish criteria based on radon in soil gas and on soil permeability that would identify zones of high radon availability that contribute to indoor accumulation [3].

Thus, in many countries criteria for radon hazard assessment have been established, that consider just the radon concentrations in soil gas. In Sweden the concentrations less than 10 kBqm^{-3} are considered as "low risk" requiring no further construction, the range 10-50 kBqm^{-3} is classified as "normal risk" and requires "radon protective" construction, and values higher than 50 $kBqm^{-3}$ are considered "high risk" and require quick intervention processes to ensure safety [4].

The effective permeabilities of soils and rocks are also highly variable, and are to some extent related to the degree of weathering, porosity, moisture content, and the presence of cracks or fissures [1].

The objective of this paper is to determine the distribution of soil gas radon concentration and estimate the effective dose in Gedarif town, eastern Sudan. This study is done to continue our researches in studying the radon concentration and effective dose in dwellings [5], water [6, 7] and building materials [8] in Sudan, in order to build a database for future studies.

MATERIALS AND METHODS

The study area

Gedarif town is located in the eastern part of Sudan, see fig. 1. It stretches between 14°02'N latitude and 35°23'E longitude. The town enjoys highly fertile soils and relatively high rain intensities all throughout the region. The soils in the town have darker colors, higher clay contents, crack deeply in the winter and crumble during the dry season. Most soils were formed from weathering products derived from the basaltic rocks of the region that seems as find basement complex rocks [9].

Radioactivity measurements

In this work, a passive integrated radon dosimeters have been used for the measurements of the soil gas radon concentration [6-11]. A total number of 187 measurements of soil samples in some locations in Gedarif town, eastern Sudan were performed. The purpose of this work was to study the radioactive contribution of radon gas emitted from soils of the town as an important source for the indoor air. A CR-39 detector of size 2 cm   2 cm was fixed inside each dosimeter.

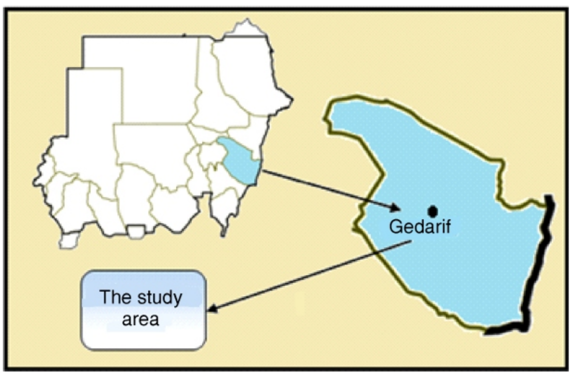

Figure 1. The map showing the study area-Gedarif town, in the eastern part of Sudan

In each location, holes with different depths were dug and a dosimeter was put upside down at the bottom of each hole.

After an exposure time of three months, the detectors were retrieved and chemically etched (30 % KOH) at 70   0.1 °C for nine hours. An optical microscope was used to count α track density registered on each detector. Then, the formed tracks in each detector were counted using an optical microscope.

The track density was determined and then the concentration values C_{Rn} [Bqm^{-3}] were calculated by using the following formula [8, 10, 12-14]

$$C_{Rn} \quad \frac{\rho_{Rn}}{K_{Rn} t} \tag{1}$$

where ρ_{Rn} is the track density (tracks per cm^2), t – the exposure time, and K_{Rn} – the calibration constant, which was determined in a previous work to be: K_{Rn} = = 3.746 10^{-3} tracks per $cm^{-2}h^{-1}$ per Bqm^{-3} [8].

Dose estimation

The calculations of the annual effective dose rate, E_{Eff} (in WLM per year), were done by converting the average radon concentration C_{Rn} into the following expression [8]

$$E_{Eff} \quad \frac{8760nFC_{Rn}}{170 \;\; 3700} \tag{2}$$

where C_{Rn} is in Bqm^{-3}, n – the fraction of time that the inhabitants spent indoors, F represents the equilibrium factor, 8760 – the total hours of the year, and 170 – the total hours per working month. The values of n = 0.8 and F = = 0.4 [1], were used to calculate E_{Eff}. The estimation of the effective dose rate for radon exposure was done by using a conversion factor of 6.3 mSv per WLM (where WLM means the working level month which is defined as an exposure to 1 working level for 170 hours) [15].

RESULTS AND DISCUSSION

In this survey, the values of the soil gas radon concentration, effective dose and the relation between the sampling depth with concentration values were determined for 187 soil samples of five locations of Gedarif town, eastern Sudan. Table 1 and fig. 2 presents the statistical summary of the soil gas radon concentration for the five locations in the town.

The distribution of the soil radon concentration was found to range from 4.20   0.61 $kBqm^{-3}$, in Location 4 (Hai Elmatar) to 15.15   1.62 $kBqm^{-3}$, in Location 3 (Deim Elnour), the overall average was found to be 9.10   1.31 $kBqm^{-3}$.

The minimum value that was recorded at Location 4 (Hai Elmatar), may be due to the moisture content of the soil which is observed to be coarse sandy

Table 1. Summary statistics of the soil gas radon concentration, for soil samples from different locations in Gedarif town, eastern Sudan

Residential area	No.	Radon concentration [kBqm^{-3}]			
		Minimum	Maximum	(Mean	s.d)
Location 3 (Deim Elnour)	38	12.17	17.32	15.15	1.62
Location 1 (Hai E1meidan)	37	6.51	14.50	11.57	1.16
Location 5 (Hai Elgamhuriya)	39	5.56	9.69	8.40	2.25
Location 2 (Deim Hamad)	37	3.87	8.10	6.20	0.68
Location 4 (Hai Elmatar)	36	1.60	7.22	4.20	0.61
All locations	187	1.60	17.32	9.10	1.31

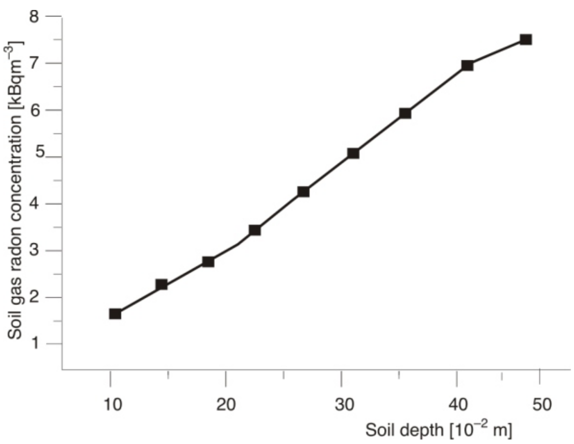

Figure 2. The soil gas radon concentration with respect to the soil depth at Gedarif town

with higher permeability. When the water content of the soil is low then the soil is described as having higher porosity, namely the pores are filled with air, and then radon will diffuse faster. On the other hand, if pores are filled with water, then this may result in decreasing the diffusion of radon even if the porosity value is high [16]. This confirms the fact that the greater the moisture content, the smaller the radon content of the soil owing to the decay process during diffusion in the soil water region [16, 17]. It might be useful to recall that, the radon concentration is lower for sandy soils near the saturation state [18].

It was recorded that more soil gas radon is likely to be emitted from drier soils more than moist and water saturated soils [19, 20]. The maximum value was recorded at Location 3 (Deim Elnour), in Gedarif town. We noticed that, the collected samples at this location were seen to be adjacent and very close to granitic formations of a small hill nearer to the sampling location, on the other hand, the soil was observed to be mixed with large amounts of suspended material which re-sediments as silt clay. In addition, granites are known to contain high uranium content and thus the originated soils. In most countries the source of indoor radon is the soil or rock adjacent to houses [21,

Table 2. Summary statistics of the annual effective dose for soil samples from different locations in Gedarif town, eastern Sudan

Residential area	Annual effective dose [mSv]			
	Minimum	Maximum	[Mean	s.d.]
Location 3 (Deim Elnour)	54.24	77.19	67.53	7.22
Location 1 (Hai Elmeidan)	29.01	64.62	51.55	5.17
Location 5 (Hai Elgamhuriya)	24.78	43.18	37.43	11.15
Location 2 (Deim Hamad)	17.25	36.10	27.62	3.01
Location 4 (Hai Elmatar)	7.13	32.18	18.71	2.73
All locations	7.13	77.19	40.57	5.86

22]. It was reported that, the soil radon concentration in France (Montipellier), is 2.71 kBqm^{-3} [23], in Jordan 2.93 kBqm^{-3} [24].

Table 2 presents the effective dose rate due to the soil gas radon concentration for the different locations in Gedarif town. The estimated annual effective dose ranged from 18.71 2.73 mSv, in Location 4 (Hai Elmatar) to 67.53 7.22 mSv, in Location 3 (Deim Elnour), with an average of 40.57 5.86 mSv.

Table 3 show the relationship between the soil gas radon concentration with respect to the sampling depth of the study area. The sample depth ranged from 10-50 cm below the surface. On average, the results clearly indicate a direct relationship between the radon concentration and the depth ranging from 1.45 0.23 kBqm^{-3} at a depth of 10 cm to 7.25 1.23 kBqm^{-3} at a depth of 50 cm. This coincides with previous findings that the maximum radon concentration in the soil is found at about a 40 cm depth [25]. The shallower sampling depths (10 cm), may be the cause of the low concentration values. This agrees with the fact that the soil radon concentration decreases near the ground surface [25].

The deeper sampling depths recorded the maximum values of concentration due to sampling depth, this may be attributed to, the soil being black clayey, in addition to having lesser amounts of moisture content,

Table 3. Summary statistics of the soil gas radon concentration *vs.* depth in Gedarif town, eastern Sudan

No.	Number of samples	Depth [m]	Soil gas radon concentration (Mean s.d.) [kBqm^{-3}]
1	19	0.10	1.45 0.23
2	20	0.15	2.21 0.45
3	21	0.20	2.93 0.56
4	18	0.25	3.69 0.44
5	23	0.30	4.70 0.75
6	21	0.35	5.45 0.76
7	23	0.40	6.17 1.11
8	20	0.45	6.79 0.88
9	22	0.50	7.25 1.23

Table 4. Comparison of results with other results in various locations in the world

Country	Soil gas radon concentration [kBqm^{-3}]	Reference
Northern Rajasthan, India	4.61	[11]
El-Hosh town, Sudan	5.50 0.75	[13]
Um-Turibat town, Sudan	11.05 4.95	[13]
Medani town, Sudan	15.10 1.47	[13]
Himalaya, India	6.46 3.1	[30]
Islamabad, Pakistan	17.34-72.52	[31]
Bulgaria	26	[32]
Slovenia	40.1	[33]
Austria	75	[34]
Iraq	5.74	[35]
Saudi Arabia	6.71	[36]
Egypt	4.35	[37]
Sri Ganganagar district, Rajasthan, India	0.09-10.40	[38]
Korea	3.9-23.1	[39]
Minnesota	25-70	[40]
Spain	24	[41]
India	1.5-15.9	[42]
Jordan	0.8-26.7	[43]
Russia	1.7-24.0	[44]
Ghana	9.9-42.1	[45]
Cameroon	5.5-8.7	[46]
Canada	6.8-74.7	[47]
Turkey	4.3-9.8	[48]
Gedarif town, Sudan	9.1	Present study

lower water saturation fraction at various depths, and being located at a more elevated area compared with its surroundings. It was reported that the water saturation fraction is related directly with radon levels [19, 20].

The recorded value of concentration values even for the deeper depths falls within the range characteristic of deep soil radon concentration of 1 to 40 kBqm^{-3} [26].

In all locations the correlation between the depth profile and the radon concentration is strong [27]. The maximum depth considered in this study is 50 cm; further investigations might be needed to consider deeper depths.

It was recorded that radon concentrations were found to be higher in the 0.5 m depth than in the 1.0 m depth [28, 29].

A comparison between our results and other findings is given in tab. 4.

CONCLUSION

In this study a total of 187 measurements of soil gas radon concentration measurements and the effective dose due to radon have been done in Gedarif town in the eastern part of Sudan. The study was conducted using previously calibrated passive dosimeters containing CR-39. From our study we can conclude that the minimum soil radon concentrations were measured in sandy moist. The maximum concentration values was were found in soil situated beside a granitic small hill, which also seems to be sedimented. The overall computed average of the soil gas radon concentration for all locations, falls within the range typical of deep soil 1-40 kBqm^{-3} and compares very well with data reported from different geographical regions. The results showed that the soil radon concentration increased with depth. From our study, the effective dose rate was also calculated.

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ОДРЕЂИВАЊЕ КОНЦЕНТРАЦИЈЕ РАДОНА УПОТРЕБОМ CR-39 У ГАСУ ИЗ ЗЕМЉЕ, НА НЕКИМ ЛОКАЦИЈАМА ГРАДА ГЕДАРИФА У СУДАНУ

Приказани су резултати испитивања концентрације радона у гасу из земље на основу мерења 187 узорака земљишта прикупљених са различитих локација града Гедарифа у Судану, применом канистер методе која садржи CR-39. Концентрација радона у земљаном гасу била је у опсегу од 4.20 0.61 kBqm^{-3} до 15.15 1.62 kBqm^{-3}, при чему је средња вредност износила 9.10 1.31 kBqm^{-3}. Годишња ефективна доза износила је од 18.71 2.73 mSv до 67.53 7.22 mSv, са средњом вредношћу од 40.57 5.86 mSv. Уочена је добра корелација између концентрације радона и дубине са које је узет узорак. Утврђено је да концентрација радона у гасу из земље расте са повећањем дубине. Концентрације радона из ових узорака земљишта веће су од граничних вредности прописаних од стране Светске здравствене организације. Резултати овог рада упоређени су са националним вредностима и вредностима добијеним у свету.

Кључне речи: радон у затвореном простору, годишња ефективна доза, CR-39, ризик за настанак карцинома плућа