Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.13, No.6, 2023

Assessment of Natural Radioactivity Levels and Some Associated Radiological Hazards of Portland Cements and Their Raw Materials from Selected Cement Industries in Eastern Uganda

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Abstract
The radiological hazards as a result of the natural radionuclides ^{238}U, ^{232}Th and ^{40}K for Portland cement from different factories were assessed using HPGe detectors. The measured mean activity concentrations for ^{238}U, ^{232}Th and ^{40}K were; 50.34±1.86, 38.01±1.48 and 331.59±13.19 Bq/kg respectively for the Portland cement raw materials, 31.15±1.49, 20.83±1.02 and 267.60 ± 8.65 Bq/kg respectively for the Portland cement products. The radium equivalent activity (Ra_{eq}), Excess lifetime cancer Risks (ELCR), external and internal hazard indices were also estimated due to the Portland cement and the respective raw materials and the results obtained were comparable to others cited. The results obtained in this study therefore indicate no significant radiological hazard that may arise from the use of these materials in construction of dwelling places.
Keywords: Natural Radioactivity levels, Portland cement, MCNP, Gamma spectroscopy
DOI: 10.7176/JEES/13-6-03
Publication date: August 31st 2023

1.0 Introduction

A number of studies have been conducted for natural radioactivity (NORM) and it has been established that to a great extent, Uranium-thorium series as well as Potassium-40 found in various natural materials largely contribute to the world's source of natural exposure. These studies have to a large extent highlighted that these NORM are found in raw materials that are used to produce building materials such as cement, limestone, gypsum, clay and sandstone among others [17]. NORM can be defined as a radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides, where the exact definition of "significant amounts" would be a regulatory decision [20]. Exposure from these materials can either be due to external or internal once such material containing NORM is either inhaled or ingested.

The external irradiation is due to direct gamma radiation whereas internal exposure is as a result of radon gas (^{222}Rn) and its short-lived secondary daughter products. The levels of radioactivity for ^{226}Ra, ^{232}Th and ^{40}K in these raw materials and their products largely depend on the geographical location and geological conditions with their geochemical characteristics of such materials [34]. It is therefore important that such radioactivity levels are assessed and this would in-turn help to establish the radiological hazards that would be associated with such materials to the health of the persons that come in contact with them. The information obtained from such study would thus be important in enhancing the Country's regulatory framework and thus promote the protection of the public and workers against the effects of ionizing radiation as a result of such materials.

In Uganda, these materials exist in various places such as, mines [4;14], and in the byproducts of some industrial processes [1]. For example, in the study carried out in Eastern Uganda to determine the radioactivity levels and dose rates due to natural radionuclides in rocks from selected mines, it was revealed that, the specific activities for ^{232}Th, ^{238}U, and ^{40}K, varied from 98.68±1.30 to 2397.78±19.64 Bq kg^{-1} for ^{232}Th, 13.95±0.31 to 698.02±3.38 Bqkg^{-1} for ^{238}U, and 45.97±2.48 to 2183.80±17.89 Bqkg^{-1} for ^{40}K. Also, the annual outdoor effective dose rates varied from 0.30 to1.37 mSvy^{-1}, which were far higher than the world wide average of 0.07 mSvy^{-1} as per the UNSCEAR, 2000 report. It was therefore noted that the mining activities had increased the background radiation levels, and this indicated possible radiological hazards to the people operating in the mines as well as the residents in such areas [2]. The growth of the mining industry has increased over the years, with a contribution of 0.6% to the Gross Domestic Product (GDP) in the Financial Year (FY) 2017/18 raising from 0.3% in FY 2012/13 [6] and this has largely been supported by export of gold and cement [26]. With more geological, geochemical, and airborne geophysical surveys, new 18 mineral resources targets have been revealed with prospects for exploration and mining of limestone, vermiculite, and Uranium among others [28].

Whereas different types of cement are produced in Uganda, Portland cement (chemically known as calcium aluminosilicate) has dominated the Ugandan market. The Portland cement as a product on market has particle size ranging from 0.05 to 0.5 µm "aerodynamic" diameter. This nature of particle sizes make it easily absorbed orally and inhaled by mankind and this may result into internal exposure after repeated exposure with mainly the

respiratory tract as being the target organ which may result into Chronic Obstructive Pulmonary Disease (COPD).

To-date, information on the natural radioactivity on Ugandan Portland cement is not available however; Regulations and guides are under development by the Atomic Energy Council (AEC) in accordance to the international acceptable limits for building materials. The objective of the present study therefore, was to assess the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and the associated radiological risks in the Portland cement and the selected raw materials in some selected cement industries in Eastern Uganda. The most important parameters being; annual effective dose, absorbed dose rate, radium equivalent activity, excess lifetime cancer risk and as well as the external and internal indices.

2.0 Materials and methods

The study was carried out at the Egypt Second Research Reactor (ETRR-2) from October, 2020 to March, 2021.

2.1 Sampling and sample preparation:

Two (02) Portland cement types and twelve (12) cement raw materials representative samples were used to measure the radioactivity concentration. These were obtained from the two cement industries located in Eastern Uganda i.e. Tororo Cement Industry and Hima grinding Station. The cement was used without any further preparation since it was already in powder form whereas the raw materials were oven dried for 3-5 hours in a controlled temperature of 105^0c to ensure complete remove of the moisture in order to avoid clumping during grinding. Upon ensuring complete removal of the moisture, the samples were allowed to cool in a moisture-free environment, pulverized into powder. For each class of samples, they were mixed and a representative sample was obtained then packed in pre-weighed air-tight glass containers of the same size and of known geometries, weighed and hermetically sealed. The samples were then kept for 30 days before measurement was done to ensure secular equilibrium of the ^{226}Ra and its short-lived decay products.

Table 2-1: Collected samples for analysis and the respective codes used in the study

#	Sample location	Sample name	Sample code
1.	Tororo Cement factory	Cement sample 1	TC1
		Pozzolana 1	TC2
		Gypsum 1	TC3
		Clay	TC4
		Bauxite	TC5
		Sandstone	TC6
		Limestone (Amudat mine)	TC7
		Limestone (Tororo mine)	TC8
		Clinker 1	TC9
2.	Hima Grinding Station	Cement sample 2	HG1
		Pozzolana 2	HG2
		Gypsum 2	HG3
		Slag	HG4
		Clinker 2	HG5

Where;

(i) ETRR-2 - Egypt Second Research Reactor laboratory
(ii) HG - Hima Grinding station;
(iii) TC- Tororo cement factory;

2.2 Measurement of specific radioactivity:

The concentration of the radioactivity of NORM was determined by use of two high-purity germanium (n and p-type HPGe) detectors and counting was performed by placing the sample containers on top of the detectors for a period between 69000 s and 82332 s until better spectra were obtained. Using Gamma vision software, the respective energies and intensities for the gamma- rays were obtained for each spectrum. Then a comparison for each peak and the standard energy peaks for the various radionuclides was made in order to identify the radionuclides from each spectrum.

The detectors were both calibrated for energy using standard calibration sources and for the absolute efficiency calibration. The energy calibration was performed using Eu-152 and Co-60 sources while efficiency calibration was determined with use of standards sources (Ba-133, Co-60, Cs-137 and Eu-152). Further, since the samples to be analyzed did not possess the same qualities such as shape and mass, as of the standard sources that are used for efficiency calibration it was therefore important to make corrections for the attenuation in order to determine the gamma ray emission rate from the whole sample, and this was performed by use of the MCNP technique [22], [23], [25], with the help of the MCNP-X soft-ware [36]. Background measurements were

determined and subtracted from the sample count in order to obtain the net count and the activity, defined as the expectation value of the number of nuclear transformations occurring in a given quantity of material per unit time [21], of the sample was determined by obtaining the difference between the background radiation counts and the areas under the photo-peak. The activity of ^{232}Th was obtained by its decay products; ^{212}Pb (238.63 keV), ^{228}Ac (911.20 keV) and ^{208}Tl (583.19 keV), and the activity of ^{238}U was obtained from its decay products; ^{214}Pb (295.22 keV), ^{214}Pb (351.93 keV) and ^{214}Bi (609.31) in secular equilibrium with radium ^{226}Ra while the activity concentration of ^{40}K was obtained from its own gamma spectrum at 1460.82 keV.

The specific activity (Asp) in Bq/kg for the samples was calculated using expression (1) below; [7], [12].

$$Asp = \left[\frac{N}{(m\ P\gamma\varepsilon\ Tc)}\right] (Bq/kg) \quad (1)$$

Where; N = the net counts of the radionuclide in the sample, m = the mass of the sample (kg), Pγ = the absolute gamma emission probability (branching ratio), where the respective branching ratios were obtained from the standard radionuclide data tables [18], Ɛ = the detector efficiency and Tc = is the counting time for each sample.

Table 2-2: Activity Concentration (Bq/kg) for the analyzed samples

Sample code	**Ra-226** (Bq/kg)	**Th-232** (Bq/kg)	**K-40** (Bq/kg)
Cement raw materials 1			
TC2	17.45± 1.14	20.16 ± 0.98	504.73 ± 15.67
TC3	9.81± 1.12	1.41 ± 0.77	42.63 ± 3.01
TC4	90.28 ± 3.15	36.38 ± 1.31	968.49 ± 29.78
TC5	60.62 ± 1.99	115.09 ± 3.67	111.84 ± 4.30
TC6	90.75 ± 3.10	73.47 ± 2.49	1522.36 ± 45.39
TC7	57.77 ± 1.87	56.44 ± 1.89	246.63 ± 8.01
TC8	64.75 ± 2.13	53.35 ± 1.80	458.44 ± 14.80
TC9	67.83 ± 2.48	32.14 ± 1.36	316.62 ± 10.20
Average	**57.41 ± 2.12**	**48.52 ± 1.78**	**521.47 ± 16.40**
Range	**9.81-90.28**	**1.41-115.09**	**42.63-1522.36**
Cement products			
HG1	31.31 ± 1.46	18.86 ± 0.94	243.43 ± 7.84
TC1	30.98 ± 1.54	22.80± 1.10	291.76 ± 9.46
Average	**31.15 ± 1.49**	**20.83 ± 1.02**	**267.60 ± 8.65**
Cement raw materials 2			
HG2	11.75 ± 0.61	22.23 ± 0.97	531.12 ± 16.35
HG3	17.0 ± 0.81	12.28 ± 0.98	114.98 ± 4.76
HG4	93.56 ± 2.86	25.33 ± 0.91	56.01 ± 2.38
HG5	22.50 ± 1.06	7.85 ± 0.60	105.20 ± 3.60
Average	**36.20 ± 1.34**	**16.92 ± 0.87**	**201.83 ± 6.77**
Range	**11.75 - 93.56**	**7.85 - 25.33**	**56.01 - 531.12**

2.3 Determination of the absorbed dose rate: The external gamma dose rate in air at one meter above the ground surface, from the samples, is calculated from the activity concentrations of the respective radionuclide using the expression (2) below and the results obtained were indicated in Table 2-3.

$$D_R\ (nGyh^{-1}) = [0.604A_{th} + 0.0417A_k + 0.462A_u] \leq 59\ nGyh^{-1} \quad (2)$$

Where; A_{th}, A_k and A_u are the activity concentrations and 0.604, 0.0417 and 0.462 (Dose coefficients in nGy/h per Bq/kg) as the conversion factors for ^{232}Th, ^{40}K and ^{238}U respectively, [34].

2.4 Determination of the annual effective dose from external gamma dose rate:

This refers to the assessment of the absorbed dose in a given year. The annual effective dose was determined by use of the dose conversion factor of 0.7 Sv/Gy for adult humans and an outdoor occupancy factor of 0.2 on the absorbed dose rate [34]. For Uganda's case, an average time spent on economic and care labor activities per week by rural dwellers is 55 hours and approximately 7.86 hours per day. Therefore, an average outdoor and indoor occupancy factors for the rural dwellers are 0.33 and 0.67 respectively, [10], whereas the world respective occupancy factors are 0.2 and 0.8, [34]. Therefore, to calculate the external outdoor annual effective dose rate (E_o), expression (3) was used, [34] and should not be more than 1.0 mSv/yr for the member of the public [16]. However, to compare well the results with other countries, the UNSCEAR, 2000 report occupancy factors were used in this work and the results from the analysis were indicated in Table 2-3

Eo (AEDR) = [D_R x DCF x OF x T] ($mSvy^{-1}$) ≤ 0.07 (3)

Where; D_R= the average absorbed dose rate in air at 1 meter above the ground (nGy/h); DCF =the dose conversion factor (0.7 Sv Gy-1); OF= the outdoor occupancy factor. For Uganda (0.33), and T = the annual exposure time. For Uganda's case, it is given by 8760 h, (365 days)

2.5 Assessment of radiation hazards in Portland cement and the raw materials:

In this study, radiological parameters such as Radium equivalent activity, Excess lifetime Cancer Risks (ELCR), External and Internal hazard indices were performed;

2.5.1 Radium equivalent activity

This was performed in order to measure the gamma radiation hazard in case these raw materials and cements were used as building materials. It gives an account of the effective dosage that would be as a result of Rn and as well as its decay products and it represents the specific activity of ^{226}Ra, ^{232}Th and ^{40}K as a single quantity and it is assumed that the specific activity of not greater than 370 Bq/kg of ^{226}Ra, would result into an annual effective dosage of 1 mSv/yr at 1 meter above the ground level and it was determined using equation (4) below, [31].

Ra_{eq}= [A_{Ra} + 1.43 A_{Th} + 0.077 A_K] $\leq$ 370 (Bq/kg) (4)

Where; A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively.

2.5.2 Excess Lifetime Cancer Risk (ELCR)

This refers to the measurement of the probability that a certain stochastic effect will occur in an individual or group of individuals exposed to low doses of ionizing radiation over a given period of time. Therefore, to estimate the number of extra cancers expected as a result of the external gamma radiation, equation (5) was used [34] with the World permissible limit of 0.29;

ELCR = [E_o x D_L x RF] $\leq$ 0.29 (5)

Where; Eo is the annual effective dose equivalent, DL is the life expectancy and estimated to be at 70 yrs, [34], and a 0.05 Sv^{-1} as RF- the risk factor per Sievert for stochastic effects as recommended by ICRP 60 for the members of the public, [10].

2.5.3 External hazard index (H_{ex})

This parameter is used to evaluate the indoor radiation dose as a result of exposure due to gamma radiation emanating from the building materials making up the dwelling places. The external hazard index was evaluated using equation (6) below [5],

$$Hex = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (6)$$

Where; A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively and the value of the index should be less than unity in order to observe a negligible radiation hazard. Thus, the radiation exposure due to building materials should be limited to not more than 1.5 mSv/y in order for the expression above stand.

2.5.4 Internal hazard index (H_{in})

This serves as an indicator for the maximum acceptable concentration of ^{226}Ra as it is halved to its normal limit. For the safe criterion, this value should be less than Unity [5]. The internal hazard index is thus due to radon (^{222}Rn) and its short-lived daughters that cause hazard to the respiratory organs and this is quantified by expression (7) below [31].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (7)$$

Where; A_{Ra}, A_{Th} and A_K are the activities concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively;

Table 2-3: Internal (H_{in}) and External (H_{ex}) radiation hazards indices, Radium equivalent activity (Ra_{eq}), Absorbed Dose rate (D_R), Annual Effective Dose Equivalent (AEDE), and Excess Lifetime Cancer Risk (ELCR) X3

Sample code	H_{in} nGy/h	H_{ex} nGy/h	Ra_{eq} Bq/Kg	D_R nGy/h	AEDE mSv/y	ELCR 10^-3
Cement						
HG1	0.297	0.212	78.45	36.68	0.045	0.158
TC1	0.316	0.232	86.05	40.34	0.049	0.173
Average	**0.307**	**0.222**	**82.25**	**38.51**	**0.047**	**0.166**
Cement raw materials 1						
TC2	0.277	0.229	85.14	41.44	0.051	0.178
TC3	0.067	0.041	15.11	7.17	0.009	0.031
TC4	0.829	0.586	216.88	104.36	0.128	0.448
TC5	0.795	0.632	233.81	102.22	0.125	0.439
TC6	1.091	0.845	313.03	150.24	0.184	0.645
TC7	0.582	0.425	157.47	71.17	0.087	0.305
TC8	0.651	0.476	176.34	81.39	0.099	0.349
TC9	0.557	0.373	138.17	64.05	0.079	0.275
Average	**0.606**	**0.451**	**166.99**	**77.76**	**0.096**	**0.334**
Range	**0.067-1.091**	**0.041-845**	**15.11-313**	**7.17-150.24**	**0.009-0.184**	**0.031-0.645**
Cement raw materials 2						
HG2	0.259	0.228	84.44	41.16	0.051	0.177
HG3	0.163	0.117	43.410	20.10	0.025	0.086
HG4	0.615	0.362	134.09	60.88	0.075	0.262
HG5	0.174	0.113	41.83	19.55	0.024	0.084
Average	**0.303**	**0.205**	**75.95**	**35.43**	**0.044**	**0.152**
Range	**0.163-0.259**	**0.113-0.362**	**41.83-134.09**	**19.55-60.88**	**0.024-0.075**	**0.084-0.262**

3.0 Results and Discussion

The activity concentrations indicated in Table 2-2 for Portland cement were 31.15±1.49, 20.83±1.02 and 267.60 ± 8.65 Bq/kg, for U, Th and K respectively. Comparing the present work with that carried out in other countries, the activity concentrations in all analyzed samples were comparable to the countries cited and more so K almost the same level as that from Turkey [30]. The values obtained were also compared to the UNSCEAR, 1993 report for building materials and it was found out that they were below the averages of 50, 50 and 500 Bq/kg for U, Th and K respectively.

According to the results obtained in Table 2-2, the average concentration for all the Portland cement raw materials from Tororo cement factory were; 57.41±2.12, 48.52±1.78 and 521.47±16.40 Bq/kg for U, Th and K respectively while for Hima Grinding Station were; 36.20±134, 16.92±0.87 and 201.83±6.77 Bq/kg for U, Th and K respectively. Comparing the obtained values with those reported average in the UNSCEAR, 2000 report of 25, 25 and 370 Bq/kg for U, Th and K respectively for NORM materials. All the average concentrations were above the averages reported by the UNSCEAR report 2000 except Th and K for Hima Grinding Station which were below the average by almost a factor of 1.5 and 1.9 respectively. Also comparing the individual raw materials in Table 2-2, these materials were within range or slightly above or below as compared to other countries except for limestone, Bauxite and sandstone all the U, Th and K activity concentrations were far above for the countries cited as in Table 3-2.

The UNSCEAR, 2000 report indicated the direct gamma population weighted average absorbed dose rate at 1 m from terrestrial radiation as 59 nGy/h and the annual effective dose of 0.07 $mSvy^{-1}$ for outdoor occupants. Comparing the results obtained in this study, the absorbed dose rate from the Portland cement was 38.51 nGy/h, a value that is almost 1.5 times below the world average according to the UNSCEAR, 2000 report though still within the typical measured range. This result also, was in agreement with other countries cited. The annual effective dose reported was 0.04 mSv, a value that was below by a factor of almost 1.5 that indicated in the UNSCEAR, 2000 report. Considering the cement raw materials, the highest absorbed dose rate was reported for sandstone with a value of 150.24 nGy/h which was almost 3 times the world average, and the lowest found to be 13.64 nGy/h, for Gypsum though an average of 63.64 nGy/h was reported a figure that was slightly above the world average. Comparing the absorbed dose for the individual raw materials, all were above the countries cited except for Gypsum that was a slightly low.

The Excess Lifetime Cancer Risk (ELCR) associated with these samples was calculated and it was found out that they were 0.166 and 0.273 for the Portland cement and the cement raw materials respectively. These

values were below the world average value of 0.29 according to the UNSCEAR, 2000 report. Thus, the probability of cancer occurring in a particular group as a result of these materials was low.

The results from this study were also considered for radiological hazards and indices associated with them. It is indicated in Table 2-3, that the average Ra_{eq} for the Portland cement and cement raw materials were 82.25 and 136.64 Bq/kg respectively. These values were below the reported value of 370 Bq/kg, [34]. Also comparing with other countries, they were found to be within the values reported except for limestone and clay whose individual values were far above the countries cited. The average external and internal indices obtained in this report were all less than unity a value reported in the Beretka and Mathew, 1985 report [5]. Thus, the radiation exposure due to the building materials from the analyzed samples would be less than 1.5 mSv/y.

Comparison of present work with work in other countries

Table 3-1: Comparison between activity concentration (Bq/kg) (^{226}Ra, ^{232}Th and ^{40}K) in Portland cement samples for Uganda with that of other countries

Country	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}	D_R	H_{ex}	H_{in}	Reference
Ghana	35.94	25.44	231.0	90.11	41.60	0.25	0.34	*D.O. Kpeglo et al, (2011)*
Nigeria	36.1	27.4	295.8	98.10	45.10	0.26	0.36	*E.O. Agbalagba et al, (2014)*
Ethiopia	28.1	33.9	240.0	95.10	43.4	0.26	0.33	*H. Geremew et al, (2019)*
Egypt	93.49	29.07	257.90	171.62	70.76	0.47	0.76	*S.M Darwish et al, (2016)*
Saudi Arabia	11.2	10.0	117.1	33.70	16.44	0.01	0.01	*A. El-Taher, (2016)*
Turkey	40.5	26.1	267.1	98.3	87.3	-	-	*S. Turhan, (2007)*
Albania	55.0	17.0	179.7	-	-	-	-	*G. Xhixha et al, (2013)*
Pakistan	26.1	28.6	272.9	-	-	-	-	*K. Khan, H.M. Khan, (2001)*
Slovak Republic	11.8	18.4	156.5	67.87	60.76	0.182	0.218	*E. Adriana, (2013)*
Sri Lanka	38.5	31.8	165.0	-	-	-	-	*D.R. Abeydeera, (2018)*
Uganda	31.15	20.83	267.60	82.25	38.51	0.222	0.307	***Present work***

Table 3-2: Comparison between cement raw materials concentrations (Bq/kg), Ra_{eq}, D_R, H_{ex} and H_{in} for Uganda and that in other countries

Raw material	^{226}Ra	^{232}Th	^{40}K	Raeq	DR	Hex	Hin	Reference
Gypsum	13.4	6.85	78.81	29.41	13.64	0.08	0.12	***Present work***
Saudi Arabia	9.0	6.5	184.8	33.0	15.9	0.01	0.01	*A. El-Taher, (2016)*
Pakistan	6.2	13.3	173.7	-	-	-	-	*K.Khan, H.M. Khan (2001)*
Sri Lanka	1363	2.23	21.4	-	-	-	-	*D.R. Abeydeera, (2018)*
Denmark	10	4	NM	-	-	-	-	*UNSCEAR, (1982)*
Turkey	10.8	3.6	44.5	17.5	-			*S. Turhan, (2007)*
Pozzolana	14.6	21.20	517.93	84.44	41.3	0.23	0.27	***Present work***
Turkey	67.9	76.7	681.6	229.8	0.84	-	-	*S. Turhan, (2007)*
Italy	187	253	1397	-	-	-	-	*R.Trevisi et al, (2018)*
Limestone	61.26	54.90	352.54	157.47	71.17	0.43	0.58	***Present work***
Saudi	6.2	3.0	155.5	12.9	6.1	0.01	0.01	*A. El-Taher, (2016)*
Pakistan	21.9	8.6	73.8	-	-	-	-	*K.Khan, H.M. Khan, (2001)*
Sri Lanka	11.4	12.2	38.6	-	-	-	-	*D.R. Abeydeera, (2018)*
Turkey	16.5	7.7	88.1	33.1	-		-	*S. Turhan, (2007)*
China	19.5	13.4	63.2	46.6	-	-	-	*Xinwei .L, (2005)*
Clay	90.28	36.38	968.49	216.88	104.36	0.59	0.83	***Present work***
Saudi	15.8	13.8	70.7	89.6	43.0	0.03	0.04	*A. El-Taher, (2016)*
Turkey	26.7	41.8	629.3	134.9	-	-	-	*S. Turhan, (2007)*
Germany	63	77	667	-	-	-	-	*R.Trevisi et al, (2018)*
Clinker	45.17	20.0	210.9	90.0	41.8	0.25	0.37	***Present work***
Ethiopia	28.8	27.4	119.8	77.3	34.6	0.21	0.29	*H. Geremew et al, (2019)*
Sri Lanka	27.4	30.4	64.9	-	-	-	-	*D.R. Abeydeera, (2018)*
Denmark	66	55	NM	-	-	-	-	*UNSCEAR (1982)*
Turkey	28.3	15.9	219.0	68.0		-	-	*S. Turhan, (2007)*

Raw material	^{226}Ra	^{232}Th	^{40}K	Raeq	DR	Hex	Hin	Reference
Slag	93.56	25.33	56.01	134.09	60.88	0.36	0.62	***Present work***
Saudi	21.8	18.4	170.8	25.2	12.2	0.01	0.01	*A. El-Taher, (2016)*
Turkey	177.9	147.8	242.5	392.95	-	-	-	*S. Turhan, (2007)*
Finland	102	69	-	-	-	-	-	*UNSCEAR, (1982)*
Bauxite	60.62	115.09	111.84	233.81	102.22	0.64	0.80	***Present work***
Turkey	17.1	19.8	43.2	48.7	-	-	-	*S. Turhan, (2007)*
Sandstone	90.75	73.47	1522.4	313.03	150.24	0.85	1.10	***Present work***
Turkey	24.8	18.0	1158.3	139.6	-	0.30	0.44	*O. Baykara, et al*
Italy	13.6	12.8	230	347.9	-	-	-	*S. Righi, (2006)*

4.0 Conclusion

Naturally Occurring Radioactive Materials (NORM) have been identified to be found in the atmosphere and in the terrestrial origins. Because of their existence, they contribute greatly to the exposure due to radiation that is received by mankind either by living around such materials where NORM is contained or through using them in the different production process like cement. The aim of this study therefore was to assess the levels of naturally occurring radioactive materials (NORM) in Portland cement produced at Tororo and Hima grinding cement industries in Eastern Uganda, raw materials for Portland cement in these factories and some associated radiological hazards. This study was motivated with the fact that there is a high increase on the use of cement as a construction material in Uganda, and as it has been reported in other countries that such contain NORM. The main focus in the study was activity levels of U-238, Th-232 and K-40 as well as the radiological risks associated with the use of these materials such as radiological equivalent activity (Raeq), the excess lifetime cancer risks (ELCR), external and internal indices.

In the study, it was found out that the U, Th and K activity concentrations for cement were; 31.15±1.49, 20.83±1.02 and 267.60 ± 8.65 Bq/kg respectively, while those for the cement raw materials were; 50.34±1.86, 38.01±1.48 and 331.59±13.19 Bq/kg respectively. A comparison with other studies was carried out in other countries as well as world average values were published before. The results in the study were largely comparable. The external gamma dose rate estimated at 1 m above the ground were 38.51 and 63.64 nGy/h for the Portland cement and cement raw materials respectively. These values were higher than the world average of 59 nGy/h [39] with exception of Portland cement. The annual effective dose rates for outdoor occupants were 0.04 and 0.07 mSv/y for the samples respectively which were also comparable to the world average of 0.07 mSv/y for the member of the public.

The radium equivalent activities (Ra_{eq}) were calculated for Portland cement and cement raw materials and were found to be 82.25 and 145.26 Bq/kg and were all less than 370 Bq/kg the maximum permissible value respectively. The external and internal hazard indices calculated in the study indicated that they were less than the maximum recommended values of unity. This implied that the materials under study were safe once used as building materials since absorbed annual dose could not reach or exceed 1.5 mSv/y. It can be therefore deduced that, once these materials are used, the dose rate criterion of 0.3 mSv/y, for building materials would not be exceeded and that the radon indoor concentration could not exceed 200 Bqm^3 [19]. Therefore, the Atomic Energy Council (AEC), should continue to monitor and establish regulatory controls on the use of these materials as building materials to ensure the activity levels are not exceeded.

5.0 Acknowledgment

The author is grateful to Tororo Cement Industry and Hima grinding Station for allowing their materials be used in the study, the supervising staff of Alexandria University, management of ETRR-2 for technical support, the International Atomic Energy Agency (IAEA) and the Atomic Energy Council (AEC) for the financial support.

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