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Concentration levels of radon in mines, industries and dwellings in selected areas of Tororo and Busia districts, Eastern Uganda

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ABSTRACT

Concentration levels and effective exposure dose of radon were determined in mines, industries and dwellings in the Districts of Tororo and Busia, Eastern Uganda in 60 indoor structures between November 2010 and April 2011, using activated charcoal canisters and sodium iodide detector. This study was undertaken to assess the radiological risk of radon exposure in selected areas in Eastern Uganda. The radon concentration levels were found to vary from 28±1 to 97±5 Bqm^{-3} and the effective dose varied from 0.71±0.03 to 2.44±0.13 mSvy^{-1}, respectively. Over all the mean radon concentration values reported were all below the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and International Commission on Radiological Protection (ICRP) recommended radon action level of 200 Bqm^{-3}. Some average radon concentration values were close 100 Bqm^{-3} an action level recommended by World Health Organization (WHO). This means radon levels are still within limits, however necessary mitigation measures need to be taken so that radon levels are not elevated beyond the mean values reported in this work.

Keywords: radon concentration, effective dose, equilibrium equivalent concentration, activated charcoal canisters, sodium iodide detector.

INTRODUCTION

Radon is a naturally occurring radioactive noble gas. It is part of the natural decay series of uranium (U) and thorium (Th) found in all soils and rocks to a varying concentration. There are three radioisotopes of radon naturally present in the environment: Radon-222 from the uranium-238 decay series, radon-220 from thorium-232 decay series and radon-219 from uranium-235 decay series. Radon-219 is of low radiological significance because of its short half-life of 4 seconds and uranium-235 represents a small percentage (0.3%) of the activity of natural occurring uranium [1].

While the concentration of thorium-232 in the environment are comparable or higher than that of uranium-238, the relatively shorter half-life (56 seconds) of radon-220 compared to radon-222 with half-life (3.82 days), makes radon-222 more important. This is so because radon-222 can migrate over much greater distances after production than radon-220. Therefore radon-222 produced in the soil is the principal source of radon concentration in buildings or walls of mines and in both indoor and outdoor air, while radon-220 is of concern from a radiation protection view point if the concentration of thorium-232 is high [2, 3].

Radon-222 gas, commonly called radon, it is colourless, odourless and tasteless and therefore undetectable by human senses. For this reason radon can only be detected or measured with special detectors. At standard temperature and pressure, radon is a monatomic gas with a density of 9.73 kgm^{-3} which is about 8 times higher than that of air at the earth's surface (1.217 kgm^{-3}). Therefore radon-222 is one of the heaviest gases at room temperature [4].

Radon is formed in the ground from the radioactive decay of uranium-238, which is present in small quantities in all rocks and soils. Because it is an inert gas, it can move freely through gaps or cracks in bedrock and soils. Radon which reaches the open air is rapidly diluted to harmless concentrations. However, underground radon is obstructed from easily escaping and therefore can build up to high concentrations. Radon is soluble in water and dissolved radon can be transported in water some distance from where it originated. In this context, fissure water can act as an entry route for radon particularly in those underground locations receiving large volumes of fissure water [5, 6].

Radon gas is one of the toxic substances that have health hazards. It has attracted the attention of environmental engineer, medical practitioners, and researchers throughout the world [7, 8]. Until the late 1970s, radon and its progenies were regarded as radiation health hazards only encountered in the mining and milling of uranium. This dramatically changed as a result of widespread indoor measurements of radon in parts of the world [9, 10]. Attention to the problem of radon exposure and the associated health risks has thus been growing around the world.

Radon is major source of natural radiation exposure to human population. Over 50% of the annual background dose from natural sources is delivered by inhalation of the short-lived radon decay products, owing to this fact, radon is the most 'popular' subject of studies on environmental radioactivity [9, 11]. Therefore measurement of radon concentration in dwellings is assuming ever increasing importance. From the surveys carried out in many countries, it has been established that radon when inhaled in large quantity causes lung cancer if concentration is high [12]. It is estimated to cause about 15,000 lung cancer deaths per year in the US [11, 13] and the World Health Organization (WHO) estimates radon to cause up to 15% of lung cancer incidences worldwide [14]. High concentration of radon is found in poorly ventilated structures and if the radon input from its sources is high, such as mines, caves, cellars, ancient tombs and air tight houses. The inhaled radon passes from lungs into the blood and body tissues and may irradiate different soft tissue causing cancers such as lung cancer, kidney cancer and prostatic cancer. Radon has also been linked with melanoma and some childhood cancers. There is also a positive association between coronary heart disease and radon exposures where an elevated risk of mortality from coronary heart disease was observed among miners with accumulative radon exposure exceeding 1000 Working Level Month (WLM) [9, 15].

Radon daughters (polonium-218 and polonium-214) are regarded as potential carcinogenic agents for the induction of skin cancer. It is also noticed that the combination of inhalation of radon gas and smoking increases the risk of lung cancer. Radon is the leading cause of lung cancer for non-smokers. Smokers exposed to radon are a greater risk of developing lung cancer. The principal health effect in breathing air containing radon-222 is due to its daughters; polonium-218, lead-214, bithimuth-214 and polonium-214. Their contribution to the radiation dose to the lung is 2-3 orders of magnitude greater than that of radon [9, 15]. Ingested radon dissolved in drinking water is also a health risk, because it may cause a stomach cancer. The risk caused by drinking water containing dissolved radon is extremely much lower than inhaling radon [14, 16, 17].

Recognizing the importance of radon as a public health issue, large-scale international Radon-program have been initiated world-wide, such as the IAEA co-ordinate research program CRP 'Radon in the Human Environment' involving over 50 countries [18] and The International Radon Project (IRP) by WHO on public health aspects of radon exposure. This project enjoys high priority with WHO´s Department of Public Health and Environment [9]. International survey efforts have also been carried out in several countries in order to establish some indoor radon level charts. The average indoor radon level varies considerably among countries, because of the soil characteristics, building materials, climate, etc. some reported annual average radon levels are: United Kingdom 20 Bqm^{-3}, United State 46 Bqm^{-3}, Germany 50 Bqm^{-3}, Finland 120 Bqm^{-3}, Sweden 108 Bqm^{-3}, Ireland 89 Bqm^{-3}, and Czech Republic 140 Bqm^{-3} [11, 19]. Also a study of airborne radon levels in Paarl houses (South Africa), using electret ion chamber and gamma-ray spectrometry showed that the concentration varied between 28 and 465 Bqm^{-3}. The average values found in houses on the west and east sides of the Bery River, which bisect Paarl, were 132±11 Bqm^{-3} and 37±3 Bqm^{-3}, respectively. This indicated that the concentration of radon in one area may not necessarily be uniform [20]

Radioactive elements were reported as early as 1940's in Uganda. To that effect, airborne geophysical surveys at 200 m interval and at 80 m terrain clearance have been flown over 80% of the country. The data collected includes radioactive elements (uranium, thorium and Phosphate). Identified Uranium bearing minerals in Uganda include euxenite, microlite, betafite, kasolite, torbenite, uranosphaerite, davidite, fergusonite and pyrochlore. Pyrochlore $(NaCa)_2(Nb,Ta)_2O_6$ F with some uranium, thorium, titanium, and cercium) is the chief niobium mineral in Uganda and is found at many localities within the carbonatite complexes of Eastern and Northeastern Uganda such as Sukulu hills in Tororo District [21]. Therefore the places around Sukulu hills and the industries which process these minerals are likely to be potential source of high radon exposure.

However, studies about the concentration levels of radon and its progeny in mines, industries (work places) and dwellings in Uganda are limited. This means that the average radon concentration levels and effective exposure doses to the entire population are not yet established. This requires that measurements be done in these places especially Eastern Uganda where mining activities have been taking place (Tiira gold mines, Limestone quarries in the Sukuru Hills and Tororo Rock, Tororo Cement Industry, Tororo steel works and dwellings near and far away from the mines and industries in Tororo and Busia Districts).

MATERIALS AND METHODS

Air Sampling for Radon using Activated Charcoal canister

A circular 10 cm diameter and 2.5 cm deep container (Activated Charcoal canister) filled with about 100 g of activated charcoal was used in collecting radon and its progeny. The activated charcoal canisters are sealed with a radon-proof cover after preparation. The measurement was initiated by removing the cover to allow radon in air to diffuse into the charcoal bed (see Figure 1) and radon is adsorbed onto the charcoal. At the end of exposure period of two days (48 minutes or 2880 minutes) the device was resealed securely and returned to a laboratory for analysis each time used. This was repeated in intervals of two weeks for each selected environment covering a period of six months in the selected study areas

To account for the reduced sensitivity of the charcoal due to adsorbed water corrections were made. Correction was done by weighing each detector using a digital weighing scale before and after the deploying the canisters in the area under study. Any weight increase was attributed to water adsorbed on the charcoal. The weight of water gained was correlated to a correction (calibration) factor, CF, which was used to correct the analytical results. The mass gain was due to relative humidity in the atmosphere the fact that while taking measurements the canisters were left open [22-24].

However, every time the charcoal canisters were to be taken to the field, they would be heated in the electric oven to the temperature of 150^0 C for 12 hours to drive off all the moisture and radiation which was absorbed by the charcoal, cooled and sealed. The use of oven dried charcoal canisters allows the use of a single correction factor determined from the weight gain of the canister, to account for humidity corrections and it avoids uncertainties resulting from two day exposure times and allows for the reuse of the charcoal canisters.

Spectra Collection

To determine the energy of the detected gamma radiation, the spectrum was first energy calibrated. This was done by using the centre of mass of each peak with the help of the computer codes of GDM20 AutoDas commands. Here the peaks were analyzed one by one, and the routine for calibration followed.

The spectra were collected from the exposed charcoal canisters using a sodium iodide gamma scintillation detector in conjunction with a multi-channel gamma spectrometer with the window set to include the appropriate gamma energy window. The canisters were placed in the detector on the thallium doped, sodium iodide crystal in order to analyze the radon daughter present adsorbed in the charcoal. The canisters were each read for 5000 seconds and the spectra were collected and stored using AutoDas commands. This process was repeated for each canister to obtain the spectra from samples obtained in industries, mines, and dwellings.

Background spectrum was also collected for 5000 seconds when there was no canister placed in the detector and then subtracted from the spectra collected when the exposed charcoal canisters were in the detector system. The spectra had pronounced peaks at around 295 keV, 352 keV and, 609 keV which are gamma energies of Lead-214 and Bismith-214 respectively see Figure 2.

Figure 1 Open Activated Charcoal Canisters

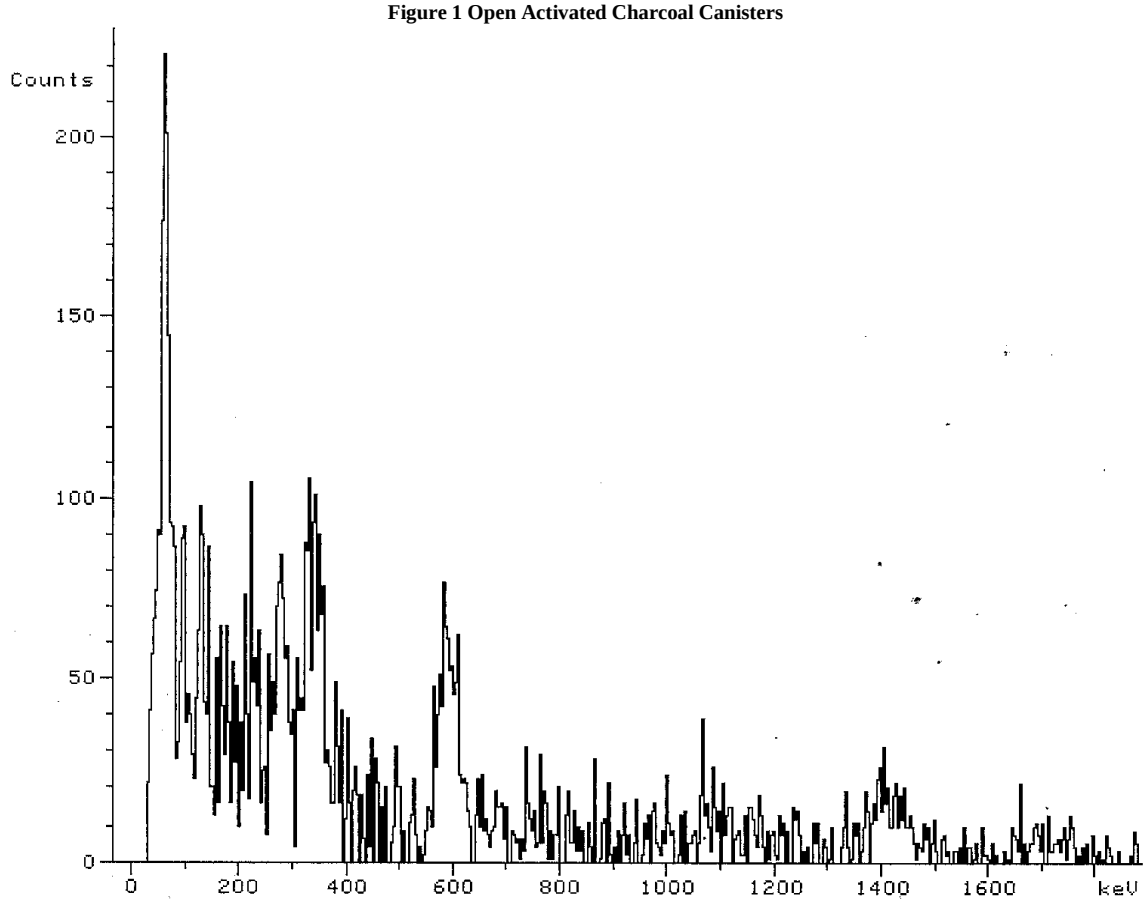

Figure 2 Energy spectrum of radon from the cement quarries with pronounced peaks at around 295 keV for Lead-214, 352 keV and, 609 keV214 Bismith-214

Spectrum Analysis
The spectra peaks were analyzed one by one with the help of computer codes of GDM20 (autoDAS software). The cross was placed immediately at the left edge of the peak and then **L** was typed to define the cross of the lower mark. The cross of the upper maker was similarly placed at the right edge of the same peak using command **U.** This was followed by typing **CEN** command which gives centroid, standard deviation, FWHM (Full Width at Half Maxima), sum between markers (net counts) and rate.

Calculation of Radon Concentrations
The radon concentration in air was calculated from the equation:

$$C_{Rn} = \frac{R}{(T_s)(DE)(CF)(DF)}$$

This required that decay factor DF, calibration factor CF, detector efficiency DE, canister exposure time T_s and net counts per minute are determined. Decay factor DF was obtained from the equation:

$$DF = e^{-\lambda_{Rn}\left(T_D + \frac{T_S}{2}\right)}$$

The decay constant (λ_{Rn}) for radon Rn-222 (in min^{-1}) was obtained using the equation:

$$\lambda_{Rn} = \frac{\ln 2}{t_{\frac{1}{2}}}$$

The half-life, $t_{\frac{1}{2}}$ of Radon Rn-222 is 5500.8 minutes, and hence

$\lambda_{Rn} = 1.2601 \times 10^{-4}$ min^{-1} [22, 23, 25, 26]

The total detector efficiency for NaI(Tl) for Rn-222 was determined using equation $DE = \frac{1}{2}\left(1 - e^{-\mu d}\right)$, where $\left(1 - e^{-\mu d}\right)$ is the intrinsic efficiency , $\frac{1}{2}$ is the geometric efficiency and μ is the linear attenuation coefficients for sodium iodide respectively. The NaI crystal used in this work was a right cylinder 7.5 cm long [26, 27].

The values of R (net counts per minute for each peak) were obtained during spectrum analysis, from which the radon concentration values in pCi/L and Bqm^{-3} for the each peak were calculated. To obtain a single value of radon concentration from each spectrum the equilibrium equivalent concentration was computed.

Calculation of Equilibrium Equivalent Concentration of Radon
The equilibrium equivalent concentration of radon was obtained using equation:

$$EEC_{Rn} = 0.105\,C_1 + 0.516\,C_2 + 0.382\,C_3 .$$

Where C_1, C_2, C_3 are the activity concentrations of the radon decay progeny namely Po-218, Pb-214 and Bi-214 respectively [[25]]. In this work only Pb-214 and Bi-214 were considered since they are the main gamma emitters whose peaks are free from overlap and superposition. Therefore the EEC was calculated from $EEC_{Rn} = 0.516C_2 + 0.382C_3$ and the values obtained were tabulated in Table 1 to Table 9.

Table 1 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in buildings at Tiira Gold Mines

Building	TRA	TRA2	TRA7	TRA8	TRA9	TRA10	TRA11	TRA15	**Mean**
EEC_{Rn} in Bqm^{-3}	30±1	92±4	31±1	80±3	50±2	55±2	38±1	32±1	**51±2**
Effective Dose (mSv y^{-1})									**1.28±0.13**

Table 2. Equilibruim Equivalent Concentration of Radon in Cement Quarries

Building	QUAR1	QUAR2	QUAR3	QUAR4	QUAR5	NOM25.1	NOM25	**Mean**
EEC_{Rn} in Bqm^{-3}	110.9	172.1	46.9	55.2	85.6	103.6	102.0	**96.6**

Table 3 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Tororo Cement Industries

Building	TCI22	TCI23	TCI8	TCI7	TCI6	TCI21	TCI1	**Mean**
EEC_{Rn} in Bqm^{-3}	132±6	64±2	99±4	45±1	54±2	186±9	94±4	**96±4**
Effective Dose (mSv y^{-1})								**2.43±0.10**

Table 4 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Tororo Steel Works

Building	STELL1	STEEL2	STEEL3	**Mean**
EEC_{Rn} in Bqm^{-3}	99±2	45±3	71±4	**72±3**
Effective Dose (mSv y^{-1})				**1.81±0.08**

Table 5 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Tororo Referral Hospital

Building	HOS18	HOS19	HOS11	HOS16	HOS13	HOS17	**Mean**
EEC_{Rn} in Bqm^{-3}	114±6	46±2	36±1	36±2	28±1	47±2	**51±2**
Effective Dose (mSv y^{-1})							**1.29±0.05**

Table 6 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in TLT Hotel

Building	TLT13	TLT15	TLT12	TLT11	TLT14	TLT17	**Mean**
EEC_{Rn} in Bqm^{-3}	27±1	24±1	28±1	27±1	30±1	33±1	**28±1**
Effective Dose (mSv y^{-1})							**0.71±0.03**

Table 7 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Home near Cement Quarries

Building	QUARH3	QUARH4	QUARH5	QUARH	QUARH2	QUARH1	**Mean**
EEC_{Rn} (Bqm^{-3})	92±5	84±3	106±6	104±4	82±3	81±2	**92±4**
Effective Dose (mSv y^{-1})							**2.31±0.01**

Table 8 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Homes far from Tororo Cement Industries

Building	FTCI1	FTCI2	FTCI3	FTCI4	FTCI5	FTCI6	FTCI7	**Mean**
EEC_{Rn} in Bqm^{-3}	25±1	27±1	35±1	53±2	43±1	38±1	48±2	**45±1**
Effective Dose (mSv y^{-1})								**1.13±0.03**

Table 9 Equilibrium Equivalent Concentration of Radon and Radon Effective Dose in Dwellings near Tororo Cement Factory

Building	TCIH6	TCIH5	TCID4	TCIH3	TCIH2	TCIH1	**Mean**
EEC_{Rn} in Bqm^{-3}	48±2	36±1	89±8	58±4	42±1	50±2	**54±3**
Effective Dose (mSv y^{-1})							**1.36±0.08**

Derivation of Indoor Radon Effective Dose Rates

In order to estimate the annual effective doses indoors, the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor was taken into account. In the 2000 report of UNSCEAR (the United Nations Scientific Committee on the Effects of Atomic Radiation), a value of 9.0 $nSvh^{-1}$ per Bqm^3 was used for the conversion factor (effective dose received by adults per unit radon activity per unit of air volume), 0.4 for the equilibrium factor of radon indoors and 0.8 for the indoor occupancy factor [27-29]. And accordingly the same

conditions were applied for radon concentration measurements in Uganda and UNSCEAR values were adopted for this study. The effective dose rate indoors in units of $mSvy^{-1}$, H_E, was calculated by the formula:

$$H_E = EEC_{Rn} \times F \times T \times D$$

Where EEC_{Rn} is the radon equilibrium equivalent concentration (in Bqm^{-3}), F is the Radon equilibrium factor indoors (0.4), T is the indoor occupancy time (0.8×24 h $\times 365.25 = 7010$ hy^{-1}), and D is the dose conversion factor (9.0×10^{-6} $mSvh^{-1}$ per Bqm^{-3}) [15, 29]. The calculated values of radon effective dose rate indoors in units of $mSvy^{-1}$ and the corresponding EEC_{Rn} used are tabulated in Table 1 to Table 9 respectively.

RESULTS AND DISCUSSION

Mines

Equilibrium equivalent concentration of radon at Tiira Gold Mines varied from 30±1 Bqm^{-3} in the office building to 92±4 Bqm^{-3} in Gold mine with the Mean of 51±2 Bqm^{-3} giving the effective dose of 1.28±0.13 $mSvy^{-1}$ (see Table 1 and Figure 3). The concentration of radon and effective dose was not high as expected of a gold mine because there was no mining activity that was taking place at that period. The mine used was old and was not active for more than two years. For 92±4 Bqm^{-3} from the mine may be due to radon emanation from the underground soil which builds up to high concentrations due to lack of air ventilation. Also EEC of radon varied from 55±2 Bqm^{-3} to 172±7 Bqm^{-3} in cement quarry with the Mean of 97±7 Bqm^{-3} giving the effective dose of 2.44±0.05 $mSvy^{-1}$ (see Table 2 and Figure 4). This shows that there was relatively high concentration of radon which is attributed to limestone. This is because water can pool in limestone and that pooling can increase the concentration of radon gas. Radon is normally found in granite, but scientists have discovered a significant risk in areas with limestone rock. This explains the increased concentrations of radon in the limestone quarries and the buildings near the quarries. The effective dose in Tororo cement quarries was higher than that at Tiira gold mines and all more than 1 $mSvy^{-1}$ which is the limit for the general public.

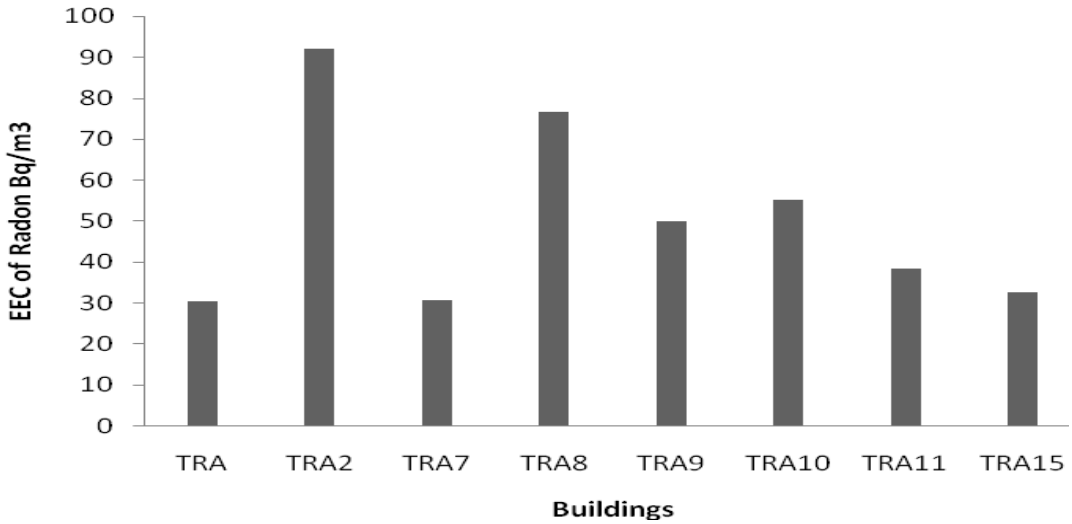

Figure 3 Equilibrium Equivalent Concentration of Radon at Tiira Gold Mines

Industries

EEC of radon varied from 45±1 Bqm^{-3} in Chemical Laboratory to 186±9 Bqm^{-3} in the Testing laboratory with the Mean of 96±4 Bqm^{-3} giving the effective dose of 2.43±0.01 $mSvy^{-1}$ (see Table 3 and Figure 5). Low values of radon concentration were obtained from the chemical laboratory which was well ventilated and was on the second floor

this explains why the concentration is low in there. High radon concentration at Tororo cement factory was found in the Testing Laboratory, this had very poor ventilation, and the room was also very small found on the ground floor. Samples of cement and other raw materials of cements are kept there for testing this attributed to the elevated radon levels in this building.

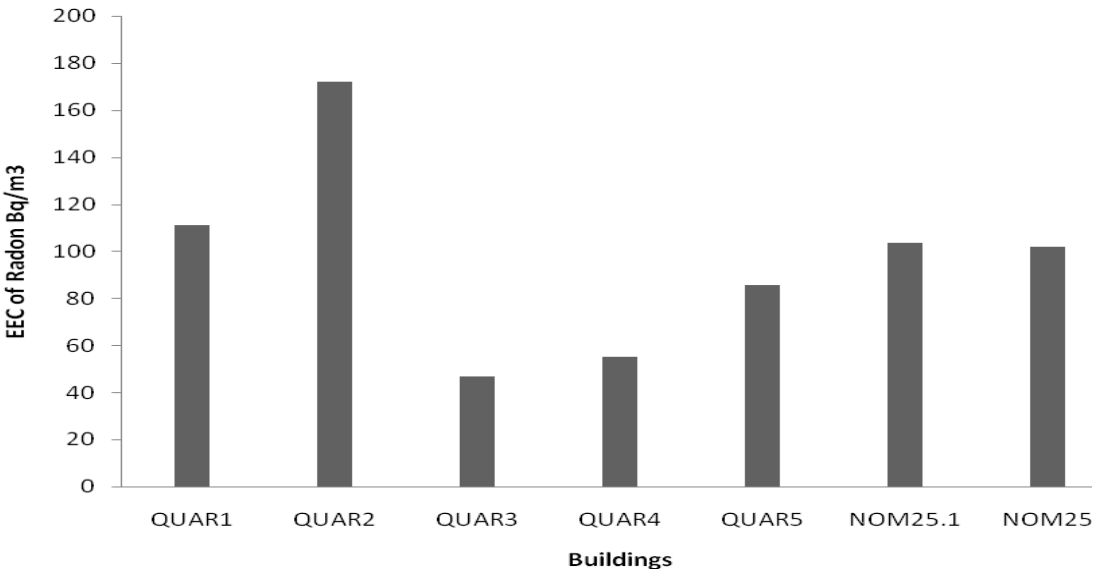

Figure 4 Equilibrium Equivalent Concentration of Radon at Tororo Cement Quarries

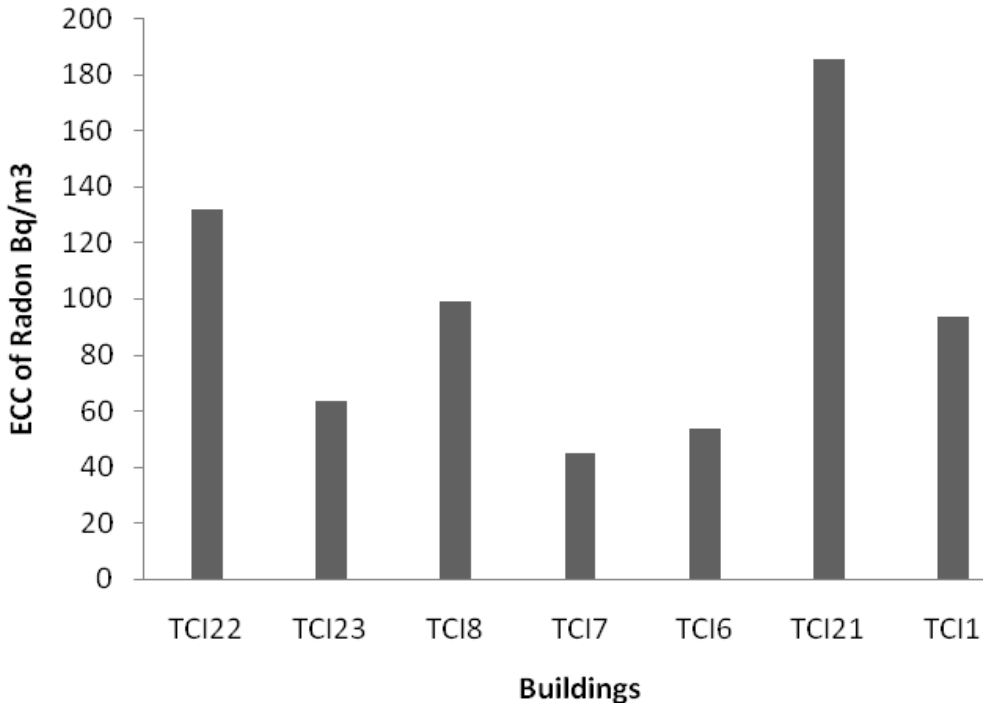

Figure 5 Equilibrium Equivalent Concentrations in Tororo Cement Factories

Also EEC of radon varied from 45±3 Bqm^{-3} to 99±2 Bqm^{-3} in Tororo Steel Works with the Mean of 72±3 Bqm^{-3} giving the effective dose of 1.81±0.08 $mSvy^{-1}$. The concentration from offices (STEEL1) was the lowest compared

to that of the store (STEEL2) and the steel rolling rooms (STEEL3) (see Table 4 and Figure 6). The stores had poor ventilation and spend most of the time closed. The offices had good ventilation and are open throughout the time. The effective dose at Tororo cement industries was higher than that at the Steel works. This is because limestone has high affinity for uranium. Also the steel works industries had better air ventilation.

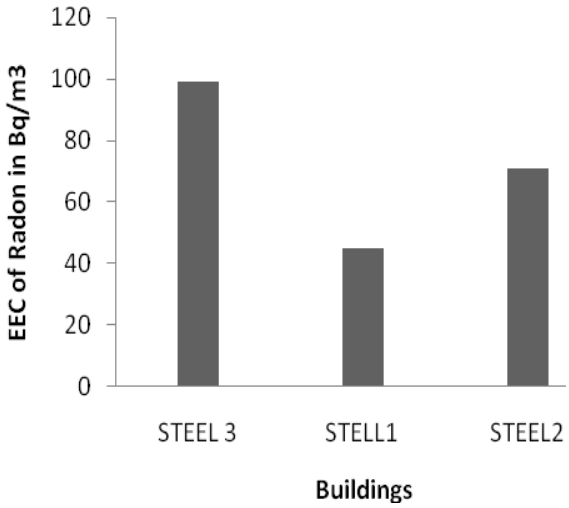

Figure 6 Equilibrium Equivalent Concentration of Radon Tororo steel Work Industry

Dwellings

EEC of radon in Tororo Hospital varied from 28±1 Bqm^{-3} in the Children Ward to 114±6 Bqm^{-3} in the in the Male Ward Duty room with the Mean of 51±2 Bqm^{-3} giving the effective dose of 1.29±0.05 $mSvy^{-1}$ (see Table 6 and Figure 7). The difference here was mainly the air ventilation and the age of the buildings. The Male word was an old structure with cracks in the basement which allows more radon in the building whereas the children ward was a new structure with no cracks at the basement and well ventilated.

The EEC of radon at TLT Hotel which is very far from both the mines and industries varied from 24±1 Bqm^{-3} in the kitchen to 33±1 Bqm^{-3} in the bath room with the Mean of 28±1 Bqm^{-3} giving the effective dose of 0.71±0.03 $mSvy^{-1}$ (see Table 6 and Figure 8). These buildings were highly ventilated and were also new with no cracks at the basement hence minimum entry of radon from the basement. The value of 33±1 Bqm^{-3} in bathroom was due radon from the water points.

ECC of radon in residential houses closeness to quarries varied from 81±2 Bqm^{-3} to 106±6 Bqm^{-3} with the Mean of 92±4 Bqm^{-3} giving the effective dose of 2.31±0.01 $mSvy^{-1}$ (see Table 7 and Figure 9). This high radon concentration in these buildings was attributed for by the nature of rocks in the basement of the buildings and being close to cement quarries which may give out reasonable amount of radon.

EEC of radon in homes far away from Tororo cement industries varied from 25±1 Bqm^{-3} to 53±2 Bqm^{-3} with the Mean of 45±1 Bqm^{-3} giving the effective dose of 1.13±0.03 $mSvy^{-1}$ (see Table 8 Figure 10). This radon concentration much lower than the concentration in Tororo Cement Industries. The variation of concentration of radon in buildings far from Tororo cement industries was majorly air ventilation and building materials. The EEC of radon in buildings near Tororo cement industries varied from 36±1 Bqm^{-3} to 89±8 Bqm^{-3} with the mean of 54±3 Bqm^{-3} giving the effective dose of 1.36±0.08 $mSvy^{-1}$ (see Table 9 and Figure 11). This radon concentration is lower than the concentration in Tororo Cement Industries and higher than the concentration of radon in homes far from Tororo Cement Industries. Cement is a product of limestone and gypsum which all release a lot of radon gas to the outdoor environment which in turn increase the indoor radon in the Tororo Cement industries and the surrounding buildings.

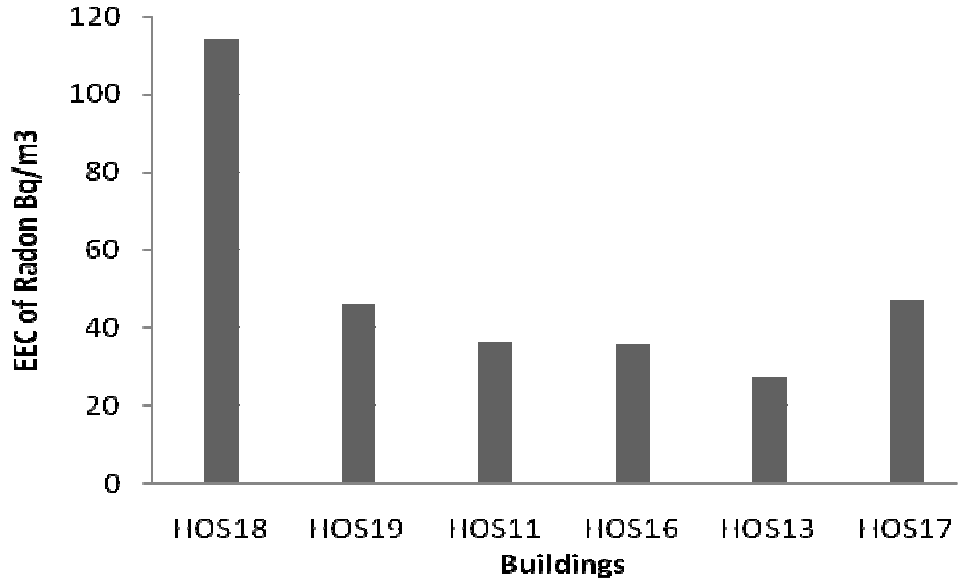

Figure 7 Equilibrium Equivalent Concentration of Radon in Tororo Referral Hospital

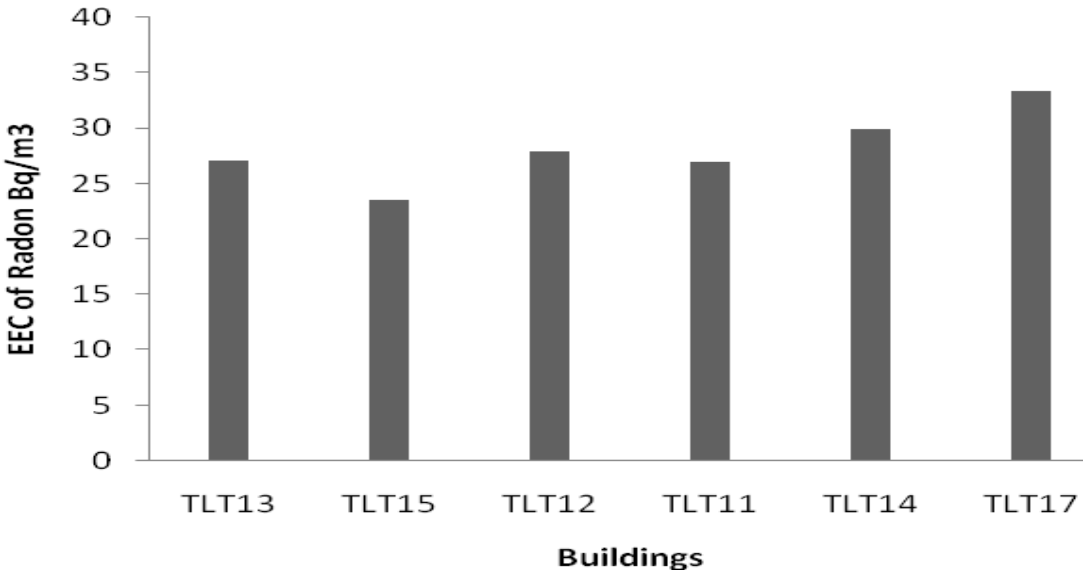

Figure 8 Equilibrium Equivalent Concentration of Radon in TLT Hotel in Tororo Town

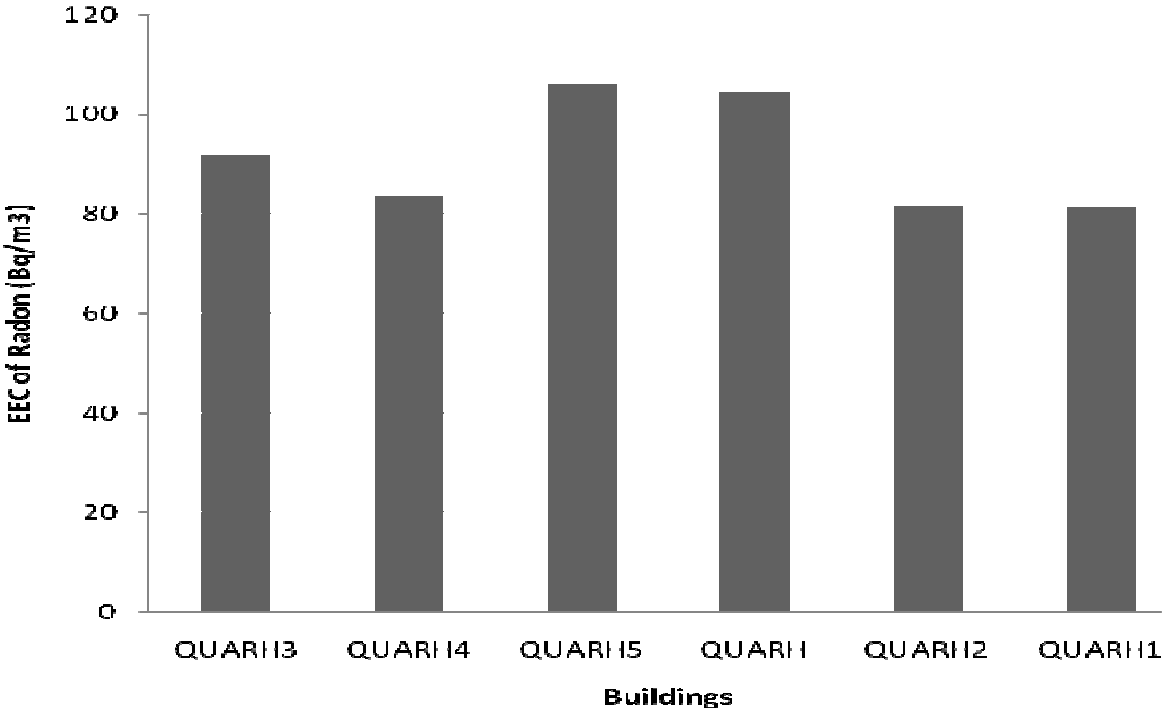

Figure 9 Equilibrium Equivalent Concentration of Radon in Home near Cement Quarries

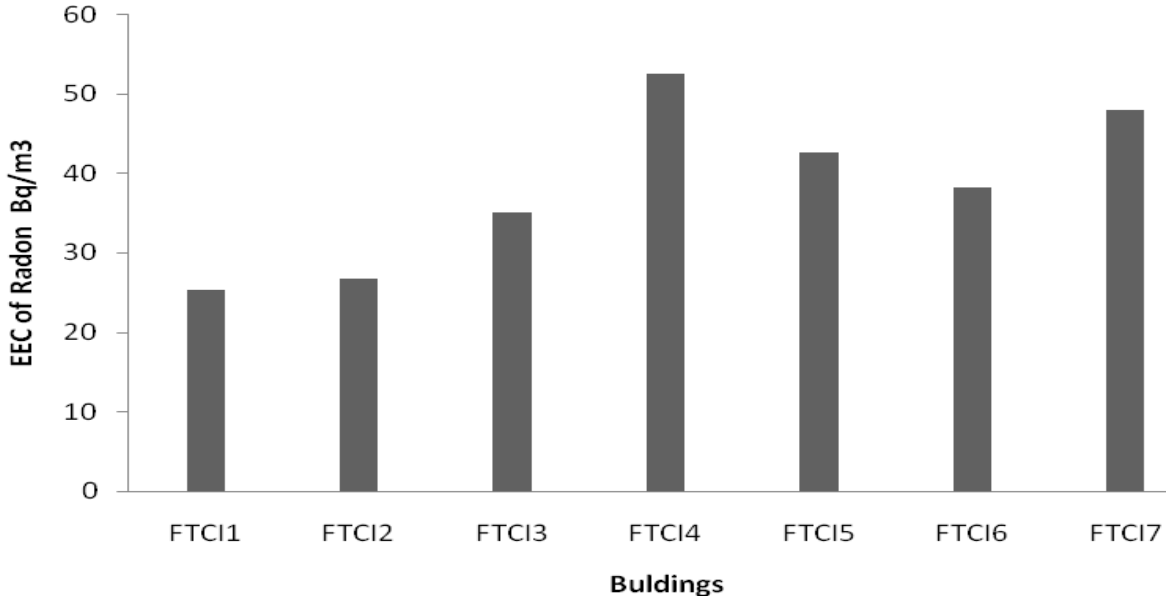

Figure 10 Equilibrium Equivalent Concentration Radon in homes far from Tororo Cement Industries

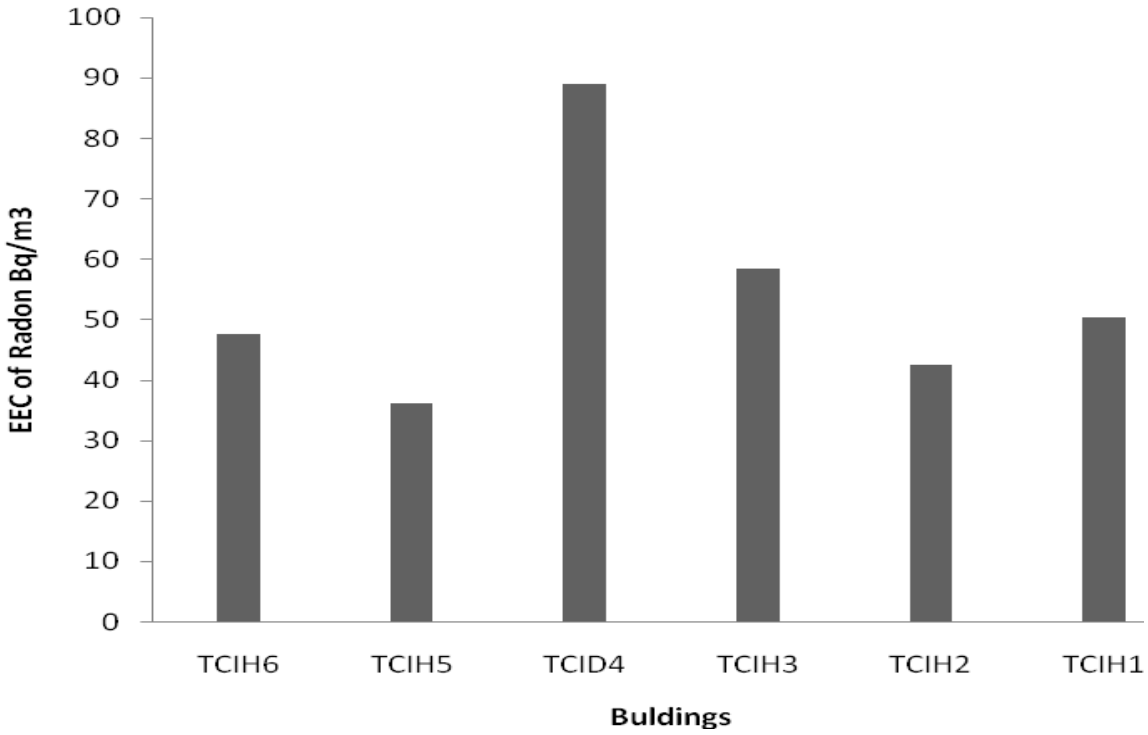

Figure11 Equilibrium Equivalent Concentration of Radon in homes far from Tororo Cement Industries

CONCLUSION

The average radon concentration and effective dose values measured from the Dwellings in Tororo and Busia Districts were found to vary from 28±1 to 97±5 Bqm^{-3} and 0.71±0.03 to 2.44±0.10 $mSvy^{-1}$, respectively. Houses at the limestone Quarries, Tororo Cement Industries and homes near the Limestone Quarries had the highest mean radon concentrations of 97±5, 96±4 and 92±4 Bqm^{-3} & high effective doses of 2.44±0.13, 2.43±0.10, 2.31±0.10 $mSvy^{-1}$, respectively. Lower mean radon concentrations and effective doses were registered from TLT hotel in Tororo town, dwellings far from Tiira Gold Mines and dwellings far from Tororo Cement Industries of 28±1, 39±1 and 45±1 Bqm^{-3} and 0.71±0.03, 0.99±0.03 and 1.13±0.10 $mSvy^{-1}$, respectively.

Tororo Cement Industries was found to have higher radon concentration levels than surrounding buildings. This was attributed to the poor ventilation, building design of the factories and radon gas emanating from the limestone and other raw materials of cement. TLT hotel had the lowest average radon concentration. This was due to the design with efficient ventilation that allows air changes and air fans which are equipped in there.

Over all, radon concentration levels and effective doses measured were found to be lower than United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and International Commission on Radiological Protection (ICRP) recommended radon action level (reference level) of 200 Bqm^{-3}. However in some places radon concentration levels are close 100 Bqm^{-3} an action level recommended by World Health Organization (WHO). Hence results of this study show no significant radiation hazards in the dwellings at the mine, industries and other dwellings for occupational works but there is evidence of radon health risk to the members of the public since most of the values of annual effective doses determined are higher than 1 $mSvy^{-1}$ as recommended by UNSCEAR, ICRP and WHO.

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