Tanzania Journal of Science 44(1): 159-168, 2018 ISSN 0856-1761, e-ISSN 2507-7961

INDOOR RADON CONCENTRATION LEVELS AND ANNUAL EFFECTIVE DOSES FOR RESIDENCE OF HOUSES NEAR URANIUM DEPOSIT IN BAHI DISTRICT, DODOMA, TANZANIA

Najat K. Mohammed and Erasto Focus
Department of Physics, University of Dar es Salaam, P. O. Box 35063, Dar es Salaam, Tanzania
najat@udsm.ac.tz

ABSTRACT

The objective of this study was to determine the levels of indoor radon concentration in houses in Bahi District situated in the neighbourhood of uranium deposit. The study aimed also to assess the annual effective dose due to indoor radon exposure to individuals residing in the houses as a step to control the radon exposure in Tanzania. Two villages were involved in this study; Bahi Makulu, which is within the proximity of Uranium deposit and Bahi Sokoni, which is about 7 km from the deposit. The Indoor radon concentration levels were detected using Alpha Guard radon monitor and the obtained mean concentration levels are presented and compared with the mean concentrations levels published in literature. The results revealed that 78% of the houses involved in this study have concentration levels of indoor radon above the reference level of 100 Bq/m^3 set by WHO 2009. The levels are higher in traditional houses which are mostly built with poor ventilation than the modern houses with good ventilation. Out of the two villages involved in this study, Bahi Makulu which is closer to the uranium deposit has significantly higher ($p<0.01$) concentrations of indoor radon than Bahi Sokoni. The calculated annual effective doses for the population in both villages are higher than the dose reference level of 1 mSv/y.

Key words: *Indoor Radon, Bahi District, Uranium deposit, Annual effective dose*

INTRODUCTION

Radon is a naturally occurring radioactive gas formed from the radioactive decay of uranium (^{238}U), thorium (^{232}Th) and uranium (^{235}U). There are three isotopes of radon; Radon (^{222}Rn), which is a daughter of ^{238}U, (^{220}Rn), a daughter of ^{232}Th and (^{219}Rn), a daughter of ^{235}U. ^{222}Rn has the longest half life of 3.83 days compared to other isotopes ^{219}Rn and ^{220}Rn which have half lives of 3.96 seconds and 56 seconds, respectively (ICRP 2009). All of the three isotopes of radon decay by alpha-emission to produce radioactive daughters. Some of the daughters are also alpha emitters (example; ^{218}Po, ^{214}Po and ^{210}Po) and some are beta emitters (example; ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi). When inside a body, alpha particles are remarkably dangerous to human tissues due to their High Relative Biological Effectiveness (RBE) (W_R=20 for alpha particle) that may results in a significant tissues damage in lungs and hence cancer induction (WHO 2009). Beta particles though with smaller radiation weighting factor (W_R=1) than alpha particles contribute also to the biological effects on body tissues.

The percentage of all lung cancers associated to radon is estimated to be between 3% and 14% depending on the average radon concentration in the area (WHO 2009). The International Commission on Radiological Protection (ICRP) recommends the reference level of radon concentration of 300 Bq/m^3 for the general public exposure (ICRP 2009) while the World Health Organization (WHO) recommends maximum residential radon level to 100 Bq/m^3 (WHO 2009).

The main source of indoor radon is the uranium present in the soil and rocks under the houses, drinking water and building materials (Abuelhia 2017). This work was conducted at Bahi District in Dodoma Region, Tanzania where uranium deposit has been discovered (URANEX 2010). The uranium deposit in Bahi is said to be shallow with high concentration of uranium and thorium in the surface soil (Kimaro and Mohammed 2015). On top of the fact that the houses in this area are built on top of the uranium deposits, the soil is also used to build houses, which have limited ventilation to allow a free passage of air into the homes for radon dilution. Within these houses, the concentrations of radon gas and its progeny are expected to be high. Therefore, the objective of this study was to assess the concentration levels of radon and the dose delivered to people living in these dwellings as a step to control radon exposure in Tanzania. The work is testing the hypotheses that the levels of radon concentration in houses at Bahi uranium deposit area exceed the set limit of 100 Bq/m^3 by WHO (2009) and the annual effective dose for residents in Bahi exceed the dose limit of 1 mSv/y set by IAEA (2011) for the general public.

Figure 1 A typical Traditional (*Tembe)* house in Bahi District

MATERIAL AND METHODS

Sample Collection

House samples were selected from two villages (Bahi Sokoni and Bahi Makulu) within Bahi District of Dodoma Region in Tanzania. The samples were collected from individual houses under the permission of the head of the house following a discussion of the objective of the study. Prior to that, permission to conduct the study was given by the Regional Administrative Secretary of Dodoma Region, the Deputy Executive Director of Bahi District and the heads of both villages. A total of 60 samples were randomly collected from Bahi in Dodma Region. Thirty two samples (32) were collected from Bahi Makulu which is closer to the proposed uranium deposit while twenty eight (28) samples were collected from Bahi Sokoni village which is about 7 km from the deposit (Fig. 2).

In each village the selected houses were dived into two groups; traditional houses known as *tembe* and modern houses. Sampling priority was given to *tembe* and traditional houses, which are close together. The *tembe* houses are the ones that have mud walls, soil floor and a roof of soil and/grass. Most of the windows in these houses are tiny or not existing and have small room size. Data were collected using Alpha Guard radon monitor obtained from the Tanzania Atomic Energy Commission.

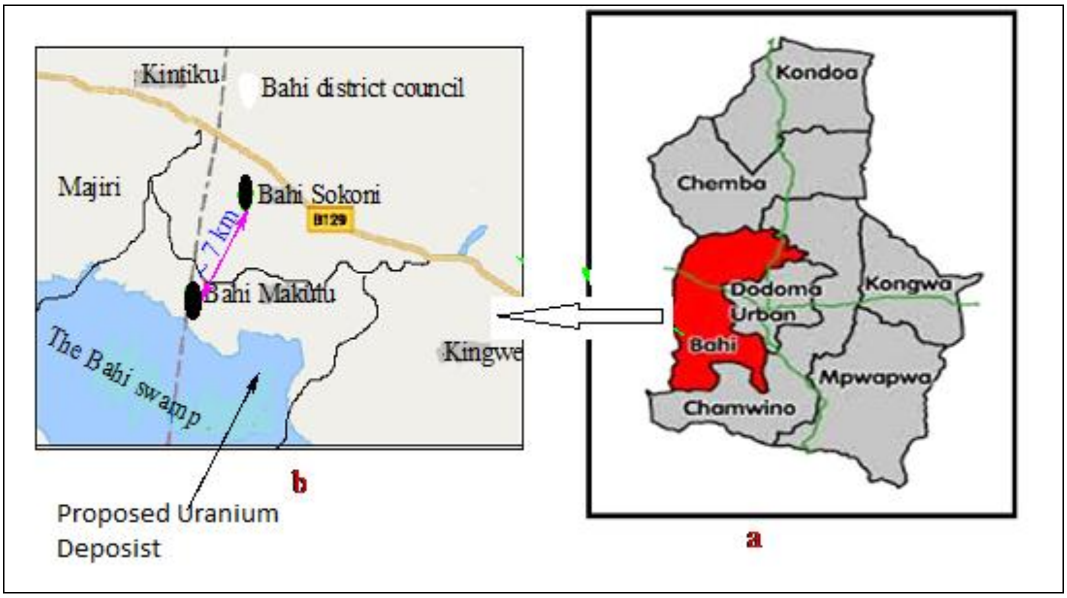

Figure 2: (a) A map showing Bahi district (with red color) in Dodoma region (b) The villages involved in this study in relation to their distance from the uranium deposit.

Measurement of Radon Gas and other parameters

The Alpha Guard radon monitor was set in 10 minutes cycle for one hour and placed in a room where air was allowed easily to interact with the device. The measurements were conducted inside the house when the window(s) and doors were closed throughout for one hour so as to measure the total indoor radon concentration as recommended by U.S EPA (2013). In the same room, the readings were taken in three phases with the interval of four hours (during morning hours, afternoon and during evening time), thereafter the total average was obtained. Moreover, while keeping the dimensions of doors constant, the dimensions of the windows for each room where radon levels concentration was recorded were taken by using a tape measure. The average area of the window(s) (WA) was determined for each room that was investigated in order to verify the relationship between radon levels and ventilation with the assumption that the radioactivity in the soil at Bahi study area is uniformly distributed.

Principle of work of Alpha guard

While in operation, the air in the room of the dwelling diffuses into its ionization chambers/ active volume (about 0.56 L) via a large- surface glass fiber. Only the radon gas will pass through the glass fiber to enter the 0.56 L ionization chamber while radon progeny will be left because they are solids and often attached to dust particles. The large surface glass fiber filter also helps in preventing the interior of the detector from contacting contamination of dusty particles. The alpha particles released by radon within the chamber ionize the gas and the charges formed are collected at the anode and cathode of the Alpha Guard radon monitor. The movement of the ions to the gathering electrodes results in an electronic signal that is translated into radon concentration (Bq/m^3) through an internal calibration built in by the manufacturer (Genitron 2015), and readings (Concentration (Bq/m^3) are recorded directly from the screen.

The exposure and annual effective dose calculation

In order to approximate the exposure to home dwellers from the decay series of radon and its progeny, it is essential to know the ambient radioactivity concentration of the radionuclide. The rate at which these atoms vanish from the room is given by $\frac{dN_d}{dt} = \lambda_p N_p - \lambda_d N_d$. The exposure due to radioactivity of the i^{th} daughter $\lambda_i N_i$ given by intake I and the annual effective dose are given by equations 1 and 2, respectively (ICRP 1993)·

$$I(Bq) = C_{R_n}(Bq/m^3) \times F_i \times H(h) \times R(m^3/h) \quad (1)$$

$$C_{R_n} = \frac{\lambda_{R_n} N_{R_n}}{V}(Bq/m^3)$$

$$D_{R_n}(mSv/y) = C_{R_n} \times D \times H \times F \times T \quad (2)$$

where: -

$I(Bq)$ is the estimated radon exposure to dwellers (Intake), C_{R_n} is the measured ^{222}Rn concentration in Bq/m^3, F is the ^{222}Rn equilibrium factor indoors (0.4), T is the occupancy factor (annual occupancy at the location) that depends on people's habit on average number of hours spent indoor, H is the indoor occupancy factor obtained using equation 3, D is the dose conversion factor $9.0 \times 10^{-6}\ mSv/h\ per\ Bq/m^3$

The occupancy factor determination

According to IAEA, the occupancy factor is the level of human exposure to an area closest to a source of radiating material (IAEA 2011). The occupancy factor is an important term in the calculations of exposure and dose received by people as shown in equation 3. UNSCEAR (2013) set the indoor value of 0.8 as the average occupancy factor worldwide assuming that the time spent indoor is about 19 hours out of 24 hours a day. But in reality, the occupancy factor differs between places and between types of people.

In this study a total of 60 interview sheets were administered to the head of the house selected for radon measurements. The questionnaires were asking the time members of the family stay in the house during measurements. The obtained data were used to calculate the indoor occupancy factor for different groups of house members (children (aged 0 to 5 years), women and men using equation 3. The occupancy factors were then used in equations 1 and 2 to calculate the exposure (intake) and annual doses derived by those groups of residents.

$$H(h) = \frac{Xhours}{24hours} \quad (3)$$

Where: $H(h)$ is the occupancy to a particular group, X hours is the average indoor time obtained from the respondents, 24 hours is the total time (a day)

On obtaining the occupancy factor for the different groups in equation 3, the following assumptions were considered:

i. Absorption rate of natural occurring radioactive materials (NORMs) is directly proportional to the amount of time in exposure.

ii. The total time spent indoor and outdoor is 24 hours for each population group.

iii. Each population group was assumed to have time fraction of leisure, occupation and other activities.
iv. Indoor and outdoor time spent is linearly dependent on the activity.
v. Each activity was assumed to have a time fraction of indoor and outdoor function.

RESULTS AND DISCUSSION

Indoor Radon concentration levels

A statistical summary of data in Bq/m^3 is presented in Table 1 for Bahi Makulu and Bahi Sokoni Villages showing the standard error of the mean. Since data from both villages followed normal distribution, a t-test was carried out to find the statistical differences between the mean concentrations of the indoor radon found in houses in the two villages. The test revealed that houses in Bahi Makulu village had significantly ($p<0.01$) higher mean concentration of indoor radon than houses in Bahi Sokoni village. The results show also that, 97% of the analyzed houses from Bahi Makulu village had indoor radon concentration levels above the WHO reference level of 100 Bq/m^3 compared to 39% of the analyzed houses in Bahi Sokoni village. Bahi Makulu village is within the proximity of the Bahi swamp where the uranium deposit is reported to exist and Bahi Sokoni is about 7 km further from the deposit.

The findings of this study follow the same trends as those reported elsewhere in relation to the radon concentration levels with distance from uranium deposits. For example, Ivanova and Victor (2012) conducted a study in an area within the vicinity of an old uranium mining region in Bulgaria. The results revealed that, the highest indoor radon concentration was in Bachkovo village which is located about 1 km from the uranium mine whereas the lowest value was reported in Eleshnista village which is about 2-3 km from the uranium mine.

The indoor radon concentration from Traditional (*tembe*) and Modern houses in each village were compared and presented in Fig 3. The traditional houses in Bahi Sokoni had 1.8 times higher concentration of indoor radon than the modern houses. High concentration in traditional houses is mainly attributed to low ventilation. 100% of *tembe* houses at Bahi Makulu village were found to have radon concentrations above the WHO reference level (100 Bq/m^3) compared to 83% found in the modern houses.

At the same time the traditional houses in Bahi Makulu had 1.7 higher concentrations of indoor radon than the modern houses. 89% of traditional houses in Bahi Sokoni village had radon concentration above the WHO reference level compared to 47% found in the modern houses in the same village. The highest value of radon concentration in both villages was found in a traditional house from Bahi Makulu village (HMV24) having the value 619 ±59 Bq/m^3 which is about 6.2 times higher than 100 Bq/m^3 reference value set by WHO. However, the mean radon concentrations in both types of houses in Bahi area are above 100 Bq/m^3.

Table 1: Mean radon concentrations levels (Bq/m^3 ±SM) in houses of Bahi Makulu and Bahi Sokoni villages and other parameters

Bahi Makulu N=32				**Bahi Sokoni** N=28			
Codes	Concentration (Bq/m^3)	Codes	Concentration (Bq/m^3)	Codes	Concentration (Bq/m^3)	Codes	Concentration (Bq/m^3)
HMV1	410 ±72	HMV17	498 ±49	HSV1	29 ±8	HSV17	143 ±9
HMV2	160 ±45	HMV18	283 ±33	HSV2	63 ±12	HSV18	192 ±18
HMV3	409 ±80	HMV19	411 ±39	HSV3	100 ±24	HSV19	325 ±35
HMV4	450 ±76	HMV20	409 ±38	HSV4	356 ±68	HSV20	270 ±25
HMV5	515 ±49	HMV21	398 ±17	HSV5	200 ±44	HSV21	70 ±6
HMV6	401 ±61	HMV22	401 ±29	HSV6	170 ±45	HSV22	282 ±28
HMV7	412 ±81	HMV23	506 ±63	HSV7	91 ±34	HSV23	312 ±31
HMV8	239 ±13	HMV24	619 ±59	HSV8	155 ±49	HSV24	235 ±23
HMV9	70 ±15	HMV25	103 ±12	HSV9	73 ±24	HSV24	235 ±23
HMV10	347 ±21	HMV26	323 ±32	HSV10	32 ±12	HSV25	231 ±24
HMV11	201 ±16	HMV27	331 ±23	HSV11	332 ±47	HSV26	398 ±38
HMV12	481 ±58	HMV28	209 ±21	HSV12	341 ±64	HSV27	109 ±11
HMV13	324 ±42	HMV29	345 ±35	HSV13	54 ±9	HSV28	156 ±16
HMV14	203 ±31	HMV30	308 ±42	HSV14	132 ±11		
HMV15	323 ±57	HMV31	276 ±25	HSV15	98 ±12		
HMV16	412 ±62	HMV32	394 ±39	HSV16	107 ±21		
Mean		**362±22**		**Mean**		**181±21**	
Min		**70 ±15**		**Min**		**29 ±8**	
Max		**619 ±59**		**Max**		**398 ±38**	

The data from both villages were combined and their mean was found to be 277 ±2 Bq/m^3 (29 ±8 Bq/m^3 to 619 ±59 Bq/m^3). The mean was then compared with the mean concentrations from other studies conducted elsewhere (Figure 4). The mean radon obtained in Bahi uranium deposit area is about 1.6 times higher than the mean value reported in houses in Manyoni, Singida region, Tanzania (Mlay 2014). The Bahi radon concentrations are also higher than those reported in studies in India with the average value of 194 Bq/m^3 (Rani et al. 2013), in Ghana with mean value of 56.7 ±2.8 Bq/m^3 (Yeboah 2014), in Kenya with mean value of 35.2 ±13.9 Bq/m^3 (Chege 2014) and in Uganda with mean value of 97 ±5 Bq/m^3 (Biira et al. 2014). However, the mean radon concentration levels obtained in this study are less than the concentration reported by Palacios (2014) in Switzerland (300 Bq/m^3), by Kobal et al. 2015 in Slovenia (400 Bq/m^3) and by Boris et al. (2014) in Belgium (400 Bq/m^3). The higher radon-222 concentration in four European countries mentioned above is due to the fact that long term air tight conditions are common practices in Europe due to the fact that double doors and double windows are used.

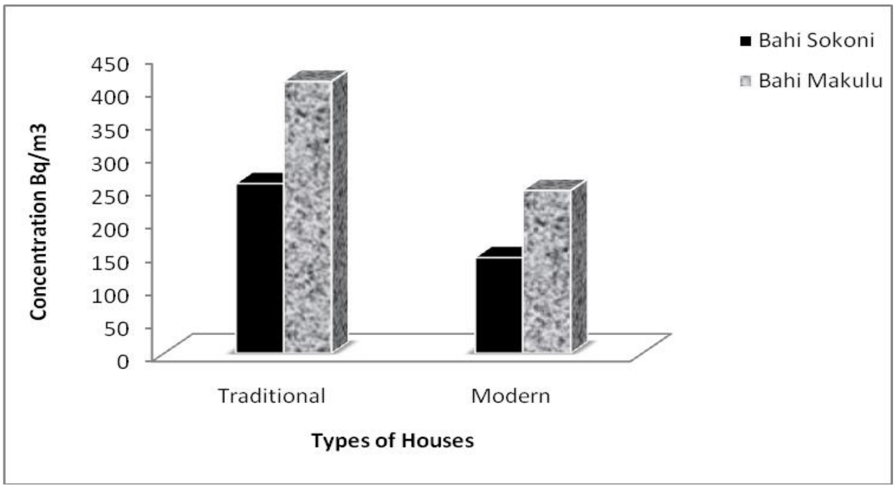

Figure 3: The comparison of indoor radon in Traditional (Tembe) and Modern Houses in Bahi Makulu and Bahi Sokoni Villages.

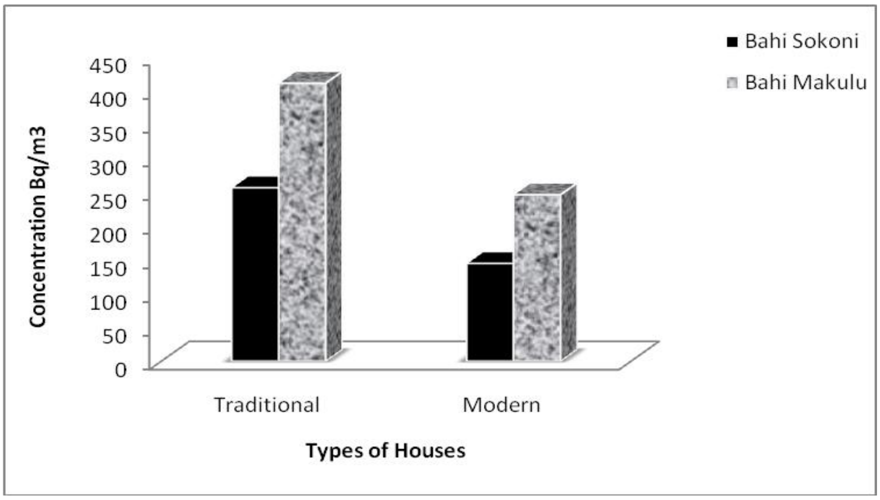

Figure 4: Comparison of mean Indoor Radon Concentrations from this study with those reported elsewhere.

Indoor Radon in relation to House Ventilation

Different literatures have revealed that ventilation is the key factor for the accumulation of indoor radon (WHO 2009, Rani et al. 2013). Inadequate ventilated houses are reported to have high level of indoor radon concentrations compared to the adequately ventilated houses. In this study house window areas were categorized into five groups ranging from 0 m^2 to 3.0 m^2; the zero value means the room has no window.

The window areas were then categorized as poor to good ventilation according to their sizes as shown in Table 2.

The one–way ANOVA test was carried out to compare mean concentration of indoor radon with window areas. The test confirmed a statistical significant difference (F (4, 55) =51.01, p =0.000) between ventilation categories. A Tukey post hoc test indicated that the indoor mean radon concentration is statistically highest in poor ventilated houses (398.8 ±17 Bq/m^3, p =0.000) followed by partial ventilated houses (284.8 ±20 Bq/m^3, p =0.000), moderate ventilated houses (152 ±12 Bq/m^3, p =0.000). As Table 2 shows, the mean radon concentrations levels in good ventilated houses were below the reference limit (100 Bq/m^3) set by WHO (WHO 2009). The poor ventilated houses have higher mean radon concentration of about 13 times that of the good ventilated houses. The maximum indoor radon concentration value in rooms with poor ventilation (619 ±59) was about 6 times higher than the tolerable limit of 100 Bq/m^3 (WHO 2009).

Table 2: The concentrations of radon in houses of area ≤ 0.6 m^2 to 3.64 m^2

Status	**Range of average area (m^2)**	**Range (Bq/m^3)** Min	max	**Number of samples**	**Mean radon concentration (Bq/m^3)**
Poor	≤ 0.6 m^2	235 ±23	619 ±59	27	398.8 ±17
Partial	>0.6 m^2 ≤ 1 m^2	170 ±45	401 ±29	13	284.8 ±20
Moderate	>1 m^2 ≤ 1.5 m^2	109 ±11	209 ±21	9	152 ±12
Good	>1.5 m^2≤ 3.0 m^2	29 ±8	107 ±21	11	81 ±6

The differences in indoor radon concentrations between the adequately ventilated rooms and the inadequately ventilated rooms have been reported in other studies. They have also been associated to the accumulation of radioactive materials such as uranium and thorium in building materials, which results into the emanation of radon gas (Amasi et al. 2015). The results in this work are also in good agreement with the study conducted by Rani et al. (2013) in India on the indoor radon measurements in the dwellings of Punjab and Himachal Pradesh. Lower values of indoor radon were obtained in houses with adequate ventilation compared to houses with inadequate ventilations. Adequate ventilation allows fresh air to inter the room and the contaminated air to go out of the rooms.

The exposure and annual absorbed dose

Using the obtained mean indoor radon concentrations and the estimated occupancy factor for each group, the exposure and effective dose rates were calculated using equation 1 and 2. The exposure and dose rates for each village are presented in Table 3. The table shows that, the exposure and dose rates are highest for children (0 – 5 years) followed by women and men. This is because the children have higher occupancy factor, which indicates that they stay inside the houses longer than women and men. Table 3 shows also that Bahi Makulu, which has higher mean radon concentration, has higher exposure and dose rates than Bahi Sokoni village. The calculated annual effective dose rates in both villages and the combined Bahi area are higher than the dose reference level of 1 mSv/y.

Table 3: The exposure (intakes) and the average dose rates to people from different categories

Category/ places	**Group estimated occupancy factor**	**Exposure (Bq/m^3)**	**Dose rates (mSv/y)**
Bahi Makulu village	Children =0.8	1216331	7.30
	Women =0.7	1058041	5.55
	Men =0.58	886908	3.86
Bahi Sokoni village	Children =0.8	607409	3.64
	Women =0.7	528362	2.77
	Men =0.58	442902	1.92
Combined villages	Children =0.8	932187	5.59
	Women =0.7	810875	4.23
	Men =0.58	679720	2.96

CONCLUSION

In this study, indoor Radon concentrations from 2 villages of Bahi District were measured and analyzed. The Bahi Makulu Village is found to have significantly ($p<0.001$) 2 times higher indoor Radon levels than Bahi Sokoni. Bahi Makulu village is about 7 km closer to Bahi swamp, where uranium deposit is reported, than Bahi Sokoni. This observation is supporting the reports in literature showing that houses near the uranium deposits have higher indoor radon levels than houses far from the deposits. The results from this study support also the reports that concentration levels of indoor radon are higher in poorly ventilated houses than good ventilated houses. In each village the traditional houses, which are mostly built with small or no windows, have higher mean concentration levels of indoor Radon than modern houses.

The results revealed that 78% of the houses in Bahi District involved in this study have concentration levels of indoor radon above the reference level of 100 Bq/m^3 set by WHO. The average indoor radon concentrations (277±2 Bq/m^3) in houses at Bahi exceed also the reference level of 100 Bq/m^3 set by WHO. The calculated annual absorbed doses in children women and men in both villages are higher than the dose reference level of 1 mSv/y set by ICRP 2009.

Therefore, results in this study indicate that, people at Bahi District are exposed to high concentrations of indoor Radon above reference level of 100 Bq/m^3 set by WHO, which might be detrimental to their health. Education on building houses with good ventilation to people living on high background areas in Tanzania is recommended.

ACKNOWLEDGEMENTS

We are thankful to the Local authorities in Bahi District and the Tanzania Atomic Energy Commission (TAEC) for their support in accomplishing this work.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest

AUTHOR'S CONTRIBUTIONS

All authors read and approved the final manuscript

REFERENCES

Abuelhia E. 2017 Evaluation of annual effective dose from indoor radon concentration in Eastern Province, Dammam, Saudi Arabia. *Radiat. Phys. Chem.* **140:** 137–140.

Amasi A, Mtei K, Dinh C, Jodlowski P 2015 Radon Mass Exhalation Rates of Selected Building Materials in Tanzania. *J. Environ. Earth Sci.* **5:** 57-63.

Biira S, Kisolo WA, D'ujanga MF 2014 Concentration levels of Radon in Mines, Industries and Dwellings in Selected Areas of Tororo and Busia Districts, Eastern Uganda. *Adv. Appl. Sci. Res.* **5(6):** 31-44.

Boris D and Michel S 2014 The Belgian Radon Action Plan, Radon National Action Plan Workshop, Paris.

Chege MW 2014 *Screening Measurement of Indoor Radon-222 Concentrations by Gamma-ray Spectrometry in Kenyatta University*. Ph. D (Physics) thesis, Kenyatta University, Kenya.

Genitron Instruments GmbH 2015 Alpha GUARD User Manual, Frankfurt, German.

IAEA 2011 Radiation Protection in the Design of Radiotherapy Facilities. Safety Reports Series No. 47, Vienna, Austria.

ICRP 1993 Protection against Radon-222 at Home. ICRP Publication 65, Ann. ICRP 23(2).

ICRP 2009 International Commission on Radiological Protection Statement on Radon. ICRP Ref 00/902/09.

Ivanova K and Victor B 2012 National Center of Radiobiology and Radiation Protection. Sofia, Bulgaria.

Kimaro E and Mohammed N 2015 Natural Radioactivity Levels in the Area around the Uranium Deposit of the Bahi District in Dodoma Region, Tanzania. *Int. Res. J. Pure Appl. Chem.* **9**(3): 1-10.

Kobal I 2015 Comparison of Approaches in Slovenia and Kazakhstan in Managing Exposure to Radon. Uranium - Past and Future Challenges. Proceedings of the 7th International Conference on Uranium Mining and Hydrogeology. 2015: 689–98.

Mlay WG 2014 *Assessment of Indoor Radon Concentrations in Manyoni District in Singida in the Vicinity of Uranium Deposit*. M. Sc. (Physics) Dissertation, University of Dar es Salaam.

Palacios MG 2014 Implementation of the New International Standards in Swiss Legislation on Radon Protection in Dwellings. *Radiat. Prot. Dosim.* **45**:103-107.

Rani A, Singh S, Duggal V 2013 Indoor Radon Measurements in the Dwellings of Punjab and Himachal Pradesh, India. *Radiat. Prot. Dosim.* **156:** 118-124.

UNSCEAR 2013 Report Sources, effects and risks of ionizing radiation ***volume 1*** *Report to the General Assembly with Scientific Annexes, United Nations, New York.*

URANEX 2010 Australian based Uranium Exploration and Development Company with a Diverse Pipeline of Projects in Australia and Africa. *New Uranium Mineralization Discovered at Bahi and Manyoni.*

U.S EPA 2013 Consumer's Guide to Radon Reduction, how to fix your Home, *EPA* **402**/K-10/005.

WHO 2009 Handbook on Indoor Radon, a Public Health Perspective, Press, 20 Avenue Appia, 1211 Geneva 27, Switzerland.

Yeboah 2014 *Indoor Radon in Selected Homes in Aburi Municipality: Measurement Uncertainty, Decision Analysis and Remediation Strategy*. M. Sc (Physics) thesis, University of Ghana.