DETERMINATION OF RADON GAS AND RESPIRABLE ORE DUST CONCENTRATIONS IN THE UNDERGROUND MERELANI TANZANITE MINES

Evarist M. Kahuluda[1] and Ismael N. Makundi[2*]
[1]Radiation Control Directorate, Tanzania Atomic Energy Commission,
P. O. Box 749 Arusha, Tanzania
*Corresponding author, E-mail: ismakundi@udsm.ac.tz
[2]Department of Physics, University of Dar es Salaam, P. O. Box 35063 Dar es Salaam, Tanzania

ABSTRACT

This study has estimated the concentrations of radon gas and respirable ore dust in the Merelani underground tanzanite mines. Two different portable monitors were used to measure the radon gas and respirable ore dust concentrations, respectively. The mean radon gas concentrations (disintegrations per second per cubic meter) ranged from 40.1 Bq/m3 to 4.2 x 10^3 Bq/m^3 with the geometric mean of 118.4 Bq/m^3 which is below the ICRP workplace guidance level of 500 - 1500 Bq/m^3. The estimated mean annual effective dose (D) was 1.6 mSv which is significantly lower than the external exposure annual effective dose of 20 mSv and the annual organ dose limit of 2.4 mSv. The overall arithmetic mean concentration of respirable ore dust was 18.2 g/m^3 and the geometric mean was 2.1 g/m^3 which is very high compared to the guidance level of 2 g/m^3. The respirable dust was mainly produced during drilling and blasting of rocks, under normal conditions the geometric mean of respirable gas concentration was 0.8 g/m^3. It is recommended that immediate intervention such as providing proper ventilation during the two processes to dilute radon levels in underground mines and the monitoring should be done regularly.

Keywords: Radon, Dust, Underground Mines

INTRODUCTION

The mining industry in Tanzania has developed dramatically during the last three decades (Phillips et al. 2001, Lugoe 2011). This industry consists of small and large scale mining (Twerefou 2009) of which varieties of gemstones are mined. At Merelani, the purplish-blue tanzanite gems are found in graphitic gneiss containing quartz and feldspar (Braveit et al. 2003). Most of the gemstone mining activities are done in underground pits, which generally follow a procedure of blasting, drilling and mucking (Nilsson and Randhem 2008), by which dust is generated and dispersed into the mine air through rock breakage, rock loading, unloading and transportation (Mukherjee et al. 2005). The working conditions are associated with health risks such as radiations and dust exposure (Bråtveit et al. 2003, Önder and Önder, 2009, Önder et al. 2009, Mikołajczyk et al. 2010). Thus, miners form the occupational group with the highest potential for radon exposure (Mudd 2008).

In order to control the radon levels in the workplace, most countries have set their radon workplace guidance levels in the range 400-1000 Bq/m^3. For drinking water the guidance level is 100-1000 Bq/l and between 200-400 Bq/m^3 for indoor environments (UNSCEAR 2008). The study by Synnott and Fenton (2005) on the evaluation of radon guidance levels in European countries showed that the workplace guidance levels for Czech Republic, Denmark and Greece were 1000

Bq/m^3, 400 Bq/m^3 and 400 Bq/m^3, respectively, whereas ICRP recommends the workplace guidance level ranges from 500 to 1500 Bq/m^3 (ICRP 1993).
Inhaled dust particles with an aerodynamic diameter smaller than 10 µm (PM10) can penetrate to the tracheobronchial regions, where they can be trapped into the mucus layer (Derbyshire 2007), this can disturb the functions of the lungs and hence cause different body reactions (Fubini and Fenoglio 2007) that can lead to several different diseases such as silicosis, fibrosis, lung cancer and cancer of the pleura (Ateş 2011, Mayer and Lockey 2012).

Epidemiologic studies in underground mines showed that miners exposed to high levels of radon have high risks of lung cancer (Tracy et al. 2006). The more dangerous is the radon progenies which are electrically charged and can attach themselves to tiny dust particles in air and when these particles are inhaled; they adhere to the lung linings where they cause radiation damage to the cells by disrupting the cell DNA that can then lead to cancer (Little 1997).

The concentrations of respirable dust measured in the underground, washing plant and power plant were 0.81 mg/m^3, 1.07 mg/m^3 and 2.50 mg/m^3, respectively. The concentrations of respirable particles at the power plant were above the guidance level of 2 mg/m^3 set by USA and Spain, though this set limit neglected the concentrations of coarse particles (Sawe 2010). Mamuya et al. (2006) at Kiwira coal mine recorded the concentrations of respirable dust and quartz of 10.30 mg/m^3 and 1.28 mg/m^3, respectively, which were very high compared to the guidance level of 2 mg/m^3.

The pilot study by Bråtveit *et al.* (2003) on respirable dust exposure during small scale mining at Merelani tanzanite mines showed that the overall median respirable dust level was 10.6 mg/m^3, and the median level of respirable crystalline silica was 1.4 mg/m^3. Also the study by Malisa and Kinabo (2005) at Merelani tanzanite mine showed that during drilling, blasting and shoveling, the concentrations for the respirable dust, respirable quartz and respirable graphite were 15.5 mg/m^3, 2.4 mg/m^3 and 1.5 mg/m^3, respectively. The total dust concentration was 28.4 mg/m^3, and when only shoveling and loading of sacks were taking place, the median levels of overall respirable dust and quartz were 4.3 mg/m^3 and 1.1 mg/m^3, respectively. Bråtveit *et al.* (2003) and Malisa and Kinabo (2005) conducted their studies on respirable dust concentrations for only three to four days and neglected the possibility of radon exposure to miners. There was a need to conduct an intensive study to determine the concentrations of radon gas and respirable ore dust in underground tanzanite mines at Merelani of which this study aimed to fill the gap.

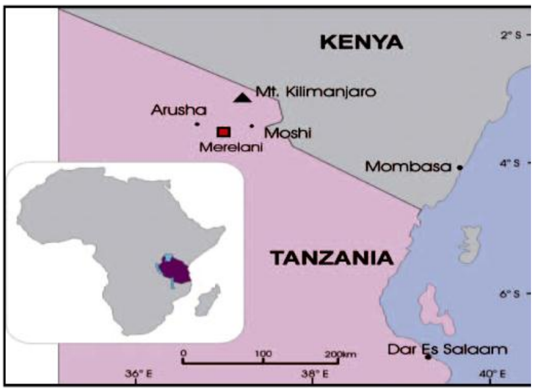
MATERIALS AND METHODS

Study area

Merelani is located at latitude 3°33'42" South of the equator and longitude 36°58'44" East, about 70 km from Arusha town. The mining area is divided into blocks, of which blocks B and D are owned by small-scale miners and blocks A and C to large mining companies (Malisa and Kinabo 2005). Map 1 shows the location of Merelani tanzanite mines and Figure 1 shows the mining blocks.

Radon and respirable dust measurements

The radon concentrations were measured from underground working areas and offices from the known 12 campsites/mines and Merelani town as a control. From each campsite/mine, respirable dust concentrations together with the temperature, pressure and relative humidity were measured at the selected working areas. Radon detection device (AlphaGUARD™) (Genitron 1998) was set to measure the radon concentration, temperature, pressure and relative humidity in every ten minutes for six hours. The hourly and overall means were recorded. The DustTruck™ II aerosol monitor was used to measure the real time mass concentrations of the particulate matter with aerodynamic diameter $d < 2.5$ µm, $2.5 < d \le 4$ µm and $d \le 10$ µm ($PM_{2.5}$, PM_4 and PM_{10}) (TSI 2012). Measurements of dust concentrations were carried out for eight working hours for four days in each camp site. The dust concentration measurements can be categorized to drilling, three hours after blasting, normal operations and in offices. The statistical analysis of radon gas and respirable dust concentrations were performed to test for normality of the data distribution in radon gas and respirable dust concentrations, calculation of the central tendency and measure the variability.



Map 1: Location of Merelani tanzanite mines (EA 2010).

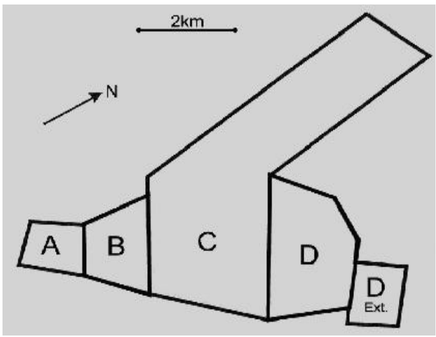


Figure 1: Mining blocks at Merelani; block C for large mining company, blocks B and D for small scale mining and blocks A and D_{Ext} are for large scale local companies (EA 2010).

RESULTS AND DISCUSSION

Radon gas concentrations in different campsites

The mean radon gas concentrations in different campsites were obtained together with the mean pressure, temperature and relative humidity. The radon gas concentrations varied from one campsite to another due to differences in ventilation conditions and elemental concentrations in the sediment at the particular depth. The mean radon gas concentrations ranged from 40.1 Bq/m^3 to 4.2 x10^3 Bq/m^3 with geometric mean of 118.4 Bq/m^3. The large scale mine C1 which is very well ventilated had low radon concentrations (84.8 Bq/m^3) compared to the small scale mines which were not well ventilated C2 (164 Bq/m^3), C3 (4.2 x 10^3 Bq/m^3), C4 (244.4 Bq/m^3), C10 (234.7 Bq/m^3) and C11 (119.4 Bq/m^3). However, some small scale mines were also well ventilated and their radon concentrations were below the overall geometric mean. The reason for elevated concentrations in C3 can be correlated to high concentrations of ^{238}U observed in most rocks found in the Merelani-Letatema zone (Malisa 2003). Except for C3, other campsites had radon concentrations below the ICRP workplace reference levels of 500-1500 Bq/m^3 as shown in Table 1.

Table 1: The overall mean radon gas concentrations in the Merelani underground tanzanite mines

Campsite	Average Radon Concentrations (Bq/m^3)	Presure (Mbar)	Temperature (C)	Relative Humidity (%)
C1	84.9	939.5	28.6	99
C2	164	912.8	27.3	64.8
C3	4171.6	911.5	25.7	94.5
C4	244.4	901.7	27.3	74.3
C5	56.8	905.4	23.5	66.2
C6	91.9	922.3	26.3	95
C7	45.3	899.8	21.7	68.2
C8	88.6	930.3	27.4	96.2
C9	63.8	906.5	26.5	95.2
C10	234.7	910	26.7	80.5
C11	119.4	913.7	24.3	91.6
C12	42.2	899.1	21.7	63.8
C13	40.12	800	26	66

Radon concentrations in all campsites together with the ICRP guidance reference level are shown in Figure 2.

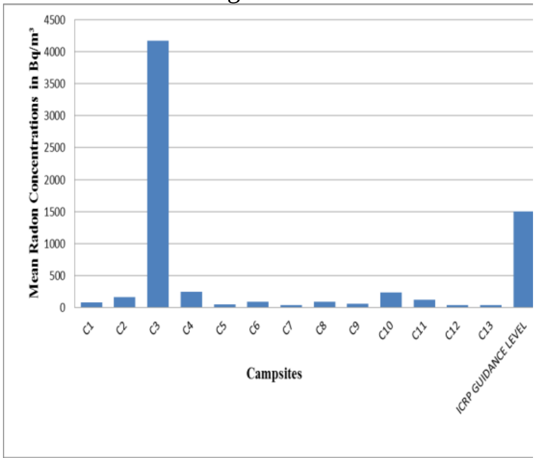


Figure 2: Radon gas concentrations in different underground Merelani mines.

The mean annual effective dose D (mSv) for each campsite was calculated as,

$$D(mSv) = C_{Rn}xF_ixPxR \qquad (1)$$

Where; C_{Rn} is the equilibrium radon concentration in $\frac{Bq}{m^3}$;

F_i is equilibrium factor equal to 0.4 for typical mining ventilation or equal to 1 for secular equilibrium;

P is occupancy factor in hours equal to 2000 h;

R is breathing rate, for normal person is about $1.2\,\frac{m^3}{h}$.

The annual effective doses for each mine are presented in Figure 3.

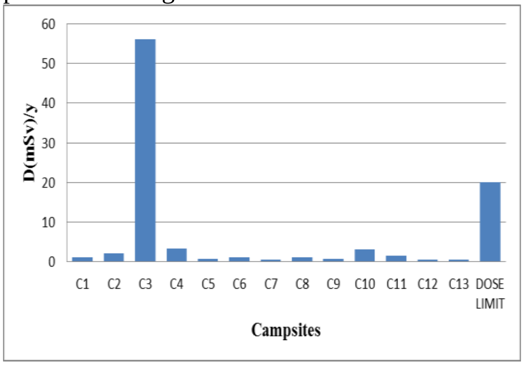


Figure 3: The mean annual effective doses in different campsites together with the annual dose limit.

The mean annual effective doses were normalized to the whole body annual dose limit (20 mSv) and to the organ dose limit (2.4 mSv) and the percentages obtained are shown in Table 2 as D/20(%) and D/2.4(%) respectively. The mean annual doses normalized to the whole body annual effective doses showed that C3 campsite was operating within unsafe conditions which need interventions, while the rest of the campsites were within the safe limits. Meanwhile, the mean annual doses normalized to the organ dose limit showed that C3, C4 and C10 were operating within unsafe conditions which need interventions, though the concentrations of radon gas at C4 and C10 were below the ICRP workplace dose limit. Figures 4 and 5 show the mean annual effective doses normalized to the whole body annual dose limit and organ dose limit, respectively.

Table 2: Calculated mean doses D(mSv) normalized to whole body doses D/20(%) and to organ dose limit D/2.4(%)

CAMPSITE	C_{Rn} (Bq/M^3)	I(Bq)	D(mSv)	D/20(%)	D/2.4(%)
C1	84.9	81493.3	1.1	5.7	47.5
C2	164	157440	2.2	11.0	91.8
C3	4171.6	4004773	56.1	280.3	2336.1
C4	244.4	234613	3.3	16.4	136.9
C5	56.8	54480	0.8	3.8	31.8
C6	91.9	88266.7	1.2	6.2	51.5
C7	45.3	43493.3	0.6	3	25.4
C8	88.6	85013.3	1.2	6	49.6
C9	63.8	61226.7	0.9	4.3	35.7
C10	2347	225307	3.1	15.8	131.4
C11	119.4	114667	1.6	8	66. 9
C12	42.2	40533.3	0.6	2.8	23.6
C13	40.1	38515.2	0.5	2.7	22.5

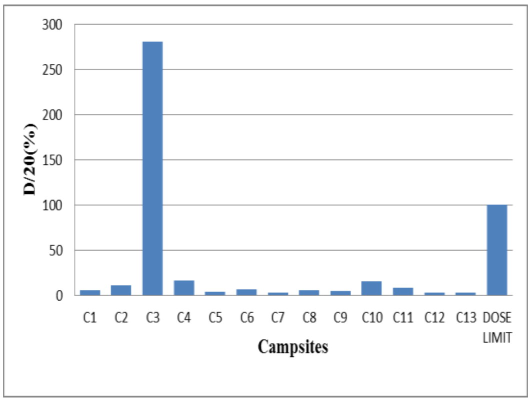


Figure 4: Mean annual effective doses normalized to the whole body annual dose limit in each campsite.

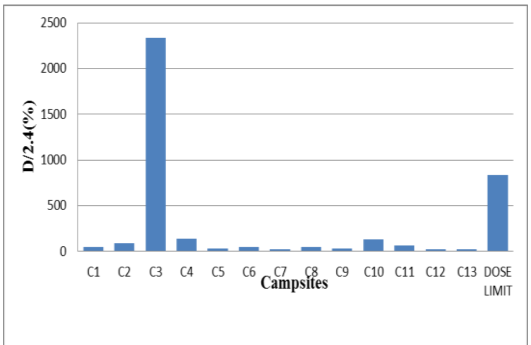


Figure 5: Mean annual effective doses normalized to the organ dose limit in each campsite.

The respirable dust concentrations in different campsites

The respirable dust concentrations in the Merelani underground mines varied from one campsite to another due to the nature of activities, i.e., normal operations, drilling and three hours after blasting. During the normal operations, the respirable gas concentrations ranged from 0.1 g/m^3 to 6.2 g/m^3 with the geometric mean of 0.8 g/m^3 which is below the safe limit of 2 g/m^3. During drilling activities the geometric mean of respirable dust concentrations was 123.5 g/m^3 and three hours after blasting of rocks, the respirable dust concentration was 47.6 g/m^3. The overall arithmetic mean and the geometric mean were 18.2 g/m^3 and 2.1 g/m^3, respectively. The respirable dust concentrations during drilling and blasting were very high and need immediate interventions (Figure 5). The variations of dust PM2.4 and PM4 are presented in Table 3. The values in C9, C10 and C11 were taken during drilling and three hours after blasting activities.

Table 3: The overall mean respirable dust concentrations in the Merelani underground Tanzanite mines

CAMPSITE	MASS CONCENTRATIONS(g/m^3)	
	Diameter 2.5μm	Diameter 4μm
C1	1.4	1
C2	3.4	4.5
C3	6.2	6.4
C4	0.1	0.3
C5	1.3	0.9
C6	0.3	0.6
C7	0.1	0.1
C8	1.3	1
C9	129.2	128.7
C10	36.5	46.8
C11	50.4	52.1
C12	0.3	0.2
C13	1.1	1.2

CONCLUSIONS

This study estimated the mean radon gas concentrations in Merelani underground tanzanite mines together with the mean pressure, temperature and relative humidity. The mean radon gas concentration varies from 40.1 Bq/m^3 to 4.2 x 10^3 Bq/m^3 with geometric mean of 118.4 Bq/m^3. The geometric mean of radon gas concentration is below the ICRP workplace reference level of about 500 – 1500 Bq/m^3. The estimated mean annual effective dose (D) was 1.6 mSv, which is significantly lower than the external exposure annual effective dose of 20 mSv and the organ dose limit of 2.4 mSv. This means that it is radiological safe to work in Merelani underground tanzanite mines. The radon gas concentration trends were observed to vary from one campsite to another due to mines ventilation conditions and sediment elemental concentrations, the mines which were well ventilated had low radon concentrations compared to those which were not well ventilated. Due to the watery conditions in the Merelani underground mines and a high relative humidity (84.1%); the adhesion between particles and water vapour is strong and reduce their concentrations in air. The respirable dust was much produced during drilling and blasting of rocks. Under normal conditions, the respirable gas concentrations had the geometric mean of 0.8 g/m^3 which is below the safe limit of 2 g/m^3. The overall arithmetic mean was 18.2 g/m^3 and the geometric mean of 2.1 g/m^3 which is close to the results presented by Malisa and Kinabo (2005). During normal activities in the underground mining, the conditions are not health hazardous, but when drilling and blasting activities take place, the respirable dust is produced in very high concentrations which need interventions. Workers working during drilling and three hours after blasting stand a great chance of developing health effects. To overcome the situation, increasing ventilation rates, respiratory mask wearing and job rotation techniques can be used during these activities.

ACKNOWLEDGEMENTS

Tanzania Atomic Energy Commission is acknowledged for financial support and the Physics Department, University of Dar es Salaam is thanked for material and technical support.

REFERENCES

Ateş İ 2011 Review: Occupational mineral dust induced toxicity and cytokines. *Turk J. Pharm. Sci.* **8** (1): 81-90.

Bråtveit M, Moen BE, Mashalla YJS and Maalim H 2003 Dust exposure during small-scale mining in Tanzania: A pilot study. *Ann. Occup. Hyg*. **47**(3): 235–240.

Derbyshire E 2007 Natural minerogenic dust and human health. *Ambio* **36:** 73-77.

EA (The Environmental Audit report) 2010 for the Tanzanite-one mining operations (Simanjiro District – Manyara) Submitted to the National Environmental Management Council.

Fubini B and Fenoglio I 2007 Toxic potential of mineral dusts. *Elements* **3:** 407-414.

Genitron Instruments GmbH 1998 *AlphaGUARD user manual. Frankfurt, German.*

ICRP 1993 *Protection against radon-222 at home and at work.* ICRP Publication 65, *Ann.* ICRP 23.

Little JB 1997 What are the risks of low-level exposure to a radiation from radon? *Proc. Natl. Acad. Sci. USA,* **94:** 5996-5997.

Lugoe F 2011 The land factor in mining gold reserves in Tanzania. Economic and social research foundation (ESRF) policy brief NO. 1/2011.

Malisa EP 2003 Trace Elements Characterization of the Hydrothermally Deposited Tanzanite and Green Grossular in the Merelani-LelatemaShear Zone, Northern Tanzania. *Tanz. J. Sci*. **29**(1): 45-60.

Malisa EP and Kinabo CP 2005 Environmental risks for gemstone miners with reference to Merelani tanzanite mining area, northeastern Tanzania. *Tanz. J. Sci.* **31**(1): 1-12.

Mamuya SHD, Bråtveit MB, Mwaiselage J, Yohana JS, Mashalla YJS and Moen BE 2006 High exposure to respirable dust and quartz in a labour-intensive coal mine in Tanzania. *Ann. Occup. Hyg*. **50**(2): 197–204.

Mayer CA and Lockey JE 2012 Occupational lung diseases. *Respiratory Medicine*. 209–227, DOI: 10.1007/978-61779-542-8_13.

Mikołajczyk U, Bujak-Pietrek S, Szadkowska-Stańczyk I 2010 Exposure to silica dust in coal-mining. Analysis based on measurements made by industrial hygiene laboratories in Poland, 2001-2005. *Med. Pr*. **61**(3): 287-297.

Mudd GM 2008 Radon sources and impacts: a review of mining and non-mining issues. *Rev Environ Sci. Biotechnol* **7**:325–353.

Mukherjee AK, Bhattacharya SK and Saiyed HN 2005 Assessment of respirable dust and its free silica contents in different Indian coal mines. *Ind. Health*. **43**(2): 277-284.

Nilsson J and Randhem J 2008 Environmental impacts and health aspects in the mining industry. A comparative study of the mining and extraction of uranium, copper and gold. Chalmers University of Technology, Sweden. *Technical report no. 2008:20*. ISSN: 1404-8167

Önder M and Önder S 2009 Evaluation of occupational exposures to respirable dust in underground coal mines. *Ind. Health* **47**: 43-49.

Önder M, Önder S, Akdag T and Ozgun F 2009 Investigation of dust levels in different areas of underground coal mines. *Int. J. Occup Saf. Ergon*. **15**(1): 125-130.

Phillips LC, Semboja H, Shukla GP, Swinga R, Mutagwaba W, Mchwampaka B, Wanga G, Kahyamra G and Keller PC 2001 Tanzania's precious minerals boom: Issues in mining and marketing. *Research paper. USAID*. Bureau for Africa, office of sustainable development, Washington.

Sawe SF 2010 *Determination of radon gas and respirable coal dust concentrations in the working environment of Kiwira coal mine*. MSc dissertation, University of Dar es Salaam.

Synnott H and Fenton D 2005 An evaluation of radon reference levels and radon measurement techniques and protocols in European countries. European radon research and industry collaboration concerted. Action European Commission contract No.FIRI-CT-2001-2014 2.

Tracy BL, Krewski D, Chen J, Zielinski JM, Brand KP and Meyerhof D 2006 Assessment and management of residential radon health risks: *J. Toxicol. Environ. Health, Part A* **69**: 735-758.

TSI 2012 Model 8530/8531/8532 DUSTTRAK™ II Aerosol monitor operation and service Manual P/N 6001893, Revision G.

Twerefou DK 2009 Mineral exploitation, environmental sustainability and sustainable development in EAC, SADC and ECOWAS Regions. *ATPC Work in Progress* **79:** 11 -15.

UNSCEAR 2008 Sources and effects of ionizing radiation. A report to the General Assembly with scientific annexes, Vol I.