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

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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 concentration (disintegrations per second per cubic meter) ranges from 40.1 Bq/m$^3$ to 4.2x10$^3$ 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 concentrations of respirable ore dust arithmetic mean was 18.2 g/m$^3$ and the geometric mean of 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 concentrations 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:

INTRODUCTION

The mining industry in Tanzania has developed dramatically during the last three decades (Phillips et al. 2001 and 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 gem 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 condition is associated with health risks such as radiation 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 has 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 environment, (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 shows that miners exposed to high levels of radon have high risk of lung cancer (Tracy et al. 2006). The more dangerous is the radon progeny 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 was 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 comparing 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 aims 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 block B and D are owned by small-scale miners and block A and C to large mining companies (Malisa and Kinabo 2005). Map 1 shows the location of Merelani tanzanite mines and Figure 1 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 area. 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 ≤ 4 µm and d ≤ 10 µm (PM$_{2.5}$, PM$_{4}$ and PM$_{10}$) (TSI 2012). Measurement of dust concentrations was 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.

**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 vary 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 concentration ranges from 40.1 Bq/m$^3$ to $4.2 \times 10^3$ 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$^3$) comparing to the small scale mines which were not well ventilated C2 (164 Bq/m$^3$), C3 (4.2 $\times 10^3$ 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 concentration in C3 can be correlated to high concentration of $^{238}\text{U}$ observed in most rocks found the Merelani-Letatema zone (Malisa 2003). Except for C3 other Campsites had radon concentrations below the ICRP workplace reference level of 500-1500 Bq/m$^3$ as shown in Table 1.

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

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

$$D (\text{mSv}) = C_{Rn} \times F_1 \times P x R$$

(1)
where $C_{Rn}$ is the equilibrium radon concentration in $\text{Bq} / \text{m}^3$; $F_i$ is equilibrium factor equal to 0.4 for a 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 $1.2 \text{m}^3 / \text{h}$.

The annual effective doses for each mine are presented on figure 3.

The mean annual effective dose 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 dose normalized to the whole body annual effective dose shows that C3 campsite is operating within unsafe conditions which need interventions while the rest of campsites are within the safe limit. Meanwhile the mean annual dose normalized to the organ dose limit shows that C3, C4 and C10 are operating within unsafe conditions which need interventions, though the concentrations of radon gas at C4 and C10 are below the ICRP workplace dose limit. Figures 4 and 5 show the mean annual effective dose normalized to the whole body annual dose limit and organ dose limit respectively.

The respirable dust concentrations in different campsites

The respirable dust concentrations in the Merelani underground mines vary from one campsite to another due to the nature of

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

**Table 2:** Calculated mean dose $D(\text{mSv})$ normalized to whole body dose $D/20(\%)$ and to organ dose limit $D/2.4(\%)$

<table>
<thead>
<tr>
<th>CAMPSITE</th>
<th>$C_{Rn}$ (Bq/M³)</th>
<th>$I$ (Bq)</th>
<th>$D(\text{mSv})$</th>
<th>$D/20(%)$</th>
<th>$D/2.4(%)$</th>
</tr>
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<tr>
<td>C1</td>
<td>84.9</td>
<td>81493.3</td>
<td>1.1</td>
<td>5.7</td>
<td>47.5</td>
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<tr>
<td>C2</td>
<td>164</td>
<td>157440</td>
<td>2.2</td>
<td>11.0</td>
<td>91.8</td>
</tr>
<tr>
<td>C3</td>
<td>4171.6</td>
<td>4004773</td>
<td>56.1</td>
<td>280.3</td>
<td>2336.1</td>
</tr>
<tr>
<td>C4</td>
<td>2444</td>
<td>234613</td>
<td>3.3</td>
<td>16.4</td>
<td>136.9</td>
</tr>
<tr>
<td>C5</td>
<td>56.8</td>
<td>54480</td>
<td>0.8</td>
<td>3.8</td>
<td>31.8</td>
</tr>
<tr>
<td>C6</td>
<td>91.9</td>
<td>88266.7</td>
<td>1.2</td>
<td>6.2</td>
<td>51.5</td>
</tr>
<tr>
<td>C7</td>
<td>45.3</td>
<td>43493.3</td>
<td>0.6</td>
<td>3</td>
<td>25.4</td>
</tr>
<tr>
<td>C8</td>
<td>88.6</td>
<td>85013.7</td>
<td>1.2</td>
<td>6</td>
<td>49.6</td>
</tr>
<tr>
<td>C9</td>
<td>63.8</td>
<td>61226.7</td>
<td>0.9</td>
<td>4.3</td>
<td>35.7</td>
</tr>
<tr>
<td>C10</td>
<td>2347</td>
<td>225307</td>
<td>3.1</td>
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<tr>
<td>C11</td>
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<td>1.6</td>
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<tr>
<td>C12</td>
<td>42.2</td>
<td>40533.3</td>
<td>0.6</td>
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<tr>
<td>C13</td>
<td>40.1</td>
<td>38515.2</td>
<td>0.5</td>
<td>2.7</td>
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Kahuluda & Makundi: Determination of radon gas ...

During the normal operation, the respirable gas concentrations range 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 concentrations 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 5. The values in C9, C10 and C11 were taken during drilling and three hours after blasting activities.

**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 4.2x10$^3$ 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 trend was observed to vary from one campsite to another due to mines ventilation conditions and sediment elemental concentration, the mines which were well ventilated had low radon concentrations comparing 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 vapor 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 dust concentrations were high and need immediate interventions.
The overall arithmetic mean was 18.2 g/m³ and the geometric mean of 2.1 g/m³ which is close to the results presented by Malisa and Kinabo (2005). During normal activities in the underground mining, the condition are not health hazardous but when drilling and blasting activities takes place, the respirable dust is produced in a very high concentrations which need intervention. Workers working during drilling and three hours after blasting stand a great chance of developing health effects. To overcome the situation, increasing ventilation rate, respiratory mask wearing and job rotation techniques can be used during these activities.

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