doi.org/10.15392/2319-0612.2025.2829
2025, 13(3) | 01-14 | e2829
Submitted: 2025-01-04
Accepted: 2025-03-06

Solid State Nuclear Track Detectors Applied to Assess Workers Exposure to Radon in Small Scale Tanzanite Mines in Tanzania

Sawe, S. F.

Tanzania Atomic Energy Commission, P O Box 743, Arusha, United Republic of Tanzania

*Correspondence: shomvi.sawe@taec.go.tz

Abstract: The Solid State Nuclear Track Detectors (SSNTD) type CR-39 were used to measure levels of radon gas in the Small Scale Tanzanite Mining blocks B, C and D at Mirerani area, Northern Tanzania. Workers Exposure to Radon was assessed using the concepts of Working Level, Working Level Month and dose conversion factors recommended by the International Commission on Radiological Protection (ICRP). Results revealed that radon levels ranged from below action level of 300 Bqm^{-3} recommended by the ICRP to 5.3 times higher. The corresponding mean annual effective doses ranged from 0.8 to 11.8 $mSvy^{-1}$, 1.4 to 4.4 $mSvy^{-1}$ and 1.9 to 2.3 $mSvy^{-1}$ for block B, D and C, respectively. These results indicate that the estimated doses are below the regulatory limit of 20$mSvy^{-1}$. However, measures to keep the exposures as low as reasonably achievable are recommended as mining advance to deeper layers where the available means of ventilation may not be sufficient to lower radon levels.

Keywords: radon, underground mines, occupational exposure, SSNTD.

doi.org/10.15392/2319-0612.2025.2829
2025, 13(3) | 01-14 | e2829
Submitted: 2025-01-04
Accepted: 2025-03-06

Detetores de estado sólido para traços nucleares aplicados na avaliação da exposição ao radônio de trabalhadores de minas de tanzanita de pequena escala na Tanzânia

Resumo: Os detetores de estado sólido de traços nucleares (SSNTD) tipo CR-39 foram utilizados para medir os níveis de gás radônio nos blocos B, C e D de mineração de tanzanita em pequena escala na área de Mirerani, no norte da Tanzânia. A exposição dos trabalhadores ao radônio foi avaliada utilizando os conceitos de nível de trabalho, nível de trabalho mês e fatores de conversão de dose recomendados pela Comissão Internacional de Proteção Radiológica (ICRP). Os resultados revelaram que os níveis de radônio variaram entre abaixo do nível de ação de 300 Bqm^{-3} recomendado pelo ICRP até 5,3 vezes mais elevado. As doses médias anuais efetivas correspondentes variaram de 0,8 a 11,8 $mSvy^{-1}$, 1,4 a 4,4 mSvy-1 e 1,9 a 2,3 $mSvy^{-1}$ para os blocos B, D e C, respetivamente. Estes resultados indicam que as doses estimadas estão abaixo do limite regulamentar de 20 mSv y^{-1}. No entanto, recomendam-se medidas para manter as exposições tão baixas quanto razoavelmente possível à medida que a mineração avança para camadas mais profundas, onde os meios de ventilação disponíveis podem não ser suficientes para reduzir os níveis de exposição ao radônio.

Palavras-chave: radão, minas subterrâneas, exposição ocupacional, SSNTD.

1. INTRODUCTION

Mining is among the fastest growing sectors in Tanzania today and this trend is likely to continue in the distant future. The industry comprises of small and large scale mining of several minerals- gold, diamond, colored gemstones, phosphate, and coal among others [1 – 3]. Although the economic benefits derived from the mining industry are well known, it is important to recognize that these benefits often come at the expense of occupational health risks such as lung cancer and silicosis due to inhalation of radioactive gas radon-222 (^{222}Rn) and silica dust, respectively [4,5]. Therefore, concerns on the possible health risk of miners due to radon exposure have been raised and efforts to address these concerns have been made [6]. Radon-222 and its daughters are the major source of radiation exposure to the lungs. According to UNSCEAR [7], radiation dose received by the human population due to the inhalation of radon and thoron and their progenies contribute more than 50% of the total dose from natural sources. Radon-222 being an inert gas can readily diffuse into solid matters and enter the atmosphere where it decays forming short-lived daughters. The particulate daughter products of radon are charged and therefore tend to attach themselves to dust particles suspended in air. The health problems arise when these particles (attached fraction) are inhaled because when inhaled, they deposit in the tracheobronchial tree delivering radiation dose to the nearby cells leading to radiogenic lung cancer. Radon constitutes a significant hazard when concentrated in some enclosures such as underground mines, caves, houses, etc. [8 – 10]. Therefore, action levels for radon in workplaces have been recommended by various countries and organizations in recent decades (Table 1).

Table1. Recommended ^{222}Rn action levels for workplaces

COUNTRY/ORGANIZATION	NAME	ENTERED INTO FORCE	^{222}Rn ACTION LEVEL FOR WORKPLACES (Bqm^{-3})
ICRP	ICRP Publication 65 [11]	1994	500 – 1500
Hungary	Hungarian Regulation 10 16/2000, 2000 [12]	2003	1000
ICRP	ICRP Publication 103 [13]	2007	300
US-OSHA	The Confusing World of Radiation Dosimetry [14]	2009	333
IAEA	Safety Standards Series No. GSR Part 3 (Interim)- [15]	2011	1,000
United States Nuclear Regulatory Commission (US NRC)	NRC Regulations Title 10, Code of Federal Regulations; Part 20 [16]	2011	1,110
EU	European Basic Safety Standards (BSS) for protection against ionizing radiation [17]	2014	300
ICRP	ICRP Publication 126 [18]	2014	300

The concentration of each radon daughter ^{218}Po (alpha), ^{214}Pb (beta), ^{214}Bi (beta) and ^{214}Po (alpha) is important when determining the exposure to individuals. Therefore, the combined radioactivity of the short-lived daughters is 3.05min, 26.8min, 19.7min and 164 microseconds for ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po, respectively is defined in terms of Equilibrium Equivalent Concentration (EEC) which is the product of radon concentration and the equilibrium factor (F) [19]. It has been reported that radon daughters have a tendency of depositing on surfaces (plate out phenomenon) making it hard to attain secular equilibrium with parent radon. Therefore, the equilibrium factor is used to describe deviations from the secular equilibrium. According to the International Commission on Radiological Protection (ICRP) Publication 137, the recommended F-value for underground mines is 0.4 [20]. The exposure to radon daughters is expressed in the units of Working Level whereby one WL is the ratio of and EEC and 3,700Bqm^{-3} [21]. Working Level Month (WLM), which is an exposure rate of 1WL for a working month of 170hours is another unit for expressing the exposure to radon daughters (1WLM = 0.0035Jhm^{-3}). This implies that measured radon concentration can be used to estimate the concentration of radon daughters and vice versa enabling the estimation of exposure to individuals using dose coefficients recommended by the ICRP. The ICRP [20] has recommended a dose coefficient of 3 mSv per mJ h m^{-3} (approximately 10mSvy^{-1} per WLM).

The quantity to be measured (radon or radon-daughters' concentration) in the study area depends on the available measuring instrument that is WL meter or radon detector or the preference of the investigator. Both active and passive techniques are used in radon dosimetry. In the active method, air is pumped through a filter and then, the alpha activity of the radon decay products trapped in the filter is counted to obtain their concentrations instantly. In other instruments (e.g. AlphaGUARD) radon diffuses into the ionization chamber of the instrument via a large-surface glass fiber filter fitted on one side of the instrument. In this case, the alpha particles emitted by radon inside the chamber ionize the gas and the charges formed are processed by the inbuilt algorithm to obtain radon concentration instantly. These are short-term measurement methods because they do not take into account hourly or daily radon variations as evidenced in Porstendörfer et al. [22] and Di Carlo et al. [23]. On the other hand, solid state nuclear track detectors (SSNTD) utilizing polymer of allil diglycol carbonate (CR-39), cellulose nitrate (LR-115 type II and CN-85), etc. are directly exposed to airborne radionuclides in order to record alpha decays which occur in the air over a long period of time [24 – 26]. In practice, the CR-39 detectors are exposed to radon for up to twelve months period then processed in the laboratory. The exposed detectors are etched using the NaOH solution at 80^{o}C for 6 hours. The etchant preferentially attacks the detector surface on locations with alpha tracks from radon decay. Consequently, the etching process enlarges alpha tracks on the detector to the extent that they can be observed with a microscope and counted. Lastly, the alpha tracks observed on the detectors are related to the radon concentrations using the pre-established calibration factors (tracks cm^{-2} per kBqm^{-3}h) were cm^2 is the surface area of the exposed detector and "h" is the CR-39 exposure time (in hours) in the study location e.g. underground mine.

In this study, levels of radon in underground mines were measured using the solid-state nuclear track detectors (CR-39) for four months period in order to account for radon variations and to avoid the limitations of short-term measurements. The purpose of the study is to investigate radon levels and to establish the resulting occupational dose in the underground working environments of Mirerarni Small Scale Tanzanite mines in Northern Tanzania.

Tanzanite is a rare gemstone, more specifically a variety of the zoisite mineral that is only found from a single deposit site in northern Tanzania. It was discovered in the 1960s and has since become a popular gemstone used in high-value jewellery [27, 28]. Originally, the gemstone was collected on the surface but the continuous and vigorous Tanzanite mining quickly gave way to pits and now tunnels which are about 2.5 kilometers beneath the surface. During the mining process, the rocks are broken into medium or small chunks using explosives such as dynamite. Once the blasting process is done, fresh air is pumped into the mines allowing sorting the gemstone from the raw stones to commence [29]. During normal operations, shallow tunnels rely on natural ventilation whereby air pressure and temperature differences create airflow while long tunnels use large fans located at the surface to circulate air mechanically.

2. MATERIALS AND METHODS

2.1. Description of Mirerani Tanzanite mining area

Mirerani area is located in Simanjiro District of Manyara Region Northern Tanzania at 3°33'42"S and 36°58'44"E about 62 km, 49 km and 6 km from Moshi town, Arusha City and Kilimanjaro International Airport, respectively. Tanzanite is found in an area of roughly fourteen square kilometers (14 km^2) close to the Mirerani Hills and this is the only place on the earth where Tanzanite can be found. The Mirerani-Tanzanite mining area is divided into four blocks namely; A, B, C and D. During this study, mining activities were concentrated in blocks B and D with only one mine operating in Block C.

2.2. Radon measurements

The CR-39 radon detectors manufactured by Nitron Laboratory of Italy with the commercial name "FIDOtrack detectors" were used to estimate levels of radon in air in the underground mines. The detectors were unpacked from their shipping packages and mounted inside 20 underground mines at different locations. Three to six detectors were placed inside each mine depending on the size of the mine. All detectors were exposed to radon and its daughters for a period of four (4) months (November 2023 to February 2024) then removed, repacked in airtight polyethylene bags and sent to the Nitron laboratory in Italy for processing and determination of radon concentrations. Security of the detectors was the main challenge during this study due careless behavior demonstrated by the miners. All detectors placed in some mines were lost or stolen or misplaced by the miners and therefore remained unaccounted for during collection. These mines were subsequently excluded from the study therefore affecting the sample size.

Figure 1: FIDOtrack detector in its shipping package (left) and when removed from its shipping package (right)

2.3. Estimation of occupational dose

Occupational exposure was derived from the Working Level (WL) and Working Level Month (WLM) as shown in Equations 1 and 2 [20, 21, 23, 27]. Then, the annual effective dose was calculated using the dose conversion factor of 1WLM = 10 $mSvy^{-1}$ [20].

$$WL = \frac{C_{Rn} \times F}{3700} \qquad \text{Eq.1}$$

Where C_{Rn} is the measured radon concentration is Bqm^{-3} and F is the equilibrium factor between radon and its progenies equal to 0.4 for underground mines [20].

$$WLM = \frac{WL \times T}{170} \qquad \text{Eq.2}$$

Where; T is the workers exposure time per year assumed to be 2000 hours [7]. Note that 2000 hours were derived from 50 weeks per year, 5 days per week and 8 working hours per day.

3. RESULTS AND DISCUSSIONS

A total of 12 mines were surveyed using the CR-39 detectors and the measured radon concentrations are presented in Table 2. The maximum radon concentrations recorded in seven mines were above the action level of 300 Bqm^{-3} recommended by the ICRP [18]. Six mines with the highest levels are in block B and one in block D whereby five mines are in block B and one mine in Block D. Block C has one operating mine which is considered to be one of the largest and deepest mine utilizing modern facilities. Despite of its size, radon levels were far below the action level mainly because of good ventilation system. The mean annual effective doses derived from the measured radon concentrations ranged from 0.8 to 11.8 mSvy-1 and 1.4 to 4.4 $mSvy^{-1}$ for block B and D, respectively. The annual effective doses for Block C ranged from 1.9 to 2.3 $mSvy^{-1}$ with a mean value of 2 $mSvy^{-1}$. These results indicate that the estimated doses are far below the regulatory limit of 20mSvy^{-1} and therefore no immediate interventions are required. However, it is necessary to make a follow up of two mines (B-2 and B-4) in Block B where the highest radon values were respectively 3.4 and 5.3 times higher than the action level of 300 Bqm^{-3}. Also, improvement of ventilation system in the underground environments of all mines can further lower the radon to almost background levels. Likewise, use of dust masks will be useful in reducing the amount of inhaled dusts which may contain attached radon daughters and silica particles which collectively affect the lungs by inducing silicosis and lung cancer for silica and radon daughters, respectively.

The estimated doses were based on the assumption that workers will be exposed for the standard 8 working hours per day, 5 days per week and 50 weeks per year used in UNSCEAR [7]. Nevertheless, it was very difficult to establish the number of hours that a miner works in the underground environment for three main reasons according to the interviewed mine supervisors. The first reason is that the number of working hours increases significantly especially when there is a production of valuable gemstone, in this case Tanzanite rock in a particular mine. Secondly, miners tend to shift from one mine to another very frequently depending on where the production is taking place and therefore exposed to different levels of radon. Thirdly, there is a tendency of some mines stopping operations for undisclosed reasons though some interviewed individuals identified lack of capital as one of the reasons. Therefore, the estimated doses should be used with caution.

Table2. Radon concentrations and the estimated annual effective doses to underground workers with mean values in the brackets

S/N	CODE	RADON CONCENTRATION (Bqm^{-3})	AED* (mSvy^{-1})
1.	B-1	260–344 (308)	3.3– 4.4 (3.9)
2.	B-2	883–1005 (925)	11.2–12.8 (11.8)
3.	B-3	180–320 (260)	2.3–4.1 (3.3)
4.	B-4	121–1575 (690)	0.7–0.9 (0.8)
5.	B-5	52–668 (343)	1.1–1.4 (1.2)
6.	B-6	109–395 (259)	1.5–20.0 (8.8)

S/N	CODE	RADON CONCENTRATION (Bqm^{-3})	AED* ($mSvy^{-1}$)
7.	C	52–70 (65)	1.9–2.3 (2.0)
8.	D-1	86–114 (97)	0.6–2.4 (1.4)
9.	D-2	146–180 (161)	0.7–8.5 (4.4)
10.	D-3	51–190 (113)	1.4–5.0 (3.3)
11.	D-4	256–403(309)	3.3–5.1 (3.9)
12.	D-5	115–250 (129)	1.5–3.2 (1.6)

**AED = annual effective dose*

Previous studies on radon in Mirerani are scarce. For example; Kahuluda and Makundi [28] reported the mean radon-222 concentrations in the range of 40.1 to 4,200 Bqm^{-3} with geometric mean of 118.4 Bqm^{-3}. A study by Muya et al. [3] showed that nine (9) mines or pits which accounts for 40.9% of the surveyed mines had radon levels above the action level of 300 Bqm^{-3}. These findings suggest that radon levels may exceed action level by several orders of magnitude if certain conditions (e.g. poor ventilation, deep mines, etc.) are met calling for periodic checks and awareness rising among the mining communities. Comparison of radon levels with those obtained in other countries was not possible because tanzanite is mined only in this part of the planet Earth.

4. CONCLUSIONS

Small scale mining is a source of livelihood for millions of people globally. Despite of the social-economic benefit derived from mining, it is necessary to monitor levels of harmful substances such as radon and dust which are known to increase the chance s of developing lung diseases namely cancer and silicosis for radon and silica dust, respectively. Therefore, the need for assessing radon levels in Tanzanite mines using solid state nuclear track detectors type CR-39 emerged. The levels of radon in the assessed mines ranged from below the action level of 300Bqm^{-3} recommended by the ICRP to 5 times above. This calls for some intervention measures in order to reduce the likelihood of high exposure to underground workers. Awareness rising to mine supervisors and workers is of paramount importance. Awareness rising to mine owners is equally important because they are the ones who will allocate resources for safety improvement in their mines, although they are not routinely involved in mining operations.

ACKNOWLEDGMENT

The Tanzania Atomic Energy Commission is highly acknowledged for providing financial, technical and logistical support.

I thank Mr. Aloyce Kinemelo from the Tanzania Atomic Energy Commission, Mr. Vincent Mahuni from Mirerani Mining area and Mr. Amani Massawe from the Ministry of Minerals for their assistance during field work.

Prof Fernando Carvalho is exceptionally acknowledged for translating the abstract of this article from English to Portuguese.

FUNDING

This work was fully funded by the employer (i.e. Tanzania Atomic Energy Commission) through funding award number RP.085. All funding requirements have been observed by the authors.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest associated with this work.

REFERENCES

[1] MOHAMMED, N.K., MAZUNGA, M.S. Natural radioactivity in soil and water from likuyu village in the neighborhood of mkuju uranium deposit. International Journal of Anal Chem. 2013; 501856, 2013. Available: https://doi.org/10.1155/2013/501856.

[2] FOCUS, E., RWIZA, M.J., MOHAMMED, N.K., BANZI, F.P. The influence of gold mining on radioactivity of mining sites soil in Tanzania. International Journal of Environmental Quality;46: 46-59, 2021.

[3] MBUYA, A.W., MBUYA, I.B.,MBOYA, I.B., SEMVUA, H.H., MSUYA, S.E., HOWLETT, P.J., MAMUYA, S.H.. Concentrations of respirable crystalline silica and radon am ong tanzanite m ining com m unities in Mererani, Tanzania. Ann Work Expo Health . 8;68(1):48-57, 2024. doi: 10.1093/annweh/wxad062.

[4] DONOGHUE, A. Occupational Health Hazards in mining-An overview. Journal of Occupational Medicine, Volume 54, No. 7, 2004.

[5] HOY, R.F., CHAMBERS, D.C. Silica-related diseases in the modern world. Allergy Eur. J Allergy Clin Immunol.75:2805 – 2817, 2020. https://doi.org/10.1111/all.14202.

[6] ZEEB, H. and SHANNOUN, F., Eds. WHO Handbook on In-Door Radon: A Public Health Perspective. World Health Organization, Geneva. 2009.

[7] UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). Sources and effects of ionizing radiation; report to the General Assembly, with scientific annexes, United Nations, New York, 2000.

[8] CIGNA, A.A. Radon in Caves. International Journal of Speleology. 34 (1-2), 1 – 18, 2005.

[9] MARGINEANU, R.M.(2019). Radon measurements in underground mines and caves from several European countries. AIP Conference Proceedings 2076, 050004 (2019); https://doi.org/10.1063/1.5091643.

[10] TEIRI, H., NAZMARA, S., ABDOLAHNEJAD, A., HAJIZADEH, Y., AMIN , M.M. Indoor radon measurement in buildings of a university campus in central Iran and estimation of its effective dose and health risk assessment. J Environ Health Sci Engineer 19, 1643–1652, 2021. https://doi.org/10.1007/s40201-021-00720-y.

[11] ICRP (INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION). Protection Against Radon-222 at Home and at Work. ICRP Publication 65. Ann. ICRP 23 (2), 1994.

[12] HUNGARIAN REGULATION 10 16/2000, 2000. Ministry of Health implementing the provisions of the law No. CXVI. of the year 1996.

[13] ICRP (INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION). The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP. 37 (2-4), 2007.

[14] BOYD, M.A. The Confusing World of Radiation Dosimetry – 9444, WM2009 Conference, March 1–5, 2009, Phoenix.

[15] IAEA (INTERNATIONAL ATOMIC ENERGY AGENCY). Safety Standards Series No. GSR Part 3 (Interim)-Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA, Vienna, (2011).

[16] NRC (US NUCLEAR REGULATORY COMMISSION). NRC Regulations Title 10, Code of Federal Regulations; Part 20 - Standards for Protection Against Radiation. The U.S. Nuclear Regulatory Commission, Washington, DC, (2011).

[17] COUNCIL OF THE EUROPEAN UNION (2014). Council directive 2013/59/EURATOM, European Basic Safety Standards (BSS) for protection against ionising radiation Official Journal of the European Union, L 13/1. http://eur-lex.europa.eu/legal content/EN/TXT/?uri=CELEX:32013L0059.

[18] ICRP (INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION). 126 Radiological Protection against Radon Exposure. ICRP Publication 126. Ann. ICRP 43(3), 2014.

[19] La VERDE, G., ROCA, V., SABBARESE,C., AMBROSINO, F., PUGLIESE, M. (2018). The equilibrium factor in the radon dose calculation in the archaeological site of Acquedotto Augusteo del Serino in Naples. IL NUOVO CIMENTO **41 C,** 2018. DOI10.1393/ncc/i2018-18218-1.

[20] ICRP (INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION). Occupational Intakes of Radionuclides: Part 3. ICRP Publication 137. Ann. ICRP 46(3/4), 2017.

[21] NCRPM (NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS). Measurement of Radon and Radon Daughters in Air. NCRP Report No.97, 1988.

[22] PORSTENDÖRFER, J., BUTTERWECK, G., REINEKING, A. Daily variation of the radon concentration indoors and outdoors and the influence of meteorological parameters. Health Phys. 67(3):283-7, (1994). doi: 10.1097/00004032-199409000-00011.

[23] Di CARLO,C., AMPOLLINI,M., ANTIGNANI,S., CAPRIO,M., CARPENTIERI,C., CACCIA,B., BOCHICCHIO, F. Extreme reverse seasonal variations of indoor radon concentration and possible implications on some measurement protocols and remedial strategies. Environmental Pollution, Volume 327,15, 2023. https://doi.org/10.1016/j.envpol.2023.121480.

[24] RAMOLA, R.C., RAWAT, R.B.S., KANDARI, M.S., RAMACHANDRAN,T.V., EAPPEN, K.P., SUBBA RAMU M.C. Calibration of LR-115 Plastic Track Detectors for Environmental Radon Measurements. *Indoor and Built Environment.* 1996; 5(6):364-366, 1996. doi:10.1177/1420326X9600500610.

[25] BAKACAK, P.K., EKINCI, N., KAVAZ, E. Determination of Radon Concentration by Using CR-39 Plastic Track Detectors in Dwellings of Bingöl and Mus Provinces of Turkey. Asian Journal of Chemistry 30(1):226-230, 2018. DOI:10.14233/ajchem.2018.21094.

[26] HASHIM, A.K., A.K., HATIF, A.R., AHMED, N.M., WADI, I.A., AL QAAOD,A.A. Comparison study of CR-39 and CN-85 detectors to evaluate the alpha radioactivity of some samples of drinks in Iraq. Applied Radiation and Isotopes. 167. 109410, 2021

[27] CHACHAGE, C.S.L. "The Meek Shall Inherit the Earth but not the Mining Rights: The Mining Industry and Accumulation in Tanzania." In Liberalised Development in Tanzania, edited by P, Gibbon, 37-109, 1995. Uppsala: Nordiska Afrikainstitutet.

[28] HELLIESEN, M.S. Tangled up in Blue: Tanzanite Mining and Conflict in Mererani, Tanzania, Critical African Studies, 4:7, 58-93, 2012. DOI: 10.1080/21681392.2012.10597799

[29] THE TANZANITE EXPERIENCE, available online at: https://www.tanzaniteexperience.com/tanzanite-mining-all-you-need-to-know/#toc-280191-1; accessed on 4th March 2025.

[30] SHAHROKHI, A., KOVÁCS, T. Characterization of environmental radiological parameters on dose coefficient - Realistic dosimetry compared with epidemiological dosimetry models. Heliyon, 2023 ; https://doi.org/10.1016/j.heliyon.2023.e19813.

[31] KAHULUDA, E.M., ISMAEL, N. MAKUNDI.. Determination of Radon Gas and Respirable ore dust concentrations in the underground Merelani Tanzanite Mines. Tanzania Journal of Science .(40): 13 – 19, 2014.

LICENSE