# Investigating the Radiological Safety of Uranium Ore Deposits from a Uranium Mine in Namibia

Vaino Indongo[1,2], Vera Uushona[1,3], Manny Mathuthu[1], Zivayi Chiguvare[2]

[1]*Center for Applied Radiation Science and Technology (CARST), North-West University (Mafikeng), Cnr Albert Luthuli Road and University Drive, 2735, Mmabatho, South Africa, vainoindongo@gmail.com, nvuushona@yahoo.com, Manny.Mathuthu@nwu.ac.za*

[2]*Namibia University of Science and Technology (NUST), 13 Jackson Kaujeua Street, P/Bag 13388, Windhoek, Namibia, zchiguvare@unam.na*

[3]*National Radiation Protection Authority of Namibia, Ministry of Health and Social Services, Harvey Street, Namibia*

*nvuushona@yahoo.com; *vainoindongo@gmail.com; Manny.Mathuthu@nwu.ac.za; zchiguvare@unam.na*

## Abstract

Namibia is one of the four leading countries in Uranium mining which results in huge tailing deposits. The main aim of this study was to assess radiological hazards posed to employees by uranium ores deposits from a uranium mine in the Erongo Region. Gamma spectrometry was used to determine the radiological health indices of primordial radionuclides of $^{238}$U, $^{232}$Th and $^{40}$K in samples. The weighted mean of activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K and their Indices were all above the WHO stipulated limits. The findings of this research indicate that uranium mining activities pose a high risk of radiation hazards to employees.

**Keywords:** NORM, Radiological Health Indices, Gamma Spectrometry

## Introduction

The increasing rate of electricity demand has resulted on more uranium mining and milling activities in the world. In Namibia, uranium was first discovered in Rossing Mountains, Namib Desert of Erongo Region. The region has a deposit containing high grade of uranium in a type of granite called alaskites. Uranium ore deposits occur in sedimentary basins deposited on top of very old basement metamorphic rocks, either from the basin (sedimentary) or basement (metamorphic) rocks.

Mining activities have also began to contribute to human exposures to radiations, which have now became an increasingly concern in the world. Background radiation is increasing continuously due to mining and milling activities in the environment. Natural occurring radioactive materials (NORM) contribute to the increase in background and protection measures need to be put in place for health and safety. Nowadays radiation protection has become one major and crucial role for the betterment of human health. Exposures to radiations on living organisms, including humans, from natural radioactivity at different levels depends on natural radioactive elements present in each area (Alzubaidi *et al*., 2016). Erongo Region is one diminutive area, in comparison to the whole world, which requires scientific approach to determine radiation exposure levels to humans, in order to scientifically report to the Policy makers on radiation level if it is in agreement with international basic safety standards (WHO, 1994). The main aim of this study was to assess radiological hazards posed to employees by uranium ores deposits from a uranium mine in the Erongo Region.

## Methods

### *Sampling technique*

Random sampling technique was employed to select the sampling sites around and within the mines. The GPS values and name of the mine under study will not be published

in this work because of the confidentiality agreements signed with the mines.

*Collection and preparation of samples*

The uranium ore deposits have been collected from randomly selected points around a mine crusher in Erongo Region. The samples were transported to the Analytical; laboratory, at the Centre of Applied Radiation, Science and Technology (CARST), North-West University (NWU), South Africa. During preparation, the samples were dried for 30 days, crushed for homogeneity (ISO18589–2, 2007). All samples were packed and sealed in Vaseline geometry (VasGeo) plastic containers. The mass for each sample was measured for use during computing to determine radioactivity concentration analyses. Each sample was sealed in a container for more than 23 days to allow radon and its progeny to reach secular equilibrium (ISO18589–3, 2007). Also, standard samples were used for calibrations of energy and efficiency of the gamma detector before counting of samples.

## Results and Discussion

*Analysis*

The gamma spectrometry techniques, which allow identification and quantification of radionuclides, was utilized to determine the gamma-emitting radionuclides present in the samples based on energies and the peak areas of the full-energy peaks of the gamma lines (ISO18589–3, 2007). The analyses where performed in the Centre for Applied Radiation Science and Technology (CARST), NWU, Mafikeng campus. A High-Purity Germanium (HPGe) detector manufactured by Canberra Industries (Meriden, CT, USA) with detector model GCW2021 and relative efficiency of ≥ 20% and a resolution of ≤ 2.100 keV for 1332 keV gamma ray emission of $^{60}$Co, was used for contng the activity of each sample. The sample data was acquired using Genie 2000 vs 3.3 Gamma Acquisition software. Counting for each sample took 12 hours (43200 s). The gamma energy 1460.63 keV was utilized to determine activity concentration for $^{40}$K (Ademola *et al*., 2014). Both $^{238}$U and $^{232}$Th are alpha emitters, hence their activities were measured based on the daughter products, which are gamma emitters. Therefore, the activity concentrations of the $^{238}$U and $^{232}$Th radionuclides were determined using the energy of their daughter products that occurred during their decay series (Durusoy and Yildirim, 2017). After radioactive secular equilibrium between $^{226}$Ra, $^{222}$Rn, $^{214}$Pb and $^{214}$Bi has been established, the short-lived decay radionuclides $^{226}$Ra, $^{214}$Pb and $^{214}$Bi of $^{222}$Rn were measured (ISO18589–3, 2007). Therefore, energy lines (285.22 keV and 351.93 keV) for $^{214}$Pb and (609.31 keV, 1120.29 keV and 1764.49 keV) $^{214}$Bi was used to determine the activity concentration for $^{226}$Ra, a daughterof $^{238}$U, as shown in Table 1. It is also assumed that $^{232}$Th and its decay radionuclides $^{228}$Ac and $^{212}$Pb are in radioactive equilibrium (ISO18589–3, 2007). Hence, energy lines (238.63keV) for $^{212}$Pb, and (338.32 keV, 911.20 keV) for $^{228}$Ac were utilized for determining activity concentration of $^{232}$Th, shown in Table 1–2.

The Genie 2000 Gamma Analysis Software was then used to determine the specific activities (bq/kg) of the radionuclides (Chhangte *et al*., 2018). It calculates using the above equation.

The activity concentrations obtained at the respective energies of their radionuclides under considerations were tabulated as indicated in Tables 1–3. All activity concentrations for daughter nuclides of $^{226}$Ra were detected. Some activity concentrations for daughter nuclides for $^{232}$Th were not detected, therefore indicated as ND – non-detectable in Table 2.

Activity concentrations for $^{226}$Ra, $^{232}$Th and $^{40}$K calculated in the ore deposits range as 2808.00 ± 27.33 Bq.kg$^{-1}$ to 7289.00 ± 56.90 Bq.kg$^{-1}$, 129.80 ± 12.62 Bq.kg$^{-1}$ to 306.90 ± 13.93 Bq.kg$^{-1}$ and 561.90 ± 8.49 Bq.kg$^{-1}$ to 984.10 ± 23.62 Bq.kg$^{-1}$, respectively. The maximum activity concentration determined here is 7289.00 ± 56.90 Bq.kg$^{-1}$ for $^{226}$Ra and minimum is 129.80 ± 12.62 Bq.kg$^{-1}$ for $^{232}$Th. Tables 1 shows the results obtained.

The weighted mean of activity concentrations (with their uncertainties) of $^{226}$Ra, $^{232}$Th and $^{40}$K calculated using equation (1) are in the range of 2855.84 ± 11.02 Bq.kg$^{-1}$ to 6700.44 ± 24.02 Bq.kg$^{-1}$, 136.62 ± 3.23 Bq.kg$^{-1}$ to 258.72 ± 3.19 Bq.kg$^{-1}$ and 261.90 ± 8.49 Bq.kg$^{-1}$ to 984.10 ± 23.62 Bq.kg$^{-1}$,

*Table 1 The summarized activity concentrations (weighted means) for $^{226}Ra$, $^{232}Th$ and $^{40}K$.*

| Sample no | Weighted means of Activity concentrations [Bq.kg$^{-1}$] | | |
|---|---|---|---|
| | $^{226}$Ra | $^{232}$Th | $^{40}$K |
| ORE1 | 5593.88 ± 20.48 | 255.85 ± 3.83 | 889.30 ± 20.65 |
| ORE2 | 6004.68 ± 22.20 | 232.20 ± 2.05 | 858.60 ± 24.69 |
| ORE3 | 3682.19 ± 13.89 | 192.89 ± 3.30 | 881.30 ± 24.81 |
| ORE4 | 2855.84 ± 11.02 | 136.62 ± 3.23 | 845.60 ± 23.50 |
| ORE5 | 4281.26 ± 15.68 | 189.09 ± 1.69 | 874.60 ± 24.47 |
| ORE6 | 3648.43 ± 13.89 | 146.35 ± 3.74 | 561.90 ± 8.49 |
| ORE7 | 6508.41 ± 23.87 | 258.72 ± 3.19 | 984.10 ± 23.62 |
| ORE8 | 6700.44 ± 24.02 | 248.35 ± 10.44 | 897.30 ± 35.40 |

respectively. These results shows that the weighted mean of $^{226}$Ra is high and $^{232}$Th is low in activity concentrations of the uranium ore deposits. The worldwide values of 35, 30 and 400 Bq.kg$^{-1}$ (UNSCEAR, 2000) were significantly lower than the average activity concentration values for $^{238}$U, $^{232}$Th and $^{40}$K, respectively, in this study.

## *Dose Rate*

### Absorbed dose

The absorbed dose rate in air is based on the activity concentration of natural radionuclides in uranium ore samples. Dose conversion factors for radionuclides present in samples are used to assess the dose rate. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) defined these conversion factors, and the gamma absorbed dose rates were calculated using the following Equation (2) (UNSCEAR, 2000):

$$D(\frac{nGy}{h}) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (2)$$

Where $A_U$, $A_{Th}$ and $A_K$ are activity concentrations for $^{238}$U, $^{232}$Th and $^{40}$K, respectively. It is also crucial to know that the activity concentration for $^{238}$U is approximated by that of $^{226}$Ra daughters because of radioactive equilibrium that has been set.

### Annual Effective Dose Rate (AEDR)

It is also best to estimate the annual effective dose rate absorbed by humans as a result of natural radionuclides present in the uranium ore samples. UNSCEAR (2000) has stipulated dose conversion coefficient that convert the absorbed dose rate in air to the effective dose of 0.7 Sv Gy$^{-1}$ and the outdoor occupancy of 0.2. The estimated average time spent on the mining site everyday of a year is 4.8 h (UNSCEAR, 2000).

$$AEDR(\mu Sv\ y^{-1}) = D(nGy\ h^{-1}) \times 8760\ (h\ y^{-1}) \times 0.2 \times 0.7\ (Sv\ Gy^{-1}) \times 10^{-3} \quad (3)$$

### Radium Equivalent

The gamma radiation hazards which may arise from uranium ore deposits if by any chance used in construction materials of offices and buildings within the mine by contractors needs to be assessed as well. For this reason radium equivalent should

*Table 2 The computed values of dose rates, annual effective dose rates, radium equivalents and external hazard indexes of uranium ores.*

| Sample no. | D(nGy.h$^{-1}$) | AEDR(μSv.y$^{-1}$) | Raeq (Bq.kg$^{-1}$) | $H_{ex}$ |
|---|---|---|---|---|
| ORE1 | 2512.31 ± 23.00 | 3081.10 ± 28.21 | 5457.48 ± 49.83 | 14.75 ± 0.13 |
| ORE2 | 2496.75 ± 25.35 | 3062.01 ± 31.09 | 5421.31 ± 54.86 | 14.65 ± 0.15 |
| ORE3 | 2641.56 ± 16.36 | 3239.61 ± 20.07 | 5729.63 ± 35.45 | 15.48 ± 0.10 |
| ORE4 | 1647.31 ± 13.21 | 2020.27 ± 16.20 | 3571.16 ± 28.63 | 9.65 ± 0.08 |
| ORE5 | 1349.73 ± 17.80 | 1655.30 ± 21.83 | 2933.08 ± 38.53 | 7.93 ± 0.10 |
| ORE6 | 1811.06 ± 18.32 | 2221.08 ± 22.46 | 3930.53 ± 39.70 | 10.62 ± 0.11 |
| ORE7 | 1792.62 ± 28.97 | 2198.47 ± 35.53 | 3898.81 ± 62.72 | 10.54 ± 0.17 |
| ORE8 | 3168.85 ± 34.74 | 3886.28 ± 42.61 | 6877.55 ± 75.42 | 18.59 ± 0.20 |

be computed which details more about the gamma output for $^{238}U$, $^{232}Th$ and $^{40}K$. The expression to calculate radium equivalent activity in the uranium ore deposits is shown in the equation (UNSCEAR, 2000):

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{K} \quad (4)$$

where $A_{Ra}$, $A_{Th}$ and $A_{K}$ are average activity concentrations for $^{226}Ra$, $^{232}Th$ and $^{40}K$, respectively. Also here, the activity concentration for $^{238}U$ is replaced by that of $^{226}Ra$. Note that the half-life of $^{226}Ra$ is very high (1600 years) and may be in disequilibrium with $^{238}U$ (UNSCEAR, 2000). The highest value of this concentration ($Ra_{eq}$) should not exceed 370 Bq.kg$^{-1}$ (Amanjeet *et al*., 2017).

The radium equivalent concentrations calculated for the samples of uranium ore analysed with the high-purity germanium detector were very high. The lowest value calculated is for ORE 5 sample which is 2933.08 ± 38.53 and the maximum was for ORE 8 which 6877.55 ± 75.42 Bq.kg$^{-1}$. These values are way too large compared to the safely defined 370 Bq.kg$^{-1}$. The management of mine should at no time allow a small fraction or portion of uranium ores to get contact with building materials used for construction in the mine. Therefore, preventative measures should be taken to avoid any contact of uranium ores with construction materials.

**External Hazard Index**

The External Hazard Index ($H_{ex}$) due to gamma rays emitted from the three primordial radionuclides was introduced as a result of external exposures from these materials. These exposures are estimated by emission of photons (gamma rays) from $^{222}Rn$ (radon) and $^{220}Rn$ (thoron) together with their short-lived products (UNSCEAR, 1988, Amanjeet *et al*., 2017). The aim was to have maximum permissible limit of 1 mSv y$^{-1}$ due to natural radioactive materials (Kamunda *et al*., 2016). The approximation of external radiation doses as measured by gamma spectrometry from building materials is known as external hazard index (UNSCEAR, 1988).

$$H_{ex} = \frac{Au}{370} + \frac{ATh}{259} + \frac{Ak}{4810} \leq 1 \quad (5)$$

where $A_{Ra}$, $A_{Th}$ and $A_{K}$ are activity concentrations of $^{226}Ra$, $^{232}Th$ and $^{40}K$ radionuclides as calculated from uranium ore samples. The maximum external hazard index calculated is for ORE 8 and minimum for ORE 5, which are 18.09 ± 0.20 and 7.93 ± 0.10, respectively.

*Discussions and conclusion*

The **absorbed dose rate (D)**, both weighted mean and average errors, were determined with a minimum of 1349.73 ± 17.80 *nGy.h*$^{-1}$ and a maximum of 3168.85 ± 34.74 *nGy.h*$^{-1}$. These results indicate that absorbed dose to workers due to all three primordial radionuclides of $^{238}U$, $^{232}Th$ and $^{40}K$ in uranium ore deposits is very higher than the recommended value of 35, 420 and 45 Bq.kg$^{-1}$ (UNSCEAR, 2000), on the earth's crust. Also, the absorbed dose rates were significantly higher than the world average of 60 *nGy.h*$^{-1}$ recommended by UNSCEAR (2000). The **annual effective dose rate (AEDR)** shows a weighted mean and average errors with minimum of 1655.30 ± 21.83 *μSv.h*$^{-1}$ and maximum of 3886.28 ± 42.61 *μSv.y*$^{-1}$. The annual effective dose rate values are significantly higher than the world permissible value of 70 *μSv.y*$^{-1}$ (UNSCEAR, 1988).

**Radium equivalent** (***Ra***$_{eq}$) shows values between 2933.08 ± 38.53 *Bq.kg*$^{-1}$ and 6877.55 ± 75.42 *Bq.kg*$^{-1}$. All ore samples presented that the calculated radium equivalent values are higher than the maximal permissible value of 370 Bq.kg$^{-1}$ for building materials (UNSCEAR, 2000). This means that uranium ore deposits should not in any way allowed to be in close contact or used in material to be used for building of dwellings or offices. The **external exposures** (external hazard index, $H_{ex}$) was calculated with a minimum of 7.93 ± 0.10 and maximum of 18.59 ± 0.20. The external hazard index of uranium ore samples were higher than the maximum permissible limit of 1 mSv.y$^{-1}$ due to natural radioactive materials in the mine (Kamunda *et al*., 2016).

To conclude, the radioactivity level of uranium ore sediments calculated from a uranium mine in Erongo Region, Namibia, indicates that uranium mining activities pose a high radiological health risk to employees. Therefore, there is a high risk of possible cancer cases that may arise as a result of

continued exposure to radioactivity from primordial nuclides of $^{238}U$, $^{232}Th$ and $^{40}K$.

## Recommendations

In addition to all protocols and radiation safety measures that are already put in place by uranium mines in collaboration with the National Radiation Protection Authority (NRPA) and in compliance with IAEA, close check-ups and examinations for employees must be put in place and implemented on a regular basis.

## References

Ademola, A. K., Bello, A. K. & Adejumobi, A. C. 2014. Determination of natural radioactivity and hazard in soil samples in and around gold mining area in Itagunmodi, south-western, Nigeria. Journal of Radiation research and applied sciences, 7, 249-255.

Alzubaidi, G., Hamid, F. & Abdul Rahman, I. 2016. Assessment of natural radioactivity levels and radiation hazards in agricultural and virgin soil in the state of Kedah, North of Malaysia. The Scientific World Journal, 2016.

Amanjeet, Kumar, A., Kumar, S., Singh, J., Singh, P. & Bajwa, B. 2017. Assessment of natural radioactivity levels and associated dose rates in soil samples from historical city Panipat, India. Journal of Radiation Research and Applied Sciences, 10, 283-288.

Chhangte, L., Rohmingliana, P., Sahoo, B., Sapra, B., Zoliana, B. & Pachuau, Z. Measurement of primordial radionuclides in soils and building materials from Mizoram, India. Mizoram Science Congress 2018 (MSC 2018), 2018. Atlantis Press.

Durusoy, A. & Yildirim, M. 2017. Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey. Journal of Radiation Research and Applied Sciences, 10, 348-352.

ISO18589–2 2007. Measurement of Radioactivity in the Environment - Soil - Guidance for the Selection of the Sampling Strategy, Sampling and Pre-treatment of Samples.

ISO18589–3 2007. Measurement of Radioactivity in the Environment - Soil - Measurement of Gamma-emitting Radionuclides.

Kamunda, C., Mathuthu, M. & Madhuku, M. 2016. An Assessment of Radiological Hazards from Gold Mine Tailings in the Province of Gauteng in South Africa. International Journal of Environmental Research and Public Health, 13, 138.

Unscear 1988. Sources, Effects and Risks of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation UN.

UNSCEAR 2000. Effects of Ionizing Radiation. United Nations, New York, 453-487.

WHO 1994. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources.