Dose rate in a deactivated uranium mine

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ABSTRACT

The Ore Treatment Unit is a deactivated uranium mine situated in Caldas, MG, BR. Although disabled, there are still areas considered controlled from the radiological point of view. In these areas, it is necessary to keep an occupational monitoring program. For area monitoring (AM), the dose rate, was measured with Geiger Müller (GM) area monitors or personal electronic monitors (PEM) and thermoluminescence dosimetry (TLD), along the years 2013 to 2016. For area monitoring (AM), 577 samples were recorded; for PEM, 2,656; and for TLD monitoring type, 5,657. The AM showed a mean dose rate of 6.42 μSv·h-1. 96 % of the samples were below the derived limit per hour for workers. For the PEM, the average of the data sampled was 15.86 μSv·h-1. 80 % of the samples were below the derived limit. Finally, the TLD showed a mean of 0.01 mSv·h-1 (TLD detection limit is 0.2 mSv·month-1). 98% of the registered values were below 0.2 mSv·month-1 and less than 2 % of the measurements had values above the limit of detection. The samples show areas with low risk of external exposure, as can be seen by the TLD evaluation. Specific areas with greater risk of contamination have already been identified, as well as operations at higher risks. In these cases, the use of the PEM is justified for a more effective monitoring. Radioprotection identified all risks and was able to extend PEM to all risk operations, even with the use of the TLD.

Keywords: Radioprotection, Occupational monitoring, Uranium mine.

1. INTRODUCTION

There are two main contributors to exposure to natural radiation: incident high-energy cosmic particles on the Earth's surface and radioactive nuclides that originated the Earth's crust and are present in the environment, including the human body. In addition, the practice, defined by the National Nuclear Energy Commission [1] as any human activity that introduces additional sources of exposure or routes of exposure or extends exposure to more people, may increase the individual's exposure to natural radiation to the point of exceeding levels recommended by accredited agencies for this purpose. One of the sectors with a high dose rate is the uranium mining plant [2-5].

Brazil possesses one of the largest uranium reserves in the world [6, 7]. Currently, the Brazilian Nuclear Industries (INB) has one mine in full extraction activity in Caetité, State of Bahia, one facility for the extraction of concentrate that is being implemented in Santa Quitéria, State of Ceará, and the Ore Treatment Unit (OTU) located in Caldas, State of Minas Gerais, whose extraction activities were closed in 1995. The latter has tailings and wastes that are sources of heavy metals that may cause a short or long term environmental impact. Even after deactivation, continuous evaluation of mines is essential because the construction of a database helps to assess the radiological impact on the environment [8, 9].

However, in Brazil, there is no regulatory control available to establish the basic nuclear safety requirements to be met during the planning and implementation of mining decommissioning of radioactive concentrate extraction, with only one standard for the decommissioning of nuclear power plants [10]. In order to minimize the undesirable effects of ionizing radiation, INB created and implemented an effluent treatment program and developed an environmental monitoring plan to verify whether effluent treatment actually mitigated impacts or maintained radiometric levels within the limits allowed by Brazilian legislation [11]. Periodically surveys are carried out in a variety of natures and, among the radiometric measurements such as personal monitoring, which aims at the need for continuous dose evaluation in the Occupationally Exposed Individual (OEI), according to Section 5.9 from CNEN-NN-3.01 Standard [1].

From the Regulatory Position PR:3.01/005, Section 3.3 [12], the necessary parameters for calculation of effective dose are found, according with the equation below.

$$E = H_P(10) + \sum_j e(g)_{j,ing}\, I_{j,ing} + \sum_j e(g)_{j,ina}\, I_{j,ina} \qquad (1)$$

The effective dose E is the sum of the external effective dose to a depth of 10 mm in soft tissue [$H_P(10)$] with committed effective doses due to the ingestion [$\sum_j e(g)_{j,\,ing}\, I_{j,ing}$] and the inhalation [$\sum_j e(g)_{j,ina}\, I_{j,ina}$]. This term of the equation can be inferred in different ways. In this work, were used the area monitoring with Geiger-Müller, the personal monitoring with electronic monitors and by TLD. This study aimed to analyze the area monitoring data, whose dose rate value is in $\mu Sv \cdot h^{-1}$ and individual monitoring with electronic monitor also in $\mu Sv \cdot h^{-1}$, and to analyze the personal monitoring using TLD, whose dose value is in $mSv \cdot month^{-1}$. The data analyzed were collected during 2013-2016.

2. MATERIALS AND METHODS

In order to meet the Occupational Radiological Protection Program (ORPP) [13-15], the external exposure assessments were conducted in more than 70 areas at OTU areas, including deactivated mining and beneficiation areas, waste deposit areas (internal and external areas, including around near surface silos of waste) and in areas within the 4 hangars containing waste initial deposition. The dose rate was estimated using a Geiger-Müller (GM) detector MRA model GP-500, reading from 10 to 500,000 CPM or from 0.1 to 5,000 CPS, with external probe, 1 meter cable and direct reading capacity multiplied by 1,000 (x 1 to x 1,000 CPM and x 1 to x 1,000 CPS) or a personal electronic monitor POLIMASTER model, PM1703M1A, detector CsI(Ti) and GM tube, Sensitivity, $100\ (s^{-1}) \cdot (\mu Sv \cdot h^{-1})^{-1}$ [$1.0\ (s^{-1}) \cdot (\mu R \cdot h^{-1})^{-1}$], energy range 0.033 -3.0 MeV, 0.01 μSv - 9.99 Sv (1 μR - 999 R), accuracy $\pm$ (20 + K1/H+K2*H) % in measurement range, 0.1 $\mu Sv \cdot h^{-1}$ - 10 $Sv \cdot h^{-1}$ (10 $\mu R \cdot h^{-1}$ – 1,000 $R \cdot h^{-1}$) and thermoluminescent dosimeters (CaSO$_4$:Dy) supplied by SAPRA LANDAUER LTDA, with detection limit of 0.2 $mSv \cdot month^{-1}$.

3. RESULTS AND DISCUSSIONS

Table 1 presents the statistical results regarding the measurements for area monitoring with GM, personal monitoring with electronic dosimeters and TLDs. For the area monitoring with Geiger-Müller, the average of the measurements was below the derived limit for occupational Exposed Individual - OEI (10 μSv·h^{-1}). For personal monitor, this average was higher than the derived limit. When we evaluated the monitoring with TLD, it was observed that the average was below the limit of detection of this technique (0.28 μSv·h^{-1} or 0.2 mSv·month^{-1}). This average is a result of the large number of values below the detection limit that were considered zero.

Figure 1 shows the frequency histogram of the area monitoring. It appears that 60 % of the measurements were below 0.5 mSv·h^{-1}, 77 % of the measurements below 1 mSv·h^{-1} and 97 % below 10 mSv·h^{-1}. Of the 577 measurements performed, only 19 were above the value of 10m Sv·h^{-1}.

In Figure 2, the frequency distribution of individual monitoring with electronic monitors can be observed. 36 % of the measurements were below 0.5 mSv·h^{-1}, 53 % below 1 mSv·h^{-1} and approximately 80 % of the samples below 10 mSv·h^{-1}.

With respect to the TLD, in Figure 3, 97.4 % had zero dose value; 40 measurements were limited; 16 measurements among the 5,657 performed were above 1 mSv·moth^{-1}, and 36 of these measurements were above 0.50 mSv·moth^{-1}, with a maximum value of 1.8 mSv·moth^{-1}. The mean dose value was 0.0104 mSv·moth^{-1} and considering 12 months of work per year, the estimated mean dose was 0.12 mSv·year^{-1}. By averaging the measurements with values equal to or greater than the limit of detection, 135 measurements had mean dose equal to 0.44 mSv·month^{-1}. Considering 12 months of work per year, the estimated average dose was 5.30 mSv·year^{-1}, see Table 2.

4. CONCLUSIONS

The area monitoring can help to identify the radiological risks of areas due to external exposure. On average, the area dose rate monitoring (6.42 μSv h^{-1}) was below the derived limit from the dose rate for OEI (10 μSv h^{-1}). The maximum value of exposure rate (0.68 mSv h^{-1}) pointed to an area where one could stay at the limit, less than one week of work per year (29.4 hours per

year). The frequency distribution of the area samplings indicated a low risk of external exposure, with approximately 60 % of the dose rate values lower than the limits derived from the public exposure rate (0.5 µSv h^{-1}).

Table 1: Descriptive statistics for the area monitoring data

| Parameters	Area monitoring (AM) with GM (mSv·h^{-1})	Personal eletronic monitoring (PEM) (mSv·h^{-1})	Personal monitoring with TLD (mSv·month^{-1})
Average	6.42	15.86	0.01
Standard error	2.01	1.20	0.001
Median	0.32	0.90	N. D.
Mode	0.73	0.20	N. D.
Standard deviation	48.31	61.74	0.09
Sample variance	2,334.45	3,812.72	0.01
Curtose	117	126	170
Asymmetry	10.40	9.46	11.8
Interval	685	1,220	1.8
Minimum	0.13	0	0
Maximum	685	1,220	1.8
Count	577	2,656	5,657

Table 2. A comparison of the average dose obtained with TLD dosimeter in some occupations

| Reference	Occupation	Mean of dose (mSv.y^{-1})
Present work	Ore Treatment Unit (OUT)	0.12
[16]	Phosphate mine	11.6
[17]	Nuclear Power Plant	1.8
	Diagnostic radiology	0.045
[18]	Radiotherapy	0.006
	Nuclear medicine	0.292
[19]	Tokyo-New York (2,000 hour-travel)	11.4

Figure 1: Histogram of the area monitoring
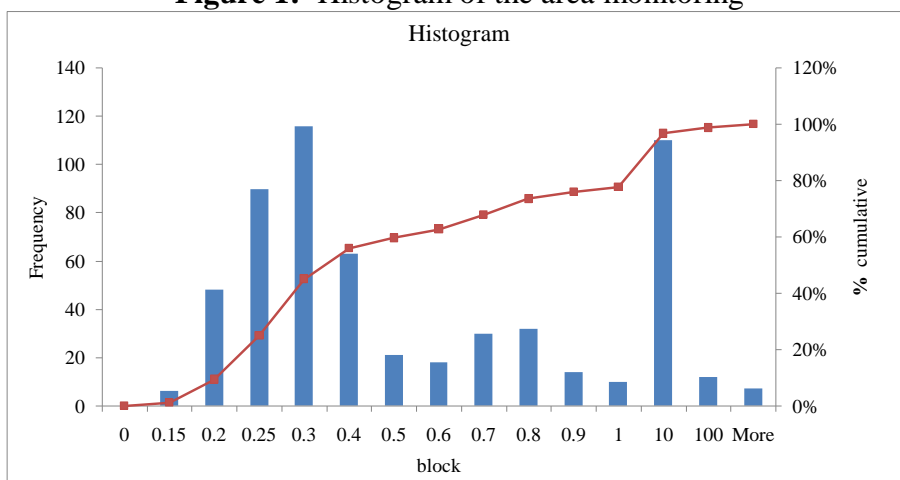
Figure 2: Histogram of individual electronic monitoring
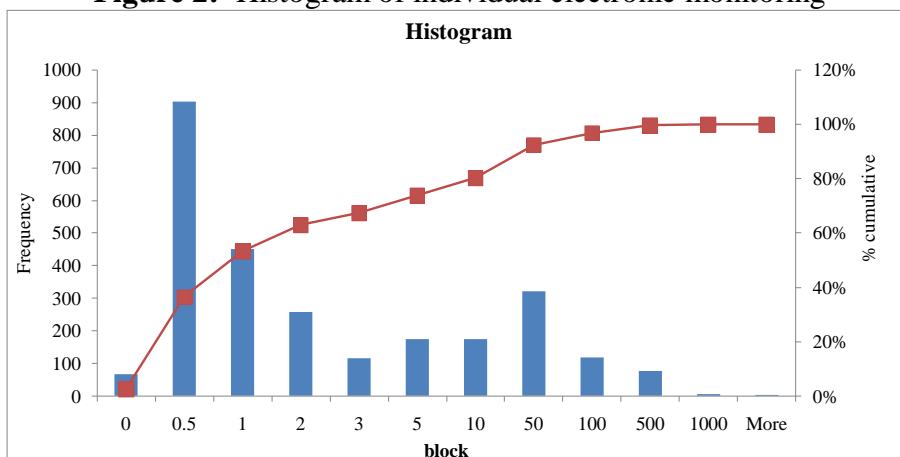
Figure 3: Histogram of TLD monitoring
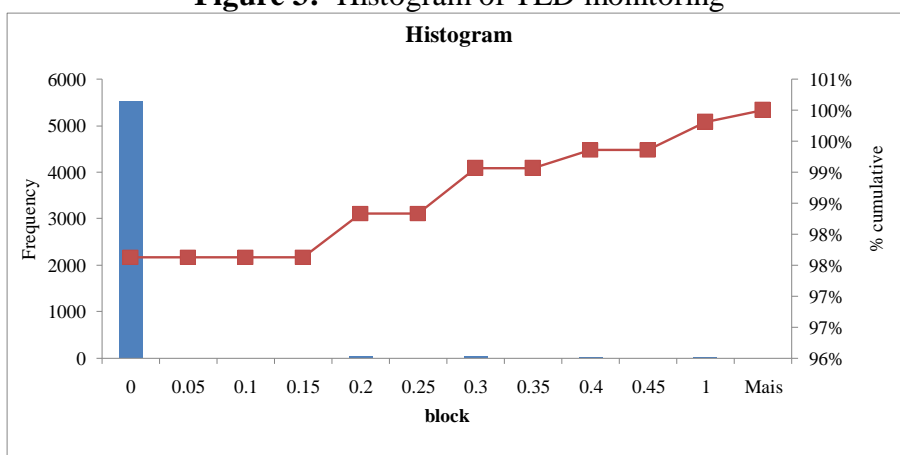
The TLD monitoring showed a large number of values below the detection limit of 0.2 mSv h^{-1} with 97,76 % and more than 98,81 % of the samples below 1 mSv month^{-1}, indicating low OEI exposure at the facility studied when compared to other situations, see Table 2. The estimated mean dose (0.12 mSv h^{-1}) again indicated a mean exposure to low radiation when the occupational exposure occurred.

The frequency distribution to the TLD values and the individual electronic dosimeter indicated a good management of these two samplings. The large number of null values in the TLDs (98 %) and the small percentage of values with a zero exposure rate in the electronic dosimeters (2.45 %) indicated that the electronic dosimeters were used as complementation of monitoring when the potential dose was identified.

Evaluating the data globally, the high frequency of low values pointed out that the installation offered low risks of external exposure. This conclusion does not mean to abandon the use of the monitors, as there are areas with high exposure rates (0.68 mSv h^{-1}).

REFERENCES

[1] CNEN – Comissão Nacional de Energia Nuclear. **Diretrizes Básicas de Proteção Radiológica.** Rio de janeiro: CNEN, 2014. 15 pp

[2] TRIPATHI, R. M.; SAHOO, S. K.; JHA, V. N.; KHAN, A. H.; PURANIK, V. D. Assessment of Environmental Radioactivity at Uranium Mining, Processing and Tailimgs Management Facility at Jaduguda, India, **Applied Radiation and Isotopes,** V. 66, n 1, 1666-1670, 2008. DOI: 10.1016/j.apradiso.2007.12.019

[3] OYEDELE, J. A.; SHIMBOYO, S. SITOKA, S; GAOSEB, F. "Assessment of Natural Radioactivity in the Soils of Rössing Uranium Mine and its Satellite Town in Western Namibia, Southern Africa," **Nuclear Instruments and Methods in Physics Research A,** V. 610, N. 1-3, 467-469, 2010, doi.org/10.1016/j.nima.2010.01.068

[4] RACHAVENDRA, T.; RAMAKRISHNA, S. U.; VIJAYALAKSHMI, T.; ARUNACHALA, J. Assessment of Randos Concentration and External Gamma Radiation Level in the Environs of the Proposed Uranium Mine at Peddagattu and Seripally Regions, Andhra

Pradesh, India. **Journal of Radiation Research and Applied,** V. 7, N. 3, 269-273, 2014, doi.org/10.1016/j.jrras.2014.03.007.

[5] SRINIVAS, D.; RAMESH BABU, V.; PATRA, I.; RAMAYYA, M.; SHAILESH TRIPATHI, S.; CHATURVEDI, A. K. Assessment of Background Gamma Radiation Levels Using Airbone Gamma Ray Spectrometer Data over Uranium Deposits, Cuddapah Basin, India and a Comparative Study of Dose Rates Estimated by AGRS and PGRS. **J. of Env. Radioactivity**, V. 167, pp1-12, 2017. doi.org/10.1016/j.jenvrad.2016.11.027

[6] MATOS, E. C.; RUBINI, L. A. Reservas Brasileiras de Urânio e Sua Capacidade de Atendimento à Demanda Interna, In: **Congresso Geral de Energia Nuclear - VII CGEN,** 1999. Belo Horizonte.

[7] CIPRIANI, M. Mitigação dos impactos sociais e ambientais decorrentes do fechamento definitivo de minas de urânio.D. Sc Thesis, Campinas, São Paulo, 332 p. 2002.

[8] E.Lespukh, P.Stegnar, M.Yunusov, H.Tilloboev, G.Zyazev, P.Kayukov, A.Hosseini, G.Strømman, B.Salbu. Assessment of the Radiological Impact of Gamma and Randon Dose Rates at Former U Mining sites in Tajikistan. **Journal of Environmental Radioactivity**. V. 126, 147-155, 2013. doi.org/10.1016/j.jenvrad.2013.07.019

[9] N. Karunakara, I. Yashodhara, K. Sudeep Kumara, R. M. Tripathi, S. N. Menon, S. Kadam, M. P. Chougaonkar. Assessment of Ambient Gamma Dose Rate Around a Prospective Uranium Mining Area of South India – A Comparative Study of Dose by direct Methods and Soil Radioactivity Measurements. **Results in Physics.** V. 4. 20-27, 2014. doi.org/10.1016/j.rinp.2014.02.001

[10] CNEN – Comissão Nacional de Energia Nuclear. **Descomissionamento de Usinas Nucleoelétricas**. Rio de Janeiro: CNEN, 2012. xx pp

[11] PEREIRA, W. S.; KELECOM, A.; PEREIRA, J. R. S.; PY JÚNIOR, D. A. Release of Uranium by an Ore Treatment Unit at Caldas, MG, Brazil, **Journal of Environment Protection**, V. 4, N. 6, pp. 570-574, 2013. **DOI:**10.4236/jep.2013.46066

[12] CNEN – Comissão Nacional de Energia Nuclear. **Critérios para Cálculo de Dose Efetiva a partir da Monitoração Individual.** Rio de Janeiro: CNEN, 2011. xx pp

[13] INB - Indústrias Nucleares do Brasil, Plano de proteção radiológica do Complexo Minero Industrial Do Planalto De Poços De Caldas (CIPC), 56 pp, (1986).

[14] INB - Indústrias Nucleares do Brasil, Plano de proteção radiológica da Unidade de Tratamento de Minério, em condição de área parada, 26 pp, (2002).

[15] INB - Indústrias Nucleares do Brasil, Plano de proteção radiológica ocupacional da unidade de tratamento de minérios – UTM, 46 pp, (2012).

[16] KHATER, A. E; HUSSEIN, M. A; HUSSEIN, M. I., Occupational exposure of phosphate mine workers: airborne radioactivity measurements and dose assessment. **Journal of Environmental Radioactivity**, V. 75. N. 1, pp 47–57. 2004. doi.org/10.1016/j.jenvrad.2003.11.001

[17] ALM-LYTZ, K; RIIHILUOMA, V; HYVÖNEN, H., Occupational exposures of nuclear power plant workers in Finland, **Radiation Protection Dosimetry**. V. 96. N. 1-3, pp 39–42. 2001, doi.org/10.1093/oxfordjournals.rpd.a006603

[18] PAKRAVAN, A. H; AGHAMIRI, S. M. R; BAMDADIAN, T; GHOLAMI, M; MOSHFEGHI, M; Dosimetry of occupational radiation around panoramic X-ray apparatus". *J Biomed Phys Eng*, doi.org/10.22086/jbpe.v0i0.466

[19] FRIEDBERG, W; COPELAND, K; DUKE, F. E; O'BRIEN, K; EDGAR B. DARDEN, E. B., Radiation exposure during air travel: guidance provided by the federal aviation administration for air carrier crews. V. 79, N. 5, **Health Physics**, pp 591-595, 2000.