# Radon and Gamma Radiation Dose to the Population Residing Near the Uranium Mill Tailings Disposal Site in Uranium Mineralized Zone at Jaduguda

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**Abstract:** Members of the public residing in the villages situated near the uranium mill disposal site, such as those in the vicinity of uranium tailings ponds, may indeed be at risk of radiation exposure. Present study focuses to evaluate the radiological exposure condition for the resident of villages situated in nearby vicinity of the tailing disposal site in the uranium mineralized region of Jaduguda, Jharkhand, India. In this study, the dose from external gamma radiation and radon concentrations, both indoors and outdoors, is evaluated. The natural background radiation dose to the residents of villages located near the uranium mill tailings disposal site is estimated to be 2.99 mSvy$^{-1}$. Radon and its decay products contribute approximately 57.6% of the radiation dose to the villagers, while gamma radiation accounts for 42.4%. Residents of villages near the uranium tailings ponds receive a radiation dose is within the typical range of global natural background radiation dose of 1-10 mSvy$^{-1}$ to the members of the public.

**Key words:** Tailings, Disposal Site, Radon, Gamma, Dose

**1. Introduction:** Natural radioactivity and radiation have always been a part of the environment since the inception of the earth [1]. The exposure to natural radiation includes cosmic, terrestrial, inhalation and ingestion through air, water and food materials etc. [2]. The average global radiation exposure from the natural background radiation sources is 2.4 mSvy$^{-1}$ with a typical range of 1- 10 mSvy$^{-1}$ [3 & 9]. Naturally occurring radioactive materials (NORMs) contribute a significant fraction to the natural background radiation exposure. The natural radiological condition may change drastically due to anthropogenic activities in the vicinity. There are some areas in India, Brazil, China & Iran where people are exposed to high level of natural background. However, anthropogenic activities like mining of minerals have the potential to redistribute the minerals in the adjoining area and may enhance natural radioactivity if adequate safety measures are not implemented [4]. East Singhbhum district of Jharkhand state of India is well known for its widespread mineral deposits. Several copper and uranium mining activities are continuing since last five decades. In the case of uranium mines, the major radiological concern is airborne radon ($^{222}$Rn) and its short-lived progeny ($^{218}$Po, $^{214}$Pb, $^{214}$Bi and $^{214}$Po). Unlike other sectors of the nuclear industry, uranium ore processing generates large volumes of low-specific-activity solid waste, commonly known as tailings. Due to the chemical and radioactive substances present in these tailings, their disposal requires special attention. Consequently, tailings disposal systems must be carefully designed and situated in geologically stable locations to ensure long-term isolation from human populations. The composition of the tailings varies based on factors such as the type of leaching process used to extract uranium, the reagents involved, and the mineralogy of the ore. After uranium recovery in the processing plant, the majority of the processed material becomes tailings. These tailings are neutralized with lime to a pH of 10 to precipitate heavy metals, radionuclides, and toxins. The neutralized tailings are then separated into coarse and fine fractions using a hydrocyclone. The coarse fraction is used as backfill in mined-out areas, while the fine fraction is stored in a tailings pond (TP) for containment. The tailings pond is an engineered earthen dam designed to hold both solid and liquid waste. Solids settle at the bottom, while the clear liquid is directed through decantation wells to an effluent treatment plant (ETP) for the removal of chemical and radioactive pollutants. At Jaduguda, three tailings ponds have been in operation for over four decades, located in a valley surrounded by hills on three sides and an engineered embankment downstream. The radioactivity in the tailings pond primarily comes from long-lived radionuclides such as $^{230}Th$, $^{226}Ra$, $^{210}Pb$, and $^{210}Po$ from the $^{238}U$ series. Radon ($^{222}Rn$) is produced by the decay of $^{226}Ra$ in the tailings. The mill tailings pose potential environmental risks due to low-level radioactivity and the release of $^{222}Rn$ gas. Radon, being an inert gas, does not significantly contribute to internal exposure. However, its short-lived progenies attach to dust particles, which are a major source of internal exposure in uranium mining sites. If proper safety measures are not implemented, the tailings pond could be a source of both external and internal radiation exposure for the nearby communities. The study assessed radon concentration and external gamma radiation around a tailings pond (TP) and nearby villages. It used a portable radon detection system and an environmental radiation survey meter. The findings indicate that while tailings ponds have a localized impact on radon levels, their effect on the general environment is minimal due to their relatively small area compared to the large land area. Radiological assessment of areas in the close vicinity of mill tailings pond in Jaduguda is the subject matter of this paper.

**1.1. Study Area:** Jaduguda uranium deposit (Lat. 22$^0$ 39’, Long. 86$^0$ 22’) in India is located in the center of Singhbhum Thrust Belt (STB) of Jharkhand State. The host rocks are autoclastic conglomerate (formed by crushing, fracturing and brecciation) and quartz-chlorite-apatite-tourmaline-magnetite schist in which uranium bearing fine grained uraninite minerals occur as disseminated grains and micro-veinlets [5]. The study area (Fig-1) is known for U mineralization in meta-sedimentary rocks [6]. The associated accessory minerals found along with uranium are the sulphide minerals of copper, nickel & molybdenum and magnetite. There are three uranium mill tailings pond at Jaduguda. One tailings pond is in operational where as other two are decommissioned. Some villages are situated very close to tailings pond. Assessment of radiological condition of these villages is essential in order to estimate the radiation exposure due to anthropogenic activity. Village Chatikocha and Tilaitand situated in the close proximity of U mill tailings pond were selected for the study. The assessment of radiological environment of these villages is the subject matter of this study.

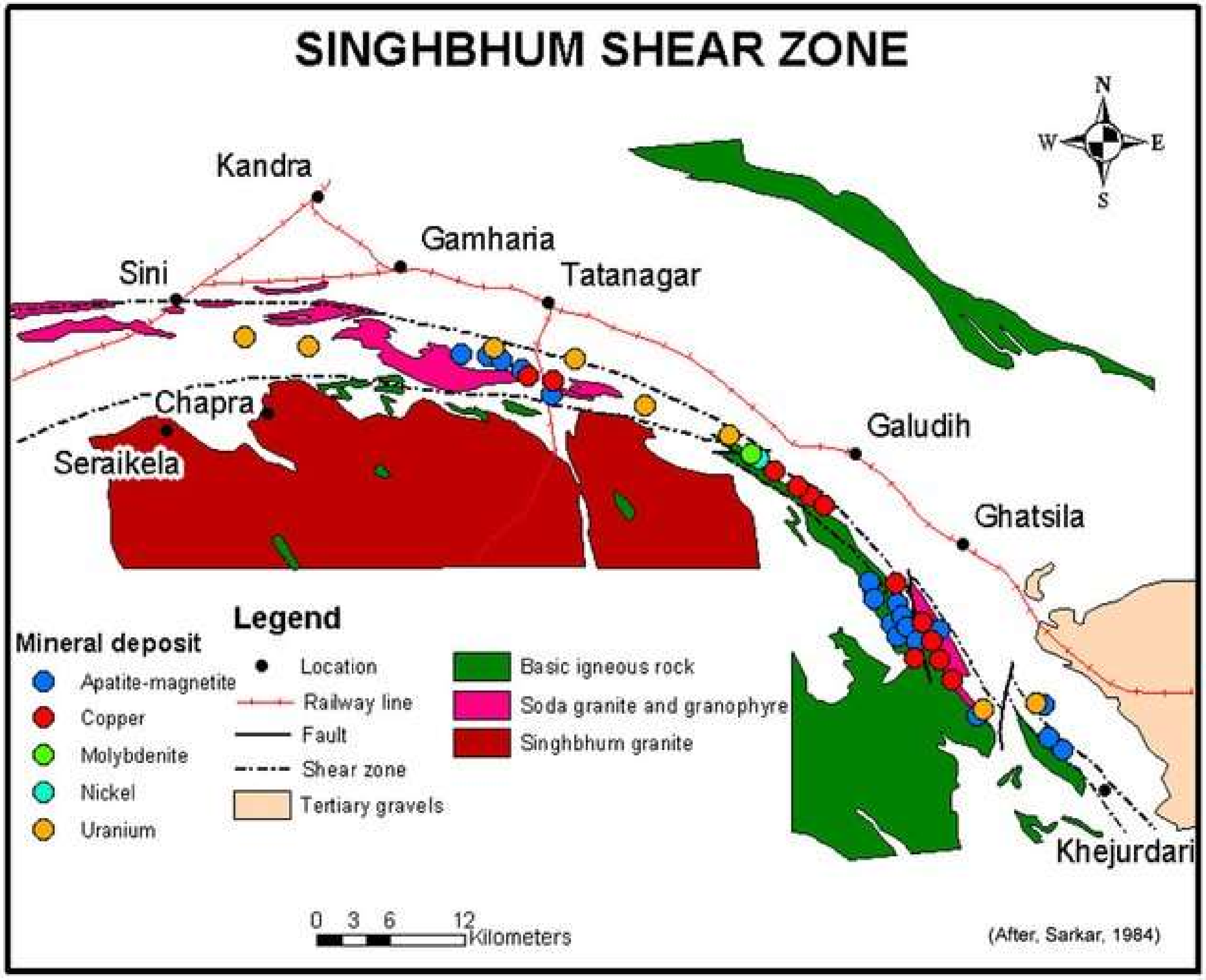


**Figure 1. The Study Area Singhbhum Thrust Belt, Jharkhand**

**1.2. The Uranium Tailings Pond:** Tailings Pond is an engineered impoundment system which is designed to hold the tailings for extended period of time. Tailings are discharged at elevated pH (> 9.5) to keep most of the radionuclide and heavy metals in precipitated state. Over the year the pH of the tailings pond may reduce by pyrite oxidation [7] in the presence of microbes creating a reduced pH condition favorable for migration of radionuclide. The reduced pH condition favors migration of radionuclide and chemical contaminates to adjoining ground water table to public domain. Reduction of pyrite also enhanced in presence of some micro-organisms and bacteria. Uranium mill tailing contains bulk of radioactivity originally present in the ore as well as traces of residual uranium. Radionuclide which are alpha emitting and long radiological half-lives such as $^{226}Ra$, $^{230}Th$, $^{210}Po$ etc. are present in the tailings.

**2. Material & methods:** External gamma radiation levels in the environment around the tailings pond are measured using pre-calibrated direct reading radiation survey meters (Nucleonix-UR705 & PLA- PRM-151S). The radiation survey meter is NaI(Tl) scintillation 1 in. x 1 in. plain detector with 1 in. PM tube and built in pre-amplifier, probe type PSP 101. The survey meter is used to measure low level radiation from 1 $\mu Rh^{-1}$ to 1 mRh$^{-1}$ with auto range selection. Atmospheric radon concentration was measured using Alpha-Guard (PQ 2000/MC 50) supplied by Genitron Instruments, Germany. One hour time integrated grab measurement technique was employed for estimation of radon and gamma dose rates at each location. The measurements were carried out at 1 m height above the surface at each location and periodically data were generated and recorded. The cylindrical ionization chamber of the Alpha Guard has an active volume of 0.56 L and its metallic interior has a potential of 750 V. Sensitivity of the system Alpha-Guard is 1 cpm at 20 Bqm$^{-3}$ and the background is less than 1 Bqm$^{-3}$. Fast response, higher sensitivity and a wide dynamic range of linear over the interval 2 – 2 x 10$^{6}$ Bqm$^{-3}$ are the advantages of the Alpha Guard.

**3. Radon & Gamma Radiation level in the Village situated near the Tailings Ponds:** The atmospheric out door radon concentration levels and external gamma radiation is measured in the villages situated near tailings ponds area and is presented in (Table-1) & (Fig.2 & Fig.3). The average concentration of outdoor radon was 26.26 Bqm$^{-3}$ which is slightly greater than the reported value of 18 Bqm$^{-3}$ [8] in the same study region and global average value of 10 Bqm$^{-3}$. The slight elevated level of outdoor radon may be attributed to the close proximity of the two villages to the tailing ponds and natural mineralization. The resident of these villages is tribal and hence most of the houses are made from mud with vegetation forming the roof. Therefore, most of the dwellings in the villages are not properly closed and having natural ventilation. The reported value of average indoor radon level in the study region is 70 Bqm$^{-3}$ and is considered for internal dose estimation. The outdoor radon concentration varies from 19 - 31 Bqm$^{-3}$ with an average of 26.26 Bqm$^{-3}$ (Table-1). In general, occupancy factors suggested by UNSCEAR-2000 is used worldwide for dose calculations [9]. But due to the different atmospheric condition and life style of the study area the indoor occupancy factor of 0.58 and outdoor of 0.29 was used for dose calculation. Annual effective dose due to exposure to radon and its short-lived progenies contribute maximum dose to the human population from natural sources of radiation. The outdoor radon exposure was calculated in terms of Working Level Month (WLM) year$^{-1}$ by using following equation.

$$\textbf{WLM year}^{-1} = [\textbf{Rn (Bqm}^{-3}\textbf{) x 0.58 x 8760 hy}^{-1} \textbf{ x 0.28}] / [\textbf{170 x 3700 Bqm}^{-3}]$$

WLM per year was estimated from radon concentration is converted to effective dose using ICRP dose conversion factor [10]. Since terrestrial gamma radiation contribute a significant portion of the radiation exposure to the public the external gamma radiation. The indoor and outdoor radiation dose is evaluated to be 1.328 mSvy$^{-1}$and 0.398 mSvy$^{-1}$ respectively (Table-3). The total dose due to radon and its progeny is slightly higher than the global and Indian average values**.** The gamma radiation (Fig.3) level was ranging from 60 to 200 nGyh$^{-1}$ with a mean value of 121 nGyh$^{-1}$. The global outdoor radon concentration in different countries are provided in (Table-2). The average outdoor radon in the vicinity of the tailings pond areas in the present study is comparable with values observed in the USA [11] & Turkey [22] and lower than that of observed value in England [15]. The total annual external dose due to exposure to background gamma (Cosmic + Terrestrial) radiation is estimated to be 1.268 mSvy$^{-1}$ (Table-3). The total dose to the public residing in the villages near the tailings pond area due to exposure to radon and gamma radiation is estimated to be 2.99 mSvy$^{-1}$. The estimated total annual dose to resident of the village situated nearby the tailing disposal site is within the typical range of global natural background radiation dose of 1-10 mSvy$^{-1}$ to the members of the public [9] and is not very significant.

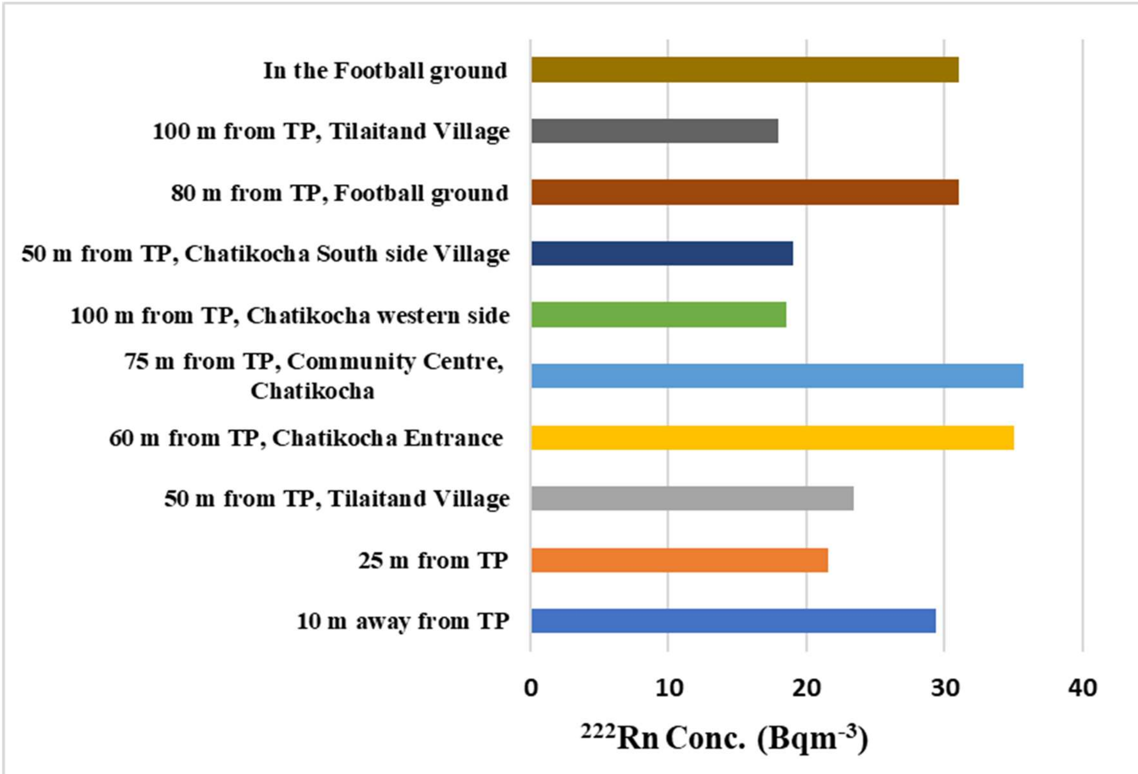


**Figure 2. Outdoor $^{222}$Rn in the villages near the Tailing Pond (TP)**

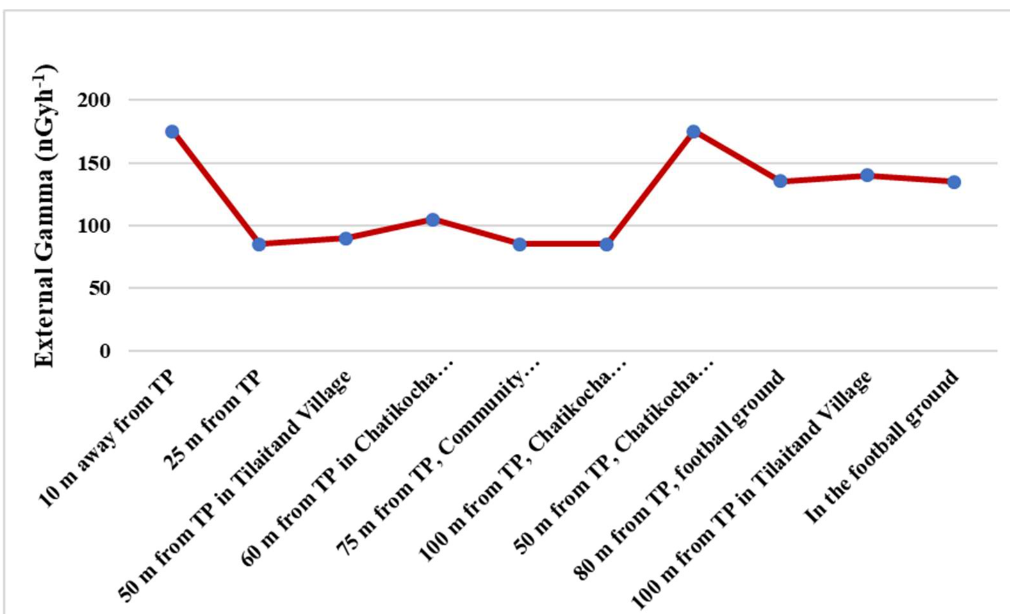


**Figure 3. External gamma radiation near the Tailing Pond (TP)area**

**Table-1. External gamma radiation & Outdoor $^{226}$Rn in the villages near the Tailing Pond (TP)**

| Locations | $^{222}$Rn Conc. ($Bqm^{-3}$) | | External Gamma Level ($nGyh^{-1}$) | |
|---|---|---|---|---|
| | **Range** | **Mean** | **Range** | **Mean** |
| 10 m away from TP | 9.2-69.0 | 29.4 | 150 - 200 | 175 |
| 25 m from TP | 7.4-91.0 | 21.6 | 60 - 110 | 85 |
| 50 m from TP, Tilaitand Village | 5.5-34.5 | 23.4 | 60 -120 | 90 |
| 60 m from TP, Chatikocha Entrance | 7.3-33.0 | 35.0 | 80 – 130 | 105 |
| 75 m from TP, Community Centre Chatikocha | 35.0-36.0 | 35.7 | 60 – 110 | 85 |
| 100 m from TP, Chatikocha western side | 7.1-40.1 | 18.5 | 60 - 110 | 85 |
| 50 m from TP, Chatikocha South side Village | 6.0-42.0 | 19.0 | 150 - 200 | 175 |
| 80 m from TP, Football ground | 22.0-36.0 | 31.0 | 120 - 150 | 135 |
| 100 m from TP, Tilaitand Village | 5.0-33.0 | 18.0 | 130 – 150 | 140 |
| In the Football ground | 24.0-36.0 | 31.0 | 120 - 150 | 135 |
| **Overall** | **5.5- 42.0** | **26.26** | **60-200** | **121** |

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**Table-2. Mean outdoor Radon in different countries**

| Country | Rn ($Bqm^{-3}$) | Reference |
|---|---|---|
| USA, Iowa | 29.0 | Steck D. J. et al. [11] |
| USA, Minesota | 19.0 | Steck D. J. et al. [11] |
| Slovenia | 19.0 | Vaupotič J. et al. [12] |
| China | 11.8 | Wu Q. et al. [13] |
| Serbia | 14.0 | Žunic Z. S. et al. [14] |
| England | 57.0 | Wasikiewicz J. M. et al. [15] |
| Ireland | 6.0 | Gunning G.A. et al. [16] |
| Japan | 6.1 | Oikawa S. et al. [17] |
| Germany | 9.0 | Kümmel M. et al. [18] |
| Cyprus | 5.6 | Sarrou I. et al. [19] |
| East Asia | 11.0 | Zhuo W. et al. [20] |
| Syria | 10.7 | Shweikani R. et al. [21] |
| Turkey | 34.0 | Özen S. A. et al. [22] |
| **Present Study** | **26.26** | |

**Table-3. Dose from external gamma radiation exposure and radon in the villages situated nearby to the tailing disposal site**

| Sources | Components | Dose ($mSvy^{-1}$) |
|---|---|---|
| External Gamma Radiation Exposure | Cosmic | 0.315 |
| | Terrestrial | 0.953 |
| Internal Exposure | Indoor radon | 1.328 |
| | Outdoor radon | 0.398 |
| | **Total Dose** | **2.99 $mSvy^{-1}$** |

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**4. Conclusions:** The annual natural background radiation dose to the inhabitant of villages in the vicinity of the uranium mill tailings pond estimated to be 2.99 $mSvy^{-1}$. The estimated dose to the resident is within the typical range of global natural background radiation dose of 1-10 $mSvy^{-1}$ to the members of the public [9]. The contribution of radon and its progeny accounts close to 57.6% of the radiation dose to the villagers whereas gamma radiation contributes 42.4%. It can be concluded that the radiation doses received by people living in the village near the tailings pond are within the typical range of average worldwide exposure to natural radiation sources for the general public. Therefore, the radiological exposure for residents of villages located near the tailing disposal site is not significantly elevated.

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**References:**

[1] ICRP-103, The 2007 Recommendations of the International Commission on Radiological Protection. Ann. ICRP. Publication: 103 (2007).

[2] IAEA Technical Report Series No. 364, Handbook of parameter values for the prediction of radionuclide transfer in temperate environments(1994).

[3] Gavrilescu M., Pavel, L. V. and Cretescu, I. Characterization and remediation of oils contaminated with uranium. J. Hazard. Mater. 163, 475-510 (2009).

[4] Hakonson-Hayes A. C., Fresquez P.R., Whicker F.W., Assessing potential risk from exposure to natural uranium in well water. Journal of Environmental Radioactivity, Elsevier, 59, 29-40 (2002).

[5] Jha S. et al. at al. Environmental Rn levels around an Indian U complex, Journal of Environ. Radioactivity,48 (2000) 223-234.

[6] Venkatraman K., Shastry, S. and Srinivasan, M. N., 1971, Jaduguda: Certain observations regarding uranium and base metals mineralization, Proc. Ind. Nat. Sci. Academy, vol.37 A. No.2 (1971).

[7] Quindos Poncela, L.S, Fernadez Navarro, P.L., Gomez, J., Arozamena, Rodenas, Palomino, C., Sainz., C., Martin Matrranz, J.L. and Arteche, J. Population dose in the vicinity of old Spanish uranium mines. Sci. of Total Environment. 329. pp. 283-288 (2004).

[8] Tripathi R. M., Sahoo S. K., Jha V. N., Kumar Rajesh, Shukla A.K, Puranik V.D. and Kushwaha H. S., Radiation dose to members of public residing around uranium mining complex, Jaduguda, Jharkhand, India. Radiation Protection Dosimetry, pp1-8 (2010).

[9] UNSCEAR-2000. Sources, Effects and Risks of Ionizing Radiations, UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes, UNSCEAR, United Nations, New York (2000).

[10] ICRP-65, International Commission on Radiological Protection for Protection against radon at home and at work. Ann ICRP 23(2), ICRP publication 65, Pergamon Press, oxford (1993).

[11] Steck D. J., Field R.W., Lynch C.F. Exposure to Atmospheric Radon. Environ. Health Perspect. 1999; 107:123–127.

[12] Vaupotič J., Kobal I., Križman M.J. Background Outdoor Radon Levels in Slovenia. Nukleonika. 2010; 55:579–582.

[13] Wu Q., Pan Z., Liu S., Wang C. Outdoor Radon Concentration in China. Nukleonika. 2016; 61:373–378. doi: 10.1515/nuka-2016-0062

[14] Žunic Z. S., Yarmoshenko I.V., Birovljev A., Bochicchio F., Quarto M., Obryk B., Paszkowski M., Čeliković I., Demajo A., Ujić P., et al. Radon Survey in the High Natural Radiation Region of Niška Banja, Serbia. J. Environ. Radioact. 2007; 92:165–174. doi: 10.1016/j.jenvrad.2006.11.002.

[15] Wasikiewicz J. M., Daraktchieva Z., Howarth C.B. Passive Etched Track Detectors Application in Outdoor Radon Monitoring. Perspect. Sci. 2019; 12:100416. doi: 10.1016/j.pisc.2019.100416.

[16] Gunning G.A., Pollard D., Finch E.C. An Outdoor Radon Survey and Minimizing the Uncertainties in Low Level Measurements Using CR-39 Detectors. J. Radiol. Prot. 2014; 34:457–467. doi: 10.1088/0952-4746/34/2/457.

[17] Oikawa S., Kanno N., Sanada T., Ohashi N., Uesugi M., Sato K., Abukawa J., Higuchi H. A Nationwide Survey of Outdoor Radon Concentration in Japan. J. Environ. Radioact. 2003; 65:203–213. doi: 10.1016/S0265-931X (02)00097-8.

[18] Kümmel M., Dushe C., Müller S., Gehrcke K. Outdoor $^{222}$Rn-Concentrations in Germany—Part 1—Natural Background. J. Environ. Radioact. 2014; 132:123–130. doi: 10.1016/j.jenvrad.2014.01.012

[19] Sarrou I., Pashalidis I. Radon Levels in Cyprus. J. Environ. Radioact. 2003; 68: 269–277. doi: 10.1016/S0265-931X (03)00066-3.

[20] Zhuo W., Furukawa M., Guo Q., Shin Kim Y. Soil Radon Flux and Outdoor Radon Concentrations in East Asia. Int. Congr. Ser. 2005; 1276: 285–286. doi: 10.1016/j.ics.2004.10.002.

[21] Shweikani R., Hushari M. The Correlations between Radon in Soil Gas and Its Exhalation and Concentration in Air in the Southern Part of Syria. Radiat. Meas. 2005; 40: 699–703. doi: 10.1016/j.radmeas.2005.06.025.

[22] Özen S. A., Celik N., Dursun E., Taskın H. Indoor and Outdoor Radon Measurements at Lung Cancer Patients' Homes in the Dwellings of Rize Province in Turkey. Environ. Geochem. Health. 2018; 40:1111–1125. doi: 10.1007/s10653-017-9991-9.