Radioactivity Risk Assessment of Radon and Gamma Dose at One Uranium Tailings Pond in China

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Abstract. A year-long monitoring of gamma radiation effective dose rate and radon concentration had been done in the reservoir area of one uranium tailings pond in Hunan province (The monitoring area included indoor and outdoor area of residential buildings and workshops, tailings dam slope). Afterwards, the annual effective radiation dose of the people in that radiation environment had been calculated based on the results of monitoring, as well as a radiation risk assessment. According to the assessment, gamma radiation effective dose rate and radon concentration in the monitoring area were low, and the annual effective radiation dose was far below the international standard (30mSv), which showed that the radiation would not put the people’s health at risk. However, the annual effective radiation dose of gamma was far above that of radon in the area of uranium tailings pond; therefore, it’s advisable to take quarantine measures in the area of uranium tailings pond to keep the surrounding residents away from unnecessary ionizing radiation.

1. Introduction

Uranium has been used as the basic energy source for nuclear power plants [1]. Environmental safety is threatened by the tailings and slags produced by uranium mining, such bad impacts are often long-term and recessive. Most of the tailings and slags are managed in the form of tailings pond storage, but the potential threats brought by the radiation material of tailings pond on its surrounding environment and residents cannot be ignored. China has begun the industry of uranium mining since 20th. After nearly 60 years of development, China has formed a large number of uranium tailings pond. As a special kind of tailings pond, uranium tailings pond is the largest radioactive waste storage site in the nuclear fuel cycle system and a long-term potential radioactive pollution source as well. The uranium tailings pond this research selected was built in the 1950s and put into use in the 1960s, which was one of large-scale uranium hydrometallurgy purification plants in China's uranium hydrometallurgy system with the the most complete production system, the largest production scale, and a variety of uranium
products. What’s more, this plant was served as an important base of raw materials for various types of nuclear fuel. This tailings pond covers an area of 1.7km² with ten dams.

2. Materials and monitoring methods

2.1. Overview of research area
This uranium tailings pond lies 15 kilometers to the south of City A, its south, west and north are surrounded by River S. It lies about 2 kilometers to the south of River S, about 5 kilometers to the north and east of River S. Located in the concave part of the concave basin in Hunan Province, this uranium tailings pond is surrounded by the ancient rock formations, forming intermittent ring belt ridge land. It lies in the hilly terrain; deep canyon valley carves it up in the meridian direction. Paddy field covers the valley bottom (see Figure 1), gentle slope covers the hill top with the slope of 5˚~15˚and absolute elevation of 75 ~ 85m.

![Figure 1. Uranium tailings pond](image)

2.2. Analytical method in distributing points for monitoring

(1) Distributing points for monitoring
\(^{222}\text{Rn}\) concentration monitoring points were R1 ~ R8, where R3, R6 stand for two different sections of the tailings pond. For each monitoring point, samples were taken 4 times in the dam slope (once every quarter). R1, R4 refers to the indoor and outdoor area of workshop, while the other four points stand for the indoor and outdoor area of residential buildings. For each monitoring point, samples were taken 2 times (once every six months). Gamma dose detection points were distributed in the surface of G1~G6 dam slope, and each dam slope has 50 monitoring points.

![Figure 2. Sampling map (from Google Maps)](image)

(2) Monitoring basis of \(^{222}\text{Rn}\) concentration and gamma radiation dose rate
Table 1. Detection of instrument specific data

| Monitoring project             | Detection method            | Testing equipment | Instrument detection lower limit |
|-------------------------------|----------------------------|------------------|---------------------------------|
| Environmental gamma radiation | Gamma radiometer (1m height) | FD-3013B         | 5×10^{-8} Gy/h                  |
| Air 222Rn concentration       | instrument measurement      | FH463A and RAD-7 | 3.7×10^{-1} Bq/m³               |

In order to measure the level of gamma radiation in the uranium tailings pond, the gamma radiation dose rate was directly measured in the dam slope. According to international standards, this instantaneous measurement was taken place in different points 1m away from the earth’s surface with the help of FD-3013B radiometer. The concentration of 222Rn was measured by FH463A with RAD-7 measuring 222Rn instrument (sampling port is about 1.5m away from the ground). Specific test items, test methods, equipment instrumentation and lower limits of monitoring instruments were shown in Table 3.

2.3. Measurement evaluation

Based on the results obtained from the test, the annual effective radiation dose (mSv / a) was calculated with the following criteria and assumptions:

1) Evaluation of $^{222}$Rn concentration

$$D_{Rn} = (F \times DCF_{Rn} \times \sum C_i \times O)$$

In the formula, O indicates the exposure time in the radiation environment (occupancy). It is generally considered that in the indoor area, the exposure time is 6000h, 2000h in public buildings, and 200h in the hospital (preliminary assumption-dose assessment be made on real exposure time). While in outdoor area, this time comes to 350-700h, 200h in other places (conservative estimate) [2-4].

DCF represents the metering conversion factor. For $^{222}$Rn, it is 9nSv/Bq/m³/h [5]. F represents the balance factor. For indoor $^{222}$Rn and short-lived $^{222}$Rn sub-cells, it is 0.4 [5].

2) Evaluation of gamma radiation dose in air

The gamma dose in air is the same as that of $^{222}$Rn. The annual dose rate in the formula is equal to the product of the gamma dose rate (μGy / h) and the exposure time in exposure sites.

$$D_a = \sum (D \times O)$$

3. Monitoring results and analysis

3.1. The concentration of $^{222}$Rn in the environment

The results of testing in 8 points were shown in Figure 3 and Figure 4. Figure 3 showed indoor and outdoor $^{222}$Rn concentration value at the six monitoring points, which ranged from 2.9Bq/m³ to 40.3Bq/m³. At the same time, it can be seen that in the R2 and R4 monitoring points, the outdoor concentration of $^{222}$Rn was higher than that in the indoor concentration of $^{222}$Rn, which was mainly caused by the nearby uranium tailings pond. However, in the R5 and R8 monitoring points, the results were just opposite. The possible reason was poor ventilation indoor, resulting in high concentration of $^{222}$Rn. However, the concentration of $^{222}$Rn inside the residential buildings is far lower than that of international standard (existing international standard for private residence is 400Bq / m³), so does the $^{222}$Rn concentration in the workshops. The international standard for $^{222}$Rn concentration in public
buildings is 1000Bq / m3) [7]. As the monitoring time is too short, it would make no sense to compare 222Rn concentration in the first half and the second half of the year. According to Figure 4, in the monitoring points R3 and R6, the concentration of 222Rn in the third quarter is obviously higher than that of the other three quarters. Consulting the climate of the region, it could be judged that the rainfall concentrates in the late spring and early summer, the third quarter has the dry air, much dust was raised by the wind, which led to a higher concentration of 222Rn. However, the uranium tailings pond began to be managed since 1990s. The tailings and the dams were covered with clay and 0.8 m slate respectively, which may be regarded as one of important reasons for the low concentration of 222Rn in the two monitoring points.

3.2. Gamma concentration in the environment
For the gamma dose rate in the environment, each monitoring point was monitored twice a year, that was the first half and the second half of the year. 40 sets of data had been obtained as Figure 5 showed. According to Figure 5, in G1 point, the maximum gamma dose rate is 0.48μGy/h and the minimum one is 0.28μGy/h. The data is in an even distribution, mostly concentrated between 0.3 and 0.5μGy/h. The
radiation dose rate of the first half of the year was significantly higher than that of the second half of the year. G5 and G6 monitoring points obtained the opposite result, that is, the radiation dose rate of the second half of the year was significantly higher than that of the first half of the year. The potential reason might be the movement of milltailings, causing the increasing of radiation dose in dam surface. The maximum gamma radiation dose rate in G5 is 0.18μGy/h and the minimum one is 0.1μGy/h. The data reached a stable level between 0.12 μGy/h and 0.15μGy/h. The maximum gamma radiation dose rate in G6 is 0.28μGy/h and the minimum one is 0.15μGy/h. The data reached a stable level between 0.2μGy/h and 0.24μGy/h. G2 and G3 monitoring point monitoring data are relatively stable. There was little difference between the data of the first half of the year and that of the second half of the year. The average value is 0.37μGy/h and 0.10μGy/h respectively. In G4 monitoring points, the former 20 groups of data and the latter 20 groups of data varied greatly, that is, the first half of the year and that of the second half of the year had opposite performance. As for the specific reasons, it is still being studied.

![Figure 5. Gamma radiation dose rate in the monitoring area](image)

3.3. Annual effective radiation dose rates calculation
As there is no hospital and other facilities around the tailings pond area, the hospital occupancy time was not included in the calculation. Indoor and outdoor areas of residential buildings and workshops
were calculated as workplaces, while dam body was calculated as other place. The random radiation dose and gamma dose in the tailings pond were zoning calculated. The zoning model was as follows: the first zone (R2, R3, R4, G2), the second zone (R5, G3, G4, R4, R6, G5, and G7) and the third zone (R1, R8, G1, G6). The maximum and minimum date were taken out and the results were shown in Table 4. The annual radiation dose rates in the three monitoring zones were 0.12~0.16 mSv/a, 0.03~0.2 mSv/a and 0.05~0.17 mSv/a respectively. The maximum annual radiation dose and the minimum annual radiation dose appeared in the second zone.

| Site           | Max or min | 222Rneff. dose nSv/a | Gamma dose rate μGy/a | Total 222Rn &Gamma(mSv/a) |
|----------------|------------|-----------------------|------------------------|----------------------------|
| The first site | max        | 1.12                  | 154                    | 0.16                       |
|                | min        | 0.05                  | 115.5                  | 0.12                       |
| The second site| max        | 1.81                  | 196                    | 0.20                       |
|                | min        | 0.0054                | 31.5                   | 0.03                       |
| The third site | max        | 0.02                  | 168                    | 0.17                       |
|                | min        | 0.009                 | 52.5                   | 0.05                       |

### Table 2. Annual effective doses and gamma dose rates

3.4. Risk assessment based on available data

| Site           | Maximum dose (mSv/a) | Risk   |
|----------------|----------------------|--------|
| The first site | 0.16                 | Low    |
| The second site| 0.20                 | Low    |
| The third site | 0.17                 | Low    |

Although the three monitoring zones are near the uranium tailings pond, the maximum annual radiation dose is still far below the extremity of 30 mSv, otherwise relative intervention would be introduced. It can be seen that the tailings pond has little radiation effects on the surrounding environment, which can be ignored. However, thinking from researchers’ safety, the annual radiation dose inside the uranium tailings was not monitored and calculated. Based on current findings, gamma radiation dose on the tailings dam is large, the dose on the banks inside the pond may be large as well, so it’s advisable to strengthen the management of this tailings pond to keep human and livestock from staying here for a long time.

4. Conclusion

The scientific monitoring of the radioactive environment in the uranium tailings reservoir area is summarized as follows:

The south part of the uranium tailings pond is detected with the highest and lowest radiation dose of 222Rn. The maximum annual radiation effective dose reaches 1.81 nSv/a, and the minimum one is 0.0054 nSv/a. The south part of the uranium tailings pond is also detected with the maximum and minimum annual effective gamma radiation dose, which ups to 196 μSv/a and downs to 31.5 μSv/a. However, gamma and 222Rn radiation doses all don’t exceed the international standard, and therefore there is no radioactive risk to the surrounding residents. For the total annual maximum radiation dose, the maximum value in the three regions is 0.2 mSv/a, which is far below the international standard of 30 mSv/a. Although the annual radiation dose in the uranium tailings reservoir area would not pose a risk to the health of the surrounding population now, it’s advisable to take quarantine measures in in the area of uranium tailings pond to keep the surrounding residents away from unnecessary ionizing radiation.
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References
[1] Tripathi R.M., Sahoo,S.K., Jha,V.N., Jha, Khan A.H., Puranik V.D., 2008. Assessment of environmental radioactivity at uranium mining, processing and tailings management facility at Jaduguda, India. Applied Radiation and Isotopes 66, 1666-1670.
[2] Lespukh E., Stegnar P., Usubalieva A., Solomatina A., Tolongutov B., Beishenkulova R., 2013. Assessment of the radiological impact of gamma and radon dose rates at former U mining sites in Kyrgyzstan. Journal of Environmental Radioactivity 123, 28-36.
[3] Stegnar P., Shishkov I., Burkitbayev M., Tolongutov B., Yunusov M., Radyuk R., Salbu B., 2013. Assessment of the radiological impact of gamma and radon dose rates at former U mining sites in Central Asia. Journal of Environmental Radioactivity 123, 3-13.
[4] Lespukh E., Stegnar P., Yunusov M., Tilloboev H., Zyzayev G., Kayukov P., Hosseini A., Strømman G., Salbu B., 2013. Assessment of the radiological impact of gamma and radon dose rates at former U mining sites in Tajikistan. Journal of Environmental Radioactivity 126, 147-155.
[5] United Nations Scientific Committee on the Effects of Atomic Radiation, 2000. Sources and Effects of Ionizing Radiation. Report to the General Assembly of the United Nations with Scientific Annexes. United Nations Sales Publication, New York. E.00IX.3.
[6] ICRP, 1991. Ann. ICRP. 21. 1990 Recommendations of the International Commission on Radiological Protection, vol. 60. ICRP Publication.
[7] IAEA, 2003. Radiation Protection Against Radon in Workplaces Other than Mines. Safety Report Series. IAEA, Vienna.
[8] ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. Annals of the ICRP, Publication 103.