

VIET NAM NATIONAL UNIVERSITY, HA NOI
CENTRAL INSTITUTE FOR NATURAL RESOURCE AND ENVIRONMENTAL STUDIES

Proceedings of the International conference on
OCCUPATIONAL SAFETY,
HEALTH AND ENVIRONMENT

INTERNATIONAL CONFERENCE

The first Occupational Safety, Health and Environment (OSHE)

Hanoi, Vietnam October 24-26, 2024



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**VIET NAM PUBLISHING HOUSE OF NATURAL
RESOURCES ENVIRONMENT AND CARTOGRAPHY**

Proceedings of “Occupational Safety, Health, and Environment (OSHE2024)”,
October 24 – 26, 2024, Vietnam National University, Ha Noi
Central Institute for Natural Resources and Environmental Studies



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Study on the level of exposure to radioactive radon gas (^{222}Rn ; ^{220}Rn) on the people's health in the Sin Quyen copper mine area, Lao Cai

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Received: 30 Sept 2024

Revised: 25 Nov 2024; Accepted: 02 Dec 2024

Abstract: Radon and its isotopes are inert gases, they do not participate in any chemical compounds. Compared to thoron (Rn-220) and radon-219, the risk of radiation exposure of radon-222 is high due to its long half-life of 3.8 days, the half-life of thoron is 55 seconds and that of Rn-219 is 4 seconds. As a gas, radon can escape from the surface of ore minerals, rocks and can move far from the location of formation. The article determined the concentration of radon gas (^{222}Rn ; ^{220}Rn) in the air to assess the level of exposure to radioactive radon gas for people in the Sin Quyen copper mine area, Lao Cai.

The results of the assessment of the average annual exposure of workers in the working positions at the mine showed that the exposure was in the range of $0.062 \div 0.828$ WLM/y. This exposure level is relatively safe for the health of workers, however, if considered in the context of long-term exposure, it is necessary to consider measures to minimize the effects of radioactive radon gas (^{222}Rn ; ^{220}Rn) on workers working at the copper mine.

Keywords: Rn-222, Rn-220, radon exposure, radon risk, cancer

1. Introduction

In recent years, along with socio-economic development, many environmental problems have

arisen, including the problem of radioactive environment related to mineral exploitation activities. In particular, radioactive gas radon

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(^{222}Rn ; ^{220}Rn) from mining activities can cause serious impacts on the environment and human health [1-4].

Radon gas is present in most places in the earth's crust, escaping from soil and rocks through cracks, holes, faults, underground water veins into the air by diffusion and convection. Radon exists in high concentrations in areas of radioactive mineral mines, radioactive minerals, mines, in houses, especially in closed rooms such as bedrooms, offices; and in construction materials. This is a type of gas that international organizations such as the American Lung Association and the US Environmental Protection Agency (EPA) have classified as a carcinogen with effects on human health.

The main hazard of radioactive radon gas to health is the exposure of alpha radiation during the process of breathing and eating. Radon has also been identified as being related to many deaths from lung cancer and is suspected to be related to some other types of cancer such as leukemia, malignant tumors, kidney cancer and some childhood cancers. Epidemiological

investigations and studies show that radon can penetrate the body, dissolve in fat cells and blood in the same way that oxygen enters the blood [5-9]; as a result, it accumulates in fat cells of the bone marrow; In other words, radon enters the human body like plants absorb sunlight silently and leaves unpredictable consequences [10, 11]. Among cancers, lung cancer is considered the most dangerous because the number of deaths is among the highest [10].

Radon exposure does not cause acute illness, irritation, or early warning signs compared to other common environmental risks. However, concentrated radon exposure increases the risk of lung cancer, especially in smokers. This risk increases with the radon concentration, the length of exposure, and the amount of tobacco smoked [10, 11].

Some studies have shown that radon is a related cause of leukemia, skin cancer, melanoma, kidney cancer in children, and some other cancers. These studies are based on statistical analyses of indoor radon and the range of cancer effects [11]. The main harm caused by chronic exposure to radon is lung cancer



(usually arising from the bronchi), including: pulmonary fibrosis, chronic obstructive pulmonary disease, pneumoconiosis, respiratory damage.

The paper presents the results of a survey on radon gas concentration and an assessment of radon exposure risks for residents and workers living and working at the Sin Quyen copper mine, Lao Cai.

2. Geological and mineral characteristics of the study area

Sin Quyen copper mine is located in Bat Xat district, Lao Cai province, with geographical coordinates of 22°37'20" North latitude, 103°45'50" East longitude. The ore area is located on the northeastern slope of Hoang Lien

Son mountain range in Lao Cai province, on the right bank of the Red River, right next to the Vietnam - China border, 1-3 km from the Red River and 25 km southeast of Lao Cai. The mountainous terrain extends from the Northwest to the Southeast. Geological features of the area include the Suoi Chieng formation (PPsc), Sin Quyen formation (PP-MPsq), Ban Nguan formation (D₁bn), Cha Pa formation (NPcp), Ban Pap formation (D₁₋₂bp) (Figure 1). The copper content in this ore type ranges from 0.1 to 4.7%; the rare earth content is < 1%. In primary copper ore, radioactive elements such as uranium, thorium... U₃O₈ content reaches 0.005–0.265%; ThO₂ content reaches 0.006–0.03% [15, 16].

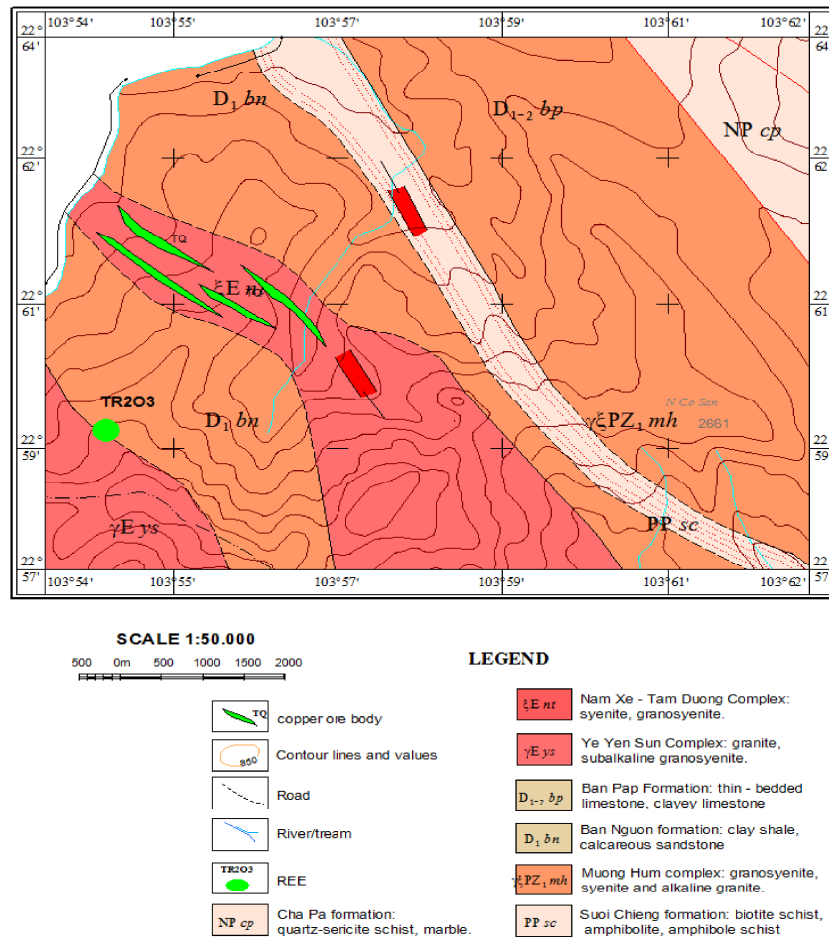


Figure 1. Geological and mineral map of the survey area [16].

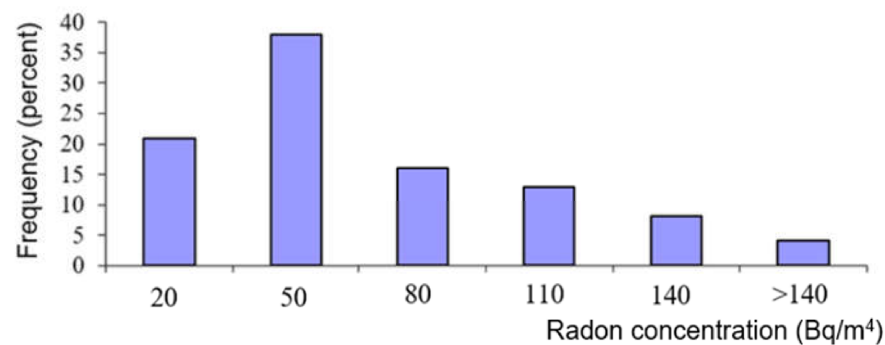


Figure 2. Radon concentration distribution graph of Sin Quyen copper mine

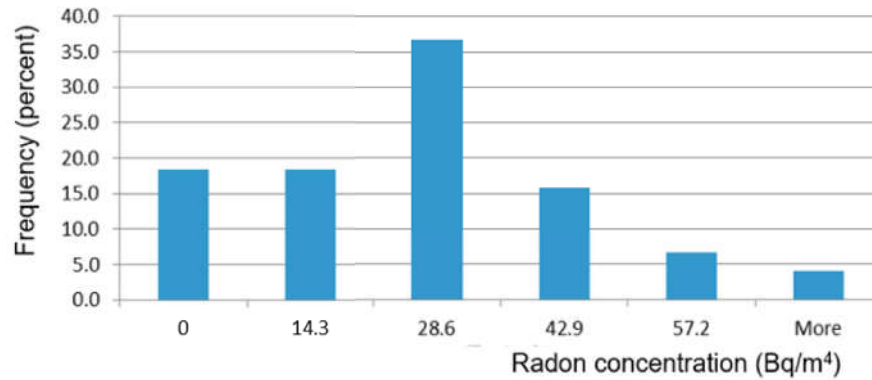


Figure 3. Radioactive gas concentration for residential houses

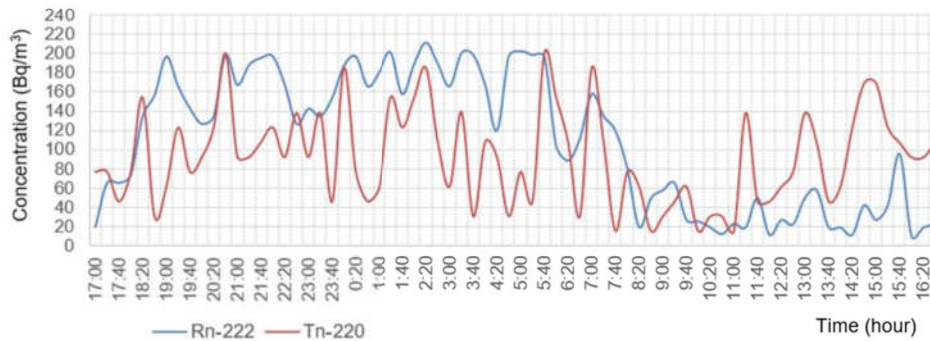


Figure 4. Radon gas monitoring by day and night

Table 2. Results of radon exposure assessment

Position	Exposure			
	Bq/m ³	pCi/l	WL	WLM/y
Mining area	431	11.64	0.116	0.828
Workshop area	136	3.67	0.037	0.254
residential area	28.6	0.95	0.009	0.062

3. Research method

3.1. Survey of radon gas concentration in the research area

Survey of radon concentration in the air in the research area, to

assess the spatial distribution of radon at the Sin Quyen copper mine and neighboring residential areas.

From there, determine the internal dose level caused by



radioactive radon gas according to the following formula [17-19]:

$$H_t(\text{mSv} \cdot \text{year}^{-1}) = 0.047 \times C_{\text{Rn}}(\text{Bq} \cdot \text{m}^{-3}) \quad (1)$$

where H_t is the internal radiation dose caused by radon in the air and $C_{\text{Rn}}(\text{Bq} \cdot \text{m}^{-3})$ is the concentration of radon in the air.

3.2. Calculating cumulative radon exposure

Accumulated exposures are defined as all activity levels (WL) multiplied by the exposure time. In the exposure assessments, this cumulative exposure is calculated by exposure for 1 month (or 170 working hours) [10, 20, 21]. Cumulative exposure is calculated using the following formula [10]:

Average exposure rate value is estimated for one year:

$$EX = \frac{C \times F}{100} \quad (3)$$

where EX is the average exposure rate estimated in a year (WLy^{-1}); C is the average radon concentration ($\text{pCi} \cdot \text{l}^{-1}$ or $\text{Bq} \cdot \text{m}^{-3}$); F is the coefficient of balance between radon and its products, e.g., $F=0.6$ in the mine.

At a concentration of 1 $\text{pCi} \cdot \text{l}^{-1}$, the exposure to offspring is calculated by:

$$EX = 1 \text{pCi} \cdot \text{l}^{-1} [0.6 \times 0.01 \text{WL} (\text{pCi} \cdot \text{l}^{-1})^{-1}] \times [12 \text{WLM} (\text{WLy})^{-1}] = 0.072 \text{WLM/y.} \quad (4)$$

At a concentration of 1 $\text{Bq} \cdot \text{m}^{-3}$, the exposure of descendants of radon is calculated by the formula:

$$EX = 1 \text{Bq} \cdot \text{m}^{-3} [0.6 \times 0.00027 \text{WL} (\text{Bq} \cdot \text{m}^{-3})^{-1}] \times [12 \text{WLM} (\text{WLy})^{-1}] = 0.00194 \text{WLM/y} \quad (5)$$

, (2)

where WLM is cumulative exposure; $(\text{WL})_i$ is the average concentration of radon and offspring during exposure; and t_i is the total exposure time with 1 $\text{WL} = C_{\text{Rn}}(\text{Bq} \cdot \text{m}^{-3}) \times 0.00027$.

The above formula is used for calculating cumulative exposures over time intervals with concentrations corresponding to those time periods. However, due to the limitations of research time and statistical data systems over a short time period, this article only intends to show the general method and calculation of the assessments for radon exposure in workers in different positions [10].



3.3. Assessing health risks due to radon exposure for officials and workers working at Sin Quyen copper mine

To assess the risk of radon exposure for officials and workers at the Sin Quyen copper mine, the authors used the risk calculation model under the guidance of EPA (2009) to use a single model instead of 2 models like BEIR VI (NAS) [10] because the two previously proposed models almost all depend on the age and time of exposure. EPA uses a concentration model for risk calculations because a concentration model can assess the health effects of exposure at levels that change over time.

In BEIR VI, the risk/WLM is

$$ERR = \beta \times (w_{5-14} + \theta_{15-24} \times w_{15-24} + \theta_{25+} \times w_{25+}) \times \phi_{age} \times y_z \quad (6)$$

where ERR is an assessment of the level of risk; β is the risk factor; w_{5-14} , w_{15-24} , w_{25+} are exposure at ages 5-14; 15-24, and 25 years or more, respectively; θ_{5-14} ; θ_{15-24} ; θ_{25+} are the risk that is relatively dependent on the time the exposure is initiated; ϕ_{age} describes the dependence on the age achieved; for mine workers and for retired people at 55 years old, $\phi_{age}=1.0$ and with retirement age of 60, $\phi_{age}=0.57$; y_z is

6.52×10^{-4} for the concentration model and is 4.43×10^{-4} for the time period model. The EPA has calculated the concentration model so that the risk/WLM will be equal to the geometric significance of these two values, i.e., 5.38×10^{-4} . The risk factor according to the concentration model is $\beta = 0.0768 \times (4.43/6.52)^{0.5} = 0.0634$, and the risk/WLM is $5.38 \times 10^{-4} \approx (6.52 \times 10^{-4}) \times (4.43/6.52)^{0.5}$ [10].

The concentration model indicates that the relative risk of excess exposure depends on the time the exposure was initiated, the age reached, and the rate of exposure (concentration) as follows [10]:

the classification from 1 for exposure $< 0.5WL$ to 0.11 for exposure $> 15WL$, which describes the exposure speed dependence. For this calculation, since all WL values are < 0.5 , $y_z = 1$.

Setting $\beta^* = \beta \phi_{age}$ and using the parameters shown in Table 1, the authors estimate the parameters for the risk model [10] with the following equation for calculating the excess relative risk:



$$ERR = \beta^* \times (w_{5-14} + 0.778w_{15-24} + 0.51w_{25+}) \times \phi_{age}, \quad (7)$$

where $\beta^*=0.0768$ for age $x < 55$ y; $\beta^*= 0.0438$ for age $55 \leq x < 65$ y;
 $\beta^*=0.0223$ for age $65 \leq x < 75$ y; and $\beta^*=0.0069$ for age $x \geq 75$ y.

Table 1. Estimated parameters for concentration model [10]

Concentration model ($\beta \times 100 = 7.68$)	
Time of exposure	$\theta_{15-24} = 0.78$
	$\theta_{25+} = 0.51$
Where β^*	0.0768 for $x < 55$ y
	0.0438 for $55 \leq x < 65$ y
	0.0223 for $65 \leq x < 75$ y
	0.0069 for $x \geq 75$ y

4. Results and discussion

4.1. Characteristics of radon concentration in air

The results of the survey document processing show that the concentration of radon in air ranges from 15 to 240 Bq/m³, with a maximum value of up to 300 Bq/m³ (Figure 2).

The area with high radon concentration is mainly concentrated in the mining area where copper ore is being exploited and in some boreholes used for blasting. This is the area where people work in the mine area, with

an average radon concentration of 46.7 Bq/m³.

4.2. Characteristics of radon concentration in the surrounding residential area

The concentration of radon in the surveyed residential area is shown in Figure 3.

Figure 3 shows that the radon gas concentration value in neighboring residential areas ranges from 8.7 to 135 Bq/m³, with an average of 28.6 Bq/m³, within the permissible limit compared to the world average indoor radon concentration (37 Bq/m³) as



recommended by UNSCEAR [22].

4.3. Results of monitoring radon gas concentration by day and night

The author has monitored the change in radon gas concentration by day and night in the mine and residential areas. At the monitoring point, continuous measurements are conducted for 24 hours a day, recording data every 20 minutes, using a RAD-7 device. The monitoring results are shown in Figure 4.

From Figure 4, shows that:

- *Radon(²²²Rn) gas concentration:* the day-night variation of Rn-222 concentration, fluctuates between 25 and 170 Bq/m³, the highest is up to 211 Bq/m³. The highest is from 8:00 pm. to 9:00 am., the lowest is from 10:00 am. to 6:00 pm.

- *Thoron(²²⁰Rn) gas concentration:* the variation is different from the rule of Rn-220, high at noon and gradually decreases at night, fluctuates between 40 and 180 Bq/m³, with an average value of about 70 Bq/m³,

the highest amplitude reaches 205 Bq/m³ at 10:00 am. during the day.

4.4. Assessment of radon exposure in the study area

From the results of the survey of radon (²²²Rn) concentration in the study area, the study assessed the radon exposure level in the mining area and the surrounding residential area. The results are presented in Table 2.

The results of the average annual exposure assessment of workers in the mine and the surrounding residential area showed that the exposure was in the range of 0.062 ÷ 0.828 WLM/y. This exposure level is relatively safe for the health of workers and residents, however, if considered in terms of long-term exposure, it is necessary to consider and assess the impact of radon (²²²Rn) in the study area.

4.5. Radon exposure risk assessment

The results of the risk estimates for workers at the Sin Quyen copper mine are presented in Table 3.



Table 3. Estimation of risks at job locations at Sin Quyen copper mine

Relatively risk Position	EER (%)	WLM/y
Field workers	147	0.828
Classification worker	119	0.711
Workers loading and transporting vehicles	117	0.651
Workers in the disposal area	35.2	0.181
Workshop workers	42.6	0.254
Office staff	0.68	0.828

Table 3 shows that the above model is applicable to risk calculations with long periods of time and different stages are carefully observed for radon concentration and exposure in each stage. However, due to the conditions and the measurement of exposure was conducted in a short period of time, the author only determined the health risks for some working positions under exposure conditions at an average measured concentration.

5. Conclusion

The article has determined the characteristics of radon gas concentration (^{222}Rn ; ^{220}Rn) in the air in the Sin Quyen copper mine area and neighboring residential

areas, in order to assess the level of exposure to radon radioactive gas and protect public health.

The results of the assessment of the average annual exposure of workers in the mine's working positions and neighboring residential areas show that the exposure is in the range of $0.062 \div 0.828$ WLM/y. This exposure level is relatively safe for the health of workers and residents, however, if considered in long-term exposure conditions, it is necessary to consider and evaluate the impact of radon radioactive gas (^{222}Rn) in the study area.

To assess the impact of radioactive radon gas (^{222}Rn ; ^{220}Rn) on the study area, it is necessary to



have programs to investigate sociology, environmental health and the impact of radiation on human health in the mining area to have a basis for a full, comprehensive and accurate assessment of the rate of radiation-related diseases, especially the

impact of radon gas. From there, there will be specific solutions to minimize the impact of radiation in mineral exploitation and processing activities in the mine, and have reasonable policies in planning residential areas and using land and water resources in the area.

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23. ANNEX A: Dose assesment methodologies
24. ANNEX B: Exposures from radiation sources.

ISBN 978-604-4986-69-2



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