Journal of Marine Science and Technology; Vol. 17, No. 4B; 2017: 130-137
DOI: 10.15625/1859-3097/17/4B/12735
http://www.vjs.ac.vn/index.php/jmst

THE INCREASE OF RADIATION DOSES DUE TO EXPLORATION ACTIVITIES IN YEN PHU RARE EARTH DEPOSIT, YEN BAI PROVINCE, NORTHERN VIETNAM

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Received: 2-11-2017

ABSTRACT: Yen Phu rare earth deposit covering over 0.7 km^2 in Yen Bai province, Northern Vietnam contains heavy elements bearing radioactive materials. The area has been studied based on data of several thousand meters of boreholes, 2000 m^3 of trenches, shallow shafts, and thousands of rock samples. This article shows the results of radioactive measurements and analysis by regular grids before and after exploration activities. The investigated area has been divided into two different subunits characterized by different levels of the radiation dose. It can be observed that after the exploration process, equivalent dose increases by 1.2 mSv/y and reaches recent value of 9.9 mSv/y. This value is still below the acceptable value according to the ICRP regulations, however, it should be noted that the increase can exceed the critical value during industrial production and processing. Therefore it will be necessary to undertake investigation and implementation of radioactive monitoring system to maintain the safety for people.

Keywords: HREE (heavy rare earth element) deposit, radiation dose, radon concentration.

INTRODUCTION

In the world, there are some scientific researches on the increase in the radioactive contents and radiation doses caused by the activities of the exploration, exploitation and processing for minerals containing radioactive materials in general and rare earth minerals in particular.

The researches on the radiation-ecological problems of mineral-material exploitation at deposits [1] has resulted in the determination for radon concentrations and the annual effective radiation doses in the open-pits and mining enterprises.

The data in Table 1 shows that:

More than half the number of the non-uranium ore mines, the individual radiation doses for Group B workers exceed the limit dose (5 mSv/y).

24% of the ore mines have exceeded the limit dose for the radiation staff (20 mSv/y), as well as some mines reaching the doses of 90 mSv/y and 740 mSv/y in maximum.

At the rare earth ore mines, the average values of radiation doses and thoron equilibrium concentrations are higher than at other ore mines. That confirms the strong relationship between rare earth ores and radioactivity mainly thorium in nature.

The researches in the UK also show that the average radiation dose (7 mSv/y) for the staff at nuclear fuel processing enterprises is significantly lower than that (26 mSv/y) in the mines of poly-metal mines and other non-uranium mines (except coal mines) [2].

The previous researches in Vietnam have mentioned only in the investigation, survey and evaluation for natural radiation environment. The Vietnam-Poland bilateral scientific cooperation project, code number 01/2012/HD-HTQTSP, was first assigned the task of evaluating the environmental impact of radioactivity caused by the activities of exploration, mining and processing for radioactive minerals in Vietnam.

This report gives an urgent problem to study the increase of radiation dose caused by the exploration activities at Yen Phu rare earth mine (Yen Bai province) to ensure radioactive safety on production and health protection for mine staff and local people.

Table 1. General results of the researches on radiation status in the open-pits and mining enterprises [1]

Ore mines	**Equivalent equilibrium concentrations** Bq/m^3 Radon	Thoron	**Radioactivity (X, µR/h)**	**Annual effective radiation doses (H, mSv/y)**
Copper ore	< 10-67 (19)	0.2-2.1 (0.7)	6-10 (8)	< 0.2-1.2 (0.4)
Coal	< 10-960 (42)	0.2-6.0 (1.9)	4-22 (9)	< 0.1-15 (0.7)
Gold and gold placer	10-1000 (83)	0.2-6.2 (1.9)	8-32 (17)	< 0.1-33 (1.6)
Non-ore minerals	< 10-2300 (270)	0.8-36 (8)	6-50 (17)	< 0.1-37 (6.3)
Rare earth ore	< 10-5800 (430)	0.3-30 (3.1)	6-140 (21)	< 0.1-94 (7.4)
Polymetal ore	< 10-48000 (570)	0.2-8.2 (2.6)	4-45 (11)	< 0.1-180 (9.3)
Iron ore	< 10-48000 (590)	0.2-12 (2.8)	5-300 (13)	< 0.1-450 (10)
Uranium open-pits	≥ 10000		≥ 1000	≥ 50

Notes: Values in parentheses ( ) are the means; H: Annual effective radiation doses based on calculation.

GEOLOGY-MINERAL CHARACTERISTICS AND EXPLORATION SITUATIONS AT YEN PHU RARE EARTH MINE

Geology-mineral characteristics

Yen Phu rare earth ore deposit was discovered by magnetic survey. Fergusonite, xenotime, and monazite… are the main rare earth minerals. Especially the heavy rare earth elements (HREE) and niobium-rare earth group minerals are dominant. Hydrothermal genesis is considered as process for this mine [3].

There are two rare earth ore bodies (named TQ.1 and TQ.2) in this mine. Quartz-rare earth magnetite is the most dominant mineral. There are rocks of quartz-sericite-carbonate schist and sericite shale belonging to Song Mua formation, as alternated or contacted with ore bodies.

Two rare earth ore bodies are not large in size, ventricular in form on both surface and vertical cross section. On the surface, two ore bodies occupy most of the mine area. Ore bodies are mostly weathered, and the weathering degree decreases with depth increases. From the top to the bottom, there are two weathering zones as follows:

Strongly weathering zone: compositions of diluvia, fluvial materials covering the surface of ore bodies with the thickness of 0.5 - 4.5 m, commonly from 1.5 m to 3.0 m. This zone consists of strongly-weathering products from rocks and ores. There are some parts completely weathered as the brownish, reddish, and porous soils with scattered boulders, debris of magnetite, quartz, rocks.

Moderately weathering zone: compositions of most of ore body mass. The thickness of zone is quite large, from a few meters to sixty meters. The weathering level in depth is reflected in color from brownish-yellow, reddish-brown to brown, dark-brown. The rock structures are determined still rather clearly as well.

Characteristics from two rare earth ore bodies are described as follows:

TQ.1 (1st ore body): Located in the center of the mine area, lens-shaped, it is about 260 m long, 190 m wide and prolonging as the Northwest - Southeast line. In vertical cross section, TQ.1 looks like the lens with the thickness from a few meters to sixty meters. The ore body's thickness reduces in two ends.

This ore body consists mainly of quartz - magnetite containing rare earth elements (REE), alternated with different layers of rock such as feldspar-sericite schist, quartz- sericite schist, siliceous shale, lime shale ... with thickness from tens of centimeters to tens of meters. They are moderately weathered. Most of the schist layers are alternating of the quartz - magnetite containing REE in the form as disseminations or stock works. Thus, these schist layers become a part of the ore body. Somewhere the TR_2O_3 contents are over 1%. At current terrain, TQ.1 is distributed at the altitudes of 30 m to 135 m.

According to the results from 1942 chemical samples, TR_2O_3 concentration ranges from 0.01% to 8.62% TR_2O_3, average of 1.18%; variation of contents (Vc) = 73.49%.

The ICP-analysis results of 176 samples have showed the average contents of REE as follows: La = 9.55%; Ce = 23.67%; Pr = 4.31%; Nd = 19.87%; Sm = 14.51%; Eu = 0.51%; Gd = 9.40%; Tb = 0.58%; Dy = 3.08%; Ho = 0.39%; Er = 3.16%; Tm = 0.09%; Yb = 0.97%; Lu = 0.04%; Y = 9.88%. The HREE oxides consist of 31.29% compared to total rare earth oxides (TR_2O_3).

Iron: Analysis results of 98 samples show the total iron contents (TFe) from 2.55% to 56.53%, average 33.28%; Vc = 39.10%.

Niobium: Nb_2O_5 from 0.01% to 0.23%, average 0.03%; Vc = 111.78%.

TQ.2 (2nd ore body): Located in the southwest of the mine area, ventricular form, about 140 m long, over 70 m wide, extending in the direction from northwest to southeast. In the vertical cross section, the ore body looks like a basin in shape, the thickness of 30 meters at most. TQ.2 consists mainly of quartz - magnetite containing REE. In addition, the ore bodies are alternated with several layers of different rocks such as shale, siliceous shale, sericite shale, thin layer quartz-sericite-calcite schist, quartz-sericite schist. They are weathered, with weathering thickness from tens of centimeters to tens of meters. Most of the schist layers contacted to quartz - magnetite containing rare earths in the form as disseminations or stock works. Thus, these schist layers become a part of the ore body, similar to TQ.1. In some places, the TR_2O_3 concentration is over 1%. TQ.2 is distributed at the altitudes of 60m to 160 m.

Results from 408 chemical samples show that concentration of TR_2O_3 ranges from 0.01% to 3.70% , average of 0.76%; Vc = 82.63%.

The ICP-analysis results from 24 samples show that the average contents of REE: La = 7.21 %; Ce = 25.72 %; Pr = 2.96 %; Nd = 15.26%; Sm = 13.57%; Eu = 0.40 %; Gd = 10.65%; Tb = 6.62 %; Dy = 2.20%; Ho = 0.39 %; Er = 1.49 %; Tm = 0.05%; Yb =0.95%; Lu = 0.04 %; Y = 8.50 %. The HREE oxides occupy 29.11% compared to total rare earth oxides.

Iron: Analysis results of 24 samples show the total iron contents (TFe) from 11.66% to 43.00%, average 29.91%, Vc = 28.52%.

Niobium: Nb_2O_5 from 0.01% to 0.04%, average 0.02%, Vc = 37.95%.

Exploration history in Yen Phu mine

From 1986 to 1991, Geological Division 150 (the member of Division on Radioactive and Rare-earth Minerals) has carried out the project “Searching for radioactive - rare earth ores at Yen Phu area” by the author Pham Vu Duong [3].

The exploration activities have been implemented as follows:

Geo-mineral and hydro-geological mapping at scale of 1:1000 on the area of 0.753 km^2.

Geological drilling 983 m long.

Hydro-geological drilling 90 m (1 borehole).

Digging wells (to 20 m deep, 2 wells).

Digging trenches (to 8 meters deep), a total of 2,001 m^3 in volumes.

Analyzing several samples of various kinds.

Gamma-ray measurements at trenches and wells: 17,352 points.

Gamma-ray measurements on drilling cores: 7,882 points.

Spectrometric gamma-ray logging: 1,028.5 m.

METHOD TO STUDY THE INCREASE ON RADIATION DOSE CAUSED BY EXPLORATION ACTIVITIES

The increase on radiation dose caused by exploration activities is determined according to the radioactive environment survey data, carried out at two times: before and after exploration activities.

Before exploration activities, 284 points of gamma radiation dose rates (GDR) and 135 points of radon concentrations in air were measured to determine the local natural radiation background.

After exploration activities, 299 points of gamma radiation dose rates and 156 points of radon concentrations in air were measured to determine the increase in radiation dose caused by exploration activities.

Making geological sections and contour maps on radioactive environment parameters, before and after exploration

To overview wholly the increase of radiation dose, we generate the contour maps of gamma radiation dose rates before and after exploration activities, and vertical section of profile No. 89 displaying the ore bodies and graphs of the gamma radiation dose rates, radon concentrations in air, which are measured before (fig. 1) and after (fig. 2) exploration activities:

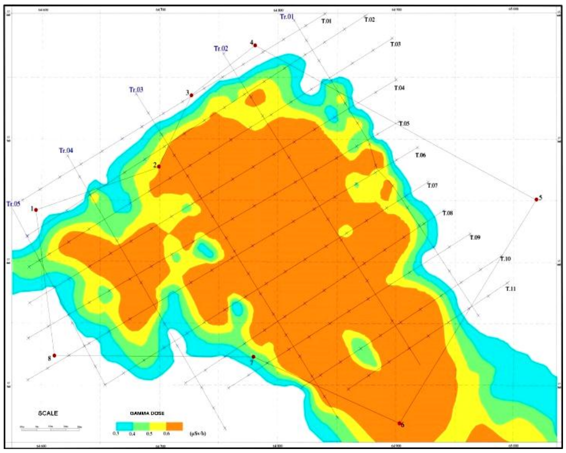


Fig. 1. Contour map of gamma radiation dose rates before exploration activities

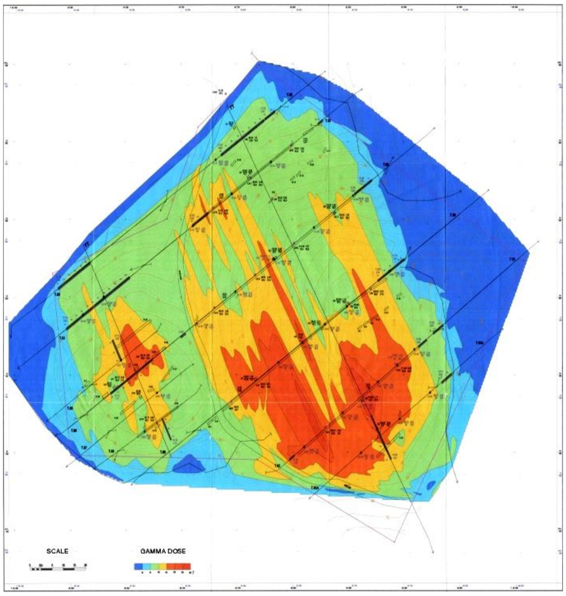


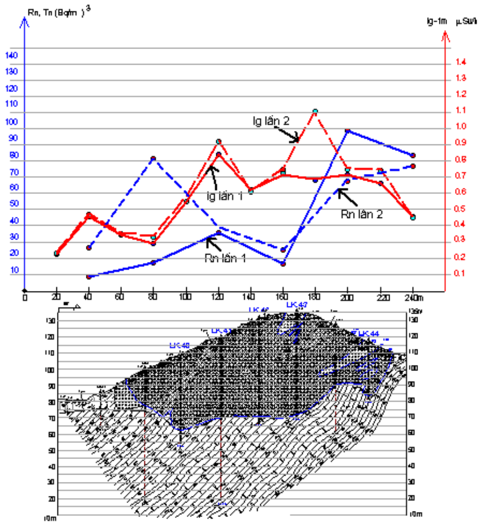
Fig. 2. Contour map of gamma radiation dose rates after exploration activities

Before exploration activities: The GDR values vary from 0.3 to 0.6 µSv/h and more, average of 0.53 µSv/h. In the most area of the mine GDR values rise up more than 0.6 µSv/h.

After exploration activities: The GDR values vary from 0.05 to 2.6 µSv/h, average of 0.84 µSv/h. In the most area of the mine GDR values range from 0.4 to 1.3 μSv/h. In the area of two ore bodies, GDR rates range from 0.9 to 2.6 μSv/h.

In the area of two ore bodies, it can be seen that the GDR values have increased much more than before exploration activities. The expansion of the gamma anomalies at the Yen Phu mine is resulted from the exploration activities.

Comparing the radon concentrations, GDR measured before with after exploration activities (fig. 3), we can see that:



——— Radon concentration in air measured before exploration (Bq/m^3);

- - - Radon concentration in air measured after exploration (Bq/m^3);

——— Gamma radiation dose rate measured before exploration (μSv/h);

- - - Gamma radiation dose rate measured after exploration (μSv/h).

Fig. 3. Vertical geo-radioactive section No. 89

Before exploration activities: Radon concentrations in air vary from around 36 Bq/m^3 to 82 Bq/m^3, average value is 44 Bq/m^3 (Hp_{before} = 44 * 0.047 = 2.1 mSv/year).

After exploration activities: Because of ore excavations, radon gas is dispersed, so radon concentrations in air increase, the values range from 39 Bq/m^3 to 68 Bq/m^3, average value is 53 Bq/m^3 (Hp_{after} = 53 * 0.047 = 2.5 mSv/year).

The GDR values measured at 1m elevation on the same site, before and after exploration, change insignificantly. The average value of before-exploration GDR is 0.54 μSv/h compared with after-exploration one of 0.60 μSv/h. The highest increase in GDR is found (increasing value of 0.4 μSv/h) at the location of new borehole.

Determining the additional radiation doses by the means calculated before and after exploration

To determine the additional radiation doses (ARD) for radioactive influences, it is necessary to get the means of GDR values in the mine. The data is collected before and after exploration activities. These means are calculated from the network points regularly distributed over the area. In fact, the radioactive survey points have been distributed irregularly in the survey area. So we have used the method of dividing the survey area of Yen Phu mine into equal grid. For every cell, the means of GDR and radon concentration are calculated. Then the external and internal radiation doses are calculated consequently at the whole survey area.

Based on the contour map of GDR values, measured before exploration activities, we have divided the survey area of Yen Phu mine into 88 cells and calculated the mentioned parameters (fig. 1):

The number of cells having the means of GDR of above 0.65 μSv/h occupies 52.2% of the whole survey area, distributed in two ore bodies. The first ore body (TQ.1) consists of 47% of the whole survey area, located in the center of the survey area. The second ore body (TQ.2) consists of 5.2% of the whole survey area, located in the southwest of the survey area. Both ore bodies extend in the west-southeast direction.

The number of cells having the means of GDR from 0.5 to 0.65 μSv/h occupies 15.4% of the whole survey area, surrounding two ore bodies.

Correspondingly, the number of cells of GDR from 0.4 to 0.5 μSv/h - 18.8%; from 0.3 to 0.4 μSv/h - 8.8% ; under 0.3 μSv/h - 11.8% of the study area.

So we can calculate the mean of GDR at the whole survey mine area, before exploration activities:

$$H_{SLbefore} = 0.53\ \mu Sv/h$$

Then the mean of the external radiation dose at the whole survey mine area, before exploration activities [4]:

$$H_{Nbefore} = 0.53\ \mu Sv/h * 8760h = 4.6\ mSv/year$$

Similarly, based on the contour map on GDR, measured after exploration activities, we have divided the Yen Phu survey mine area into 62 cells and calculated the mentioned parameters (fig. 2):

The number of cells having the means of GDR of 2.25 μSv/h occupies 5% of the whole survey area, in the southeast.

Correspondingly, the number of cells of GDR of 1.3 μSv/h - 35.6%; 0.65 μSv/h - 40.4%; 0.32 μSv/h - 8.1%; and 0.13 μSv/h - 9,7% of the survey area.

So the mean of GDR at the whole survey mine area, after exploration activities:

$$H_{SLsfter} = 0.84\ \mu Sv/h$$

And the mean of the external radiation dose at the whole survey mine area, after exploration activities [4]:

$$H_{Nafter} = 0.84\ \mu Sv/h * 8760h = 7.4\ mSv/year$$

Similarly we calculate the means of the internal radiation doses at the whole survey mine area caused by radon in air (by inhalation), before and after exploration activities:

$$Hp_{before} = 2.1\ mSv/year$$

$$Hp_{after} = 2.5\ mSv/year$$

Based on these results, we can calculate the radiation doses, before and after exploration activities, then the additional radiation dose caused by the exploration activities at the Yen Phu rare earth mine.

Total equivalent radiation dose is calculated as the formula [5]:

$$H_{\Sigma}(mSv/year) = H_n + H_p + H_d$$

Where: H_{Σ}: Total equivalent radiation dose; $H_{n:}$ External radiation dose; H_p: Internal radiation dose by inhalation; H_d: Internal radiation dose by ingestion.

Table 2. Results of determination for the additional radiation dose caused by the exploration activities at the Yen Phu mine

Doses **Mine**	**Radiation doses, calculated before exploration activities (local radiation dose background) (mSv/year)**			**Radiation doses, calculated after exploration activities (current radiation dose) (mSv/year)**			**Additional radiation dose caused by the exploration activities (mSv/year)**
	H_n	H_p	H_{Σ}	H_n	H_p	H_{Σ}	
Yen Phu	4.6	2.1	8.7	7.4	2.5	9.9	1.2

Notes: Since there is no data for the analysis of radioactive substances in food and water samples, it results in a lack of data on internal radiation dose by ingestion; $H_{n:}$ External radiation dose; H_p: Internal radiation dose by inhalation; H_{Σ}: Total equivalent radiation dose.

Assessing the impact of radioactive environment caused by the exploration activities at Yen Phu mine

The assessment of the impact resulted from additional radiation doses for the environment and human health caused by exploration activities based on the following legal documents:

Recommendations of International Commission on Radiation Safety (ICRP) (1999) for natural radiation doses: The current radiation dose of 10 mSv/y is the critical value taking the interventions [5].

Yen Phu rare earth mine has conducted the exploration activities causing the increase of the radiation doses, considered as “the radiation works”. Therefore, it is necessary to be based on International Radiation Safety Standards (IAEA, 1996) and Vietnamese Standards (Circular 19/2012 of the Ministry of Science and Technology) [6, 7].

Due to the exploration activities, the total annual radiation dose (H_Σ) at Yen Phu mine is 9.9 mSv/y (table 1). Taking account of the contribution of the internal radiation dose by ingestion (H_d), the total current annual dose of Yen Phu mine will certainly exceed 10 mSv/y, consequently, it is necessary to have the interventions. It should be noted that the interventions here are understood as carrying out some procedures to reduce the radiation doses down to below 10 mSv/year. For reducing the external radiation doses, some solutions can be used: thick brick walls for houses, not building houses on the high level radiation places... For reducing the internal radiation doses (reducing the radon concentrations in air), it is necessary to live in the houses on stilts; the houses facing the southeastern direction for being airy; using fans as well...

Exploration activities at Yen Phu mine have resulted in the ARD of 1.2 mSv/y, exceeding the limit value of 1 mSv/y. According to the radiation safety standards of IAEA and Vietnam, the ADR is 1 mSv/y higher than the limit level for civilians, but it is too low for the radiation staff (the limit level of ARD for radiation staff is 20 mSv/year). Fortunately, there are no inhabitants at this mine area, so the impact of the current radioactive environment at the Yen Phu mine remains under the allowable limits of the radiation doses.

CONCLUSIONS

Based on dividing the area of the Yen Phu rare earth mine into equal cells, we have determined the values of radiation dose, calculated after exploration activities (current radiation dose) of 9.9 mSv/y, and the ARD of 1.2 mSv/y. Taking account of the contribution of the internal radiation dose by ingestion (H_d), the total current annual dose of Yen Phu mine will certainly exceed 10 mSv/y.

According to the recommendations of the International Commission on Radiation Safety (1999), the current radiation dose of 10 mSv/y is the level at which it is necessary to carry out the interventions for reducing the radiation dose down to below 10 mSv/year.

According to the radiation safety standards of IAEA (1996) and Vietnam (Circular 19/2012/TT-BKHCN), at Yen Phu mine, the ARD of 1.2 mSv/year is exceeding the safety standard for civilians (1 mSv/year) but still too low for the radiation staff (20 mSv/year). Fortunately there are no inhabitants in this mine area, so the impact of the current radioactive environment at the Yen Phu mine remains under the allowable limits of the radiation doses.

In the coming time, the Yen Phu rare earth mine will be put into the exploitation and processing, which will surely increase the radioactivity and radiation doses at this mine and the adjacent area. So it is necessary to survey the radioactive environment for determining ARD caused by mining and processing activities to ensure the radioactive safety for staff and human health.

The report is completed by collecting and processing data from Division on Radioactive and Rare-earth Minerals and research results of the Vietnam-Poland bilateral cooperation project No. 01/HD-HTQTSP.

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