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Influence of Radon Radionuclide for the Development of an Ultra-Low Background Gamma Spectrometer in an Underground Research Tunnel

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1. Introduction

An ultra-low background gamma spectrometry system (ULGS) based on a HPGe detector is an useful tool for a measurement of low-level radioactivity, but a background reduction is needed for achieving detection limits [1-3]. A background reduction at the surface level can be achieved by active shielding using an anticoincidence system for a cosmic-ray veto and passive shielding using selected materials including high purity lead. If possible, installation in an underground level is very good to reduce the background induced by cosmic rays. A system in a surface laboratory is difficult to achieve enough reduction of the background, and an underground system has one main disadvantage in that researchers or workers are inconvenienced in accessing from office to laboratory, even though the background reduction is enough. KAERI (Korea Atomic Energy Research Institute) has performed ultra low-level background spectrometry using an active and passive shield at a surface laboratory [4]. Based on our research experience of ultra-low level background system at a surface laboratory for many years, an underground gamma-ray spectrometry system is more effective for background reduction, but convenient access to an underground laboratory should be considered. The KAERI Underground Research Tunnel (KURT) is an infrastructure for a validation of the high-level waste disposal technology, which is located at a small mountain of KEARI. The geology of this mountain is composed primarily of granite. The ultra-low background system with passive and active shielding at KURT is developed, which is located underground with 156 m of water-equivalent below a surface level. Here, the influence of radon radionuclide is studied to test the performance of the developed system. Firstly, the background increase by radon radionuclide is examined, and secondly, a radiological dose assessment via radon radionuclides is evaluated.

2. Methods and Results

An ultra-low background gamma spectrometer (ULGS) at an underground laboratory using passive shielding and active shielding by an anti-coincidence method is designed. Fig. 1 shows KURT (KAERI Underground Research Tunnel), which is located within KAERI (Korea Atomic Energy Research Institute) so it is easy to access by workers or researchers. This system is installed at the middle of KURT and is located at a depth of 59 m granite rock from the ground-level. The water equivalent level is about 150 m depth.

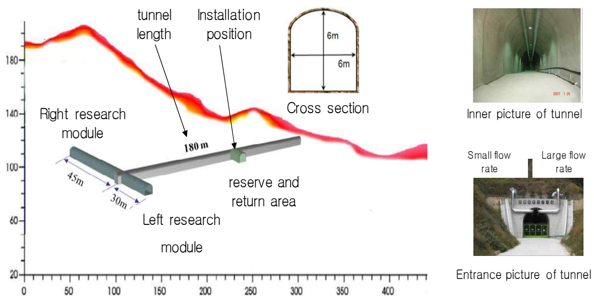

Fig. 1. KAERI underground research tunnel (KURT, ULGS will be installed at reserve and return area of KURT; depth from ground level is 59 m) and two type of ventilation equipment are shown at the entrance picture.

The designed ULGS is composed of a HPGe detector shielded by special materials including high purity lead, large plastic scintillation sensors as a guard detector for the background reduction, and electronic circuits for signal processing [5]. The lower right side of fig. 1 shows a ventilation system in KURT. There are two ventilation systems; one has small flow rate and the other has a large flow rate. Fig. 2 shows a block diagram of the designed system.

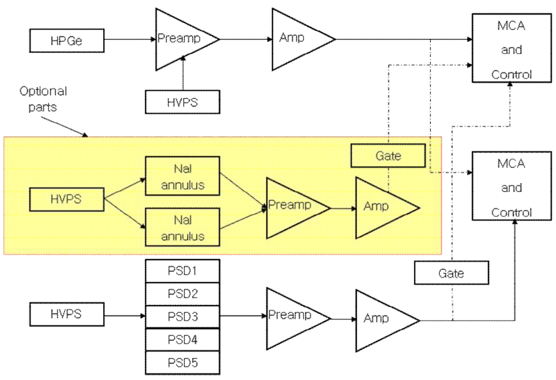

Fig. 2. Block diagram of the ultra-low gamma-ray background system designed at KURT (PSD stands for plastic scintillation detector, HVPS is high voltage power supply).

This system will have an additional optional function of Compton suppression if it is needed. The main detector of the ULGS consists of an intrinsic n-type germanium crystal of about 210 cm^3, fabricated by Canberra Company, with a relative efficiency of 50% and the energy resolution of 2.2 keV at 1.33 MeV energy. The passive shielding is composed of a lead shield of 10 cm thick, tin and copper to prevent interference by lead X- rays.

The underground ULGS has some advantage including background reduction, but it has a radon problem. To measure the radioactivity by radon and daughter radionuclides, an Alpha Guard detector manufactured by Genitron Co. is used.

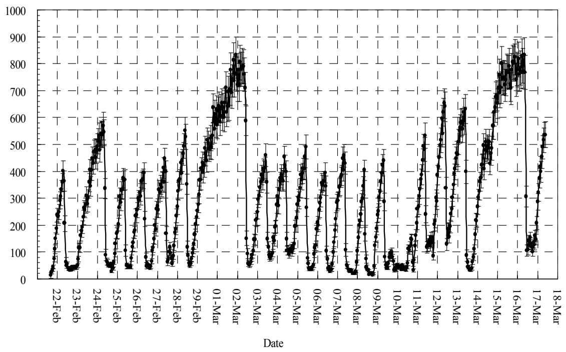

Fig. 3. The measurement of radon concentration at the KURT in Feb. 2008.

The fluctuation of radon concentration in KURT is measured as shown in Fig. 3. Radon concentration is the average value of 1 hour measurements, and an experiment time was between 2008 February 22nd and 2008 March 19th. The maximum value of 1 hour measurement data is 832 Bq/m^3 without ventilation operation and the total average value during the measurement time is 299 Bq/m^3. At night time, when the operation of the ventilation system is stopped, the average value is 370 Bq/m^3. However the average value of working time from 9 to 18 pm for operating ventilation equipment is 109 Bq/m^3. According to the measurement results from 2008 March 1st to March 3rd, the radon concentration is gradually increasing when the ventilation system is off for 3 days. The ventilation starting time is usually 9:00 am, and the radon concentration of the KURT after ventilating for 3 hours is similar with that value of the ground level. The average value from 12:00 until 18:00 is about 52 Bq/m^3. The difference in the concentration between with and without a ventilation operation is more than 7 times. From these results, the ventilation system should be operated during the operation of the ULGS for the reduction of background radiation and effective dose.

To assess the health risk of workers or researchers from high radon exposures in an underground laboratory, the effective dose concept applied in the UNCSEAR 1993 Report is used and expressed by equation (1).

$$H = Q \cdot F \cdot T \cdot K(Sv/yr) \qquad \text{Eq. (1)}$$

where Q is the radioactivity of radon (Bq/m^3), F is the equilibrium factor of 0.4 indoor and 0.6 outdoor, T is occupancy time ($8760 \times \frac{working\ time}{24} (hr/yr)$), and K is the dose conversion factor ($Sv/Bq \cdot hr \cdot m^{-3}$).

Here, the effective dose is calculated by Eq. (1) and the average value from 12:00 to 18:00. The calculated effective dose is 0.40 mSv/yr and is below the limit effective dose of public, which is 1 mSv/yr by Korea atomic energy law based on ICRP 60.

Q is 52 Bq/m^3, F is 0.4 indoor, T is 2190 hr/yr (working time is 6 hours), K is 9×10^{-6} mSv using UNCSEAR 93.

The extra exposure by work in KURT is very low when considering the background level at the surface. Therefore, the ULGS at KURT can be used like a laboratory at a surface level without extra dose exposure if it is sufficiently ventilated.

3. Conclusions

Underground radon concentration of day time with ventilation is similar with that of a ground laboratory. Therefore the background increase by radon will be solved using ventilation. Extra dose exposure by radon can be negligible in the day but time without ventilation has some problems. So the ventilation system for the experiment period in underground laboratory should be operated in order to protect extra dose exposure. This provides the effective solution of background increase induced by radon for the development of ULGS. By the usage of this proposed method, the ULGS will be equipped having convenient access as well as the enough background reduction.

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