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Design of Radiation Shielding Structure for Low-Background Gamma Spectrometry

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1. **Introduction**

An 80% high-purity germanium (HpGe) detector (CANBERRA GR8023) will be used at POSTECH as the basic tool for natural radioactivity measurements. Because of low level of natural radioactivity it's necessary to use, low-background gamma spectrometry for environmental researches. The background in gamma spectra comes from cosmic radiation, ^{238}U and ^{232}Th decay chains isotopes mainly gaseous ^{222}Rn and ^{220}Rn, gamma rays from other external natural radioactivity, radioactive impurities in the shielding structure, and so on. To reduce the background one have to use some radiation shielding materials such as lead, steel, copper, and so on. In addition, active shielding using anti-coincidence system can reduce cosmic muons background. Therefore, radiation shielding structure was designed for low-background gamma spectrometry.

In this paper, we discuss shielding materials for low-background shielding structure and calculate transmission ratio (TR) using the MCNP simulation code when the detector is shielded. We also briefly discuss the future plan for comparison in the ratio of detected background radiation at shielded to bare HpGe detector.

2. Design of radiation shielding structure

2.1 Determination of shielding materials

Table 1 shows various shielding structures. Several papers and reports were reviewed to determine shielding materials and their thickness. All references in Table 1 are using lead to shield external gamma radiation. Advantages of lead for shielding gamma radiation are large atomic number and high density. Tin and copper are widely used to reduce lead K shell X-rays. Typical graded Z shields have used lead-copper-copper as the shielding materials in order to absorb the lead X-ray and emit a secondary X-rays of lower energy [8]. Borated-paraffin or polyethylene is used to reduce background radiation generated by neutrons. The background radiation due to neutron is about 1.7% of that due to gamma ray [9]. Therefore, it was decided not to shield detector against by neutrons in the design of the shielding structure. Finally, lead, tin, and copper were selected as materials composing the shielding structure.

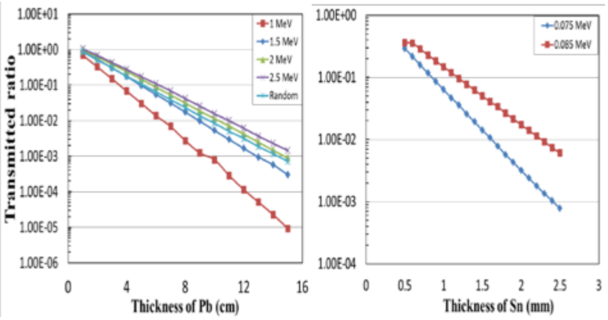
2.2 Determination of the thickness of materials

We used the MCNP simulation code to determine the thickness of materials. If TR (I/I_0) at a thickness of material is in the range of $10^{-3} \sim 10^{-2}$, we decided it as a design thickness according to Table 1. We simulated three different sources, such as γ-rays of 0.04 MeV ~ 2.6 MeV, 1-, 1.5-, 2-, and 2.5-MeV radiations, and random energies in the range of 0.5- to 3-MeV radiations, were shot to the shielding material. We can see that the thickness of lead is about 10 ~15cm as shown in Figure 1 (a). Tin layer is used to reduce photons due to about 0.08 MeV of K shell X-rays from the lead. To estimate the thickness of tin, we used photons with 0.075- and 0.085 MeV. The thickness of tin in order to reduce the K shell X-ray from lead is about 2.5 mm as shown in Figure 1 (b). Copper layer is used to reduce the tin X-rays with 0.025 MeV. The MCNP simulation result showed just 1 mm thickness of copper can reduce the transmitted ratio of tin X-ray to less than 10^{-4}.

Table 1 : Comparison of shielding structures in other references (mm)

Reference / Material	[1]	[2]	[3]*	[4]	[5]	[6]	[7]
Lead	120, ①	Ordinary (100), ① Low (50), ②	Ordinary (87), ② Low (15), ③	150, ①	<3 Bq/kg (76), ① <20 Bq/kg (76), ②	Roman (50), ③ Standard (100), ①	Plate (50), ② 130 ,③ < 20 Bq/kg (15), ⑤
Tin	3.5, ②	×	1, ④	×	1.5, ②	×	×
Copper	0.5, ③	50 ,③	1.5, ⑤	30, ③		×	4, ⑥
Steel	Wall (250)	×	10, ①	20, ②	steel room (152)	×	50, ①
Borated-paraffin or polyethylene	×	×	×	×	×	80, ②	100 , ④
I/I_0	$10^{-3} \sim 10^{-2}$	×	×	×	$\sim 10^{-3}$	×	$\sim 10^{-3}$

* Cylindrical shielding structure.
Circled number : Order from outside to inside.
I/I_0 : Ratio of background radiation at shielded detector to bare detector when the active shield is equipped



(a) (b)

Figure 1: Transmission ratio calculated by MCNP code as functions of thickness for (a) lead and (b) tin for various photon energies.

2.3 Design of radiation shielding structure

The shielding structure will consist with layers of lead, tin, and copper with calculated thickness from outside to inside. The thickness of each material is 100 mm, 3 mm, and 2 mm, respectively. The size and shape of the structure was determined by considering Marinelli beaker, which is often used to measure the environmental radiation. Therefore, the structure was designed to insert the detector in vertical direction and internal size of the structure is determined to be 250 × 250 ×300 mm^3 with 210× 210 mm^2 of sample inlet because the diameter of Marinelli beaker is 201 mm. An air tight-chamber will be made to fill with N_2 gas. It will remove radon gas contained in air.

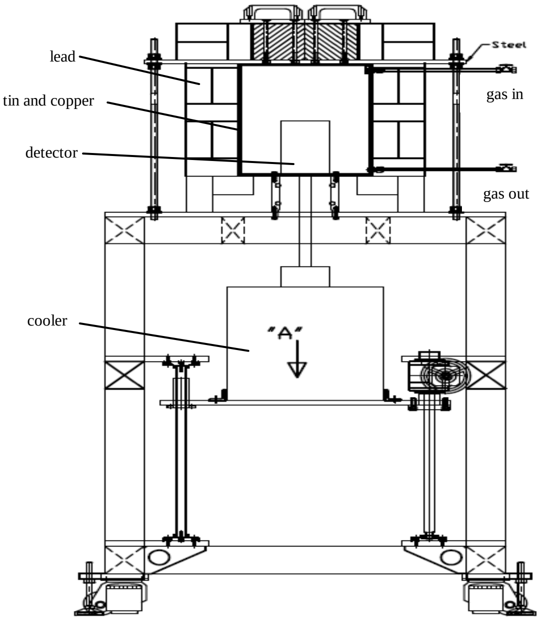


Figure 2 : The scheme of POSTECH shielding structure.

3. Summary and future plan

With reference to other papers and reports, materials of radiation shielding structure was determined. Then, the thickness of each material is determined by the MCNP code. It is expected to achieve the TR to be less than 10^{-2}. Nevertheless, the background of HpGe detector is needed to reduce further using active shielding. This structure will be upgraded using two or more plastic scintillators. These scintillators will be operated in anti-coincidence mode. In such a system, the background radiation by cosmic muons will be reduced.

The background radiation will be measured by shielded detector and non-shielded detector and the actual TR will be calculated by using these two values. Then, this TR will be compared with the results obtained by the MCNP simulation.

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