Comparison of Transmission Ratio as Existence of Shielding Structure for Low-Background Gamma Spectrometry

Y. U. Kye [a], S. G. Shin [a], W. Namkung [b], G. N. Kim [c], M. W. Lee [d], M. H. Cho [a, b*]
[a] *Department of Advanced Nuclear Engineering , POSTECH, Pohang 790-784, Korea*
[b] *Pohang Accelerator Laboratory, Pohang 790-784, Korea*
[c] *Kyungpook National University, Daegu 702-701, Korea*
[d] *Dongnam Inst. of radiological & Medical Science, 40 Jwadong-gil, Jangan-eup, Gijang-gun, Busan, Korea*
[*] *mhcho@postech.ac.kr*

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 a low-background gamma spectrometry for environmental researches. The background in gamma spectra comes from cosmic radiation, gaseous ^{222}Rn and ^{220}Rn from ^{238}U and ^{232}Th decay chains isotopes, gamma rays from other external natural radioactivity, radioactive impurities in the shielding structure, and so on. To reduce the background, it has to be used some radiation shielding materials such as lead, steel, copper, tin, and so on. In addition, active shielding using anti-coincidence system can reduce the background of cosmic muons.

In this paper, we discuss shielding materials for low-background shielding structure and calculate transmission ratio (TR) by comparing the amounts of radiation count between with and without shielding state.

2. Transmission ratio (I/I_0) comparison

2.1 Transmission ratio (I/I_0) by MCNP simulation

The MCNP code is used to determine the thickness of shielding materials. Advantages of lead for shielding gamma radiation are large atomic number and high density. Typical graded Z shields have used lead-tin-copper as the shielding materials in order to absorb the lead X-ray and an emitted secondary X-rays of lower energy [1]. 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 [2]. Therefore, it was decided not to shield detector against by neutrons in the design of the shielding structure. Tin and copper are widely used to reduce the K shell X-rays form the lead shielding. Finally, lead, tin, and copper were selected as materials composing the shielding structure.

The MCNP simulation has been performed with three different sources, such as γ-rays of 0.04 ~ 2.6 MeV and radiations with 1-, 1.5-, 2-, and 2.5-MeV, and random energies in the range of 0.5- to 3-MeV. Those gamma sources were shot to the shielding materials. 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. 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}.

Figure 1. shows the POSTECH shielding structure. The shielding structure consists of copper, tin, and lead. Their thicknesses are 2mm, 3mm and 150mm, respectively.

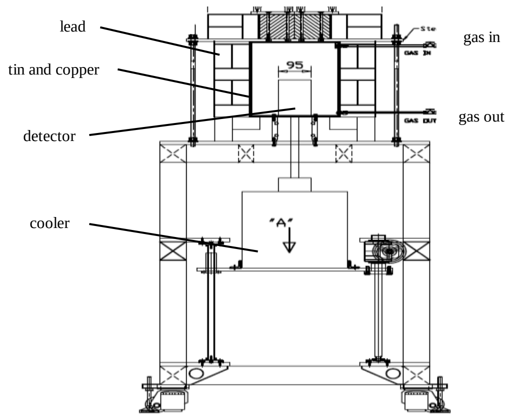

Figure. 1: The scheme of POSTECH shielding structure

2.2 Transmission ratio (I/I_0) measurement

The TR value was measured by comparing the amounts of count with and without shielding structure. Figure.2 shows the measured γ-rays spectrum according to the existence of shielding structure for 24 hours.

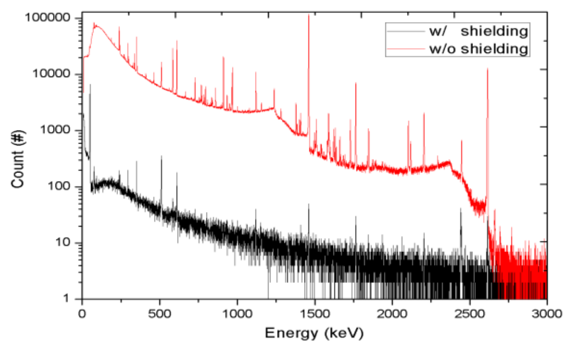

Figure. 2: The comparison of γ-rays counting number according to existence shielding structure

Table. 1 shows the total counting numbers and the calculated TR values at each energy interval of 15 ~ 2900 keV, 60 – 2900 keV, and 15-60 keV.

Table. 1: Total counting number and transmission ratio

E(keV)	w/ shielding(#)	w/o shielding(#)	I/I_0(%)
15 - 2900	246,949	46,846,016	0.527
60 - 2900	160,180	43,736,737	0.366
15 - 60	86,856	3,152,816	2.755

2.3 Analysis of photo-peaks transmission ratio (P/P_0)

Average energy and the sigma value of photo-peak were determined by Gauss-fitting. The photo-peaks of natural isotopes, which are Bi-204, Pb-214, Ac-228, Pb-212, K-40, and Tl-208, were compared to measure the transmission ratio.

Table. 2 shows their transmission ratios of the photo-peaks. Statistic properties are acquired by using the ROOT code. The transmission ratio of photo-peaks was calculated by comparing the area of peaks at same energy interval. The peaks are integrated at the $\pm 3\sigma$ region from the peak value.

Table. 2: The properties and transmission ratio of photo-peaks

	Gamma-ray energy(keV)	Peak mean (keV)	Sigma (keV)	P/P_0 (%)
K-40	1460.82	1460.51	0.97	0.0464
Tl-208	2614.51	2613.67	1.36	0.1879
Pb-212	238.63	238.56	1.02	0.3295
Pb-214	351.93	351.83	0.79	0.5637
Bi-214	2204.06	2203.44	1.42	0.6485
Ac-228	911.20	911.08	0.94	0.1978

*Gamma-ray energy from NNDC(http://www.nndc.bnl.gov/)

2.4 The comparison of transmission ratio (I/I_0) with other reference

The TR value depends on shielding structure. The TR values according to energy interval are compared with other literatures [3, 4]. The values are on Table. 3. The shielding system of the reference [4] is set up to the detector shielded with passive shielding flushed with nitrogen gas. In case of the reference [3], the shielding system is set up to passive shielding only. The detecting system of the POSTECH has tested with just passive shielding without flushing nitrogen gas.

Table. 3: Comparison of (I/I_0) with references as energy interval

	Energy interval(keV)	I/I_0 (%)
POSTECH	40-2700	0.480
[3]	40-2700	0.633
POSTECH	50-1800	0.418
[4]	50-1800	0.520

3. Summary and future plan

With references to other papers and reports, materials of radiation shielding structure were determined. Then, the thickness of each material is determined by the MCNP code.

The background radiation was measured by the shielded detector and the none-shielded detector. The actual TR value was calculated by using these two background values. The TR value is 0.527% from 15 keV to 2900 keV in the POSTECH shielding structure. The value is lower than referred papers.

The background of the 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 the cosmic muons will be reduced. And an air tight-chamber was made to fill the nitrogen gas. It will remove radon gas containing in the air.

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