Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

The design of shielding material for ultra low-background gamma-ray spectrometry

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1. Introduction

Development and performance of an ultra low-background γ-ray spectrometer in Figure 1 will be performed at Dongnam Inst. of Radiological & Medical Sciences (DIRAMS) as basic tool for various radioactivity measurements. Gamma-ray spectrometry with a HPGe detector is widely used for the identification and activity measurements of radionuclides in a sample, impurity checks of a standard source, determination of emission probabilities in radioactive decay, and low level counting's. In low-level counting's, a variety of techniques to reduce the background have been employed and makes it possible to radio assay an environmental sample containing a trace of γ-emitting radio nuclides. The application of γ-spectrometry for environmental monitoring of radioactivity requires as low detection limits as practically achievable due to the limited amount of sample provided for measurement and the relatively low concentrations.

We present in this paper a study of shielding materials for ultra low-background shielding structure and a calculation of transmission rate (TR) of the shielded structure using the GEANT4 simulation code.

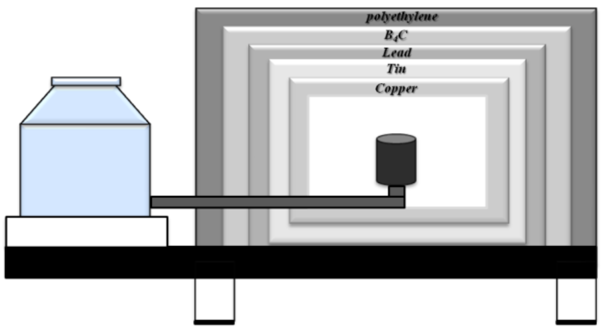

Fig. 1. A diagram of the ultra low-background *γ*–ray spectrometer.

2. Shielding study of Background Radiation

2.1 Background Radiation

The background of a *γ*-ray spectrometer has three basic components[1,2]; radioactivity of the detector and its assembly, surrounding environment (natural radionuclides from the ^{238}U and ^{232}Th decay series and from ^{40}K decay in the laboratory floor and walls ^{222}Rn in the air), and the cosmic rays. In order to decrease the latter two background sources to a minimum extent it is necessary to apply passive or active shielding.

Atmosphere cosmic rays originate from the interaction of primary cosmic rays with the nuclei of Earth's atmosphere. The interaction produces extensive air shower (EAS) containing a soft or electromagnetic component (electrons and γ-ray), a hard component(muons), and a nuclear active component (neutrons)[3,4].

Atmospheric muons are mainly produced in the decay of charged pions and kaons. At sea level, muons are the most abundant component of the cosmic radiation. Electrons and photons of the electromagnetic component are normally absorbed by the overburden from building ceilings and shielding materials. Cosmic ray muons are an avoidable contributor to the measured background even in experiments located deep underground.

Neutron associated with local radioactivity arises mainly from the neutron of spontaneous fission via (α,n) reactions from isotopes of ^{238}U or ^{232}Th decay series or the neutron yield from cosmic ray muons in the shielding on the top of the detector. Those neutrons induce background in the *γ*-ray detector through inelastic scattering and radioactive capture in the detector and surrounding materials[5,6]

2.2 Passive and active shielding

Muon induced background events can be suppressed by performing the measurements underground or by the aid of an additional muon veto shield as an active shielding. An additional neutron absorber is also useful. A neutron moderator is used to reduce the speed of fast neutrons and thereby turn them into thermal neutrons. Then thermal neutrons can be removed by the interaction with elements that have a high neutron capture cross-section like Li, B and Gd. Therefore, the detector can be properly shielded against the neutrons by using polyethylene as a neutron moderator and $^{10}B_4C$ as a thermal neutron absorber by producing α-particles, γ-ray (478 keV) and ^{7}Li from the stable isotope ^{10}B,.

Lead (11.34 g/cm^3) is very effective as a radiation absorber. When a gamma-ray strikes the lead surface, a characteristic lead X-ray (around 74 keV~85 keV) may escape and hit the detector. Graded-Z shielding can be used to stop about 98% of the X-rays. Unfortunately lead is not radio pure material. It is normally contaminated with radiogenic ^{210}Pb and its daughters ^{210}Bi and ^{210}Po. The 46.5 keV γ-ray from ^{210}Pb is readily stopped by the graded liner used to suppress lead K-shell X-rays. However, the ^{210}Bi daughter of ^{210}Pb is beta emitter with endpoint energy of 1161 keV. It has been suggested that bremsstrahlung from this beta leads to a significant increase in the background continuum up to several hundred keV.

Again there are trade-offs between background continuum and lead X-ray peaks. The graded liners typically used to suppress the lead X-rays(74~85 keV) consist of 1.5 mm thick layers of copper. This graded liner has the undesirable effect of increasing the background continuum.

2.3 Design of the ultra low level shielding structure

The ultra low level shielding structure of DIRAMS will be composed of Polyethylene, B_4C, lead, tin, copper. We used the GEANT 4 simulation code to determine the thickness of materials as shown in Figure 1. Figure 2 shows the simulation results of TR of fast neutron through polyethylene or paraffin, TR of thermal neutron through B4C, and TR of photon through lead, tin, or tin and copper. 10 % of fast neutron can pass 120 mm of polyethylene or paraffin. 99.9 % of thermal neutron can be absorbed in 0.55 mm of B4C. 99.9% of 1 MeV photon can be shielded in 100 mm of lead. Lead characteristic x-ray (87.367 keV) could be removed using 2 mm of tin and 7 mm of copper.

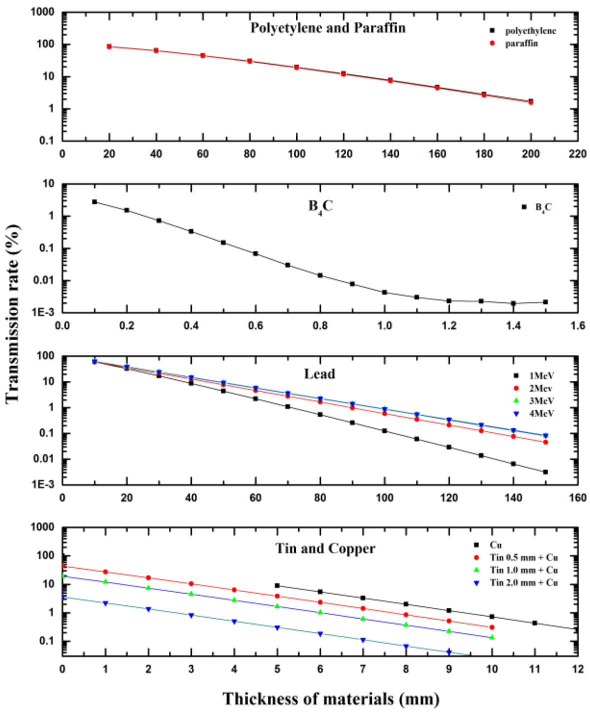

Fig. 2. Relative Transmission rate versus material thickness

3. Conclusion and future improvements

A study of gamma and neutron backgrounds has been performed, based on Monte Carlo simulations combined with radio purity data. With reference to other papers and reports, materials of radiation shielding structure was determined. Then, the thickness of each material is determined by the GEANT4 simulation.

In the future the gamma and neutron background radiation will be measured with shielded detector and non-shielded detector to calculate the actual TR. It will be compared with the results of the GEANT4 simulation. Also it is planned an active shielding to reduce cosmic muons with an anti-coincidence of a pair of plastic scintillators and a passive shielding with nitrogen gas.

Acknowledgment

This research was supported by National R&D Program through the Dongnam Inst. of Radiological & Medical Sciences funded by the Ministry of Science, ICT & Future Planning (50491-2013)

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