A Study on Gamma Spectrum Simulation from Natural Uranium

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1. Introduction

A PyRoprocess Integrated Inactive Demonstration facility (PRIDE) is currently being constructed inside Korea Atomic Energy Research Institute (KAERI). PRIDE is an engineering scale (10 ton/yr) pyroprocess demonstration facility and will use un-irradiated materials (natural uranium and surrogate materials) in its process. A safeguards system, included the process monitoring technology is being developed. A gamma monitoring system is being optimized by using simulation. To ensure the accuracy of the simulation, the gamma spectrum from natural uranium was compared between simulation and measurement. The simulation process is described herein and the representative results are presented.

2. Method

In this section, the source and detector modeling are described first, followed by measurement and simulation description. The measurement and simulation results are then compared.

2.1 Source Modeling

The source is natural uranium (NU) which is inside a can and putted inside a SUS container. Its configuration is shown in Fig. 1.

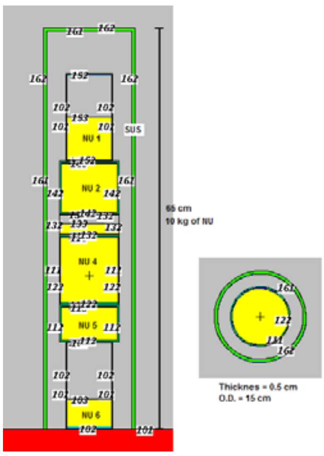

Fig. 1. Geometry plot of the source configuration.

It contains a small amount of U_{234} and U_{235} (5.4e-5 and 0.007) and large amount of U_{238} (0.992946). The NU is in pellet and powder form with density (10.40 g/cc and 2.75 g/cc) which is inside polyethylene (density=0.90 g/cc) or aluminum (density = 2.70 g/cc) can. The total amount of NU is about 10 kg. The NU was putted inside a SUS container (density = 7.92 g/cc). This configuration is representative of the natural uranium that will be used in PRIDE facility.

Complex geometry of the source was used in the simulation, included the cylindrical source with different gamma strength for each NU type (6 types). The energy lines of natural uranium were taken from Los Alamos data. The important energy lines are U_{235},186 keV with 3.01e+2 photon/s/g NU, the U_{238}, 766 keV with 3.972e+1 photon/s/g NU, and the U_{238},1001 keV with 9.929e+1 photon/s/g NU.

2.2 Detector Modeling

The detector that was used is the model 802 scintillation detector manufactured by Canberra. It has the resolution of 7.5% at 662 keV peak of Cs_{137}. The detector configuration is shown in Fig. 2.

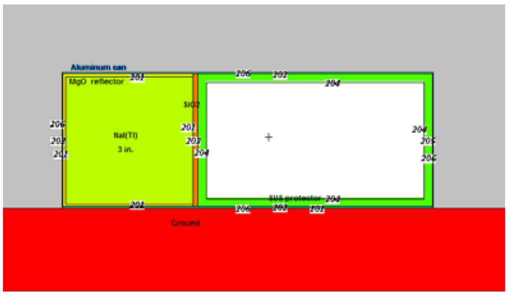

Fig. 2. Geometry plot of the detector configuration.

It includes the modeling of the NaI(Tl) crystal (3×3 in.), aluminum window (0.5 mm thick; density = 147 mg/cm2), MgO reflector (1.6 mm thick; density 88 mg/cm2), photocathode (3 mm thick; density = 2 g/cc), and photomultiplier tube covered by lined steel shield.

2.3. Measurement

The gamma measurement took place inside a laboratory as shown in Fig. 3 and 4. Laboratory room and wall were also included in the simulation (concrete with 30 cm thickness and density= 2.30 g/cc).

To ensure that the correct source definition was used, the pulse height spectrum for NU powder and NU pellet were measured for 10 minutes. In the measurement, the detector was covered with lead and there was a collimator in front of the detector. This to ensure that there is low background count and only source was counted. The configuration is shown in Fig. 3.

The configuration of PRIDE source model is shown in Fig. 4. The source is located on the ground while the detector sits on the detector support as shown in the figure. The experiment and simulation were done at three detection positions which were 50 cm, 100 cm, and 200 cm from the source.

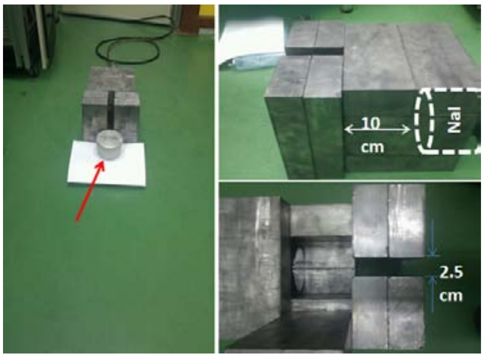

Fig. 3. Measurement of source pulse height spectrum.

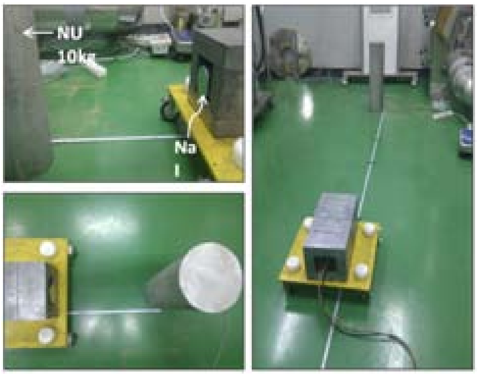

Fig. 4. Measurement of PRIDE source model.

2.4. Simulation

Simulation was done using MCNPX 2.5.0 and used the modeling described previously. F8 pulse height tally is used. To simulate the detector resolution, the special treatment called the Gaussian Energy Broadening (GEB) in the MCNPX code is used. The coefficients of GEB were a=-0.00789; b=0.067669; c=0.21159. These values come from the least square approach to fit the Eq. (1) from various energy peaks. By using these coefficients, the resolution at 662 keV peak of Cs_{137} is 7.7%.

$$FWHM = a + b\,E + cE^2 \quad (1)$$

FWHM is the full width half maximum and E is the peak energy.

3. Results

The first simulation ensured that the source definition is correct. For each important peak, the count rate has a good accuracy with difference about 5%. Fig. 5 shows the pulse height spectrum. In the measurement, there is an increasing count rate below 1001 keV. It was ensured that the event came from scattering near the detector. If the collimator thickness is increased, this event count rate was decreased. MCNPX shows the theoretical count rate with correction using GEB.

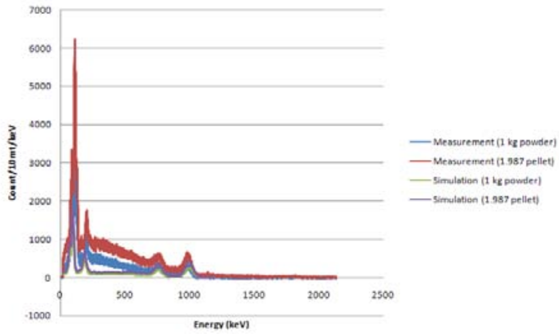

Fig. 5. Pulse height spectrum of NU powder and pellet.

The second simulation produced the gamma spectrum from 10 kg NU inside SUS container as shown in Fig. 6. Count rate at each energy peak was compared. The results are shown in Table 1.

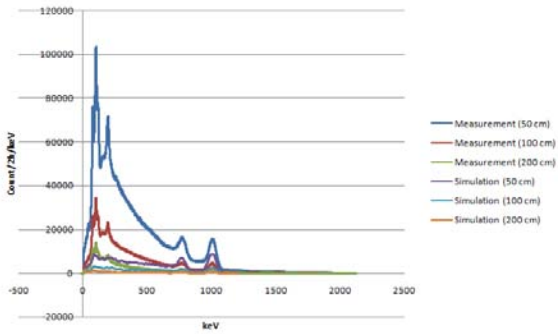

Fig. 6. Pulse height spectrum of PRIDE source model.

Table 1. Count rate at each peak of 10 kg NU

Energy	Count rate/2h/keV					
	Measurement			Simulation		
	50 cm	100 cm	200 cm	50 cm	100 cm	200 cm
186 keV	347511	104793	35640	45207	19928	7356
766 keV	417521	119175	26473	328484	105794	28221
1001 keV	642096	175952	55173	612430	172802	48082

4. Conclusions

Gamma spectrum from natural uranium was simulated using MCNPX. Good accuracy was produced when checking the source definition since the problem is simple. In PRIDE source model problem, the low energy count rate was different between simulation and experiment; but in the high energy, it was accurate.

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