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Verification of Simulation for Neutron-Induced Prompt Gamma Emission Using PHITS

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1. Introduction

PGAA (Prompt Gamma Activation Analysis) is an established nuclear analytical technique for the non-destructive determination of elemental and isotopic compositions. The neutron activation analysis research group in KAERI (Korea Atomic Energy Research Institute) has been developing a fake gold bar detection method using a PGAA. However, a real experiment to verify the detection method was not performed because of the seismic retrofit for HANARO. As an alternative method, a computer simulation based on the Monte Carlo method was used to confirm the detection method. Prompt gamma-ray is the most important element for a PGAA. MCNPX and PHITS, Monte-Carlo radiation transport simulation codes, have succeeded in simulating a prompt gamma-ray spectrum. However, the prompt gamma-ray spectrum generally simulated by MCNPX did not show accurate gamma-ray energy peaks [1]. In this study, the neutron-induced prompt gamma-ray spectrum is calculated after thermal neutron beam is irradiated onto the target sample using PHITS. A comparison between the result of PHITS simulation and that of MCNP6 photon transport with IAEA reference data, and an efficient method for simulation of neutron-induced prompt gamma-ray is discussed.

2. Methods and Results

2.1 PHITS code

The PHITS (Particle and Heavy Ion Transport code System), is a general purpose Monte Carlo particle transport simulation code developed under collaboration between JAEA, RIST, KEK, and several other institutes. It can deal with the transport of all particles over wide energy ranges, using several nuclear reaction models and nuclear data libraries. A new theoretical model to simulate gamma de-excitation nuclei was developed based on the Evaluated Nuclear Structure Data File (ENSDF) in 2014 [2]. The model is applicable for neutron capture products and spallation products of 1071 nuclear species from Li to bk. Except for some of the light nuclei with a discrete level structure, simulated isomer production and prompt gamma-ray spectra agree generally within 40% and a factor of 3, respectively.

2.2 Input of PHITS simulation

For simulating the neutron-induced prompt gamma-ray using PHITS version 3.02, the parameter of igamma is set as 3 for activating the new theoretical model. The thermal neutron from HANARO reactor is adopted as a source. The simple geometry of the neutron irradiation system in the simulation is modeled after the fake gold detection system. The tracks of neutrons irradiated onto the target and prompt gamma-rays emitted from the target are simulated using a T-track tally. The prompt gamma-rays entered to the detector region are also calculated using a T-cross tally. All calculations were carried out using 10^6 particle histories for reliability.

2.3 Target sample modeling

A fake gold bar is commonly made by filling the bar inside with other substances, particularly tungsten, which has a density (19.3 g/cm^3) nearly the same as gold (19.25 g/cm^3) but with a cheaper price. Tungsten is selected as a representative fake candidate and the common standard thickness of gold bar is considered for assuming a case of fake gold bar. The fake tungsten gold bar is modeled to be a 6-mm-thick tungsten bar plated with 1 mm of gold.

2.4 Tracks of neutrons and prompt gamma-rays

Using the T-track tally, the particle fluence in any specified region can be obtained. For checking the fluence of neutron and prompt gamma-ray in the cells, region mesh and unit value 2 are used. The tracks of neutrons irradiated onto the target are showed in fig.1. In this figure, most neutrons are captured in front gold layer (cell 1) and tungsten layer (cell 2).

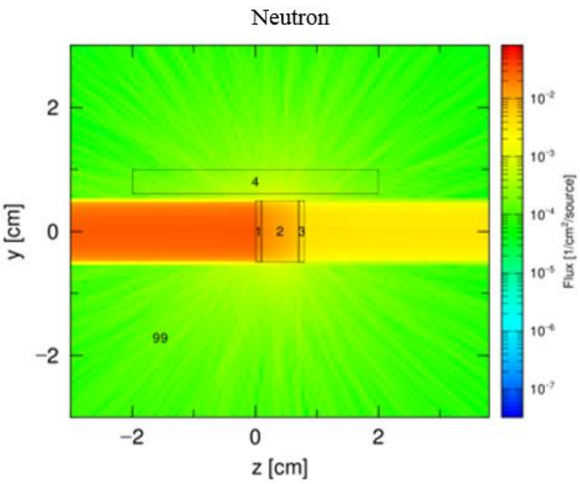

Fig. 1. The tracks of neutrons irradiated onto the sample.

The tracks of prompt gamma-rays emitted from the target are showed in fig.2. Most prompt gamma-rays are generated in front gold layer (cell 1) and tungsten layer (cell 2), also the prompt gamma-rays entered in the detector region (cell 4) are confirmed.

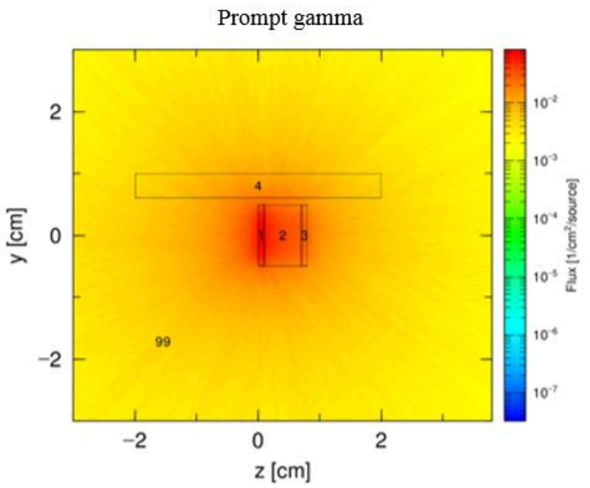

Fig. 2. The tracks of neutron-induced prompt gamma-rays emitted from the sample.

2.4 Prompt gamma-ray spectrum

The T-cross tally can be used to obtain the fluence on any specified surface. For setting the geometry mesh, cell number 99 (air) and 4 (detector) are defined as the outgoing and incoming region. For obtaining an energy spectrum of prompt gamma-rays, the generated prompt gamma-rays are scored from 0.01 to 6.00 MeV in bins of 0.01 MeV width using energy mesh of e-type=2.

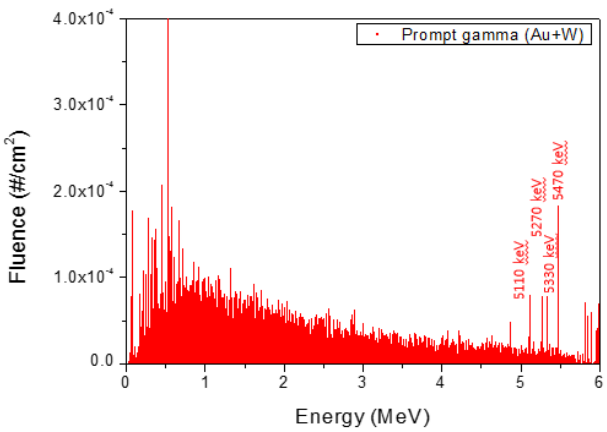

Fig. 3. The neutron-induced prompt gamma-ray spectrum simulated by PHITS code.

The prompt gamma-ray spectrum simulated by PHITS code is showed in fig. 3. Various energy peaks of prompt gamma-ray emitted from the activated gold and tungsten elements can be seen. In comparison with fig. 4, which is the prompt and delay gamma-ray spectrum calculated with IAEA reference data and MCNP6 photon transport simulation, most energy peaks are incorrect except 5270 and 5330 keV peaks [3].

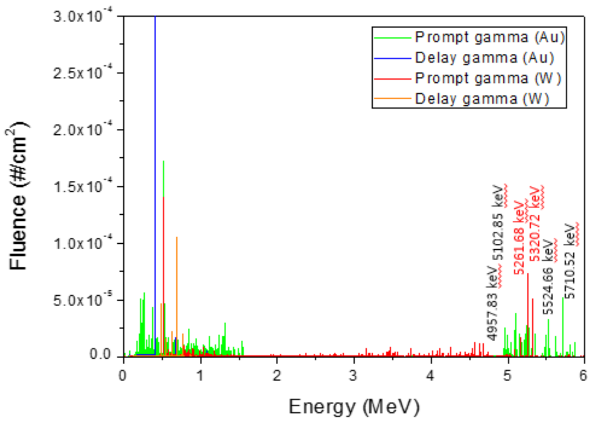

Fig. 4. The neutron-induced prompt and delay gamma-ray spectrum calculated with IAEA reference data and MCNP6 photon transport simulation [1].

4. Conclusions

A simulation for neutron-induced prompt gamma-ray is conducted. Through a comparison between the result of PHITS simulation and that of MCNP6 photon transport with IAEA reference data, it is concluded that the prompt gamma-rays simulated by PHITS is not accurate. Although overall trend of the prompt gamma-ray spectrum of PHITS is better than the result of MCNP6 simulation, but the library for prompt gamma-ray generation should be improved.

Acknowledgments

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