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Fast neutron flux calibration based on neutron inelastic scattering with germanium crystal

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1. Introduction

The fast neutron flux measurements is necessary for neutron detector calibration and the development of a neutron generator, which can be applicable for neutron activation analysis, non-destructive inspection, and neutron radiography.

A high-purity germanium (HPGe) detector can measure the fast and thermal neutron flux simultaneously by several interactions of germanium isotopes [1-3]. The prompt peaks from germanium isotopes, ^{70}Ge, ^{72}Ge, ^{73}Ge, ^{74}Ge, and ^{76}Ge, can be distinguished by an HPGe detector (Table I). The peak area from each interaction is proportional to the neutron flux (Fig. 1).

In this study, the fast neutrons from a ^{252}Cf source were measured by an HPGe detector, and the fast neutron flux incident to the HPGe detector was calibrated.

Table I. Neutron scattering and absorption peaks of germanium isotopes [3].

Energy (keV)	Reaction
174.96	^{70}Ge(n, γ)^{71}Ge*
418.50	^{76}Ge(n, γ)^{77}Ge
595.84	^{74}Ge(n, n’γ)^{74}Ge*
608.35	^{70}Ge(n, n’γ)^{71}Ge*
691.43	^{72}Ge(n, n’e)^{72}Ge*
708.19	^{70}Ge(n, γ)^{71}Ge*
834.01	^{72}Ge(n, n’γ)^{72}Ge*
1039.51	^{70}Ge(n, n’γ)^{70}Ge*
1204.20	^{74}Ge(n, n’γ)^{74}Ge*
1463.75	^{74}Ge(n, n’γ)^{74}Ge*

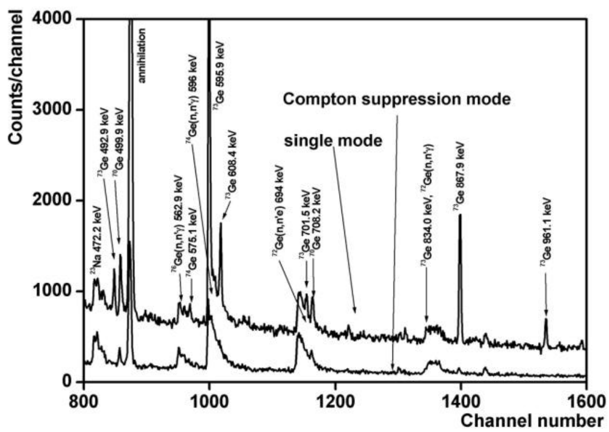

Fig. 1. Prompt γ-ray peaks induced by germanium isotopes [4].

2. Materials and methods

The fast neutron flux calibration using an HPGe detector was divided by two steps: 1) neutron irradiation using a spontaneous fission neutron source of ^{252}Cf and 2) prompt peak fitting of neutron inelastic scattering and peak area calculation.

2.1. Neutron irradiation using a ^{252}Cf source

The ^{252}Cf source for neutron detector calibration in Korea Atomic Energy Research Institute is used to calibrate the neutron flux from the peak area. The emission rate of the ^{252}Cf source was 5.24×10^{6} neutrons/s. With the different source-to-detector distances (SDDs) of 100, 150, and 200 cm, prompt energy spectra were measured by the HPGe detector (Fig. 2). In order to reduce γ-ray background and avoid highly increased dead time, the HPGe detector was shielded by several lead blocks. At each SDD, the fast neutron was irradiated to the HPGe detector during 1 hour. The peak area of the neutron inelastic scattering at a prompt energy of 692 keV was used to calibrate the fast neutron flux.

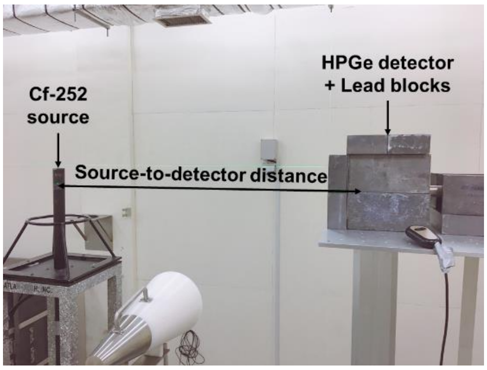

Fig. 2. Setup of fast neutron irradiation from a ^{252}Cf source

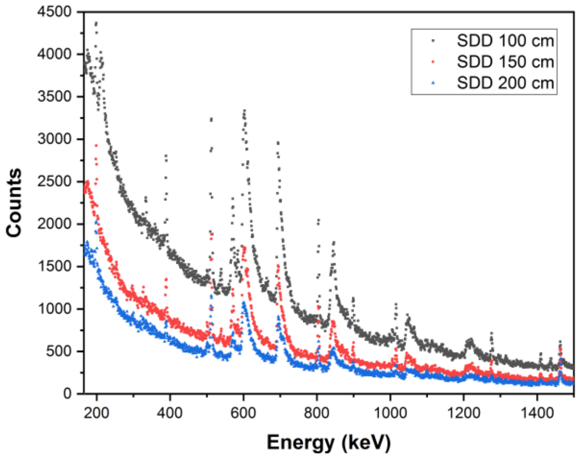

Fig. 3. Prompt γ-ray energy spectra after neutron irradiation using the ^{252}Cf source at different source-to-detector distances (SDDs)

2.2. Calculation of the fast neutron flux

With the known emission rate of the ^{252}Cf source, the fast neutron flux was calculated by a proportional relationship between the peak area and the neutron flux.

For fast neutron flux, the neutron inelastic scattering peak at 692 keV was fitted using the multiplication of error function and exponential function. The background was fitted using a linear function.

In order to consider the difference in neutron energy spectra between the ^{252}Cf source and the calibrating neutron source, the average neutron inelastic scattering cross-section of ^{252}Cf was calculated. The energy spectra of the ^{252}Cf source were calculated by Monte Carlo simulation with a simple spherical geometry. The cross-section of the neutron interactions from the JEFF-3.3 nuclear data library was used. The neutron inelastic scattering cross-section was calculated by the neutron non-elastic scattering cross-section minus the neutron capture cross-section.

3. Results

The prompt peak areas of the neutron inelastic scattering at 692 keV were calculated by an integration of the fitted curve from 685 keV to 740 keV (Fig. 4). The peak areas at 692 keV were 8.87×10^4 counts·keV for an SDD of 100 cm, 4.46×10^4 counts·keV for an SDD of 150 cm, and 3.02×10^4 counts·keV for an SDD of 200 cm. The fast neutron flux of the ^{252}Cf source and the prompt peak areas were linearly related, and the R^2-value was 0.9998.

In the energy range of the ^{252}Cf source, the averaged neutron inelastic scattering cross-section of ^{72}Ge was 1.33 barns.

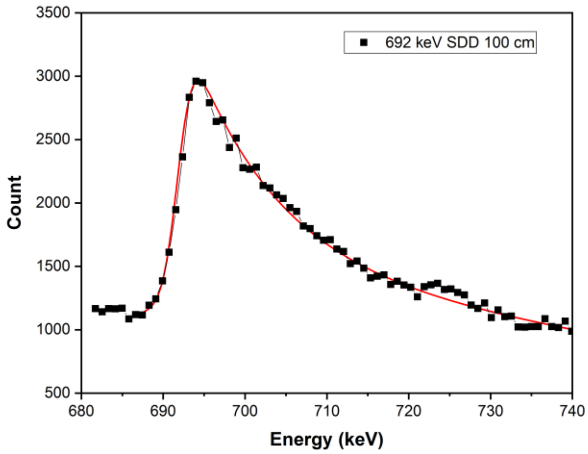

Fig. 4. Prompt peak of fast neutron inelastic scattering at 692 keV (black) and its fitted curve (red).

4. Discussion

Some prompt peaks of the fast neutron inelastic scattering were not easily distinguished because the neutron scattering peaks from aluminum or lead were overlapped at the germanium peaks. The peak at 692 keV was easily distinguished from the other peaks and clearly fitted.

The multi-foil activation method, including a gold foil was also performed for the neutron flux measurement. However, it was not possible to distinguish the peaks of neutron activation.

At an SDD of 200 cm, there were the prompt γ-ray peaks of thermal neutron absorption. This is caused by the fast neutron thermalization by surrounding materials.

5. Conclusions

In this study, we calibrated the fast neutron flux incident to an HPGe detector using a ^{252}Cf source. The calibrated neutron flux would be applicable for fast neutron flux calibration of neutron generators.

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