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Reprint of The improvement of the energy resolution in epi-thermal neutron region of Bonner sphere using boric acid water solution moderator

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HIGHLIGHTS

- Boric acid solution is useful to improve the energy resolution of Bonner sphere.
- Uncertainty of the device configuration is critical for neutron spectrometry.
- It is important to reduce and evaluate the uncertainty.

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ABSTRACT

Bonner sphere is useful to evaluate the neutron spectrum in detail. We are improving the energy resolution in epi-thermal neutron region of Bonner sphere, using boric acid water solution as a moderator. Its response function peak is narrower than that for polyethylene moderator and the improvement of the resolution is expected. The resolutions between polyethylene moderator and boric acid water solution moderator were compared by simulation calculation. Also the influence in the uncertainty of Bonner sphere configuration to spectrum estimation was simulated.

1. Introduction

In epi-thermal neutron irradiation fields for boron neutron capture therapy (BNCT), the neutron energy spans over a wide range. Because neutron biological effectiveness on tissue greatly vary depending on its energy (Blue et al., 1993), it is necessary to evaluate the energy dependency of neutron flux. Thereby, it is important to obtain the detailed information for the neutron energy spectrum before clinical irradiation.

Activation detectors are suitable for neutron spectrometry compared to active detectors which suffer from dead time problem and gamma ray background in the BNCT irradiation field. Combined with a neutron moderator, they can be used to perform neutron spectrometry on a wide energy range including the keV region (Liu et al., 2013). So, the Bonner Sphere Spectrometer (BSS), which consists of a set of moderating spheres housing a thermal neutron detector at their centre, is useful to evaluate the neutron energy spectrum in BNCT irradiation field. Activation foils were used as thermal neutron detectors in this work.

Usually, neutron spectrometry based on Bonner sphere of polyethylene moderator has poor energy resolution in the keV region because of its broad response peaks (Alevra and Thomas, 2003). The energy resolution is improved using moderators including thermal neutron absorbers which make the Bonner sphere response peaks narrower (Aroua et al., 1997).

We are improving the energy resolution of Bonner sphere in epi-thermal region, using boric acid water solution (^{10}B 0.14 wt%) as a moderator. Its response function peak is narrower than that for polyethylene moderator and the improvement of the resolution is expected. Boric acid water solution moderator has the advantage of its uniform chemical composition. It is easy to change the Bonner sphere response function by changing the ^{10}B concentration and validate the concentration by an analysis (e.g. PGAA) device installed in the BNCT facility.

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The energy resolution depend on a measurement device, pre-information, and an unfolding procedure. In this study, we investigated the dependency only on the moderator. The energy resolution between polyethylene moderator and boric acid water solution moderator were compared by simulation calculation. Also the influence of the detector displacement from the sphere center and the uncertainty of boric acid concentration to the spectrum estimation was investigated.

2. Materials and methods

Bonner sphere: In this study, Bonner sphere consists of a spherical neutron moderator shell and activation foils placed in the sphere center as thermal neutron detector. Manganin (^{55}Mn) and gold (^{197}Au) are used as the activation foil material. The specific saturated activities per neutron flux for each energy group were calculated as the response function of Bonner spheres. Calculations were performed for the sphere diameter of 10, 15, 20 cm, with the MCNP5 radiation transport code (X-5 Monte Carlo Team, 2003).

Comparison of energy resolution: For the comparison of energy resolution between polyethylene moderator and boric acid water solution moderator of ^{10}B 0.14 wt%, unfolding tests were performed using step-wise neutron spectrum in epi-thermal neutron energy region. In the tests, the response functions were calculated for aligned and expanded beams in vacuo. The foil activities were calculated using the calculated response functions and the step-wise neutron spectrum. The normally distributed errors, whose deviation is 3%, were added to the calculated activities, which were unfolded into the estimated spectrum using uniform spectrum as the initial by UMG unfolding package (Reginatto, 2004). We used the uniform spectrum to eliminate the energy resolution dependency on pre-information, considering the case we have no pre-information about the spectrum. We terminated the unfolding procedure iterations when the two different unfolding procedure results began to show some difference. Their results were same and did not depend on the unfolding procedures. Thus we evaluated only the dependency on the BSSs. The energy resolution comparison was made judging from the peak shapes of the estimated spectrum. The used neutron energy group structure comprised 91 groups in the energy range from 10 meV to 10 MeV for the same lethargy width of 0.23.

Influence of the uncertainty of the Bonner sphere configuration to the spectrum estimation: The ^{10}B concentration of 0.14 wt% corresponds to the boric acid solubility in water at 20 °C (IUCLID Dataset, 2000). In a prolonged storage of the boric acid water solution, boric acid may precipitate due to evaporation and falling temperature. In addition, it is difficult to place the activation detector exactly in the sphere center, and the displacement of the detector from the sphere center generates measurement error. The uncertainty of the Bonner sphere configuration significantly influences the spectrum estimation accuracy. The influence of the uncertainty for the moderator concentration and the detector placement to the spectrum estimation was investigated.

In this study, the spectrum estimation was performed for the epi-thermal neutron irradiation mode in the Heavy Water Neutron Irradiation Facility of Kyoto University Reactor (KUR-HWNIF) (Sakurai and Kobayashi, 2000). Water and boric acid water solution (^{10}B 0.14 wt%) were used as the moderator material. Each Bonner sphere response function was calculated by MCNP5. Also, the saturated activities were calculated varying the detector placement or the ^{10}B concentration. The calculated activities were unfolded into the estimated spectrum by UMG together with the calculated response functions which have no deviation. The used neutron energy group structure comprised 144 groups in the energy range from 1 meV to 16.1 MeV.

3. Results

Comparison of energy resolution: Figs. 1 and 2 show the calculated response functions of Bonner spheres using gold activation detector with polyethylene moderator and boric acid water solution moderator, respectively. D10, D15 and D20 represent 10, 15 and 20 cm diameter of the Bonner sphere, respectively. The statistical uncertainties of the simulated response functions are showed with error bars. As expected, the response functions of the BSS loaded with boric acid show a narrower trend in the epi-thermal region. The same trend was observed for the manganin activation foils. From the results, it is expected that the improvement of the energy resolution in the epi-thermal region can be achieved.

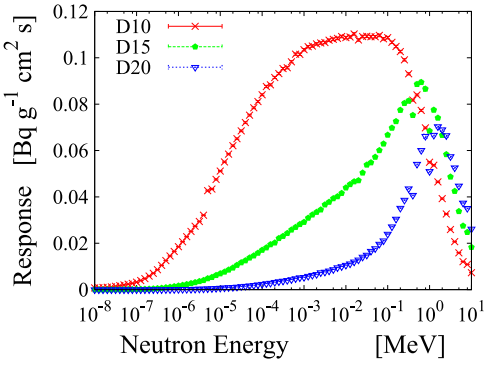

Fig. 2. Response functions of Bonner spheres using gold activation detector with boric acid water solution moderator.

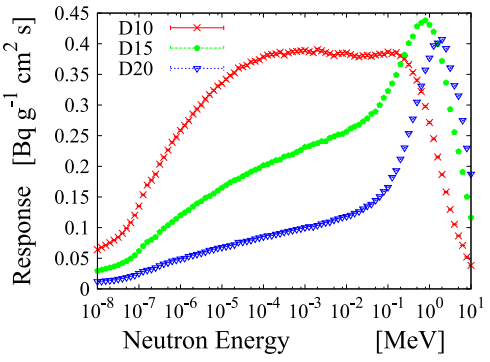

Fig. 1. Response functions of Bonner spheres using gold activation detector with polyethylene moderator.

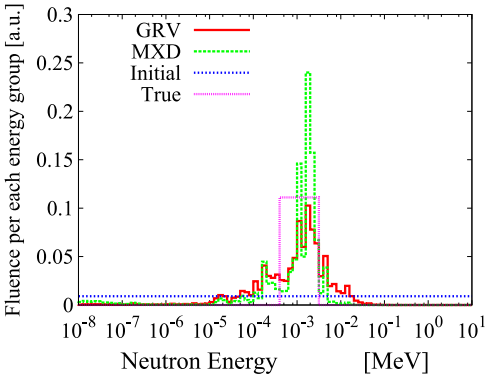

Fig. 3. Unfolding results for the step-wise spectrum of 10^{-3} MeV in the lethargy center using polyethylene moderator.