Recent Activities on Neutron Standardization at NMIJ/AIST (1)
- Characterization of a Thermal Neutron Field at the Heavy Water Neutron Irradiation Facility of the Kyoto University Reactor -

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1. Introduction

The Heavy Water Neutron Irradiation Facility (HWNIF) at the Kyoto University Reactor (KUR) has been utilized since 1964 for many research fields such as physics, engineering, biology and so on. In 1996 the HWNIF was updated mainly for boron neutron capture therapy (BNCT). The main feature of the new facility is that it can provide both a thermal neutron field and an epi-thermal neutron field, or a mixed field of these two. The details of the facility and the fundamental characteristics of the neutron field were well described in the references [1, 2].

Prior to BNCT it is necessary to make a treatment plan for each patient for an effective therapy. It is desired to measure neutron flux distributions in a phantom for making the treatment plan, because the distribution and the intensity may vary due to reactor conditions or physical features of the patients. A gold wire or foil activation method is usually used for this purpose. It takes, however, long time to obtain the distribution. It is also desired to continuously monitor the neutron flux intensity in the vicinity of a tumor that is irradiated. Gold foils or wires, and TLD elements cannot be used for real time monitoring but only for integrated neutron fluence. In this paper we describe an application of a small neutron probe for these purposes.

2. Neutron Probe Detector

The probe detector used in this work was originally developed by C. Mori *et al.*[3] The detector consists of an optical fiber and a small neutron probe. The neutron probe is made of ZnS(Ag) scintillator and neutron converter, such as ^{6}Li or ^{235}U for thermal neutrons, and ^{232}Th or ^{238}U for fast ones. The powder of ZnS(Ag) and an appropriate neutron converter are mixed and bound with transparent adhesive material. The bound mixture is attached to an end surface of the optical fiber. The scintillation light photons are transmitted through the fiber and detected by a photomultiplier that is connected to the other end of the fiber. Because the probe is very small (less than about 1mm) and an active electronic circuit is

not necessary near the probe, it can be used in small spaces, high radiation fields, or in fields where neutron flux distributions are disturbed by the existence of normal-size detectors. The small probe does not disturb the neutron field so much. The probe is mechanically moved so that neutron flux distribution can be obtained. The spatial resolution is almost the same to the physical dimension of the probe.

One of the problems of this detector is that the detector is sensitive to gamma rays or electrons because the energy deposited by an high-energy electron is considerably high, roughly on the order of a few tens to several hundreds keV, and is not far smaller than that deposited by an alpha particle and/or a triton that are nuclear reaction products of ^{6}Li(n, α)t. Although the Q-value of this reaction is 4.78 MeV, the apparent deposited energy in the probe is less than this value because of self-absorption within the LiF grains and opacity of the ZnS(Ag) scintillator. The pulse height spectrum of gamma-ray events and that of neutron ones overlap each other and cannot clearly be separated by an ordinary pulse height discrimination method. It was, therefore, necessary to conservatively set the discrimination level high enough to cut all gamma-ray or electron induced events. Another problem is that the pulse height spectrum of the probe is monotonically decreasing shape as shown in Fig.1. It is difficult to set the discrimination level at exactly same point at different runs for such a pulse height spectrum.

Kawata *et al.*[4] have proposed to use a thin ZnS(Ag) layer that is deposited on a transparent backing sheet. The scintillator is so thin that electrons cannot deposit high energy, a few tens keV at most. A thin plate or film of LiF is put on the ZnS(Ag). Figure 2 shows the pulse height spectrum of the new probe that a LiF thin plate with a thickness of 300 μm is contacted to the ZnS(Ag) layer with a thickness of 25 μm deposited on a cellulose acetate sheet with a thickness of 12 μm. The pulse height spectrum was taken at the mixed neutron and gamma-ray field of the HWNIF. The electron induced events could clearly be distinguished from the neutron induced ones. The shape of the pulse height spectrum of neutron events became rather flat and distinction between the gamma-ray events and neutron events was clear. It is, therefore, easier to set the discrimination level for different experiment runs.

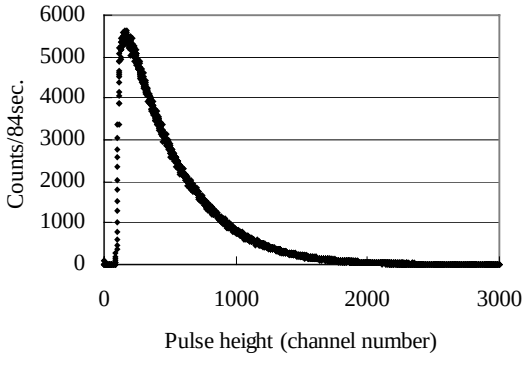

Fig.1. Pulse Height Spectrum of the Old-Type Neutron Probe.

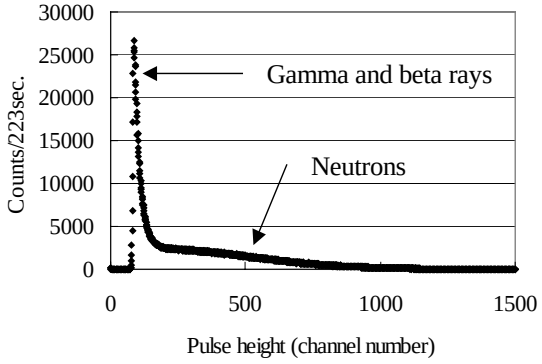

Fig. 2. Pulse Height Spectrum of the New-Type Neutron Probe.

3. Measurement of Thermal Neutron Flux Distribution

The neutron flux distributions were measured with the probe at three different positions; 1) in front of the Bi filter, 2) at the aperture of the clinical collimator, and 3) in a phantom placed in front of the clinical collimator. The phantom consisted of acrylic resin frames with a thickness of 3 mm and water inside the frame. The dimension of the phantom was 180 mm in diameter and 200 mm in length. In case 3), the relative thermal neutron flux distributions were also obtained with numerical calculations.

Figure 3 shows the thermal neutron flux distribution in front of the Bi filter. Figure 4 shows the thermal neutron flux distribution in front of the clinical collimator. It took only about ten minutes to obtain

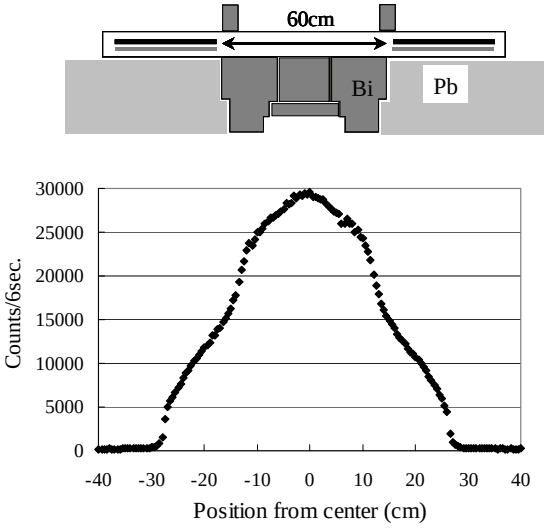

Fig.3. Thermal Neutron Flux Distribution in Front of the Bi Filter.

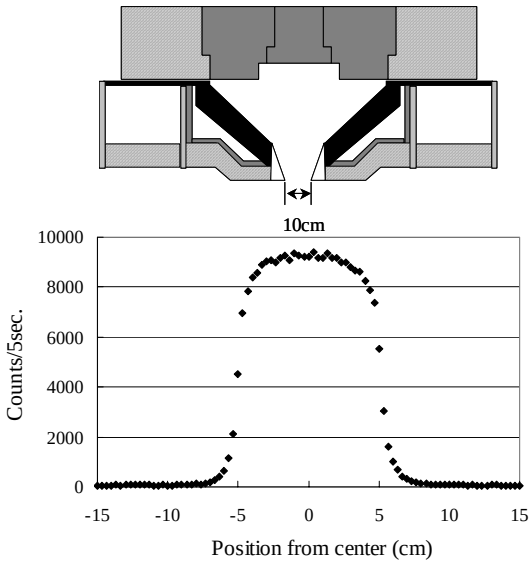

Fig.4. Thermal Neutron Flux Distribution in Front of the Clinical Collimator.

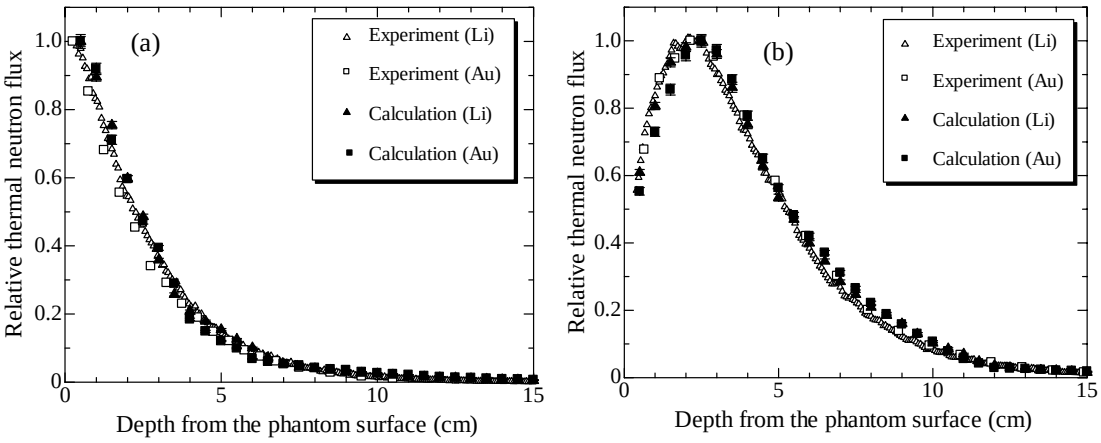

Fig. 5.Thermal Neutron Distribution Obtained with Experiments and Calculations under (a) Thermal and (b) Epi-Thermal Neutron Irradiation Mode.

each profile. Figure 5 shows the thermal neutron flux distribution in the phantom region along the axial direction measured with the probe under the thermal and the epi-thermal neutron irradiation modes. Also shown in Fig. 5 are the thermal neutron flux distributions measured with the conventional gold wire activation method. For the thermal neutron irradiation mode, a bare gold wire with a diameter of 0.25 mm was used. The data obtained with the gold activation method for the epi-thermal neutron irradiation mode were taken from the reference[2]. The thermal neutron flux distributions obtained with the present probe and the gold wire activation method agreed well each other for both the thermal and the epi-thermal irradiation modes. If the absolute value must be measured with the probe detector, it should be calibrated before the measurement.

The numerical calculations were executed for the case 3 with the Monte Carlo calculation code MVP.[5] In the MVP calculation, the neutron spectrum[1] was given beforehand by the neutron transport calculation with 10-energy-group. The Cadmium subtraction technique, which was used in the experiments, was also used in the calculation for the Au wire under the epi-thermal neutron mode. For the thermal neutron irradiation mode, the experimental and calculated results agrees well as are seen in Fig.5(a). On the other hand for the epi-thermal irradiation mode, the calculated result for the Au wire are slightly different from other three results as shown in Fig. 5(b). It is considered that this discrepancy is related to the MVP calculation where the 10-energy-group are used. Although the gigantic resonance peak of the Au neutron capture cross section plays an important role in reaction of the gold wire, the effect of the resonance might not be handled properly in the calculation.

4. Summary

Several thermal neutron flux distributions at the HWNIF were measured with the small neutron probe detector that adopted the thin ZnS(Ag) layer instead of powder. The new probe detector was superior to the old one as regards the gamma-ray discrimination ability. The distributions obtained with the probe detector and those with the gold activation method agreed well each other. On the other hand the distribution obtained with the Monte Carlo calculation was slightly different from the experimental ones especially for the epi-thermal irradiation mode due to some problems of the calculation condition.

5.References

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