

Recent Activities on Neutron Calibration Fields at FRS of JAERI

Yoshihiko Tanimura, Yoshiaki Uchita¹, Jun Saegusa and Michio Yoshizawa
Department of Health Physics,
Japan Atomic Energy Research Institute

1. Preface

Recent activities on neutron calibration fields at the Facility of Radiation Standards (FRS) of the Japan Atomic Energy Research Institute (JAERI) from 2003 to 2005 can be divided into 4 topics; 1.Characterisation of thermal neutron fields using a graphite pile, 2.Development of mono-energetic neutron fields using $^{45}\text{Sc}(p,n)^{45}\text{Ti}$, 3.Fluence measurement using hydrogen filled proportional counter for 144, 250, 565keV fields, 4.Development of spectrum-changeable neutron calibration field using an accelerator. This report describes the characteristics of thermal neutron fields using a graphite pile. In addition, we report neutron spectrum from a thick scandium target, which relates to the development of mono-energetic neutron calibration fields using $^{45}\text{Sc}(p,n)^{45}\text{Ti}$ reaction.

2. Characterisation of Thermal Neutron Calibration Fields using a Graphite Pile.

Thermal neutron fields were established at FRS using moderated neutrons from a graphite pile with a ^{252}Cf neutron source in early 1980s. The pile was renewed due to deterioration in 2003. The new graphite pile has a dimension of 1.50m(W) × 1.64m(L) × 1.50m(H). The neutron source (100 μg) is settled in the centre of the pile. We have two calibration points, #1 and #2, in front of two different faces of the pile as shown in **Fig. 1**. The calibration points are set at 40cm from each surface and 75cm above the floor. The distances from the ^{252}Cf source to the calibration points are 122cm and 115cm for the calibration points, #1 and #2, respectively. Then the neutron fluence rates and spectra are a little different at between the points, #1 and #2.

Because epi-thermal and fast neutrons mixed in thermal neutrons may affect the calibration of the dosimeters, it is necessary to evaluate these neutrons. Then the neutron spectra at the calibration points were measured with a Bonner multi-sphere spectrometer system and calculated with the MCNP-4C code[1].

The Bonner multi-sphere spectrometer system consists of eight spherical moderators

¹ Now at the Institute of Radiation Measurements

with a spherical BF_3 proportional counter with 5.08cm in diameter. The moderators are made of polyethylene and the thicknesses are 1, 2, 3, 4, 6, 8, 10, and 14cm. Their outer surfaces were covered with 1mm thick cadmium shells to measure neutrons above 0.5eV. Additionally, thermal and epi-thermal neutrons were measured with the BF_3 counter without a moderator in conditions of being covered with and without a 1mm cadmium shield. Response functions of this system, shown in **Fig.2**, are determined by adjusting calculated results using the MCNP-4C code to measured response for a bare ^{252}Cf source. The neutron spectra were unfolded using the SAND-II code[2]. The spectra calculated with the MCNP-4C were used as the first guess spectra. The measured neutron spectra are shown in **Fig.3**. The fluence ratios of epi-thermal and fast neutrons to entire neutrons were 2% and 3% at the calibration points, #1 and #2, respectively. The ratios of the ambient dose equivalent rate $H^*(10)$ were 9% and 13% at the points, #1 and #2, respectively. Although these ratios were not so high, epi-thermal and fast neutrons could affect the calibration of dosimeters, especially the ones with high sensitivities to these neutrons. Therefore it is necessary to apply the cadmium differential method for accurate calibrations.

The accurate estimation of the personal dose equivalent rate requires to evaluate the angular distribution of the neutron fluence. However, it is difficult to directly measure the angular distribution. Then we employed the calculation technique using the MCNP-4C code. Two plane detectors with 5cm diameters parallel to the surfaces of the pile were set at the calibration points, #1 and #2, in the calculation. **Fig.4** shows the angular distributions of the neutron fluence calculated at the calibration points. The results show that thermal neutrons have the range of incident angle up to about 65 degree. This range is influenced by the angle of elevation to the edge of the pile from the calibration point. Thermal neutron fluence was divided into the angular bins shown in **Table.1**. The personal dose equivalent rates $H_{p,slab}(10,\alpha)$ were calculated by multiplying the neutron fluence and the conversion coefficients[3] together at each angular bin. Moreover the personal dose equivalent rates $H_p(10,0)$ were calculated on the assumption that thermal neutrons entered the calibration points perpendicular to the ICRU-slab phantom. The ambient dose equivalent rates $H^*(10)$ and the personal dose equivalent rates $H_p(10,0)$ and $H_{p,slab}(0,\alpha)$ were summarised in **Table.2**. The $H_p(10,0)$ is about 40 % higher than the $H_{p,slab}(10,\alpha)$ for both calibration points.

3. Mono-energetic Neutron Calibration Fields

Mono-energetic neutron calibration fields have been developed at FRS of JAERI using an 4MV Pelletron accelerator[4]. We are planning to employ $^{45}\text{Sc}(p,n)^{45}\text{Ti}$ reaction for 8

and 27keV neutron production. The cross section of this reaction has many resonance peaks[5-6]. To examine the structure of this resonance, the neutron spectrum was measured by using time-of-flight method. A scandium foil with 25 μ m thick was bombarded with a pulsed proton beam. The terminal voltage of the accelerator was 2.95MV and the frequency of the beam was 0.5MHz. A ^6Li glass scintillation detector was used in the flight time measurements. Because the sensitivity of the detector is high for thermal neutrons, the detector was surrounded with a B_4C rubber sheet as a thermal neutron shield except the front face. The scattered neutrons were eliminated by another measurement using a shadow cone. The neutron energy spectrum was shown in **Fig.5**. The 8 and 27keV neutron peaks were clearly found in the spectrum. However, there are many peaks near the objective energies. This means that the accuracy of the proton energy is necessary.

References

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- [4] Tanimura, Y., et al.: Radiat. Protec. Dosim. 110, 85 (2004).
- [5] Cosack, M., et al.: EUR-9762-EN, 1., 597(1985).
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Table 1 Angular distribution of thermal neutrons at the calibration points of the graphite pile

Incident angle [deg.]		Conversion coefficient	Calibration point #1		Calibration point #2	
Lower	Upper	$H_{p,slab}(10,\alpha)/\phi$ [pSv-cm ⁻²]	Fluence rate [cm ⁻² -s ⁻¹]	$H_{p,slab}(10,\alpha)$ [μSv-h ⁻¹]	Fluence rate [cm ⁻² -s ⁻¹]	$H_{p,slab}(10,\alpha)$ [μSv-h ⁻¹]
0.0	7.5	11.4 (α=0)	1.80E+01	7.37E-01	1.82E+01	7.47E-01
7.5	22.5	10.6 (α=15)	1.25E+02	4.79E+00	1.49E+02	5.69E+00
22.5	37.5	9.11 (α=30)	1.77E+02	5.81E+00	2.30E+02	7.55E+00
37.5	52.5	6.61 (α=45)	1.45E+02	3.45E+00	1.93E+02	4.60E+00
52.5	67.5	4.04 (α=60)	4.87E+01	7.08E-01	6.45E+01	9.39E-01
67.5	82.5	1.73 (α=75)	7.83E+00	4.88E-02	7.61E+00	4.74E-02

* Reference date on 1 May 2003

Table 2 Characteristics of thermal neutron calibration fields

Calibration point	$H^*(10)$ [μSv-h ⁻¹]	$H_p(10,0)$ [μSv-h ⁻¹]	$H_{p,slab}(10,\alpha)$ [μSv-h ⁻¹]
#1	19.9	21.4	15.5
#2	25.3	27.2	19.6

* Reference date on 1 May 2003



Fig.1. Photograph of the graphite pile for the thermal neutron calibration fields: There are two calibration points, #1 and #2, in front of different faces of the pile.

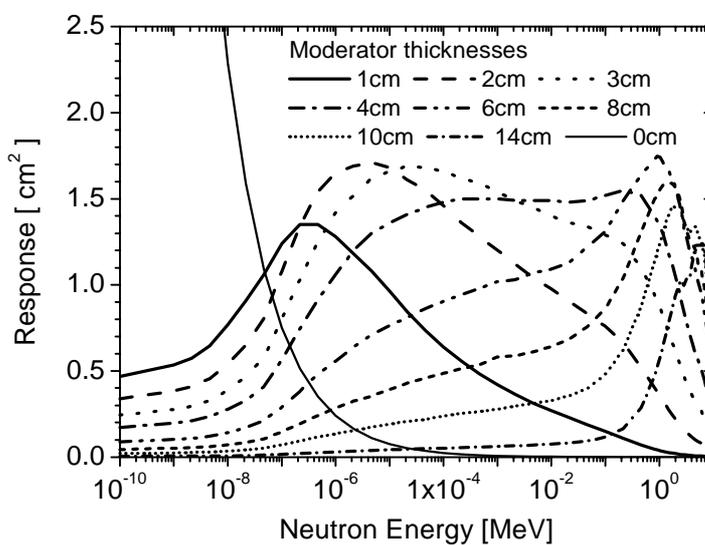


Fig.2. Response functions of the Bonner multi-sphere spectrometer system: They were calculated using the MCNP-4C code and adjusted to the measured response for a bare ^{252}Cf source.

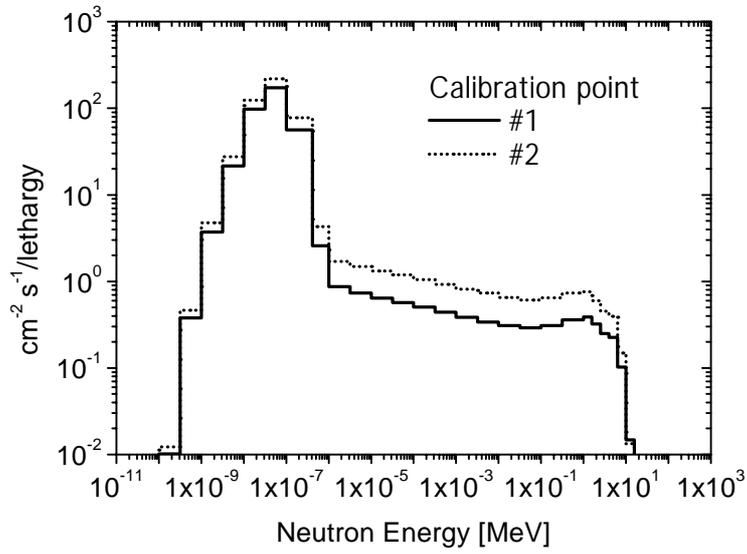


Fig.3. Neutron spectra at the calibration points of the thermal neutron fields using the graphite pile: They were measured with the Bonner multi-sphere spectrometer system and unfolded using SAND-II code. The calculated spectra with the MCNP-4C code were used as the first guess spectra.

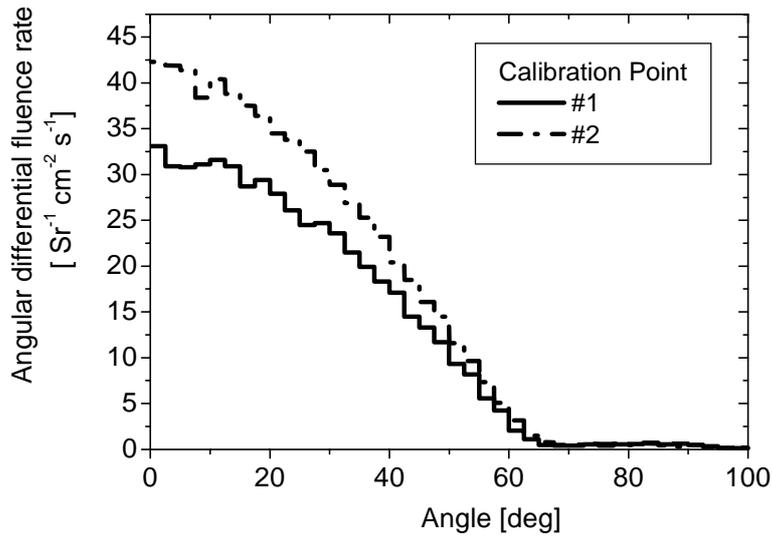


Fig.4. Angular distribution of the incident thermal neutron calculated with the MCNP-4C code at the calibration points, #1 and #2:

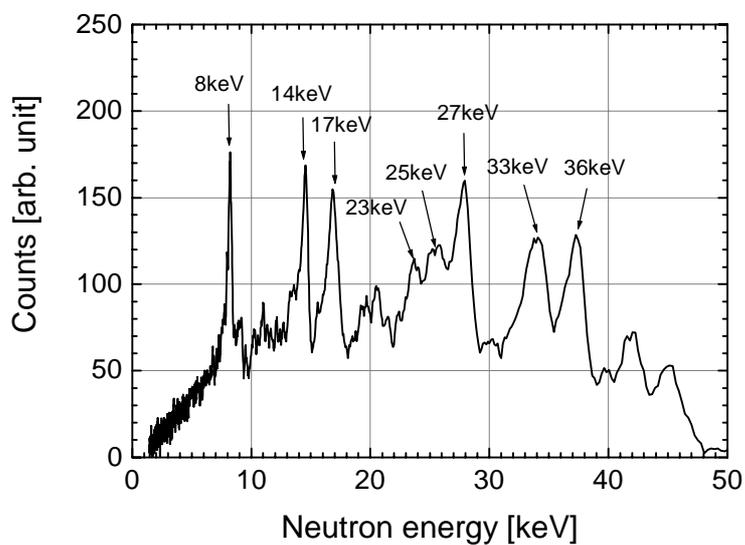


Fig.5. Neutron spectrum produced in the scandium foil with 25 μ m thick: The ^6Li glass scintillation detector (5.08cm in diameter and 1.27cm in length) was used. It was measured at 1.0m from the target by the time-of-flight (TOF) method using a pulsed proton beam.