Recent activities in neutron standardization at NMIJ/AIST

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1. Introduction

This report described recent activities on neutron standardization at the National Metrology Institute of Japan (NMIJ) in the National Institute of Advanced Industrial Science and Technology (AIST). The development of the 19 MeV monoenergetic neutron fluence standard is in progress. We prepared calibration services based on the Japan Calibration Service System (JCSS) for thermal neutron fluence rate and neutron emission rate standards and will start the service in 2012. We are developing a new thermal neutron calibration field using a thermal neutron guided beam at the research reactor JRR-3M of the Japan Atomic Energy Agency (JAEA). Aiming at the establishment of the high-energy (20 MeV to 100 MeV) neutron standard field at TIARA of JAEA and CYRIC of the Tohoku University, collaboration is in progress with the Tohoku University, the High Energy Accelerator Research Organization (KEK) and JAEA. We are installing a pulsing system on the 4 MV Pelletron accelerator in order to apply the time of flight technique.

2. High energy neutron fluence standard

We have developed measurement technique of quasi-monoenergetic neutrons from 45 MeV to 75 MeV for establishing the high-energy neutron standard at TIARA (Takasaki Ion Accelerators for Advanced Radiation Application) of JAEA [1] [2]. The neutrons are produced in the $^{7}Li(p,n)^{7}Be$ reaction where a proton beam from an AVF cyclotron impinges on a metal natural lithium target. A thickness of the target is determined such as proton energy loss in the target is 5 MeV. The neutrons reached an irradiation room through a collimator of a 10 cm diameter made of an iron and a concrete. A transmission plastic scintillator with a thickness of 0.5 mm placed on the neutron beam line and fission chambers placed around the lithium target are used as a neutron monitor. The neutron fluence was determined using a proton recoil telescope (PRT) that consists of a Si semiconductor detector (Depletion depth: 500 μm) and an NE213 liquid scintillator (Diameter: 7.62 cm, Thickness: 7.62 cm). A polyethylene radiator was set in the center of the beam axis and the PRT was placed out of the beam axis as shown in figure 1. The discrimination for the protons and other particles are available by using the NE213 detector. The time of flight (TOF) for the proton is further measured by the NE213 detector in order to improve the reliability for results of peak fluence.

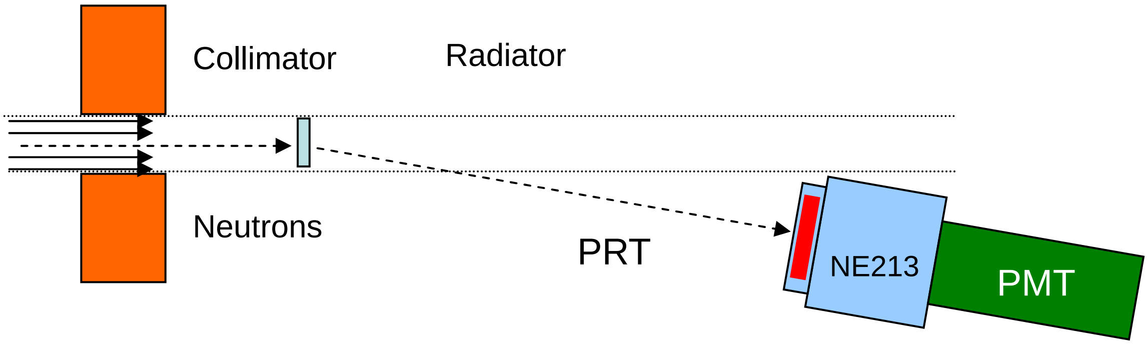

Fig.1. Typical arrangement of fluence measurement with PRT

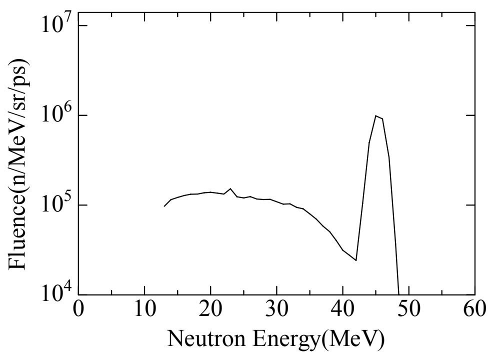

Fig.2. Neutron spectrum measured with the NE213 scintillation detector at TIARA. The peak energy is 45 MeV.

The neutron spectra were measured with the NE213 detector by means of the TOF method as shown in figure 2. In the TOF measurements, the beam burst from the cyclotron are chopped by an electrical chopper at a sub-multiple (1/5 or 1/6) of repetition rate of the cyclotron. The neutron spectra from thermal to several MeV were evaluated with a Bonner sphere spectrometer.

We will also start tests in high-energy neutron field at RCNP. Quasi-monoenergetic neutrons with an energy region from 140 to 400 MeV are produced using the ^{7}Li(p,n) reaction and a proton beam from a ring cyclotron. We tried to calibrate response functions of Bonner spheres with a ^{3}He spherical proportional counter for energies of 250 MeV and 390 MeV [3]. Measurements at two angles of 0 and 30 degrees were performed to obtain monoenergetic response by subtracting the tail contribution. Reference energy spectra for 0 and 30 degrees were measured with an NE213 scintillation detector (25.4 cm diameter and 25.4 cm thickness) by means of the TOF method [4].

We will establish the high-energy neutron standard by 2015. These experiments have been performed in cooperation with the Tohoku University, KEK and JAEA.

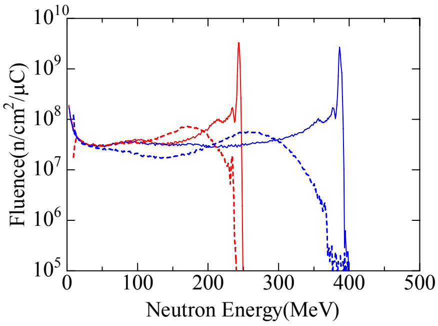

Fig.3. Neutron spectra measured with the NE213 scintillation detector at two angles of 0 and 30 degrees at RCNP. The peak energies are 243.5 MeV and 386.6 MeV.

3. Installing a pulsing system on the 4 MV Pelletron accelerator

To experimentally determine energy distribution of neutrons produced by an accelerator, a time of flight method is usually used. A pulsed neutron beam is necessary to measure the neutron energy with the time of flight method. We are installing a pulsing system with the crystron bunching method on the 4-MV Pelletron accelerator. The pulsing system will be able to produce a pulsed ion beam of repetition rate from 0.5 MHz to 4 MHz and a pulse width of 1.5 ns.

4. development of calibration method with a white neutron field

We are developing a pulsed white neutron calibration field and a new calibration method for scintillators and dosimeters. White neutrons from 10 keV to 20 MeV are produced by the ^{7}Li(d,n) reactions with a thick metal target at NMIJ. The ^{9}Be(α,n) and ^{7}Li(p,n) reactions are also used. White neutrons below 10 keV are produced by the photonuclear reaction with a linear accelerator at the Kyoto University Research Reactor Institute. The energy response of a neutron detector to be calibrated is experimentally obtained from two-dimensional measurements of pulse height and TOF in the white neutron fields.

5. Japan calibration service system for neutron emission rate and thermal neutron fluence rate standards

The Japan Calibration Service System (JCSS) consists of the national standards provision system and the calibration laboratory accreditation system introduced by the amended measurement act enforced in November 1993. In the national measurement standards provision system, the Ministry of Economy, Trade and Industry (METI) designates national primary standards and NMIJ calibrates the reference standards of accredited calibration laboratories (i.e. secondary standards) with national primary standards. In the calibration laboratory accreditation system, calibration laboratories are assessed and accredited as accredited calibration laboratories to meet the requirements of the measurement act, relevant regulations and ISO/IEC 17025. Calibration laboratories are also required to periodically take assessment as well as proficiency testing. Calibration certificates with the JCSS symbol (see Figure 4) issued by accredited calibration laboratories assure the traceability to National Measurement Standards as well as a laboratory's technical and operational competence and are acceptable in the world through the ILAC and APLAC MRA.

JCSS is scheduled to start on thermal neutron fluence rate and neutron emission rate in the fiscal years of 2012. A gas proportional counter will be specified as the secondary for the thermal neutron fluence rate. As for the neutron emission rate, we developed an emission rate detector composed of a polyethylene moderator and two ^{3}He proportional counters (figure 4) that will be specified as the secondary.

Fig.4. Simple emission rate detector composed of a polyethylene moderator and two ^{3}He proportional counters

6. Two-dimensional differential calibration method using a research reactor JRR-3M

We have developed an intense thermal neutron calibration field and a new calibration method using a reactor produced neutron beam in JRR-3M of JAEA [5]. In this beam line, neutron induced prompt gamma ray analysis has been usually performed. Curved neutron guide after the reactor provides a pure thermal neutron beam. Neutron spectrum was measured by means of a TOF method with a mechanical chopper made of ^{6}LiF+PTFE plate. Neutron flux was normalized by the results obtained from a gold foil activation method. Under the experimental conditions, the fluence rate of the thermal neutron beam was 2.54 x 10^4 cm^{-2}s^{-1}.

We develop a new thermal neutron calibration method, the "two-dimensional differential calibration method", to experimentally determine the energy response function of a neutron detector using a pulse parallel beam and the TOF technique, . The response $R(E, I)$ of a neutron detector is expressed as a function of neutron energy E and channel number I for the pulse height analysis observed with a neutron detector:

$$R(E,I) = \frac{N(E,I)}{\eta(E)} \quad (2),$$

where $N(E, I)$ is the count rate obtained for E and the I-th channel in the pulse height spectrum, and $\eta(E)$ is the neutron spectrum in the thermal neutron field. Figure 5 shows a schematic view of the concept of the two-dimensional differential calibration method. By using a pulsed parallel neutron beam in combination with the TOF technique, $N(E, I)$ and $\eta(E)$ can be experimentally obtained. The neutron energy is determined by the equation

$$E = \left(\frac{72.3 \times L}{T_n} \right)^2, \quad (3)$$

where T_n (μs) is the TOF of a neutron and L (m) is the flight path length. The reference neutron spectrum is simultaneously measured by installing a thermal neutron detector on the beam

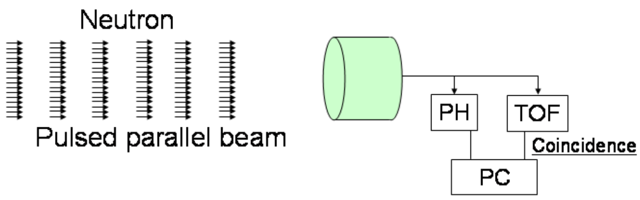

Fig. 5. Schematic view of the concept of the calibration method proposed in the present study.

axis. $N(E, I)$ is extracted from the two-dimensional data of TOF and pulse height based on coincidence measurements. The response R_{th}' for any thermal neutron spectrum $\nu(E)$ field, such as the work place of a reactor facility, can be reconstructed using $R(E, I)$ as follows:

$$R'_{th} = \frac{\iint R(E,I)\nu(E)dEdI}{\int \nu(E)dE} = \frac{\sum_i R(E_i,I_i)\nu(E_i)}{\sum_i \nu(E_i)}, \quad (4)$$

where E_i is i-th energy bin in the neutron spectrum $\nu(E)$. The energy region of $\nu(E)$ should be within the energy range of $\eta(E)$.

The calibration method was experimentally demonstrated for a ^{3}He proportional counter and an electric personal dosimeter using a pulsed thermal neutron beam from the research reactor JRR-3M.

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