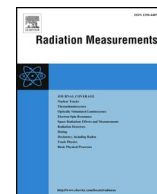




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Reference thermal neutron field at KRISS for calibration of neutron detectors

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ABSTRACT

A reference thermal neutron field has been established at the Korea Research Institute of Standards and Science (KRISS) by using a $^{241}\text{Am-Be}$ neutron source and a high-purity graphite pile constructed by stacking graphite blocks. The properties of the graphite blocks such as impurities, density, and dimensions were studied thoroughly to understand the characteristics of the generated field. The energy spectrum and thermal neutron fractions were simulated with the Monte Carlo N-Particle eXtended code using measured physical parameters. The neutron effective temperature was 308 K, and the fraction of thermal neutrons was approximately 95% at the reference position of the thermal neutron field. The thermal neutron fluence rate was determined by adopting the Westcott convention method based on neutron activation analysis using a gold foil. The Westcott fluence rate for thermal neutron at the reference position was $(2326.7 \pm 8.4) \text{ cm}^{-2}\text{s}^{-1}$. The true thermal neutron fluence rate at the reference position in the KRISS thermal neutron field was $(2700 \pm 29) \text{ cm}^{-2}\text{s}^{-1}$ (at the reference date of June 30, 2014). The response of a spherical proportional counter with He-3 (SP9 neutron detector) was evaluated in the newly established field as $(3.083 \pm 0.045) \text{ cm}^2$ for the reference calibration condition (a parallel neutron beam with a Maxwellian energy distribution having a most probable energy of 0.025 eV).

1. Introduction

A thermal neutron field is essential for calibrating thermal neutron detectors used for neutron monitors and dose-equivalent meters. A thermal neutron field can be generated by moderating fast neutrons from various neutron sources using a material such as graphite. The neutron energy distribution and fluence rate of the resulting neutron field should be accurately evaluated for the precise calibration of thermal neutron detectors. Although the thermal neutron fluence can be measured with neutron activation analysis using activation detectors (Williams and Gilliam, 2011), the neutron energy distribution must also be evaluated for the precise measurement of thermal neutron fluence and for the calibration of thermal neutron detectors. However, the measurement of the energy distribution in the thermal region is difficult. In many cases, neutron transport calculations using Monte Carlo codes such as the Monte Carlo N-Particle eXtended code (MCNPX) are utilized to evaluate the energy distribution.

Other difficulties in calibrating thermal neutron detectors arise from differences among actual thermal neutron fields, such as differences in calibration spaces, energy distributions, and the direction of neutron

incidences (Nolte et al., 2015). The calibration constant or detector response should be evaluated under pre-agreed reference conditions. The reference conditions used at the present study are assumed to be those of parallel-incident neutron beams with a Maxwellian energy distribution having a most probable energy of 0.025 eV. The differences between the reference conditions and the actual calibration conditions should be corrected. In actual conditions, the neutrons are not parallel-incident, and the neutrons having an energy distribution with a 1/E shape are still included in the thermal neutron energy region owing to incomplete thermalization. In many cases, the space for calibration is not sufficiently large to ignore backscatter thermal neutrons.

At the Korea Research Institute of Standards and Science (KRISS), a thermal neutron field has been established with a high-purity graphite pile and a $^{241}\text{Am-Be}$ neutron source, and various field characteristics were studied. In the present article, we detail the facility's construction and the characteristics of the thermal neutron field (Section 2), the measurement system and the determination of thermal neutron fluence based on neutron activation analysis (Section 3, 4), and the calibration of a neutron detector using the constructed facility (Section 5).

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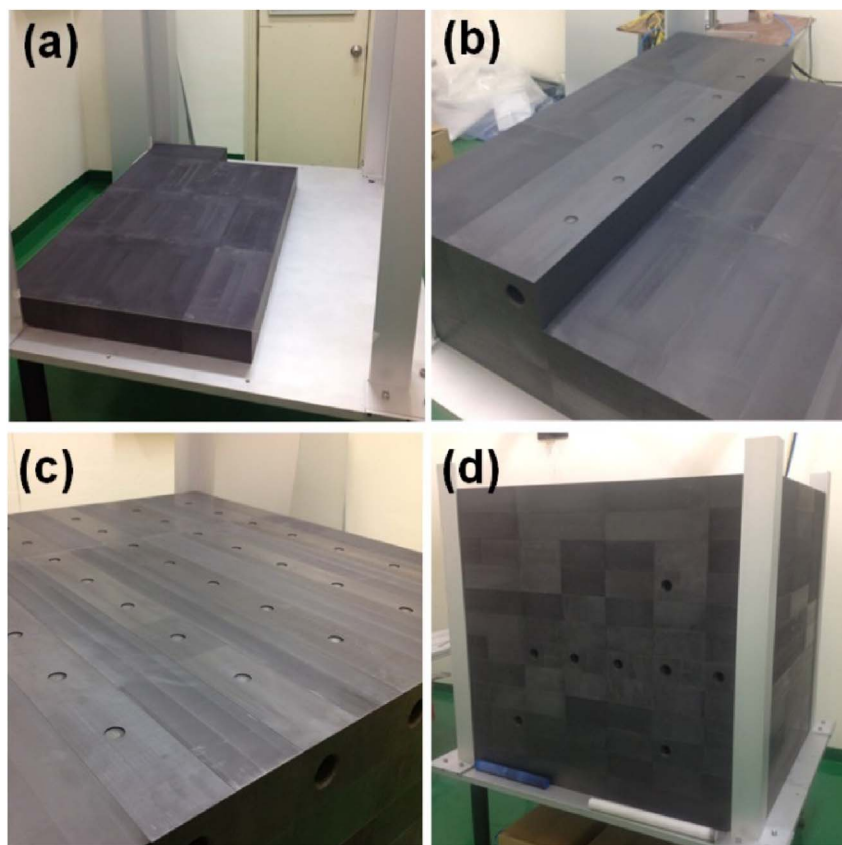


Fig. 1. Construction process of the graphite pile.

2. Thermal neutron field at KRISS

2.1. Construction of graphite pile

A 120 cm (width) $\times$ 120 cm (height) $\times$ 140 cm (length) graphite pile was constructed at KRISS, as shown in Fig. 1. To understand the thermal neutron field, the properties of the graphite pile, including its impurities, boron concentration, density, structure, and dimensions, were thoroughly studied. In total, 239 graphite blocks (manufactured by Morgan Advanced Materials plc.) were stacked on an aluminum plate positioned 60 cm above the floor to reduce the scattering of neutrons by the floor. The density of each block was measured by weighing to obtain the density distribution of the graphite pile. The average density was $(1.786 \pm 0.015) \text{ g/cm}^3$.

To measure the boron concentration, 16 graphite chips (20 mm in diameter and 2 mm in thickness) were prepared from various locations of the graphite block, and their boron concentration was measured with a cold-neutron prompt gamma-ray activation analysis (PGAA) instrument in the NG7 beam line in the NIST Center for Neutron Research (NCNR) at NIST (the National Institute of Standards and Technology, U.S.A. (NIST) (Arif et al., 1993). The natural boron concentration was $(0.628 \pm 0.028) \mu\text{g/g}$. Other impurities such as natural lithium and lead were tested with glow discharge mass spectrometry (GDMS) (SHIVA Technologies, U.S.A.) and were found to be less than 0.1 ppm in weight.

Fig. 2 shows a schematic of the graphite pile. The y-axis denotes the axis from the neutron source to the reference position. The z-axis and x-axis denote the vertical direction and horizontal direction, respectively. An X-14-type $^{241}\text{Am-Be}$ radionuclide neutron source (manufactured by Amersham) was used; its emission rate was approximately $1.2 \times 10^7 \text{ s}^{-1}$ (Park et al., 2005). The neutron source was inserted at a distance of 35 cm from the surface along the y-axis and positioned at the center in the vertical direction. The source was not positioned at the center of the thermal pile in order to maintain sufficient neutron moderation in the

small pile. As shown in Fig. 2 (b), seven wells (filled yellow green circles) with diameters of 2.4 mm and depths of 2.1 mm were prepared on eight graphite blocks at various positions (boxes with diagonal shading) for installing the activation foil. The reference position of the graphite pile for the measurement of thermal neutron fluence was 70 cm from the source along the y-axis.

The density, boron concentrations, impurities, and detailed structure inside the constructed pile were included in the modeling of the thermal neutron field.

2.2. Monte Carlo simulations of thermal neutron field

MCNPX 2.7.0 code (Pelowitz, 2011) was utilized to model the thermal neutron field in the graphite pile. The neutron source was defined as a beryllium cylinder with a density of 1.75 g/cm^3 positioned inside a stainless-steel capsule. Neutrons were generated uniformly inside the beryllium cylinder with such an energy distribution that the energy spectrum of neutrons from the source capsule's surface reproduced the neutron energy spectrum of a $^{241}\text{Am-Be}$ source given in ISO8529-1 (ISO, 2001). In this manner, the anisotropic angular dependence of the $^{241}\text{Am-Be}$ source was well reproduced too (Park et al., 2005). Structural details, such as the insertion hole for the neutron source and the activation wells in the pile, were incorporated precisely in the modeling, in which the measured boron concentration and the density of the graphite pile were considered. To account for the effects of the surrounding materials, structures such as the wall of the experiment room, the door, and the graphite support were also considered. The ENDF/B-VII.0 cross-section library and special $S(\alpha, \beta)$ data (at $T = 293 \text{ K}$) were used for neutron transport (Pelowitz, 2011).

Fig. 3 shows the calculated spectral fluence at the reference position. The dotted curve shows the neutron energy spectrum at the reference position in the activation hole of a graphite block. The curve drawn with the solid line shows the energy spectrum at the same position with a cadmium case 1 mm in thickness. The spectra were aligned

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