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Investigation of reflection properties of applied reflectors for thermal neutrons by considering the albedo and spectral shift

S. Azimkhani [a], F. Zolfagharpour [a, *], F. Ziaie [b]

[a] Department of Physics, University of Mohaghegh Ardabili, P.O. Box 179, Ardabil, Iran
[b] Radiation Application Research School, Nuclear Science & Technology Research Institute, P.O. Box 11365-3486, Tehran, Iran

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ABSTRACT

In this paper, thermal neutrons reflection coefficient has been measured experimentally for water, graphite, polyethylene, and lead reflectors at average incident angle 56° by using ^{241}Am-Be neutron source (5.2 Ci) and BF_3 detector. Based on obtaining experimental data from different thicknesses for four reflectors, the maximum saturation value of the thermal neutron albedo is for polyethylene reflector and the minimum value of spectral shift is for lead reflector. The best reflector is a compromise included both high albedo and low spectral shift which causes to increase the safety of reactor. The measured value for thermal neutron albedo is 0.95 ± 0.03 at about 8 cm reflector thickness. Also, there is suitable agreement achieved between the experimental values and simulation results by using MCNPX Monte Carlo code.

1. Introduction

Neutron reflector has essential role in preserving neutron chain reaction in nuclear reactors. The assembly when is surrounding with neutron reflector, increase the thermal flux throughout the moderating assembly (Hussein, 2004). In a reactor core of given shape and volume, the reflector reduces the leakage of neutrons in the course of their slowing (Yamanaka and Kurosaki, 2012). A reflector directly contributes to the neutron economy and indirectly, helps to decrease the critical volume of the reactor core. The key requirements for reflector include a high reflectivity, a large macroscopic scattering cross section, and efficient neutron slowing. Also, neutron reflection method used for the determination of hydrogen and moisture for bulk samples (Csikai and Doczi, 2007; Yousif Ali et al., 1995). The concept of the reflection cross section of thermal neutrons has been introduced as a macroscopic parameter for the characterization of the reflection property of substances (Csikai and Buczko, 1999). A reflector is characterized by its coefficients of reflection, or albedo, defined as the total probability that a particle incident on a wall will be reflected in an arbitrary direction (Utsuro and Lgnatovich, 2010; Reuss, 2008). The reported albedo coefficients in the literature are shown that neutron albedo coefficient depended on experiment geometry and elemental composition (Mirza et al., 2006; Mehboob et al., 2013; Schonfeldt et al., 2015). For example, the geometrical effects on thermal neutron reflection investigated for different source-detector-sample geometries, it concluded that the neutron reflection depended on geometrical arrangement of source-detector-sample, moderator, and its thickness (Akaho et al., 2001). Therefore, it is essential to obtain material and optimal thickness for neutron systems. Also, the changing of the initial energy of neutrons, i.e., the spectral shift is important for a nuclear designing. In this work, different thicknesses of water, graphite, polyethylene, and lead reflectors are investigated for calculating thermal neutron reflection coefficients. Scattering neutron flux from different thicknesses of different reflectors are measured by using an instrument of 5.2 Ci ^{241}Am-Be neutron source, BF_3 neutron detector, Cadmium as neutron absorber, and water as neutron moderator. Then, neutron reflection coefficient and saturation value are calculated. Also experimental geometry are designed by using MCNP4X code and simulation results are compared with experimental results. The spectral shift calculations of reflected neutrons are accomplished for selecting the best reflector by using MCNPX code.

2. Theory

The albedo neutron defined as the ratio of outward neutron flow from reflector to inward neutron flow to reflector. By considering

* Corresponding author.
E-mail address: zolfagharpour@uma.ac.ir (F. Zolfagharpour).

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neutron diffusion equation, where there are no sources within the reflector, ie (Lamarsh and Barata, 2001):

$$\frac{d^2\Phi(x)}{dx^2} - \frac{\Phi}{L^2} = 0, \quad (1)$$

where Φ and L are neutron flux and thermal diffusion length. The thermal neutron albedo for a reflector layer can be expressed as (Brockhoff and Shuitis, 2007)

$$\alpha = \frac{J_n^{out}(\theta)}{J_n^{in}}, \quad (2)$$

J_{in} and J_{out} are incoming and scattering neutrons flow at reflector, respectively. The incident particle flow on surface at an angle θ_0 with respect to the surface normal **n**, in does units, across a unit area of the surface is related to the incident fluence Φ_0 as

$$J_n^{in} = \Phi_0 \cos\theta_0 R(E_0), \quad (3)$$

where $R(E_0)$ is the fluence to dose conversion factor for the incident radiation of energy E_0. In this work, the fluence to dose conversion factor was extracted from Ref. (Lamarsh and Barata, 2001). The current out of a unit area of the surface in a unit solid angle about the direction $\Omega(\theta)$, again in dose units, can be expressed as

$$J_n^{out}(E,\theta) = \int_0^{E_{max}} \Phi(E,\theta)\cos\theta R(E)dE, \quad (4)$$

where $J_n^{out}(E,\theta)$ and $\Phi(E,\theta)$ are the angular energy dependent flow and fluence at the surface, respectively, and E_{max} is the maximum neutron energy (Brockhoff and Shuitis, 2007).

3. Experimental procedures

The experimental set up which is used in this investigation is shown in Fig. 1. The measuring equipment consist of a ^{241}Am-Be neutron source (5.2 Ci) and BF_3 detector. The ^{241}Am-Be neutron source emitted fast neutrons. Therefore water with 10 cm thickness have been utilized as neutron moderator to thermalization of fast neutrons. Thus, the uniform source of thermal neutrons can be considered at energy 0.025 eV. The beam of thermal neutrons which is enter on the reflector, are at an average angle 56° according to configuration in Fig. 1. Because water moderator is a gamma productive source, therefore lead with 5 cm thickness is used in three sides of water container as gamma shielding. The BF_3 detector have 2.5 cm in diameter and 20 cm in length. The operating voltage of the detector is 2320 V. The cadmium sheet (23 cm × 31 cm × 0.4 cm) is located between neutron moderator and detector at distance of 4 cm from both moderator and detector, in order to BF_3 detector only respond to the thermal neutrons reflecting from the reflector. Cadmium has high absorption cross section for thermal neutrons (2450 barn) (Lamarsh and Barata, 2001). At first, the counts of thermal neutrons was recorded for 20 min without reflector. Then, reflector layers (length 30 cm and width 20 cm) placed above BF_3 detector and the thermal neutron counts obtained with reflectors with increasing thickness for water, graphite, polyethylene, and lead. Multi-channel analyzer (MCA) and NTMCA software used for results analyze.

4. Results and discussion

The spectrum of neutron energy obtained is been shown in

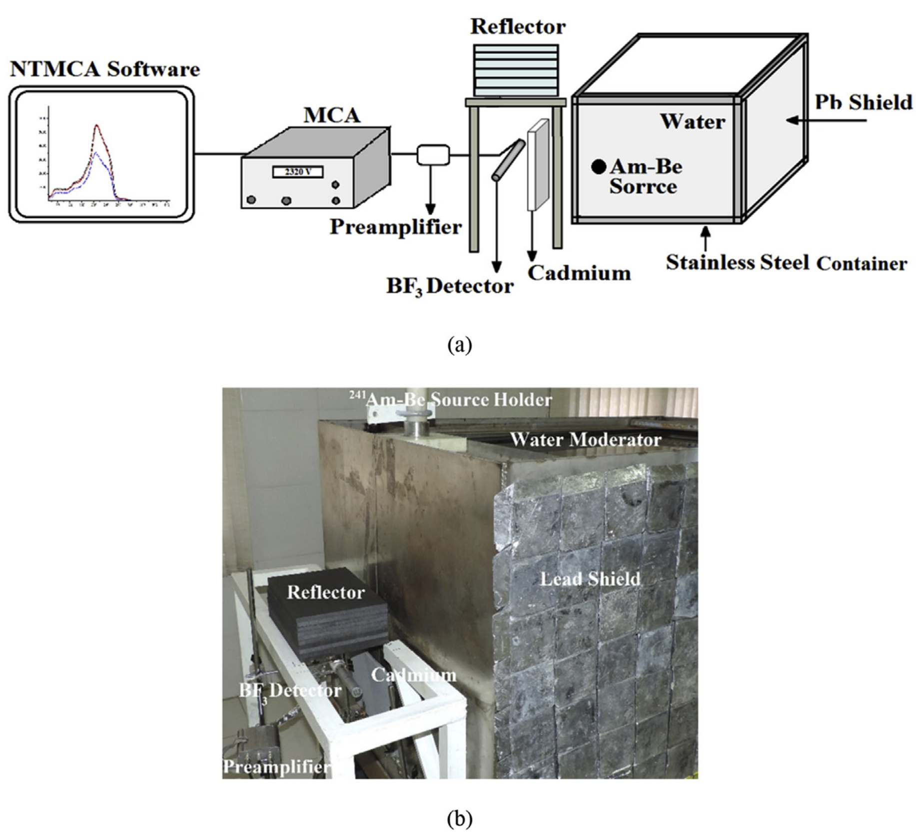

Fig. 1. (a) Schematic Photograph of experimental setup, (b) Geometric measuring system.