Applied Radiation and Isotopes 135 (2018) 155–159

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Measurement of thermal neutrons reflection coefficients for two-layer reflectors

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HIGHLIGHTS

- Thermal neutrons reflection coefficients are increasing with adding reflector thickness and saturating in certain thickness.
- Thermal neutron reflection coefficients of reflectors slightly increase by addition of the second layer.
- The maximum value of growth is obtained for lead-polyethylene compound.
- Suitable agreement have been found between the experimental data and simulation results by using Monte Carlo code shown in our figures.

ARTICLE INFO

Keywords:
Thermal neutrons albedo
Two-layer reflector
Polyethylene
Excess count
Reflection
Saturation thickness

ABSTRACT

In this research, thermal neutrons albedo coefficients and relative number of excess counts have been measured experimentally for different thicknesses of two-layer reflectors by using ^{241}Am-Be neutron source (5.2Ci) and BF_3 detector. Our used reflectors consist of two-layer which are combinations of water, graphite, polyethylene, and lead materials. Experimental results reveal that thermal neutron reflection coefficients slightly increased by addition of the second layer. The maximum value of growth for thermal neutrons albedo is obtained for lead-polyethylene compound (0.72 ± 0.01). Also, there is suitable agreement between the experimental values and simulation results by using MCNPX code.

1. Introduction

Neutron reflection method commonly used in chemical analysis of bulk samples, neutron dosimetry, detection of land mine and explosive, determination of moisture contents in hydrogenous materials, improvement of neutron beam performance in Boron Neutron Capture Therapy, and enhancement of the multiplication factor in nuclear reactors. Neutron reflectors with different material types are used in the nuclear reactors to reduce the critical size and fuel mass of the reactor core (Dawahra et al., 2015). Reflectors should have a small atomic weight, a high scattering cross section, a high slowing-down power, and a low absorption cross section (Albarhoum, 2011). A reflector is characterized by its coefficient of reflection, or albedo which is defined as the proportion of neutrons leaving the core that are send back towards the core (Reuss, 2008). The neutron reflection depends on the elemental composition of the reflector substance and the geometrical circumstances of the measurement (Csikai and Buczko, 1999). In recent years, there have been attempts to measure the thermal neutron albedo coefficients for different materials and configurations. Thermal neutron albedo coefficients have been calculated for monolithic and geometric voided reflectors (Mirza et al., 2006). Also, thermal neutron albedo coefficients have been investigated for multilithic reflectors in copper-wood, copper-aluminum, wood-paraffin, and paraffin-iron combinations (Mehboob et al., 2013). Both researches studied increasing of the thermal neutron albedo coefficients for reflectors. However, few studies have been reported the effect of second layers on the reflection properties. In this work, thermal neutron albedo coefficients and relative number of excess counts are measured for different thicknesses of water, graphite, polyethylene, and lead reflectors and determined their saturation thicknesses by using the instruments of 5.2Ci ^{241}Am-Be neutron source (13.47×10^6 neutron/s), BF_3 neutron detector, Cadmium as neutron absorber, and water as neutron moderator. Next, each of used materials have been fixed in its saturation thickness and different thicknesses of other three materials are added as second layers. Then, the effect of second layer are investigated for reflection coefficients of reflectors. Also experimental geometry are designed by using MCNPX code and simulation results are compared with experimental results.

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https://doi.org/10.1016/j.apradiso.2018.01.031
Received 16 December 2016; Received in revised form 19 October 2017; Accepted 20 January 2018
0969-8043/

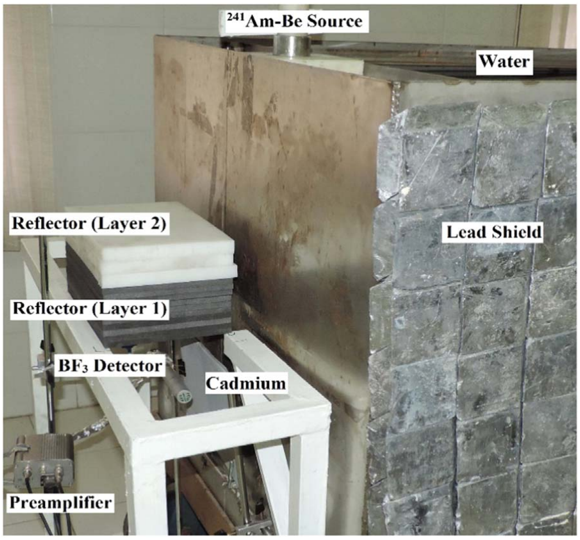

Fig. 1. Photograph of experimental setup.

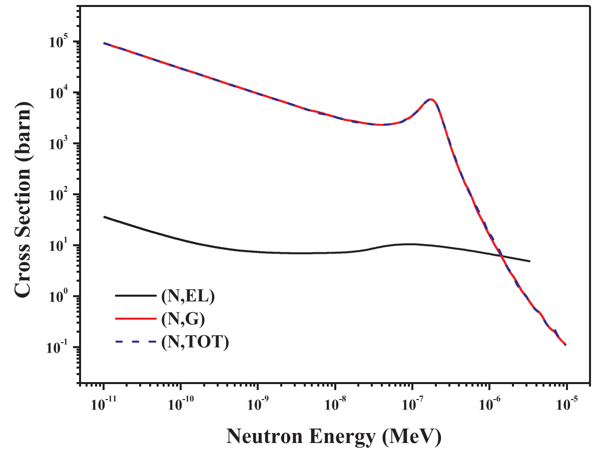

Fig. 2. Total, elastic and (N, G) capture cross sections for natural cadmium versus neutron energy (data are taken from ENDF/B-VII.1).

2. Experimental procedures

The measuring instrument used in this work is shown in Fig. 1. A cylindrical ^{241}Am-Be neutron source with 5.2Ci activity is placed in water container (150 cm × 100 cm × 100 cm) at distance of 10 cm from one of the container wall. The neutron yield per 10^6 primary alpha particles of ^{241}Am-Be source is 70 experimentally (Knoll, 2000). Therefore, the activity of used ^{241}Am-Be source is 13.47×10^6 neutron/sec. The ^{241}Am-Be neutron source is a fast neutron source and we use a moderator to slow down the fast neutrons to the thermal energy range. So, we used water as neutron moderator. Water container shielded by using lead bricks which have 5 cm thickness. BF_3 detector has 2.5 cm in diameter, 20 cm in length and 2320 V operating voltage located at distance of 14 cm from neutron source. The benefit of using the BF_3 detector is high efficiency (greater than 90%) for thermal neutrons (with energy up to 0.5 eV) due to the presence of ^{10}B in the detector (Castro et al., 2011). Cadmium plates with dimension 23 cm × 31 cm × 0.4 cm are placed between neutron moderator and detector. In this dimension, counted thermal neutrons without reflectors reach to background amount. Absorption cross section of natural cadmium for thermal neutrons is 2520 barn (Sears, 1992). Cross sections of natural cadmium isotopes have been extracted from Evaluated Nuclear Data File (ENDF, 2011). Then, cross sections of natural cadmium have been calculated according to isotopes abundance of natural cadmium in energy range of thermal neutrons (Vertes et al., 2011). Variation of natural cadmium cross sections with neutron energy are shown in Fig. 2. Cadmium plates as neutron absorber cause to BF_3 detector only respond to the thermal neutrons reflecting from the reflector. Multi-channel analyzer (MCA) and NTMCA software are used for results analyze. At first, the different thicknesses of water, graphite, polyethylene, and lead reflectors with length 30 cm and width 20 cm located above BF_3 detector and the counts of thermal neutrons was recorded for 20 min. Then, the second reflector layers with different thicknesses added to first layers and the thermal neutron counts are recorded by BF_3 detector.

3. Results and discussion

Fig. 3 shows the spectrum of pulse height obtained using BF_3 detector for several thicknesses of water, graphite, polyethylene, and lead reflectors and their combinations. The ^{10}B(α, n) reaction produces in result of alpha particles interaction with ^{10}B in BF_3 detector. The productions of this reaction are ^{7}Li and ^{4}He which ^{7}Li is produced about 94% in the excited state and 6% in the ground state. Q values of the reaction are 2.310 MeV for the excited state and 2.792 MeV for the ground state. Also, because of the wall effect, the discontinuities are observed in 1.47 MeV and 0.84 MeV according to Fig. 3. We obtain the thermal counted neutron values from sum of the counts under the curve of the channel-energy spectrum. In BF_3 detector the peak locating in low channels are in association with gamma rays and thermal neutrons have been counted in channels higher than channel number 50. To calculate the thermal neutrons albedo coefficients, the following equation is used

$$\alpha = \frac{J_{out}}{J_{in}} \tag{1}$$

where J_{in} and J_{out} indicate the incoming and scattering neutrons from reflector, respectively (Brockhoff and Shuitis, 2007). The net flow of neutrons in a reactor is described by J, which is called the neutron current density vector (The net number of neutrons passing outward through the surface per cm^2/sec). The uncertainty in thermal neutron albedo is given by the following equation (Knoll, 2000)

$$\sigma_\alpha = \sqrt{(\frac{\partial\alpha}{\partial J_{in}})^2\sigma_{J_{in}}^2 + (\frac{\partial\alpha}{\partial J_{out}})^2\sigma_{J_{out}}^2} \tag{2}$$

where $\sigma_{J_{in}}$ and $\sigma_{J_{out}}$ are the uncertainty in experimental measurements of J_{in} and J_{out}, respectively. Also, the counts of thermal neutrons have been obtained from sum of counts under the curve of the channel-energy spectrum (N_1, N_2, …, N_n), ie

$$N = N_1 + N_2 + \ldots + N_n \tag{3}$$

Therefore, the uncertainty in the counts of thermal neutrons is calculated by

$$\sigma_N = \sqrt{\sigma_{N_1}^2 + \sigma_{N_2}^2 + \ldots + \sigma_{N_n}^2} \tag{4}$$

where

$$\sigma_{N_1} = \sqrt{N_1};\ \sigma_{N_2} = \sqrt{N_2};\ \ldots;\ \sigma_{N_n} = \sqrt{N_n} \tag{5}$$

At first, detector has been located in the reflector place and measured the entered thermal neutrons to the reflector by using BF_3 detector (J_{in}). Then, water, graphite, polyethylene, and lead reflectors