Annals of Nuclear Energy 68 (2014) 10–14

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Optimization of thermal neutron flux in an irradiator assembly with different isotopic sources

A.M. Osman [a,*], A.M. Abdel-Monem [a], A.M. Ali [a,b]

[a] Laboratories for Detection of Landmines and Illicit Materials, Reactor Physics Department, Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt
[b] Physics Department, Faculty of Science, Jazan University, Jazan, Saudi Arabia

ARTICLE INFO

Article history:
Received 23 June 2013
Received in revised form 2 December 2013
Accepted 26 December 2013
Available online 22 January 2014

Keywords:
Thermal neutron flux
Isotopic neutron sources
Irradiator and MCNP code

ABSTRACT

This work aimed to determine the distribution of thermal neutron flux in an irradiator assembly to study the possibility of use this irradiator for Neutron Activation Analysis; NAA. To establish the facility specifications, the thermal neutron flux values of ^{252}Cf and Pu-Be isotopic neutron sources along the horizontal irradiator axis were determined experimentally and calculated by Monte Carlo N-Particle; MCNP transport code. The irradiator assembly characterized by supplying a stable neutron flux for a long period, eliminating the need to use standard material i.e. comparative method, so that the process becomes efficient, compact, economical and more reliable. The measurements were carried out at different position inside the irradiator assembly using proportional ^{3}He-detector and gold foil activation method. As well as, these measurements were performed without and with two types of neutron reflector such as water and steel to determine the thermal neutron distribution along the irradiation points. The experimental results were compared to the calculations performed with MCNP Code. The calculated and experimental results were in reasonable agreement for both ^{252}Cf and Pu-Be sources. This indicated that the material and geometrical properties of the irradiator were modeled well.

1. Introduction

Neutrons with different energies are required in nuclear medicine, radiotherapy and industry. For example, fast neutron are used in radiobiological research and radiotherapy, epithermal neutrons are used in boron neutron capture therapy (BNCT), and thermal neutrons are used in Neutron Activation Analysis (Vega-Carrillo and Torres-Muhech, 2002; Lakosi and Nguyen, 2005). Neutrons can be produced from different sources such as nuclear reactors, particle accelerators and isotopic neutron sources. Due to their simplicity of installation, operation and low price, comparing to other neutron sources, isotopic neutron sources have many applications. However, some of these neutron sources have deficiencies such as low neutron yield and short half life (Vega-Carrillo et al., 2002; Vega-Carrillo et al., 2003). Isotopic neutron sources usually were fabricated in the form of capsules with equal height and diameter (about centimeters), while miniature neutron sources diameters are less than 3 mm. By decreasing the capsules, diameter, the achievement of miniature neutron source will become possible. Traditional radiation treatment in radiotherapy makes use of gamma rays or X-rays. In some cases neutrons can be more effective than gamma and X-rays, due to the fact that they can deposit more concentrated energy at the sub-cellular level, yet, the neutron will damage surrounding normal tissue unfortunately.

This work demonstrates a constructed irradiator assembly incorporate radioisotopic neutron source such as ^{252}Cf or Pu-Be. This irradiator consists of three main parts; the fast neutron reflector, moderator and thermal neutrons reflector. A brief description for these parts is given and discussed below.

2. Irradiator assembly

Basically, this irradiator consists of PVC cylinder of 1 cm thick, 25 cm long and 25 cm diameter filled with paraffin. The irradiator incorporate isotopic neutron source/sources i.e. ^{252}Cf of $\sim 10^{7}$ n/s or two Pu-Be sources of strength 5×10^{6} n/s for each. The cylinder has a central steel tube of 1.0 cm thick, 5.0 cm diameter and 8.4 cm long with perpendicular cylindrical cavities which cross the geometric centre, where the neutron sources are placed. This tube is used for two purposes; firstly as a fast neutron reflector to increase the intensity of the incident beam and the second to degradation the fast neutron energy through inelastic scattering reaction. The later helps to reduce the volume of moderator. The two neutron sources are positioned symmetrically and face to face, at the same distance from the geometric centre. Fig. 1 shows a schematic diagram for the details of the constructed irradiator with the modeled axes configuration. This figure shows as well

* Corresponding author. Tel.: +20 1007545299.
E-mail address: ahmed2004ge@yahoo.co.uk (A.M. Osman).

0306-4549/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.anucene.2013.12.016

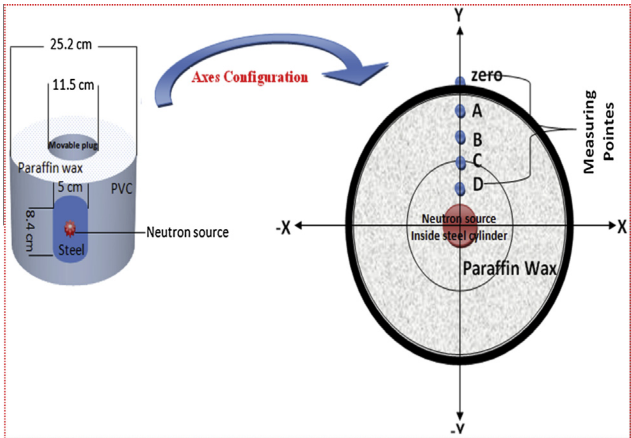

Fig. 1. Schematic diagram of the irradiator arrangement with modeled axis configuration.

the arrangements and the inner-distances between the key measuring points. The distance between the neutron source and position D is 4.1 cm and the distance between two consequence positions is about 2 cm.

To study the effect of the reflector on the neutron flux distribution along the irradiation positions, two types of neutron reflector were used during this work. Firstly, the water reflector which constructed as a cylindrical shape of 4 cm wall thick and 20 cm height. Secondly, steel reflector which was shaped as cub of 1 cm wall thick and 20 cm height.

3. Experimental measurements

In this work the measurements of thermal neutron flux distribution were performed using two techniques; ^{3}He proportional counter and gold activation foil. A brief description for these techniques and experimental procedures are given below.

3.1. Gas proportional counter measurements

A Hellium-3 gas proportional counter (1.2 φ × 13 cm height) was used for the measurement of thermal neutrons flux at the irradiation positions as shown in Fig. 1. An operating voltage of 800 V was applied. The output signal is directly connected to multichannel analyzer of 1024 channels. The measuring time is 5 min. Measurements were carried out at five positions as shown in Fig. 1.

3.2. Irradiation of the activation foils

This work uses gold foils as activation detectors to determine the thermal neutron flux. These foils are chosen to make reduce the effects of self-shielding avoiding the use of complex correction factors in the calculations of thermal neutron fluxes. The weights of these foils are 0.0108, 0.008, 0.0087, 0.0066 and 0.0064 g. Thus, a total of 5 foils were irradiated in the irradiation points (Zero, A, B, C and D) as shown in Fig. 1.

After the foils irradiation, the emitted gamma-ray are counted and analyzed in the detection system with hyper-pure germanium; HPGe detector (Canberra model GEM-30185). The detector relative efficiency is 30%. It has a resolution of 1.85 keV FWHM at 1332.5 keV and peak to Compton ratio of 58. The detector is surrounded by 10 cm lead shield (Canberra model 747E). The output signal from the detector is amplified (Canberra amplifier model 2026) and then fed to Multi Channel Analyzer; MCA (Canberra MALTIPORT II) of 16,384 channels ADC. Genie-2000 software is installed on PC for data acquisition and analysis. The measured photon values of the net area under the peak at E_γ = 411.80 keV of the ^{198}Au produced through the nuclear reaction ^{197}Au(n, γ)^{198}Au for each foil was used to obtain the thermal neutron flux from the following equation (Robert et al., 2011):

$$\Phi_{th} = C\frac{\lambda}{(1-e^{-\lambda t_i})e^{-\lambda t_d}(1-e^{-\lambda t_m})m_x\sigma_{eff}\Gamma\varepsilon}\cdot\frac{M_a}{\theta N_{Av}} \tag{1}$$

The description and dimensional units of the physical constants in this equation are:

λ: Decay constant (2.978×10^{-6} s^{-1})
σ_{eff}: Spectrum averaged cross-section, cm^2
Γ: Fraction of decays producing gamma-ray of E_γ
θ: Isotopic abundance of the target isotope
Φth: Thermal neutron flux n/s cm^2
ε: Detection efficiency for gamma-ray of E_γ
t_i: Irradiation time, s
t_m: Measuring time, s
t_d: Decay time to start of count, s
m_x: Mass of the irradiated gold foil, g
C: Net count in the gamma ray peak of E_γ
M_a: Atomic mass, g mol^{-1}
N_{Av}: Avogadro's number.

3.3. Monte Carlo calculations

Monte Carlo Neutron Particle Transport MCNP code; version MCNP 4B (Briesmeister, 1997) was used to estimate the flux in five positions without and with two types of reflector; steel and water. The calculations were performed for both ^{252}Cf and Pu-Be neutron sources. In these calculations the energy ranges considered were: (a) thermal below the cadmium cut-off energy (0.50 eV) and (b) fast neutrons above cadmium cut-off energy up to 1 MeV.

For the neutron flux calculations, the tally F4:N was used. This tally allows the calculation of the flux average over a cell (particles/cm^2). In this Monte Carlo simulation, 5×10^7 histories were run, thus providing an estimated relative error less than 0.09, producing reliable confidence intervals. In most cases the simulated results do not pass 1 of 10 statistical checks.

4. Results and discussions

4.1. Calculated neutron flux spectrum

The results for the calculated neutron flux distribution of ^{252}Cf and Pu-Be neutron sources are shown in Table 1. This table shows that, the value of the thermal neutron flux is generally higher than the value of epithermal and fast neutron fluxes. In case of ^{252}Cf the epithermal neutron flux is higher than the fast neutron flux. Opposite results has been found in the case of Pu-Be source. This can be attributed to the mean energy of each source (the mean energy is 2.3 MeV for ^{252}Cf and 4.5 MeV for Pu-Be). In addition, these figures clearly show that the position C have the highest value of the thermal neutron flux.

4.2. Results of ^{252}Cf source

Fig. 2 shows the spatial distribution of thermal neutron flux along the irradiation position which measured by ^{3}He-detector. It is clear from this figure that the thermal neutron flux at position C is slightly higher than that at position D, then the thermal neutron flux decreases gradually through position B, A and Zero. The effect of reflector is slightly clear at positions A and Zero.