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Comparison of different geometric configurations and materials for neutron radiography purposes based on a ^{241}Am/Be neutron source

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Abstract

The present work examines two different geometric configurations and three different lining materials that are suitable for thermal neutron radiography purposes based on a ^{241}Am/Be neutron source. The same source was also used for fast neutron radiography. Appropriate collimators were simulated for each of the radiography modes, comparing the effectiveness of Cadmium, Gadolinium, and Boral as lining materials for thermal neutron radiography and evaluating the efficiency of Iron and Tungsten as interior wall materials of the collimator in the case of fast neutron radiography. The presented facilities have been simulated for a wide range of parameter values to characterize neutron radiography using the MCNP4B Monte Carlo code.

Keywords: Monte Carlo simulations; Thermal neutron radiography; Fast neutron radiography; ^{241}Am/Be

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1. Introduction

Neutron radiography (NR) is a powerful non- destructive method that works in the same way as X- or gamma ray imaging techniques, but exploits a neutron beam instead. The method has been established as a non-destructive technique and as a research tool for over 70 years and is usually used in security applications, engineering studies and industry to determine structural defects as well as in geology, medicine and biological research [1–7].

Because of the availability of high-intensity thermal neutron beams from nuclear research reactors and based on the fact that thermal neutrons interact with various materials with very specific cross-sections that are largely independent of the atomic number (*Z*) of the material, thermal NR has been thoroughly developed and is commercially available. However, for objects with more than a few centimeters of thickness, the use of neutrons with higher energies is necessary. Fast neutrons that have an energy higher than 1 MeV have considerably higher penetrating capabilities, but have smaller differences in cross section from element to element, and are able to offer the prospect of expanding the range of NR applications [8].

Both in thermal and fast NR, high flux neutron sources and well-collimated neutron beams are the main essential

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components of a high performance neutron radiography facility. The primary goals of this work are to find the optimum design and materials for neutron collimators based on neutrons from a ^{241}Am/Be source. All of the proposed designs have been simulated using the MCNP4B Monte Carlo code [9].

2. Materials and methods

2.1. Neutron source

There are a number of neutron sources that are available both for thermal and fast NR. Unfortunately, all of them have a number of drawbacks. Research nuclear reactors provide high intensity thermal neutron beams, but because of thermalization, their fast neutron flux is very poor. In addition, nuclear reactors have a high capital cost and have limited facilities (availability and location).

Deuterium–Deuterium (DD) neutron generators emit neutrons with an average energy of approximately 2.5 MeV and offer on/off switching of the emitted neutrons. In addition, these generators have a compact size and a relatively low neutron flux; however, their lifetime is extremely short (usually no more than 2000 h). Deuterium–Tritium (DT) neutron generators produce neutrons with an average energy of approximately 14 MeV and, for this reason, are mainly suitable for fast neutron radiography. DT neutron generators have the same drawbacks and benefits as DD generators, except for the fact that the neutron flux of DT generators is approximately two orders of magnitude higher than that of DD generators. Accelerator-driven neutron beams also offer on/off switching of the emitted neutrons and provide higher intensity neutron beams that are mainly suitable for epithermal or fast neutron imaging. Neither accelerator is inexpensive, but both usually require a series of ancillary systems, which may occupy a large space [10–13].

A variety of commercially available isotopic neutron sources are suitable for both *in situ* fast and thermal radiography. Usually, these neutron sources emit a low intensity of neutrons, require adequate shielding and represent a major waste-disposal problem. However, isotopic neutron sources can be easily incorporated in transportable radiography units and, for this reason, have mostly found application where maximum portability is required. ^{252}Cf and ^{241}Am/Be are the most commonly used isotopic sources for radiography purposes. ^{252}Cf has a neutron emission rate and average neutron energy of approximately 2.3×10^6 s^{-1} per µg and 2.3 MeV, respectively. ^{252}Cf is best for thermal NR because of its low average emitted neutron energy and small size, but unfortunately, it has a short half-life (2.6 years) and emits 1.3×10^7 photons s^{-1} per µg with a mean energy of 0.8 MeV [14].

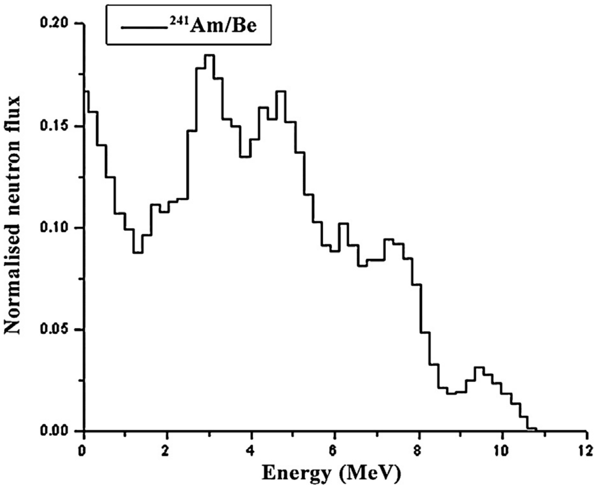

Fig. 1. Normalized neutron spectrum for ^{241}Am/Be.

For the purposes of this study, the ^{241}Am/Be neutron source is used. ^{241}Am/Be with a long half-life (432.7 years) emits approximately 2.7×10^6 s^{-1} per Ci with an average neutron energy of approximately 4.5 MeV (Fig. 1). Additionally, the ^{241}Am/Be neutron source emits low energy photons with energies of 60 keV (almost 36% of decays) and 14 keV (approximately 42% of decays) [15,16].

2.2. Thermal neutron radiography design

In any radiography system, the collimator ratio (L/D), where L is the length of the collimator and D is the diameter of the entrance aperture, defines the quality of the image for a given radiation source type, which is described by the following equations:

$$\phi_i = \frac{\phi_\alpha}{16(L_S/D)^2} \qquad (1)$$

and

$$u_g = L_f \frac{D}{L_s} \qquad (2)$$

where φ_i is the neutron flux at the image plane, φ_a is the neutron flux at the aperture, L_s is the source to object distance, D is the inlet aperture diameter, u_g is the geometric unsharpness and L_f is the image surface to object distance. In addition, the beam divergence is a

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