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The design of a multisource americium–beryllium (Am–Be) neutron irradiation facility using MCNP for the neutronic performance calculation

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HIGHLIGHTS

- Thermal neutron flux for single Am–Be source varies at different position.
- The proposed channel has higher neutron flux than the existing channels being used.
- Multi source Am–Be was design has neutron flux more than three folds that of the single source.
- NAA and PGNAA were experiment discovered to be feasible for this new design.
- Research institutes that cannot purchase research reactor could adopt the Multi source Am–Be design.

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ABSTRACT

The americium–beryllium neutron irradiation facility at the National Nuclear Research Institute (NNRI), Ghana, was re-designed with four 20 Ci sources using Monte Carlo N-Particle (MCNP) code to investigate the maximum amount of flux that is produced by the combined sources. The results were compared with a single source Am–Be irradiation facility. The main objective was to enable us to harness the maximum amount of flux for the optimization of neutron activation analysis and to enable smaller sample sized samples to be irradiated. Using MCNP for the design construction and neutronic performance calculation, it was realized that the single-source Am–Be design produced a thermal neutron flux of $(1.8 \pm 0.0007) \times 10^6\ n/\mathrm{cm}^2$ s and the four-source Am–Be design produced a thermal neutron flux of $(5.4 \pm 0.0007) \times 10^6\ n/\mathrm{cm}^2$ s which is a factor of 3.5 fold increase compared to the single-source Am–Be design. The criticality effective, k_{eff}, of the single-source and the four-source Am–Be designs were found to be 0.00115 ± 0.0008 and 0.00143 ± 0.0008, respectively.

1. Introduction

It is possible to fabricate a small self-contained neutron source by mixing an alpha emitter isotope with a suitable target material because energetic alpha particles are available from the direct decay of a number of conveniently available radionuclides. Several different target materials can lead to the (α, n) reaction with the alpha particle energies that are readily available in radioactive decay. The maximum neutron yield is obtained when beryllium is chosen as the target and produces neutrons through the reaction (Knoll, 1989).

$$^{9}_{4}\mathrm{Be} + ^{4}_{2}\propto \ \rightarrow ^{12}_{6}\mathrm{C} + ^{1}_{0}n \qquad (1)$$

Most of the alpha particles simply are stopped in the target and only 1 in approximately 10^4 reacts with a beryllium nucleus. The same yield can be obtained from a mixture of the alpha particle emitter and beryllium provided the alpha emitter is homogeneously distributed throughout the beryllium in a small relative concentration. All of the alpha emitters of practical interest are actinide elements and investigations have shown that a stable alloy can be formed between the actinide and the beryllium. There are several choices for alpha emitters. However, the choice is

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primarily based on availability, cost and half-life. Preferably, the half-life should be as short as possible and consistent with application so that the specific activity of the emitter is high. The Am–Be source is probably the most widely used of the (α, n) isotropic neutron sources. To increase the neutron yield without increasing the physical source, alpha emitters with higher specific activities are used. Therefore, sources incorporate ^{241}Am (half-life of 433 yr) for high neutron yields (Knoll, 1989).

The Am–Be neutron source is widely employed as a calibration source for neutron instrumentation, and as a portable source for a variety of applications. It is well known that the neutron source also gives off penetrating γ-rays of 4.438 MeV that are mainly associated with the neutron group leaving ^{12}C in the first excited state in the ^{9}Be$(\alpha, n)^{12}$C reaction. There is a compacted mixture of AmO_2 and ^{9}Be fine powder in the source construction. It is obvious that the cluster size, mixture ratio and compacted density of the active zone and the physical size of the source have strong influence on the neutron yield and the finer structure of the emerging neutron spectrum (Lui et al., 2007).

The IAEA supplied and installed a 20 Ci ^{241}Am–Be neutron irradiation facility at the National Nuclear Research Institute (NNRI) of the Ghana Atomic Energy Commission in 1977 for Neutron Activation Analyses (NAA) (Osae and Amoh, 1996; Osae and Akoto-Bamford, 1986; Tetteh, 1980). Figs. 1 and 2 show schematic diagrams of the Am–Be source at NNRI. The main advantage of the Am–Be neutron source irradiator is its very stable neutron flux, thus eliminating the need for a standard material in the measurement of induced activity in samples (Zevallos-Chávez and Zamboni, 2005).

The main objective of this research was to redesign the Am–Be neutron source with multiple sources to increase the thermal flux of the Am–Be neutron source. This will enable us to reduce the physical size of samples being irradiated (the existing Am–Be neutron source produces a relatively small thermal flux; as such large samples must be irradiated to obtain good sensitivity). The Am–Be neutron source is an important neutron source for neutron activation analyses. It is relatively inexpensive, easy to shield and portable in addition to producing a stable neutron flux.

2. Methodology

The simulation of the neutron particle histories was performed in the computer simulation laboratory at NNRI in March, 2011. The first Am–Be source design contained an AmO_2 compound in a mixture of beryllium powder in a double layered stainless steel shell (Lui et al., 2007). The source was surrounded by water for moderation and for a shielding effect. The MCNP5 program was used to model 36 irradiation channels in a concentric ring pattern around the source in other to monitor the neutron fluxes in all directions. The whole system is housed in a plastic containment. Fig. 3 shows a well-labeled cross-sectional view of the single-source Am–Be irradiation facility design. The arrows in the diagram show the direction in which the radial neutron flux distributions were monitored.

The second Am–Be source was designed with four americium–beryllium sources. The four sources were chosen to create a

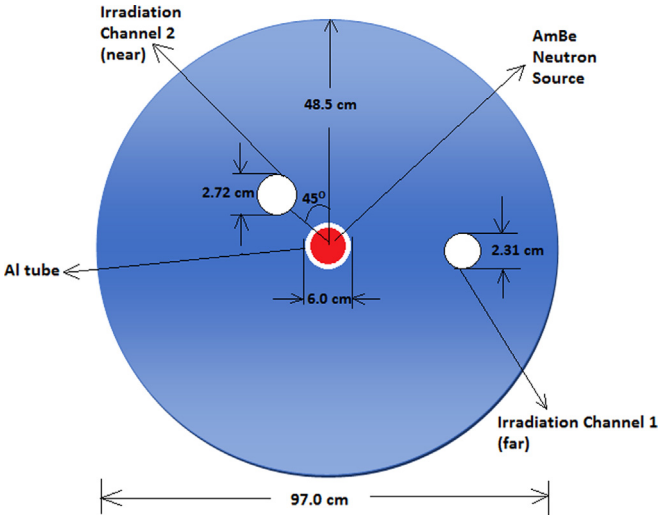

Fig. 2. Horizontal cross-section of the Am–Be neutron source facility at NNRI.

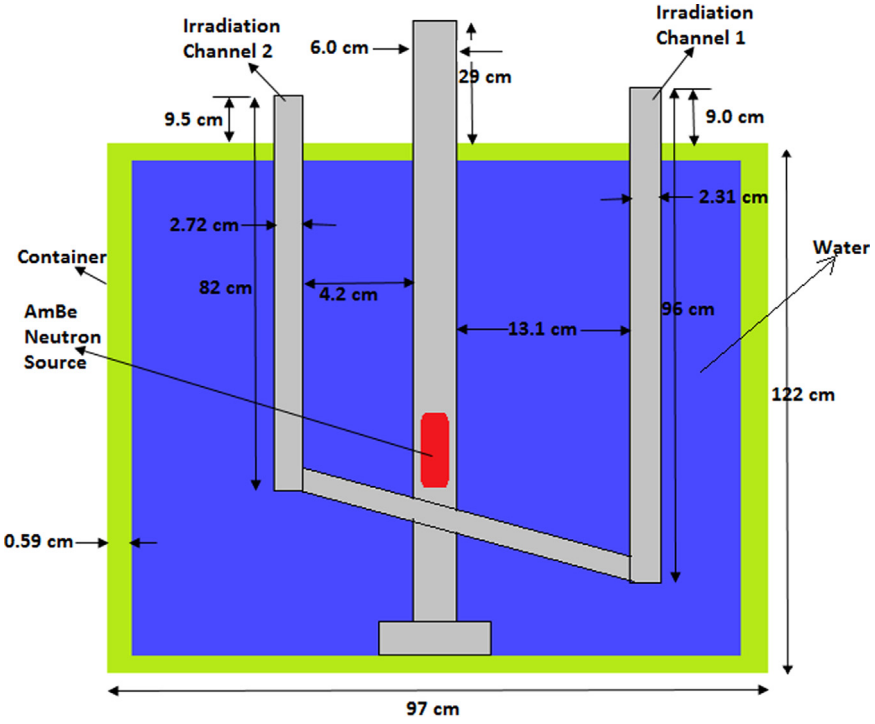

Fig. 1. Schematic vertical cross-sectional view of the Am–Be neutron source facility at NNRI.