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A portable shield for a neutron howitzer used for instructional and research purposes

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HIGHLIGHTS

- MCNP5 was used to characterize the neutron dose and the gamma flux from a 1 Ci ^{239}PuBe neutron howitzer.
- A portable neutron and gamma shield with a removable port was designed and built.
- Measured neutron rates for both unshielded and shielded howitzer were compared with simulated rates.

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ABSTRACT

Neutron howitzers are routinely used in universities to activate samples for instructional laboratory experiments on radioactivity. They are also a convenient source of neutrons and gammas for research purposes, but they must be used with caution. This paper describes the modeling, design, construction, and testing of a portable, economical shield for a 1.0 Curie neutron howitzer. The Monte Carlo N Particle Transport Code (MCNP5) has been used to model the ^{239}PuBe source and the howitzer and to design the external neutron and gamma shield.

1. Introduction

Neutron howitzers are versatile resources for university physics departments (Xu et al., 2015). Typically they were manufactured in the 1960s when radiation exposure limits were higher than those currently in effect. A standard design for a howitzer is shown in Fig. 1: a PuBe neutron source in a small stainless steel capsule is located in a cavity at the center of a cylinder of paraffin cast into a large steel container. Four radial access ports have plastic plugs that can be removed so that metal foils can be inserted close to the source where they are activated by the high neutron flux. A vertical access port is also available so that the source can be removed and inspected. Neutron and gamma radiation levels are significant in the immediate vicinity of a howitzer when the radial ports are open and above the vertical port even when it is closed. In a typical pedagogical setting these howitzers are used mainly for teaching laboratory courses in radiation and for activating samples for research (DuBard and Gambhir, 1994) or other instructional purposes. As a result, students and instructors or researchers usually do not come in contact with the howitzer with its port(s) open for an extended period of time. However, when used as a neutron source over an extended period in a laboratory setting, additional shielding is required. The neutron howitzer at San Francisco State University (SFSU) is being used for preliminary characterization of a compact, robust neutron detector being developed for seaport security applications. As such, it was necessary to build a shield to protect experimenters and ancillary detectors from neutrons and gammas while the prototype neutron detector is being exposed to neutrons. The shield had to be portable, and it had to have an access port in which various moderators and absorbers could be placed to modify the energy spectrum and intensity of the neutrons emerging from the howitzer.

2. Neutron and gamma spectra from the howitzer

2.1. The PuBe source

The first step in designing the shield was to model the neutron and gamma spectra produced by the howitzer by using the Monte Carlo N Particle Transport Code (MCNP version 5) (X-5 Monte Carlo Team, 2003). The howitzer in question is a Cenco Model # 71864-001. The neutron source is a mixture of plutonium (^{239}Pu)

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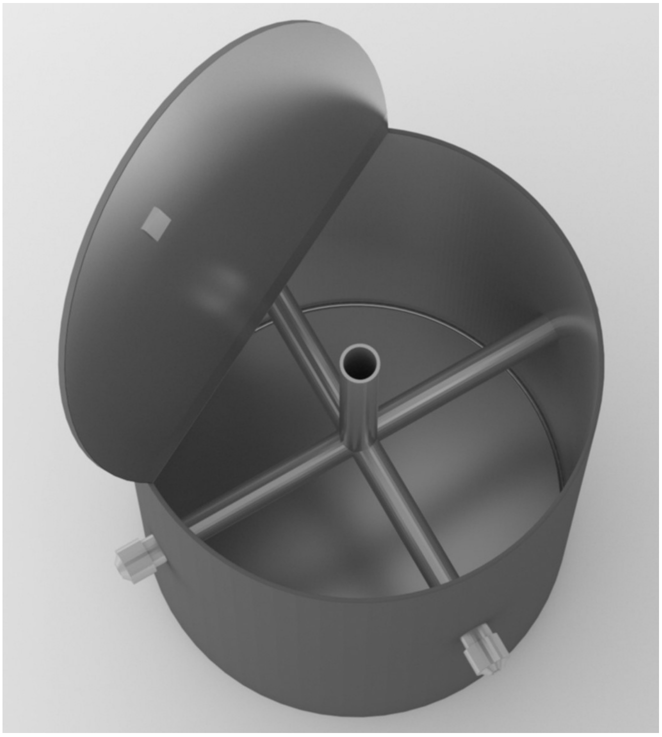

Fig. 1. Diagram of an empty howitzer with four horizontal beam ports and the vertical source port.

and beryllium (Be) powder encased in a stainless steel capsule. It has a nominal strength of 1 Curie (Ci) (Manual, 1964). The source was made by Magna Research, and the capsule is stamped with the serial number MRC PuBe73. Neutrons are produced when alpha particles emitted by ^{239}Pu react with ^{9}Be to produce ^{13}C* nuclei, which decay predominantly through the following reaction: $^{13}C^{*} \rightarrow {}^{12}C^{*} + n$ (Leo, 1994). The neutrons produced in (α,n)

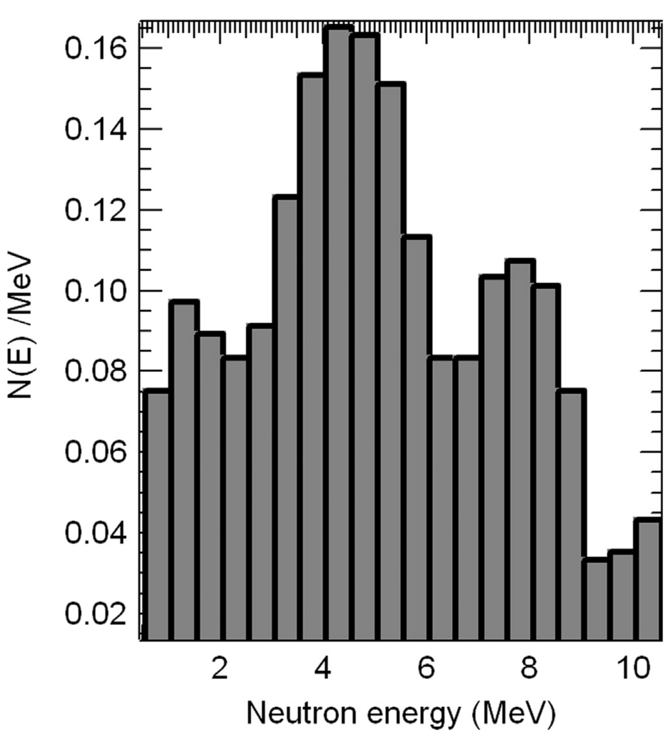

Fig. 2. Normalized number density N(E)/MeV of neutrons in a typical spectrum of ^{239}PuBe.

reactions have energies up to about 10 MeV. The high energy neutron flux for a ^{239}PuBe source diminishes with age as more and more carbon atoms are generated by the (α,n) reaction (Martoff et al., 1996). On the other hand, activity of the source can increase if some of the daughter products of decay are also alpha emitters. Since we do not know the exact composition and age of the ^{239}PuBe source in our howitzer, we ran our simulations using a neutron spectrum for a typical ^{239}PuBe source (Cember, 1996) as shown in Fig. 2. The average neutron energy for such a source is 4.5 MeV, and the neutron flux for a 1 Ci source is 1.7×10^{6} neutrons/cm^{2} s (Shores, 2000).

The howitzer is also a significant source of gamma radiation, which is often not taken into consideration. Gammas are produced by two different processes in the howitzer. The ^{239}PuBe source emits a flux of 4.4 MeV gammas created when the excited ^{12}C* nuclei decay. This flux is roughly one-third of the total neutron flux (Cember, 1996; Cooper, 1986) and for our source is estimated to be about 0.6×10^{6} gammas/cm^{2} s. Moreover, many of the high energy neutrons are moderated to the "thermal" energy range (0.025 eV) through elastic scattering with the hydrogen in the paraffin. Because hydrogen has an appreciable cross section (0.33b) for absorbing thermal neutrons and turning into deuterium, the howitzer body glows with 2.224 MeV gammas emitted during the capture reactions (Rinard, 1991).

2.2. Structure of the howitzer

In order to simulate the neutron and gamma spectra from our howitzer we need to take into account not only the characteristics of the PuBe source but also the physical details of the housing. In the SFSU howitzer the ^{239}PuBe neutron source is contained in a 24 in tall by 24 in diameter cylinder made of 18-gauge steel that is filled with paraffin to within 1.5 in of the top. The source is introduced into the howitzer through a central 14 in long by 1.7 in diameter vertical steel tube. The four radial beam ports consist of 12 in long by 1.5 in diameter tubes located 90° apart. The vertical tube has a polyethylene (PE) plug, and the four beam ports have Lucite plugs that fit snugly inside of the beam tubes. The paraffin and the PE and Lucite plugs moderate and absorb most of the neutrons emitted by the source, but they do little to shield users from gamma rays that are produced by the source and by absorption of neutrons in the paraffin.

2.3. Preliminary measurements

A preliminary on-axis survey of our neutron source at a distance of 17 cm from the open beam port showed the neutron and gamma doses to be 3 mrem/h and 1.3 mrem/h, respectively. With the Lucite plug in place, both neutron and gamma doses were reduced to 0.7 mrem/h. Although we could not directly measure the neutron flux of our source we could measure the angular dependence of the neutron dose rate using a Thermo Scientific BF_3 neutron detector (see Fig. 3).

2.4. Modeling neutron and gamma fluxes using MCNP5

We used Monte Carlo calculations by applying the MCNP5 code to estimate the neutron and gamma energy distribution fluxes outside of the howitzer. The analog F2 tally was used to simulate both neutron and gamma fluxes. The neutron source and the howitzer were modeled as a spherical ^{239}PuBe capsule of 1 cm radius at the center of a set of six 4-cm and one 2-cm thick concentric spherical shells of paraffin enclosed in an 18 gauge spherical steel shell. As noted earlier, the ^{239}PuBe source was modeled by the idealized spectrum shown in Fig. 2. For simplicity only one beam port was included in the idealized model. The approximation of