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Characterization of a 6 MeV accelerator driven mixed neutron/photon source

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Abstract

There are many applications which require high yield radiation sources with mixed fluxes of photons and neutrons. In particular, such sources are necessary to test radiation detectors and materials. This study was concerned with the determination of photon and neutron fluxes generated by the interaction of a 6 MeV linear electron accelerator driven photon beam with a beryllium photoneutron converter. The double step procedure of an (e,γ) reaction followed by an (γ,n) emission results in a mixed radiation environment. The optimal converter geometry was determined by comparison of the computed neutron fluxes for each converter position. Computational results have shown that photon fluxes up to 10^{11} photons/cm^2/s and neutron fluxes up to 10^7 neutrons/cm^2/s are achievable with the optimal setup. This paper is focused on the results of the MCNPX modeling and experiments and discussion of the converter orientation which leads to the largest radiation fluxes.

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1. Introduction

Electron accelerators generate bremsstrahlung photons through the interaction of an electron beam impinging on a heavy metal target. This interaction produces a cascade of photons whose spectrum has endpoint energy value that is equal to that of the electron beam. These photons may then be used to produce neutrons by the means of an appropriate

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photoneutron converter. If the energy of bremsstrahlung photons is greater than that of the photoneutron threshold energy of the converter material, neutrons are produced. Photoneutron converter materials must have threshold energies below that of the bremsstrahlung spectrum. In this study, the spectra of photoneutrons produced using a beryllium converter and a Varian M6 electron linear accelerator (linac) were computationally determined using MCNPX and compared to experimental data using the gold foil neutron activation analysis.

The use of electrons for the production of photoneutrons is well understood and documented, with studies existing as early as 1959 (Barber et al. 1959). Nowadays, photoneutrons find use in a wide variety of applications including radiography (Yang et al. 2013), production of medical isotopes (Tsechanski et al. 2016), and detection of special nuclear material (Stevenson et al., 2011). The presence of photoneutrons within high energy (greater than 10 MeV) medical accelerators (Ma et al. 2008) was also investigated, as photoneutrons serve as undesirable secondary radiation producing doses to the patient and medical staff. Whatever the intended application of the photoneutron source is, its characteristics including energy spectra must be understood.

Recent studies have examined the spectra of photoneutrons produced by linacs with impinging electron energies of 5 MeV (Auditore et al. 2005), 15 MeV (Huang et al. 2005 and 2006), 18 MeV (Vega-Carrillo et al. 2011), 25 MeV (Torabi et al. 2013) and 18, 28, and 38 MeV (Kosako 2011). The MCNP4 code was used to compute neutron fluxes for a ^{252}Cf source (Zhao et al. 1999) while the MCNPX code was used to determine neutron fluxes for a PuBe source (Harvey 2010; Sadineni 2002).

To characterize the photoneutron source in this study, computational modeling using MCNPX code (Pelowitz, 2011) was performed. The effect of the beryllium converter position on neutron flux was studied by performing calculations of M6 operation with the converter in different orientations. Next, a gold foil was placed on the beryllium converter in the optimal orientation and irradiated. After the irradiation, a high purity germanium detector (HPGe) was used to measure the radioactivity present within the gold foil. The results from the gold foil activation analysis were then compared with the computational results.

2. Background

Radiation source terms must be accurately understood and modeled correctly if the computational results are to be accurate. Photoneutron production using a linac occurs through the double conversion process of (e,γ) followed by the (γ,n) reaction. The first conversion occurs when bremsstrahlung x-rays are produced through the interaction of an electron beam with the linac target materials. For this study, the linac target was modeled according to proprietary manufacturer's drawings. The bremsstrahlung x-rays are then directed towards the Be converter. If the x-ray energy is greater than the neutron separation energy of beryllium (1.66 MeV), neutron production may occur.

In order to measure the fluxes of photoneutrons produced within the beryllium converter, neutron activation analysis was performed. Activation occurs when a stable isotope is converted into an excited radioisotope by the absorption of a neutron. The radioisotope de-excites through the release of radiation to a more stable form according to its decay scheme. This de-excitation energy is often released in the form of a gamma ray and may be detected through conventional spectroscopy. In this experiment, a gold foil was placed on top of the beryllium converter, and the linac was operated. The gold in the foil is activated by the photoneutrons, resulting in the production of excited ^{198}Au nuclei. De-excitation occurs by the emission of a 411.8 keV gamma ray which in turn was measured by the HPGe detector.

3. Computational Model

Evaluation of the x-ray and neutron sources was performed by computing the angular and energy distribution of the respective emitted radiations on a series of thin, concentric ring surfaces at a distance of 1 cm behind the beryllium converter (see Fig. 1). F4 tallies were placed on these surfaces allowing for determination of the radiation fluxes of interest at enclosed conic segments at 10° degree intervals from the centerline of the converter target. Photon energy distribution was determined for 200 equally spaced intervals between zero and 6.5 MeV, while neutron energies were determined at increasing orders of magnitude starting at the thermal energy (0.025 eV) and continuing up to 3.5 MeV. Analog photonuclear particle production was turned on in the MCNPX model by setting the following values: the *ispn* entry on the Phys: P card was set to -1, and the photonuclear cross section library to .70u. The material compositions