DESIGN OF A PHOTONEUTRON SOURCE BASED ON A 5 MeV ELECTRON LINAC

L. Auditore, R.C. Barnà, D. De Pasquale, A. Trifirò, M. Trimarchi,
INFN - Gruppo Collegato di Messina and Dip. di Fisica, Università di Messina,
C.da Papardo Salita Sperone 31, 98166 Messina, Italy
A. Italiano, INFN - Gruppo Collegato di Messina,
C.da Papardo Salita Sperone 31, 98166 Messina, Italy

Abstract

A photoneutron source, based on a 5 MeV electron linac was designed by means of the MCNP (Monte-Carlo-N-Particle) simulation code. Although higher electron energies are required to produce acceptable neutron fluxes, the availability of a 5 MeV electron linac at Dipartimento di Fisica (Università di Messina) has suggested this project, in sight of a future development of the studied neutron source. The final neutron flux, at a 50 cm distance from the photoneutron target, thermalized by a PE layer, was estimated to be $8.48 \cdot 10^7\ n/cm^2/sec/mA$ with Be target and $1.23 \cdot 10^8\ n/cm^2/sec/mA$ with BeD_2 target.
This neutron flux could find application in industrial and medical fields such as BNCT (Boron-Neutron-Capture-Therapy) and neutron radiography.

INTRODUCTION

The importance of compact neutron sources has been enhanced during last years due to the growing interest of industrial and medical institutes to neutron applications. The availability of a 5 MeV electron Linac at our laboratory suggested the idea to design a neutron source as compact as possible, employing the simple technology provided by low-energy electron linacs.
As known, to produce neutrons by means of an electron linac, a (γ,n) reaction has to be induced in a suitable photoneutron target after an $e - \gamma$ conversion has taken place [1, 2, 3, 4].
Although low energy electron induced photoneutron reactions provide a low (γ,n) conversion efficiency and only few materials can be used as a photoneutron target, the use of a low energy electron linac provides several advantages such as compactness, transportability and simplicity of the device, making such a neutron source an interesting tool for some applications.

PHOTONUCLEAR REACTIONS

Electrons impinging on a heavy target generate a cascade shower of bremsstrahlung photons which energy spectrum shows an end point equal to the electron beam energy. By varying the target thickness, it could be found an optimum thickness for which, at the defined energy, the photon flux is maximum. Photons produced in this way can be redirected towards a suitable photoneutron target, producing excited compound nuclei which show an energy equal to the sum of the binding energy of the last neutron and the kinetic energy (in the center-of-mass system) of the X-rays. If the excitation energy is larger than the binding energy of the last neutron in the compound nucleus, a neutron is emitted. The remaining energy is shared as kinetic energy between the neutron and the residual nucleus. Due to the separation energy for intermediate and heavy nuclei, an electron energy around 10 MeV is required to produce neutrons by (γ, n) reactions. With 5 MeV electrons, only two material could have been considered, Beryllium and Deuterium, or some their compound, which show a (γ, n) energy threshold of 1.66 MeV and 2.2 MeV, respectively. The (γ, n) cross sections for these two materials are of the order of *mbarn* in the 0-5 MeV energy range.
In this paper we shall describe the neutron source designed by considering Be and BeD_2, *beryllium deuteride* [5, 6], as photoneutron targets. The BeD_2, as suggested by V.L. Chaklov *et al.* [7], seemed to be a good choice due to the compromise of the low (γ, n) beryllium threshold and the higher (γ, n) deuterium cross section.

SOURCE DESIGN

The MCNP-4C2 (Monte-Carlo-N-Particle, version 4C2) code [8] was used to carry out simulations. The code was used in the multiprocessing mode both on Linux workstations of Dipartimento di Fisica, Università di Messina, and on Aix workstations of the ENEA calculation system of Frascati.
The e-γ conversion was first studied to enhance the bremsstrahlung emission in the energy region 1.6-5 MeV, using an energy cut of 1.6 MeV both for photons and electrons. As a result of a comparative study of different materials performances, a 1.698gr/cm^2-thick tungsten target was chosen as a converter. This thickness corresponds to the maximum X-rays emission in the energy range 1.6-5 MeV as it can be deduced from Fig.1, showing the number of photons per unit angle. The bremsstrahlung spectrum obtained with the chosen converter is shown in Fig.2.
Although the photon flux is strongly peaked in the forward region, the W converter has been put in contact with the photoneutron target, thus enabling X-rays and electrons

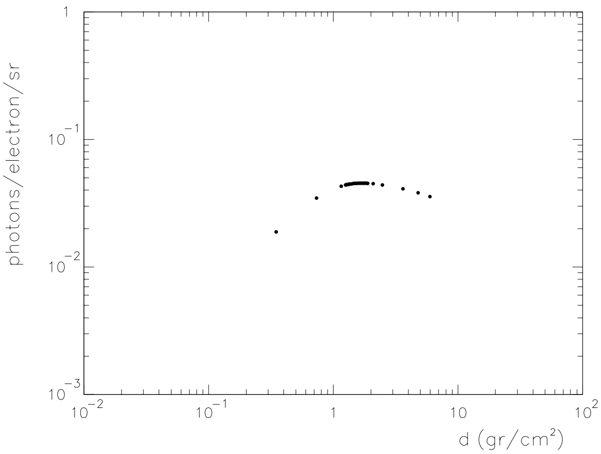

Figure 1: *Number of produced photons/electron/sr as a function of the W thickness.*

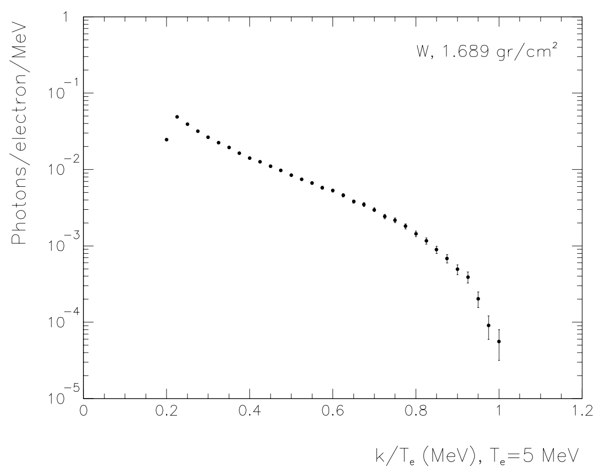

Figure 2: *A 1.698 gr/cm^2 thick W converter Bremsstrahlung spectrum.*

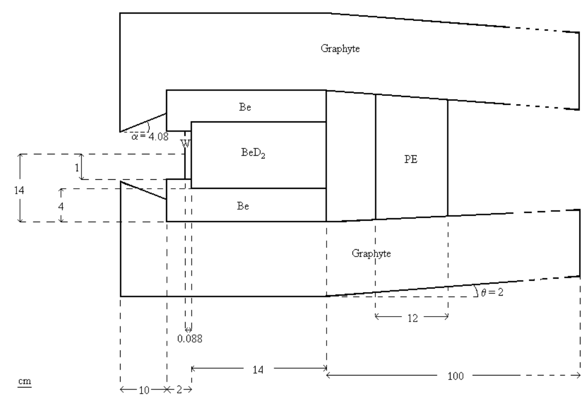

Figure 3: *Scheme of the photoneutron source with BeD_2.*

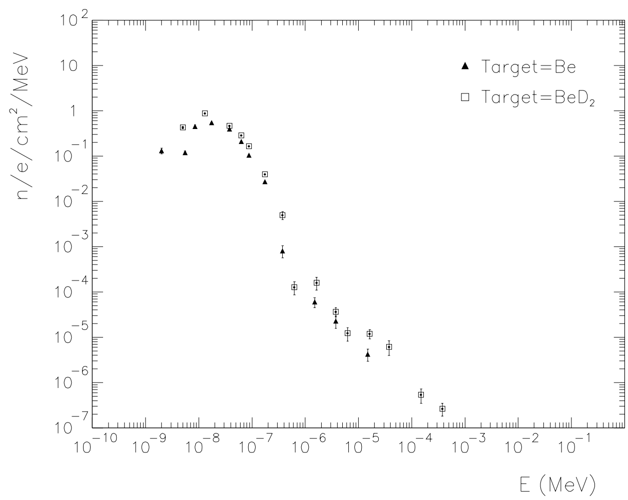

Figure 4: *Neutron energy spectrum from Be and BeD_2 based sources.*

escaping from the W converter to be entirely collected by the target. The photoneutron target sizes were optimized by preliminary simulations. A graphyte reflector surrounding the target was inserted, to avoid neutron losses from the side walls. The reflector thickness, 50 cm, seems to be a good compromise between the need of a compact neutron source and to forward reflect the produced photoneutrons. A 50 cm-thick graphyte collimator was inserted after the photoneutron target both to avoid neutron losses and to better collimate the neutron beam. A 12.2 cm -thick PE (C_2H_4) slab was inserted at a 5 cm distance from the photoneutron target, inside the collimator, as a moderator, thus thermalizing the produced neutrons to 25-30 meV energy. The scheme of the neutron source is shown in Fig. 3, BeD_2 target. A similar structure was considered for the Be target. The design of the BeD_2 target shows a Be coating surrounding a BeD_2 core. The Be coating would enhance the probability that low-energy photons, which could not produce neutrons in deuterium, produce neutrons in the Be layer where a lower (γ,n) energy threshold is requested.

The neutron flux intensity inside the collimator and energy spectra has been calculated [9]. In Fig.4, the neutron energy spectra from Be and BeD_2 targets, at a 50 cm distance from the photoneutron target, are shown. A thermal neutron flux of $8.48 \cdot 10^7\ n/cm^2/mA/sec$ from Be and of $1.23 \cdot 10^8\ n/cm^2/mA/sec$ from BeD_2 was obtained.

Comparing the results from the two different photoneutron target materials, BeD_2 provide a neutron flux 1.4-1.5 times more intense than the neutron flux from Be.

Among the several applications of such a neutron source, BNCT and Neutron Radiography are here considered.

The BNCT, the cancer therapy consisting in inducing the $B(n,\alpha)Li$ reaction in the cancer cells to destroy them [10], generally requires fluxes which intensity depends on the composition of tissue, boron concentration, filters and neutron source. By optimizing these parameters, the designed source could be successfully employed in this therapy.

A neutron industrial radiographic setup generally consists in a neutron source, an X-ray background filter, a collimator and an image acquisition system [11]. Providing a collimator with a L/D ratio of 20, a neutron flux of $10^4 n/cm^2/sec/mA$ would be available at the sample position which seems to be enough to make neutron radiography obtaining good images.

CONCLUSIONS

As a result of the performed calculations, it seems that this neutron source design could be employed in industrial radiography and medical field where a $10^7/10^8\ n/cm^2/mA/sec$ neutron flux could satisfy the beam and time requirements and where compactness and simplicity of the device could play an essential role in choosing the neutron source.

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