DESIGN OF A PHOTONEUTRON SOURCE BASED ON A 10 MEV CIRCE III ELECTRON LINAC

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ABSTRACT

This paper presents a numerical investigation of a photoneutron source, based on a 10 MeV electron linac. It's done by means of the FLUKA simulation code. For that purpose, we will use a CIRCE III electron linac available at the CNSTN (National Center of Sciences and Nuclear Technology) in Tunisia. This project is suggested for a future development of neutron sources. So, a clear description of the way of production of neutrons is given. As a result, the neutron flux was estimated to be $2 \cdot 10^6$ n/cm^2/sec/mA with a Pb target, at a 60 cm distance from the photoneutron target. To find these results, the neutron flux was thermalized by water. The importance of this work is due to his application in many fields specially industrial and medical applications.

KEYWORDS: *Photoneutron generation; Monte-Carlo simulation; electron linear accelerator.*

I. INTRODUCTION

Many advanced technology have contributed for several decades to the development of the accelerators of electrons devoted formerly tore each on the structure of matter. Nowadays, they find from now on various medical and industrial applications. An electron beam can be used to produce photoneutron. The availability of a 10 MeV electron Linac installed at CNSTN 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]

This paper reports the results of calculations using Monte Carlo computer code (FLUKA) for the neutron yield and the energy distributions of the neutrons and photons are presented. We have used a 10 MeV electron linear accelerator at CNSTN to generate neutrons using lead target. In this work, we begin with a careful description of photoneutrons production mechanism. Then, we enumerate different materials used in the prototype of simulation. Finally, we illustrate different results and discussions.

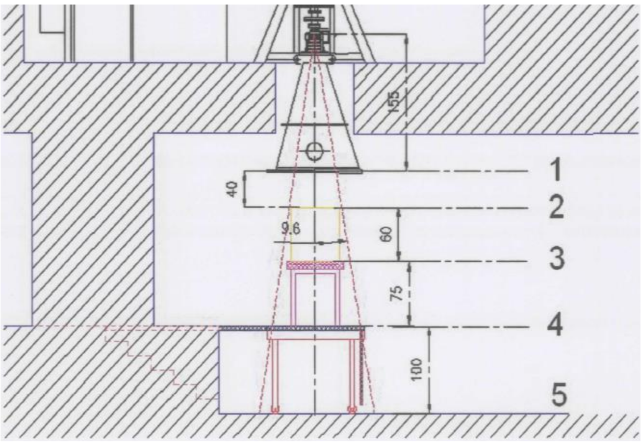
II. PHOTONEUTRONS PRODUCTION MECHANISM

The mechanism of the production of photoneutrons is when electrons impinge on a target material; a continuous spectrum of bremsstrahlung photons is generated.

These photons subsequently interact with the nucleus of the target material, resulting in the emission of the nucleons. This interaction is known as a photonuclear interaction. As the nucleons are bounded with the nucleus by binding energy (5-15 MeV), the photon should have energy above a threshold value to participate in the photonuclear reaction [5]. Photonuclear interaction is mainly the result of three specific processes: giant dipole resonance (GDR), quasi-deuteron (QD) production and intranuclear cascade.

III. MATERIALS AND METHODS

The electron accelerator investigated in this study was the CIRCE III using 10 MeV X-rays at CNSTN. The pulse width is 2.5 µS. The rate can vary between 10 and 300 Hz. The accelerator can deliver electrons with energy being in the range (5-10 MeV) in 2.5MeV steps. The FLUKA Monte Carlo code version 2008.3c [6] was used to simulate neutron production and transport. The electron beam is incident on lead target (90*20 cm) of thickness 5 cm.



Dimension (cm)	Plan 1	Plan 2	Plan3	Plan4	Plan5
Spot diameter	2	15	36	60	100
Balayage sens	54	80	120	170	240

Fig. 1. Sheme of beam of a CIRCE III electron linac .

Detection of all particles takes place in two 20 × 20 cm detections plane, placed at 60 cm from the lead target. As many as 1 E+9 histories were run in order to produce reliable confidence intervals. The estimated relative error of the FLUKA simulation was found to be between 1% and 5%. The scheme of geometrical setting for FLUKA calculation is shown in Fig2.

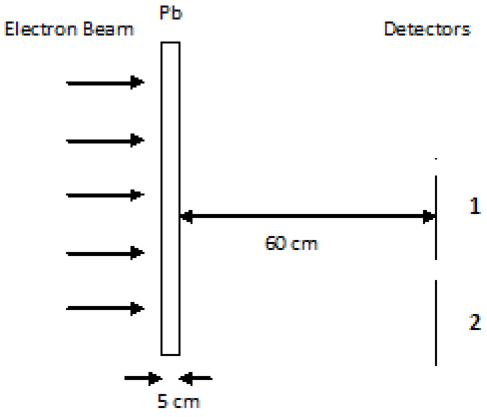


Fig.2. Geometry of the system used in simulation with the Fluka Monte-Carlo code.

IV. RESULT AND DISCUSSION

We have performed calculations using the Monte Carlo computer code (FLUKA) to optimize the neutron conversion targets and to study the properties of the obtained photoneutron source. The calculations assume beams of monoenergetic and Gaussian (rectangular distribution 80*15 cm) electrons are incident perpendicularly on a target. We have simulated the photo-neutron and photon production for 10 MeV electron energy on a lead target. The energy spectra of secondary particles generated by the primary electron 10 MeV beam, for both monoenergetic and Gaussian energy distribution (rectangular distribution 80*15 cm) beams, on the 5 cm lead conversion target are shown in Fig. 2. As one can see, the shape of spectrum is slightly different than while the primary beam energy distribution changes from mono-energetic to Gaussian but the number of neutrons and photon is almost 10 times more for mono-energetic distribution.

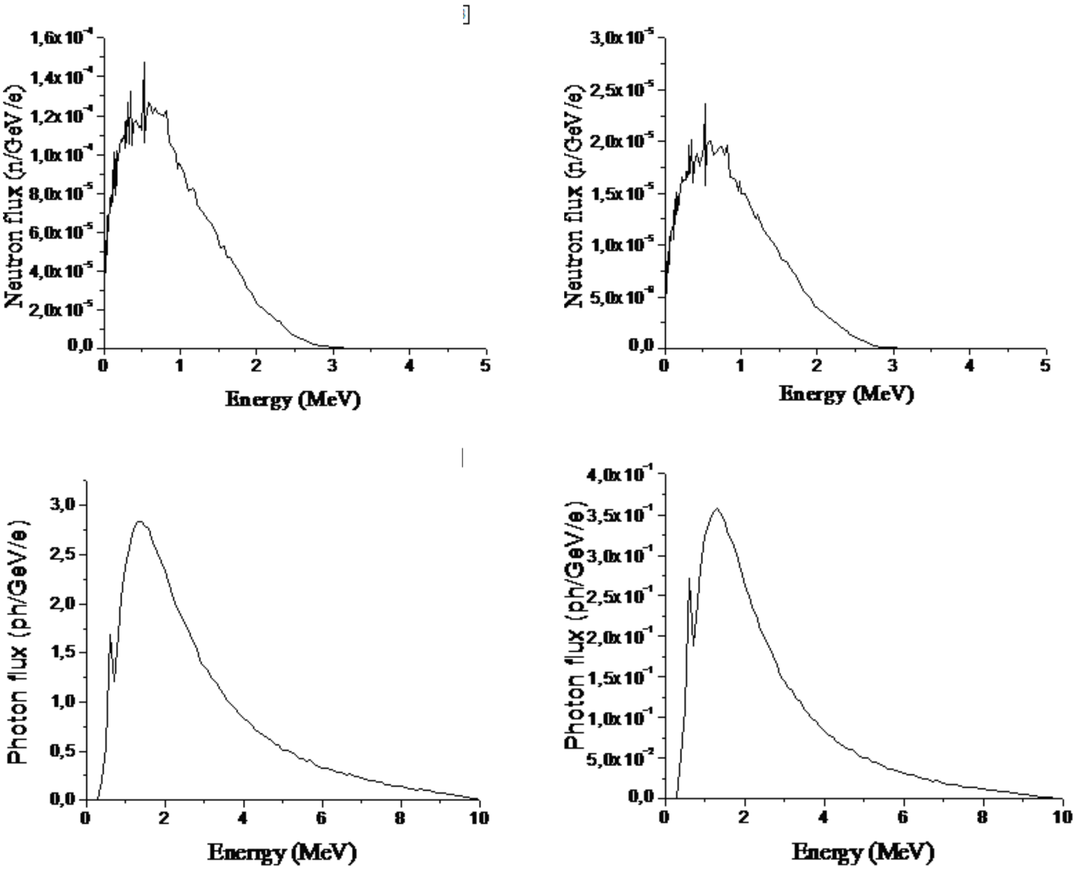


Fig. 3. Energy spectra of produced neutron (the first raw) and photon (the second raw) for monoenergetic beam (right column) and guassien energy distribution electron beam (left column) detected in detector 1

The angular distribution of the direct neutrons was assumed to be in the form of 1+Csin2θ, where θ is the angle between the incoming photon and the emitted neutron and C is a constant dependent on neutron energy and the media isotope [7,8]. For neutrons with energies ≤ 2.5 MeV, the emissions are assumed to be isotropic, i.e., C=0. To study the angular distribution of the neutrons and the photons produced after a single lead converter one has to place the detector 2 presented in Fig. 3. Energy spectra of neutron and photon generated by the primary electron 10 MeV Gaussian energy distribution (rectangular distribution 80*15 cm) beam, on the 5 cm lead conversion target is detected in detector 2 are presented in Fig. 3. As one can see, there is no significant difference in the energy spectra of photons and neutrons detected in detectors 1 and 2. The emission of secondary particules. It is mainly centred around forward in the direction of the incident beam.

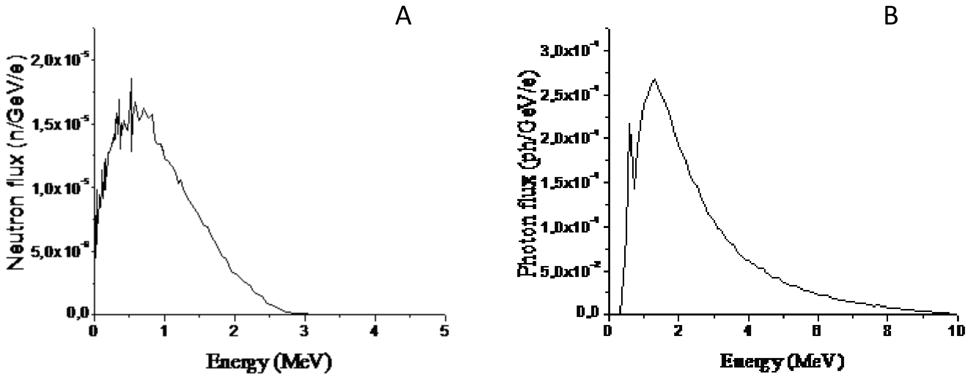


Fig. 4. Energy spectra produced of neutron (A) and photon (B) detected in detector 2

Energy spectra shows that the neutrons produced have energies up to mega-electron volts, so their wave lengths are too short and then can't study condensed matter. Thermalization will then be carried out through successive collisions between neutrons and nuclei they encounter. This is particularly the role of moderators, light elements, which can't absorb the neutrons like water or liquid hydrogen. Neutrons enter the moderator and lose energy tore coiling moderator atoms. After a few tens of collisions, the energies of the neutrons are similar to those of the atoms of the moderator. We simulated the energy distribution of the moderated photo neutrons by a 5 cm heavy water moderator after Lead target. The simulation was done for incident electron energy of 10 Mev. The energy spectrum of the moderated neutrons is shown in Figure 5.

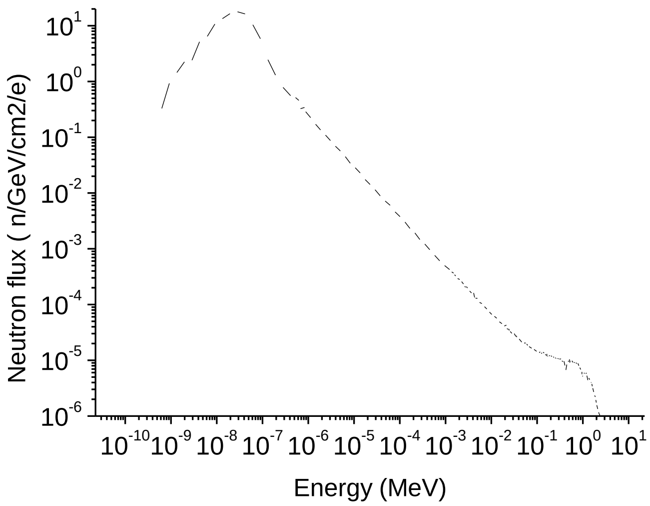


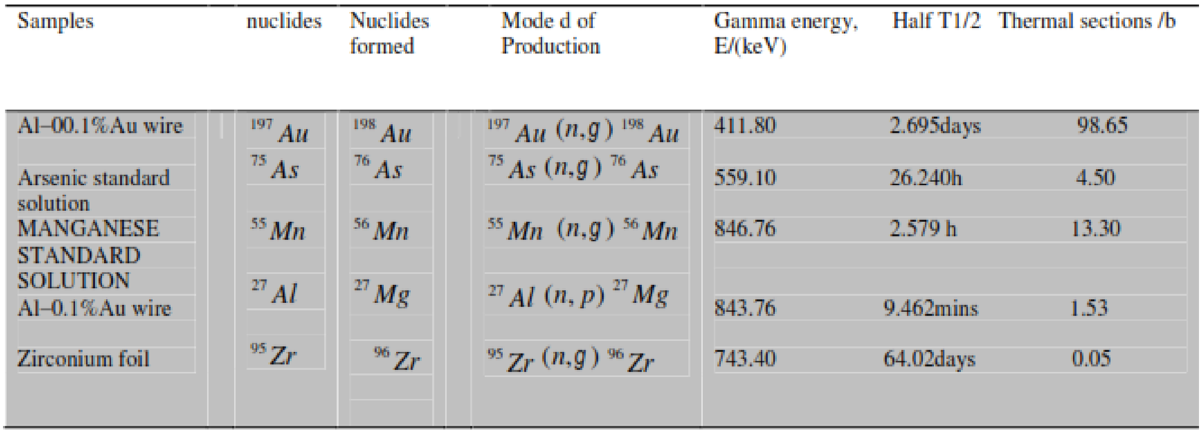
Fig 5. Neutron yield as a function of energy for the moderated neutron from the photoneutron source.

The graph (fig.5) shows that the average energy of the neutrons from a heavy water moderator is about 25 meV. A thermal neutron flux of $2 \cdot 10^6$ n/cm^2/mA/sec from was obtained at a 60 cm distance from the photoneutron target. Neutron Activation Analysis Neutron Activation Analysis (NAA) is a quantitative and qualitative method of high efficiency for the precise determination of a number of main-components and trace elements in different types of samples. NAA, based on the nuclear reaction between neutrons and target nuclei, is a useful method for the simultaneous determination of about 25-30 major, minor and trace elements of geological, environmental, biological samples in ppb-ppm range without or with chemical separation. In NAA, samples are activated by neutrons. During irradiation the naturally occurring stable isotopes of most elements that constitute the rock or mineral samples, biological materials are transformed into radioactive isotopes by neutron capture. Then the activated nucleus decays according to a characteristic half-life; some nuclides emit particles only, but most nuclides emit gamma-quanta, too, with specific energies. The quantity of radioactive nuclides is determined by measuring the intensity of the characteristic gamma-ray lines in the spectra. For these measurements a gamma-ray detector and special electronic equipment are necessary. As the irradiated samples contain radionuclides of different half-lives different isotopes can be determined at various time intervals.

The detection of neutrons with activation foils occurs in two steps:

- the neutrons interact with the foil material,
- the activity of radionuclides produced by neutrons in the foil during the irradiation is analyzed. In the first step, foils are irradiated and part of their material is activated through e.g. (n,xn), (n,α), and (n,γ) reactions. The new isotopes are unstable, decaying (β+, β−, EC) and emitting characteristic gamma photons. These photons are registered with semiconductor detectors (usually HPGe) in the second step. The amounts of produced isotopes are calculated from the measured activities. The information about the neutron field can also be obtained, providing that the mechanisms of the isotope production are well known. A description of the targets materials and nuclear data of reaction of interest are given in Table1.

Table1. Some properties of the isotopes used during the calculation of activity against their nuclear constants (De Corte and De Wispelaere, 2003; IAEA, 1990)



Samples	nuclides	Nuclides formed	Mode d of Production	Gamma energy, E/(keV)	Half T1/2	Thermal sections /b
Al–00.1%Au wire	^{197}Au	^{198}Au	$^{197}Au\ (n,g)\ ^{198}Au$	411.80	2.695days	98.65
Arsenic standard solution	^{75}As	^{76}As	$^{75}As\ (n,g)\ ^{76}As$	559.10	26.240h	4.50
MANGANESE STANDARD SOLUTION	^{55}Mn	^{56}Mn	$^{55}Mn\ (n,g)\ ^{56}Mn$	846.76	2.579 h	13.30
Al–0.1%Au wire	^{27}Al	^{27}Mg	$^{27}Al\ (n,p)\ ^{27}Mg$	843.76	9.462mins	1.53
Zirconium foil	^{95}Zr	^{96}Zr	$^{95}Zr\ (n,g)\ ^{96}Zr$	743.40	64.02days	0.05

The detailed reason of the relationship between the measured material foil detector activity and the neutron fluence was presented in the works which we refer to as [9, 10, 11] and in some others. In this paper we give the final formula for thermal activity:

$$A_{ther} = \frac{\phi_{ther} \cdot d_m \cdot S \cdot N_0 \cdot \sigma_{ther}(1 - e^{-\lambda t_n})}{W \cdot e^{\lambda t'}} \tag{1}$$

Where

Φ_{ther} = thermal neutron fluence; Ather = measured material foil detector activity due to neutrons;

σ_{ther} = thermal neutron simple capture cross section;

d_m = foil density;

t_n = time of exposing to neutron radiation;

t' =time between the end of the neutron exposure and the beginning of the measurement of the activity induced in the detector,

λ =decay constant;

W = atomic weight of material used as the neutron activation detector;

S= foil area;

No= Avogadro's number.

A material foil was irradiated in the detector 1 placed at 60 cm from the photoneutron target. The thermal neutron flux at this point was 2 x10^6 n/cm^2/sec.

V. CONCLUSIONS

In this paper are presented the calculation results obtained by using the Monte Carlo code (FLUKA) to study the properties of photons and photoneutron obtained for 10 MeV CIRCEIII electron beam on a lead target. As a result of the performed calculations, it seems that 2 x10^6 n/cm^2/sec neutron flux could be employed in industrial radiography .

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