# POSSIBILITIES TO APPLY LINEAR ELECTRON ACCELERATORS AS A PULSED NEUTRON SOURCES

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Abstract

The paper presents the exprimental data and calculation to optimise some conversion targets for fast and thermal neutron fluxes, obtained with linear electron accelerators.

## 1. TARGET TO PRODUCE GAMMA RADIATION (BREMSSTRAHLUNG).

### *1.1 Selection of Target Material*

Electrons passing through a target material is accompanied by the following phenomena:

a) loss of energy due to the bremsstrahlung radiation

b) loss of energy due to ionization

c) multiple Coulomb diffusion.

The quality of the target to convert the electron energy into gamma radiation is given by the ratio between the energy lost by the electrons due to bremsstrahlung and the energy lost by the electrons due to ionization radiation.

Herewith we define the conversion efficiency to produce bremstrahlung radiation as a ratio between the energy lost by the electrons due to the bremsstrahlung radiation and the initial electron energy. This value will depend on the target material.

The ratio between the energy loss by bremsstrahlung and the energy loss by ionization per unit of path is proportional to Z and E [1].

The variation of conversion efficiency to produce bremsstrahlung for three target materials is presented in Fig. 1.

For electron energies greater then 10 MeV, it is preferable to use $^{238}$U targets because uranium also contributes to conversion of gamma quanta into neutrons.

### *1.2 Selection of Target Thickness*

For a target with a t-mass thickness, the probability of a gamma quantum (which is subject to the angular distribution and multiple Coulomb diffusion phenomena), to be emitted in the electron beam direction, can be calculated by the relation:

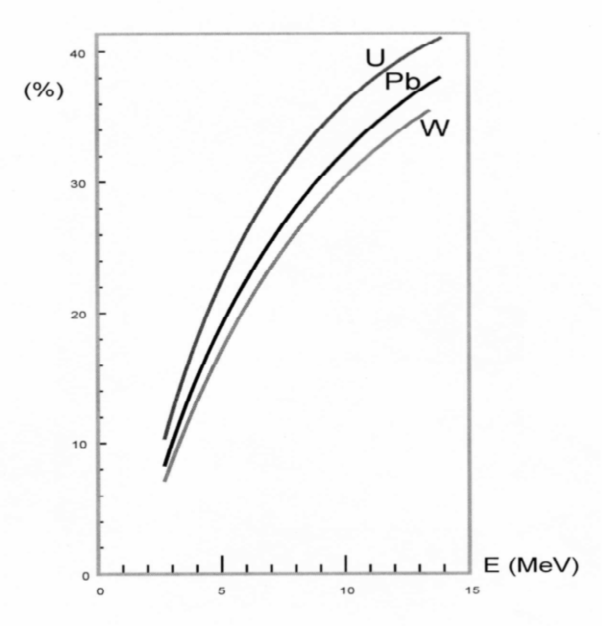

Fig.1.The dependence of conversion efficiency versus gamma - radiation energy for three material used as target: W, Pb,and U

$$R(E_0,t)=\frac{\sigma}{c\beta^2}\left(\alpha_0+\beta E_0\right)^2\int_0^t e^{-2\beta t}\times$$

$$\left(\frac{1.102}{1+k_1 t}+\frac{k_2}{1+k_2 t}\right)dt-2\alpha_0\left(\alpha_0+\beta E_0\right) \qquad (1)$$

$$\int_0^t e^{-\beta t}\left(\frac{1.02}{1+k_1 t}+\frac{k_2}{1+k_2 t}\right)dt+\left(\frac{1.102}{1+k_1 t}+\frac{k_2}{1+k_2 t}\right)dt$$

where t is the mass thickness of the target (g/cm$^2$) and $k_1=c/\mu^2\theta_1^2$, $k_2=c/\mu^2\theta_2^2$, $\sigma=NE_0\Phi_{irrad.}$ . The values of the constants $\alpha_0,\beta,c,\theta_1^2,\theta_2^2,$ were experimentally determinated for a gold target, at on electron energy of 10 MeV.

The extrapolated electron path in the target can be calculated with:

$$R_0=0.526T-0.094 \qquad (2)$$

The production of gamma - quanta with an energy above the photonuclear threshold is obtained for a thickness of the target not grater than electron path.

### *1.3. The Calculation of Photons Number in the Photonuclear Reaction.*

The number of photons with the energy grater than the threshold energy, is given by relation:

$$N = \sum_{i}^{n} \left( \frac{dE_{rad}}{dx} \right) \frac{R_u}{\langle E_\gamma \rangle} \Delta x \qquad (3)$$

where: n - is the number of target layers required that the energy lost by electrons to be equal with the threshold energy

$E_\gamma$ - the average energy of gamma - quanta with energies exceeding the threshold energy of the photonuclear reaction

$R_u$ - the ratio between the total energy of photons with an energy exceeding the threshold and the total energy of the of bremstrahlung.

$\Delta x$ = 100 μm (selected pitch).

The number of photons estimated by relation (3) is $5 \cdot 10^{11}$ photons /s·μA at 10 MeV.

## 2. TARGETS TO OBTAIN PHOTONEUTRONS

A target can produce neutrons by photonuclear reaction, if bremsstrahlung radiation has an energy grater than the energy coresponding to the threshold of the respective reaction.

Within the energy range upto 10 MeV, the quanta obtained by electron bremsstrahlung can produce photoneutrons only with beryllium (threshold energy of 1.67 MeV) and deuterium (threshold energy 2.2 MeV). In our experiments it was used only target beryllium. In order to determine the beryllium target thickness, we considered the following phenomena developed inside the target:

a. Formations of neutrons by photonuclear reaction for a x thick target, with a probability given by the relation:

$$f_1 = 1 - e^{-n\sigma x} \qquad (4)$$

were n is the number of beryllium nuclei per $cm^3$ and σ is the cross section of the reaction (γ,n).

b.Photons passing thru beryllium target are subject to electromagnetic interactions, and the probability that one photon should not be absorbed within the thickness x is given by relation

$$f_2 = e^{-\mu x} \qquad (5)$$

It is possible to calculated the fast neutron flow rate considering the effects from (a) and (b) in each beryllium layer, at the given distance from conversion target. The fast neutron generated during the photonuclear reaction are slowed-down inside the target. The requirement to have as many neutrons as possible implies a large thickness for beryllium target.

In the process of slowing-down, the spatial distribution of neutrons is given by the equation [3]:

$$q = \frac{Q}{(4\pi\tau)} e^{-\frac{r^2}{4\tau}} \qquad (6)$$

where: q - the slow-down density (the number of neutrons passing in a certain time-unit within energy range (E, E+dE)

r - distance of the neutrons emitted by a point source of Q flow rate

τ - the age of neutrons

The slow-down density may be connected to the flux Φ of neutrons, by the relation:

$$q = \zeta \frac{nv}{\lambda} = \frac{\zeta}{\lambda} \Phi(\tau) \qquad (7)$$

where: nv - Φ(τ) is the flux of energy neutrons

ζ - is the logarithmic decrement for neutrons slowing-down in the beryllium target

λ - is the length of the neutron mean free path.

Considering a point source, it's possible to make an approximation which leads to an underevaluation of the neutron flux. An upper limit of the neutron flux can be determined if an infinite plane emitting source is considered. The flux value obtained by activation measurements is between the two limits because the beam is spatially extended.

To calculate the irradiation position $X_0$, and the length, $X_1$, the beryllium target have an optimal size in order to get a maximum number of thermal neutrons in $X_0$ position (Figure 2):

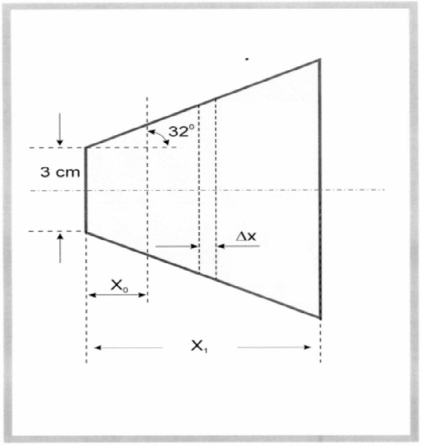

Fig. 2. The beryllium target for thermal neutrons ($X_0$ - the irradiation position, $X_1$ - the length of target)

The contribution of all neutrons produced in the beryllium target to the thermal neutron flux in point $X_0$, may be estimated by integral:

$$\Phi = \frac{\lambda N_{\gamma} n\sigma}{\zeta(4\pi\tau)^{3/2}} \int_{0}^{x_1} e^{-\mu x} \times e^{-\frac{(x-x_0)^2}{4\tau}} dx \qquad (8)$$

For a constant irradiation point $X_0$=5 cm and a variable target length $X_1$, the curve of Fig. 3. it was obtained . One may consider that 20 cm is a thickness large enough for the beryllium target. A larger thickness doesn't lead to a significant increase of the neutron flux (<10%).

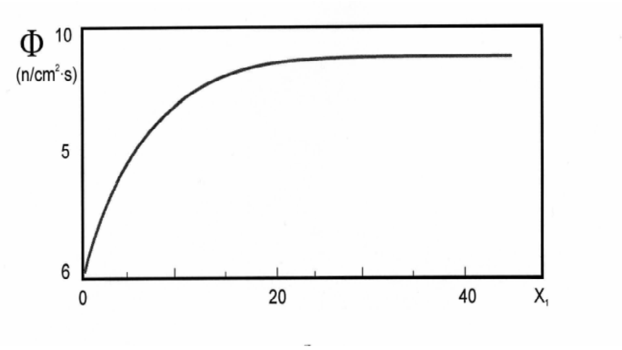

Fig.3. The dependence thickness of the beryllium target ($X_1$) versus the neutron flux (Φ)

Similarly, for a constant target length $X_1$=20 cm, and a variable irradiation point $X_0$, it was obtained the curve of Fig. 4.

On can notice that the position $X_0$=7.5 cm is the optimum value corresponding to the maximum of function defined by equation (8).

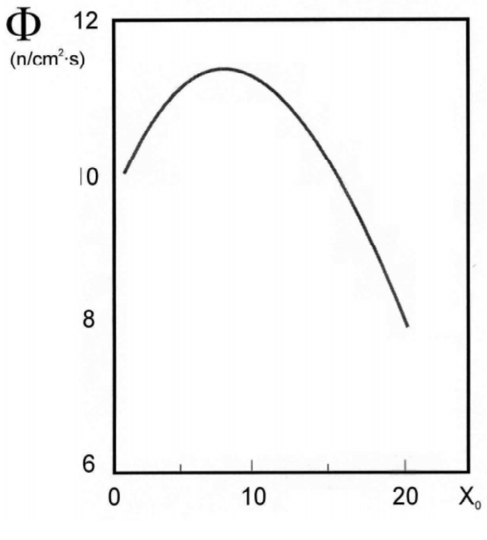

Fig. 4. The dependence of the optimum position for neutron irradiation ($X_0$) versus neutron flux (Φ)

For environmental protection the beryllium target is wrapped up by a 20 cm thick wax and than surrounded by one mm cadmium sheath.

The obtained results allow us to conclude that:

**.** a thermal neutron flux of 2.3 $10^7$n /cm$^2$s·µA is obtained for a 10 MeV electron energy

**.** a thermal neutron flux of ~ $10^{12}$n / cm$^2$s·µA is obtained for a 15 MeV incident electron energy.

In order to increase the neutron number it's necessary to increase the electron energy above 15 MeV and to use fissionable target.

## REFERENCES

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