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INTERACTION OF 14 MeV NEUTRONS WITH HYDROGENATED TARGET. PROTON EMISSION CALCULATION.

Abstract. Using neutron emission data of a 14 MeV neutron generator, a paraffin target, and based on the $n + H_t \rightarrow n' + p$ reaction, have been obtained the characteristics of the proton emission in a proton-neutron mixed field. It was used Monte Carlo simulation and it was obtained the proton output as function of the converter width and the energy spectrum of protons corresponding to different converter thickness. Among 0.07 and 0.2 cm there is a maximum zone for the proton emission. The energy spectrum agrees with such obtained on previous papers. Figures showing these results are provided.

INTRODUCTION.

The use of neutron-proton mixed field in radiotherapy and radiation biology makes necessary the calculation of physical magnitudes of such field. In this work, making use of Monte Carlo simulation, the proton emission function obtained by placing a hydrogenated target within a neutron beam is calculated.

The method is based on producing protons through the $n + H_t \rightarrow n' + p$ reaction, using as neutron source a D+T neutron generator and paraffin converters as H_t-target. Many papers describe computer codes for neutron transport simulation based on the Monte Carlo method [1-3]. One of them, the TCG code [1], was modified to obtain the proton flux and the proton energy spectrum. The obtaining of the neutron flux and the neutron energy spectrum are reported in [1] and it was calculated by such code. In this paper we just describe the method to obtain, from there, the proton emission characteristics.

THEORETICAL FORMALISM OF THE SIMULATION.

Proton formation and its target interaction.

Protons with energy Ep are formed from the $n + H \rightarrow n' + p$ reaction. After the proton formation process, it suffers nuclear and coulomb scattering in the medium. The nuclear collisions and the bremsstrahlung energy lose are not appreciable in the 0.1 to 15 MeV range of energy. Therefore, it is possible to consider, as a good approximation, only the proton interactions with the Coulomb field of the target nucleus. Hence, we considered rectilinear trajectory of protons with continuous energy loses [4,5].

Proton energy loses.

The physical behavior of the proton energy loses is described mathematically by the linear energy transference dE/dx. This expression depends on the energy and charge of the particle and the density and charge of the target. Proton's dE/dx and its range R, were taken from [6] for paraffin $(CH_2)_n$. After the proton formation with energy E_p, it is determined, according to the R function, if the proton reaches the target outside. We also consider the straggling effect. This effect is experimented by charged particles when they are crossing the medium and it causes an R value variation according to Gauss's function around a middle value $R(E_p)$.

The parameter of the Gauss distribution σ is obtained with an error less than 10 % according to $\sigma = 0.01 \cdot R(E_p)$. The outgoing proton energy E_p^s is then:

$$E_p^s = E_p - \frac{dE}{dx}\left(E_p\right) \cdot R\left(E_p\right)$$

Data used to make the calculations were taken from the evaluated data library with ENDF format [7] for Carbon (total cross section) and hydrogen (elastic and total cross section and the angular distribution of the elastic scattering).

Simulation steps

In the numeric experiment it was considered a parallel neutron beam interacting with a cylinder converter, perpendicular to the Z axis. After the neutron reaches the sample it is forced to interact on it with a hydrogen nucleus (in the sample are present C^{12} and H^1). Then a point in the outside converter is played and the proton emission angle to this point is calculated. Proton energy is calculated using a relativistic kinematics reported in [8]. At any of the steps mentioned above a statistical weight is computed and accumulated, and each proton produces a score in the spatial-energy histogram. This histogram records the proton score according to its energy and spatial distribution.

RESULTS AND DISCUSSION.

Figure 1 shows the proton output plotted as function of the converter thickness. The neutron flux used in the calculation was $\Phi_n = 2 \cdot 10^7 n/cm^2$. It is important to establish such dependence, because of, it is possible to obtain the best thickness for proton production corresponding to the maxim value of the function.

Figure 2 shows in a higher scale the first part of the figure 1, where a maximum zone is observed between 0.07 cm and 0.2 cm. At 0.2 cm converter thickness begin to decrease the proton output due to the range of the 14 MeV protons is just 0.2 cm. So, it is not possible that a proton formed 0.2 cm before the converter outside can leave the target.

Figure 3 shows the characteristic energy spectrum of protons for thickness higher than the maximum of the emission function. The inelastic collision process is a statistical process. That is, the collision number and the transferred energy on each collision oscillate around a more probable value describing certain function. The energy fluctuations have the asymmetric form obtained in this figure, and it agrees with the reports of [4,5] The asymmetry of this function is due to the collisions with high energy transference and big scatter angles are less probable than those ones in which it is transferred low quantity of energy. The most probable energy of the proton obtained is around 4.3 MeV.

It is shown in figure 4 the behavior for thickness less than the maximum of the emission function. In this range all the energies of the emission spectrum are almost equal probable. When the converter thickness grows up, and it is close to the maximum width, it is obtained the particular form of the emission spectrum.

Proton production.

From the performed calculations it was obtained that it is necessary $7 \cdot 10^4$ neutrons to produce a proton. Using a neutron generator having a flux of 10^{10} n/cm^2, it is possible to obtain a proton flux about 10^5 p/cm^2.

Fig.1 Proton output.

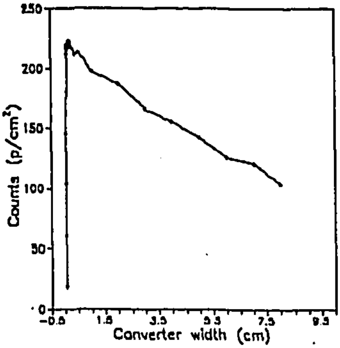


Fig.2 Proton output. Unfolding of the maximum zone.

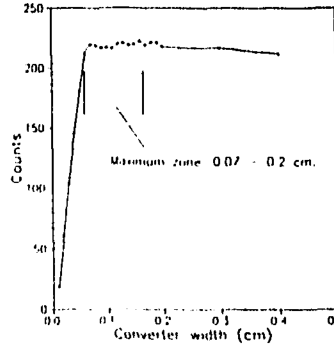


Fig.3 Emission function.

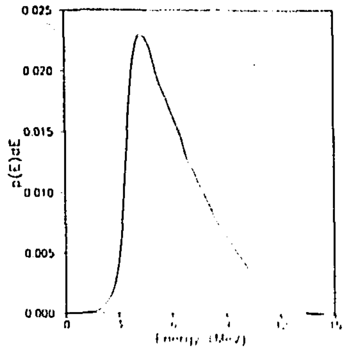
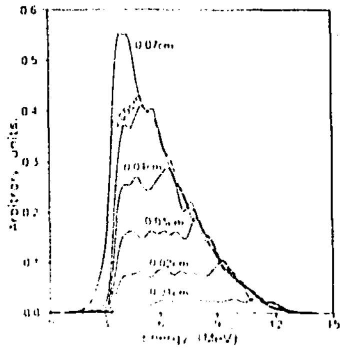


Fig.4 Emission function for different widths.



CONCLUSIONS.

According to the results obtained through the simulation it is possible to know the main characteristics to take into account for obtaining the most quantity of protons through the use of a neutron beam. The best converter thickness to obtain that result is in a range among 0.07 and 0.2 cm where the emission function has a maximum zone. The proton-neutron ratio in this zone is $7 \cdot 10^{-4}$. To increase it, low density converters with higher amount of hydrogen, should be used. The proton spectrum characteristics are obtained and shown. The known particular form of the emission spectrum is obtained when the converter width is in concordance with that one corresponding to the maximum of the emission function.

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