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THE $^1H(t,n)^3He$ REACTION AS MONOENERGETIC NEUTRON SOURCE IN THE (10-20) MeV ENERGY INTERVAL

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SUMMARY.

The $^1H(t,n)^3He$ reaction, considered as neutron source in the (10-20) MeV energy interval presents properties such as intensity, directionality and absence of break-up neutrons, which look advantageous in some technological and biomedical applications.

1. - INTRODUCTION.

This article examines the problem of finding a neutron source in the (10-20) MeV energy interval, having convenient properties for controlled thermonuclear fusion researches and biomedical applications$^{(1)}$.

It is known in fact that a rather large part of the neutron energy spectrum in fusion reactors lies in the neutron energy interval 10-15 MeV, and that in this energy region the neutron cross section data are scarse$^{(2)}$.

This energy region is indeed accessible with the lower energy tandems (E_i below 15 MeV) and with the reactions d-d and p-t, but these reactions present the drawback of not only producing monoenergetic neutrons but also neutrons having a continuum energy spectrum due to three-bodies break-up reactions.

For example monoenergetic 15 MeV neutrons are accompanied by break-up neutrons having relative intensities of 40 % in the p-t reaction and of 150 % in the d-d reaction$^{(3)}$.

In this paper it is shown that the t-p reaction does not present this drawback and has other useful properties.

Furthermore, the t-p reaction used with a thick hydrogen target at incident triton energies of (20-25) MeV, which will be soon available with the tandem accelerator at Legnaro, is a "white" neutron source having intensity, mean energy, and directionality which may prove advantageous in biomedical researches and in cancer radiotherapy.

2. - THE $^1H(t,n)^3He$ REACTION.

The symmetrical reactions p-t and t-p, in which the incident and target nuclei are exchanged, occur with the same center of mass energy, and therefore with the same characteristics when, in the laboratory system, E_t is equal to $3E_p$; E_t and E_p being respectively the energies of the incident tritons and protons.

While the threshold of the reaction $^3H(p,n)pd$ is 8.34 MeV, that of the reaction $^1H(t,n)pd$ is 25 MeV. Therefore with the t-p reaction, for incident triton energies below 25 MeV, corresponding to an energy of 17.6 MeV of the neutrons emitted at 0°, the break-up neutrons are absent.

The $^1H(t,n)^3He$ reaction, whose threshold is 3.05 MeV, generates at 0° in the laboratory system two groups of monoenergetic neutrons corresponding to neutrons emitted at 0° and 180° in the center of mass system.

In Fig. 1 the energies of the two neutron groups emitted at 0° in the laboratory system are reported as a function of the laboratory energy of the incident tritons. The energy of the second

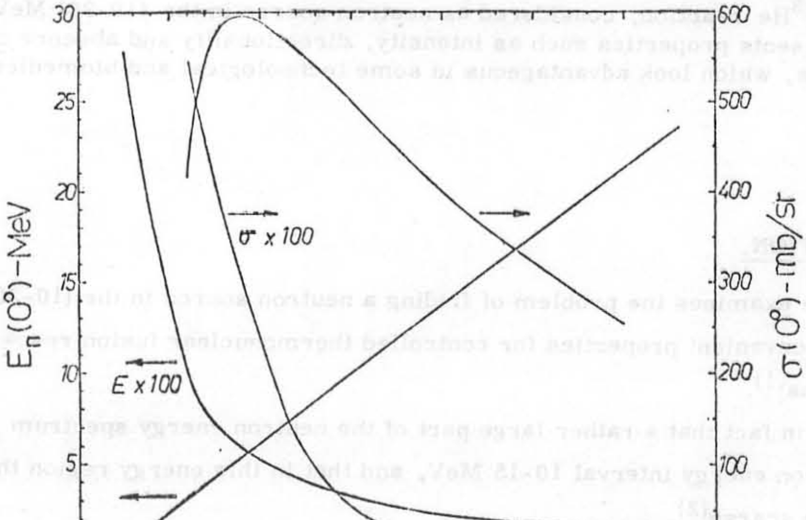

FIG. 1 - Forward differential cross section $\sigma(0^o)$ of the $^1H(t,n)^3He$ reaction, and forward neutron energy $E_n(0^o)$, as a function of the incident triton energy E_t. The two couples of curves are relative to the two neutron groups with high and low energy contemporaneously produced in the reaction. The values of $\sigma(0^o)$ and $E_n(0^o)$ relative to the low energy neutron group were multiplied by 100 for the sake of graphical clarity.

group is much smaller than that of the first.

The same figure also indicates the differential zero degree cross sections in the laboratory system of the two neutron groups. The values were calculated from the corresponding values given in ref. (1) for the symmetrical reaction p-t. The cross section of the low energy neutrons is from two to three orders of magnitude lower than that of the high energy group.

The t-p reaction may therefore practically be considered a monoenergetic neutron source having energies from a few to about 18 MeV.

A second interesting property of the p-t reaction is due to its angular distribution. The differential cross sections of the two reactions p-t and t-p at the energies of 24 MeV of the incident tritons and of 17.6 MeV of the incident protons, for which the neutrons emitted at 0^o have the same energy of $\sim$17 MeV, are reported in Fig. 2 as a function of the emission angle θ in the laboratory system. The same figure also reports as a function of θ, the energies of the emitted neutrons.

The neutrons produced in the t-p reaction are only emitted forward within a cone whose half-aperture θ_{max} is given by the relation

$$\theta_{max} = \arcsin(1-E_{thr}/E_t)^{1/2},$$

E_{thr} = 3.05 MeV being the threshold energy. For E_t = 24 MeV, for example, one has $\theta_{max} = 69^o$. Above 30^o the intensity is practically negligible.

The zero degree cross section of the t-p reaction is almost an order of magnitude larger than the corresponding cross section of the p-t reaction.

The same intensity of neutrons emitted at 0^o with the same energy is therefore obtained with a much smaller incident triton current

This fact reduces the neutrons background due to t-n reactions in the windows of the hydrogen target and in the beam stop. The absence of the backward neutrons which are the most difficult to screen also helps in this sense.

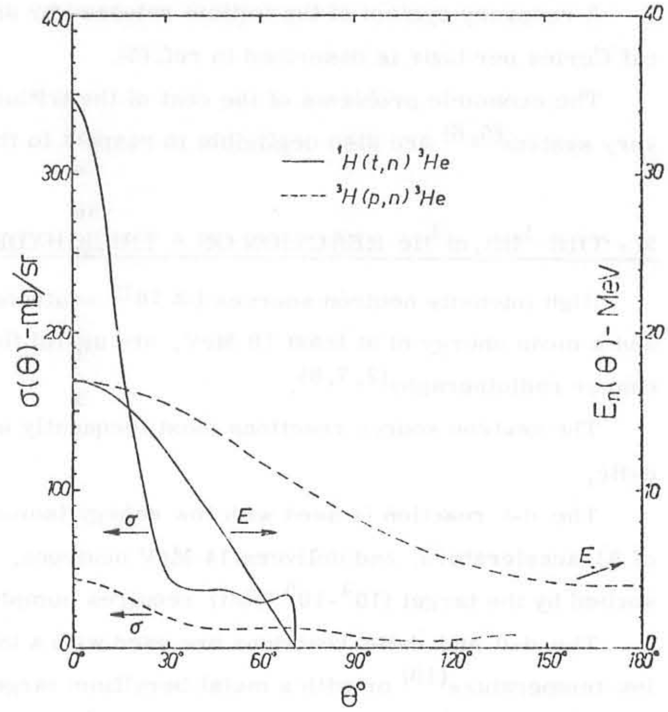

FIG. 2 - Differential cross sections $\sigma(\theta)$ and energies $E_n(\theta)$ of the neutrons produced in the $^1H(t,n)^3He$ reaction, for the incident triton energy of 24 MeV (continuous curves), and in the $^3H(p,n)^3He$ reaction for the incident proton energy of 17.6 MeV (dotted curves), as a function of the neutron emission angle θ in the laboratory system.

Moreover the stronger 0^o intensity, and the rapid decrease of the neutron energy as the emission angle increases, facilitates the neutron beam collimation.

A further advantage of the t-p reaction with respect to the p-t, is due to fact that the hydro gen target does not present the safety problems of the radioactive tritium target and may therefore be used with higher pressure or thinner windows again favoring the signal to background ratio.

Finally the t-p reaction allows a precise calculation of the neutron intensity because the hydrogen of the target is usually very pure and easily changeable while the tritium purity is generally low and not well known.

The use of tritium gives rise to safety problems both when it is used as projectile and as target. These problems have however been solved in both cases.

At Los Alamos(1) and at Hamilton(4) for example, triton beams of the order of a μA have been used in experiments lasting many days. Tritium gas targets have been used for several years in many Laboratories including Legnaro.

A recovery system of the tritium released by an accelerator at Wisconsin at a rate of several Curies per hour is described in ref. (5).

The economic problems of the cost of the tritium and of a sophisticated dosimetry and recovery system(5, 6) are also negligible in respect to the exercise cost of the accelerator laboratory.

3. - THE ^{1}H(t, n)^{3}He REACTION ON A THICK HYDROGEN TARGET.

High intensity neutron sources ($\gtrsim 10^{12}$ neutrons/s·sr) having a continuous energy spectrum and a mean energy of at least 10 MeV, are useful for medical and biological researches and in cancer radiotheraphy(2, 7, 8).

The neutron source reactions most frequently used for this purpose are the d-t, d-d and d-Be.

The d-t reaction is used with low energy (some hundred kV) and high current (some tenths of A) accelerators, and delivers 14 MeV neutrons. The dissipation of the high thermal power absorbed by the target (10^4-10^5 Watt) requires complex cooling apparatus(9).

The d-d and d-Be reactions are used with a thick deuterium target at high pressure and low temperature(10) or with a metal beryllium target(11), with deuteron beam energies of at least 20-30 MeV and currents of the order of 10 μA.

The high zero degree cross section of the t-p reaction suggests its usefulness as a high intensity neutron source.

Its yield is here calculated for a triton beam energy of 25 MeV incident on a hydrogen target at the pressure of 80 Bar, liquid nitrogen temperature, 10 cm thick, giving rise to an incident triton energy loss of 15 MeV. Such a target(10) has been successfully used with current up to 20 μA.

The calculation was performed by taking the 0^o cross section given in Fig. 1 and the stopping power of tritons on hydrogen of ref. (12).

The forward neutron intensity $I(0^o)$, in neutrons per μC, sr and MeV, as a function of the neutron energy E_n, is represented in Fig. 3 together with the intensities from the d-d reactions on a target 10 MeV thick, taken from ref. (10), and from the d-Be reaction on a beryllium target stopping the 25 MeV deuteron beam(13).

The total yields of the three reactions, of the order of 10^{11} neutrons per μC and sr, and the mean energies (10-12) MeV, are not very different.

Also the t-p reaction, with (20-25) MeV triton energy and (5-10) μA current, seems therefore to be useful for neutron radiotherapy. Its directionality should facilitate the screening problems and reduce the low energy neutron background whose presence is therapeutically negative.

A drawback with this application may be due to t-n reaction in the target windows and in the beam stop. The amount of this background is at present not known, its experimental determination seems at this points useful.

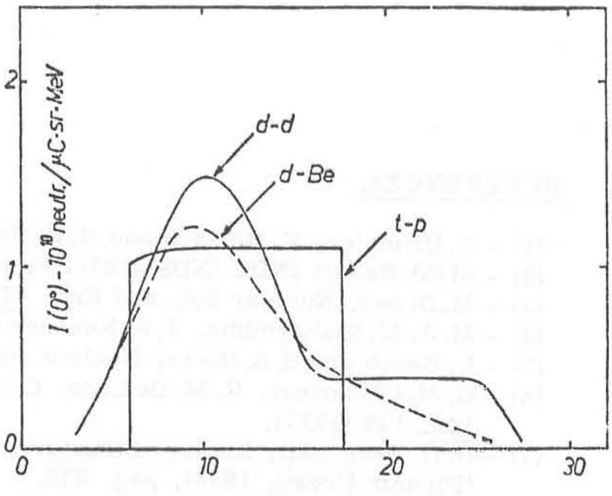

FIG. 3 - Forward intensity I(0^o) of the neutrons produced in the three indicated reactions, as a function of the forward emitted neutron energy E_n, for the incident ion energy of 25 MeV. The targets of hydrogen and deuterium are respectively 15 and 10 MeV thick and the beryllium target thickness stops the incident deuteron beam. The curves relative to the d-d and d-Be reactions have been taken respectively from ref. (10) and ref. (13).

4. - CONCLUSIONS.

The $^1H(t,n)^3He$ reaction, considered as neutron source in the energy interval from about 10 to 18 MeV, presents properties such as intensity, directionality and absence of break-up neutrons, which may be advantageous in nuclear cross section measurements interesting controlled thermonuclear fusion technology.

The reaction, with tritium ion current of some μA and (20-25) MeV energy on a thick hydrogen target, delivers neutron beams having mean energy and intensity which may prove useful in medical and biological researches and in cancer radiotherapy.

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