THICKNESS CONSIDERATION FOR LI AND BE TARGETS FOR FAST NEUTRON PRODUCTION BY CYCLOTRONS OF DIFFERENT SIZES

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ABSTRACT

Thick target neutron yields from Li and Be targets, and from backing materials of Cu and Ta, have been presented for different bombarding energies of protons and deuterons. The proton energies considered are from 15 MeV to 60 MeV in steps of 5 Mev while the corresponding energies of deuterons are from 10 MeV to 30 MeV in 2.5 MeV steps. From the presented data the optimum required target thickness of Be or Li targets for the production of therapy neutrons, under given bombarding conditions with protons and deuterons, can be calculated, and the contribution of the backing material to the total neutron output estimated. Based on our results, the use of moderately thick, rather than infinitely thick, targets for therapy neutron production, is suggested. Such targets could produce enough neutron intensity, more penetrant neutron beams, and would be simpler in the design due to lesser heat dissipation in them, as compared to thick targets.

Introduction

It has been shown (1), and is now generally believed, that moderately thick targets of Li and Be would produce more penetrant neutron beams, when bombarded with protons and deuterons, than "infinitely" thick targets which stop the incident beams completely. A number of laboratories around the world are now using moderately thick targets for therapy neutron production. However, it appears from the literature that the target thicknesses are selected more or less arbitrarily. There is, to the best of our knowledge, no systematic data to help select the optimum thickness of Li and Be targets, for different energies of protons and deuterons, for therapy neutron production.

In this paper the result of our extensive calculations and compilations on neutron production from thick targets of Li, Be, and from backing material of Cu and Ta, for incident proton energies of 20-60 MeV (in 5 MeV steps), and 10-30 MeV deuterons (in 2.5 MeV steps) are presented. From this data the optimum required thickness of Li and/or Be targets, can easily be calculated for any given bombarding conditions and the neutron output from the "moderately-thick" targets estimated. Furthermore, the contribution of the backing material, Cu or Ta, to the total neutron output can also be easily estimated which would help in assessing the effect of the backing material on the thick-target neutron spectrum.

Method

The neutron output values from thick targets of Li and Be, for different protons and deuteron energies, have been taken from Lone et al (2), which summarizes forward direction experimental data of a number of investigators. However, in the absence of any systematic experimental data on the neutron production from Cu and Ta targets, empirically constructed excitation functions and total 4π (rather than the forward direction) neutron yields from these targets (3,4), were used for this study.

For protons and deuterons all kinematically possible reactions, (p.n), (p.2n), (p,3n), (p,4n), (p,5n), (p,pn), (p,p2n), (p,p3n), (p,α n), and, (d,n), (d,2n), (d,3n), (d,4n), (d,5n), (d,p2n), (d,p3n), (d, α n), were considered for each of the stable isotopes of Cu, and Ta at all the bombarding energies. However, due to the unavailability of any data on (d,pn) reaction, this reaction was not included in this study. But, it is expected that the contribution of this reaction to the total neutron yield, especially at higher deuteron energies, would not significantly change the results. However, for greater accuracy, its contribution could be assumed to be similar to that of the (d,n) reaction, and included in the total neutron output values.

For certain reactions there was no cross section data available beyond a certain maximum incident energy. For such cases, the neutron yield, at the highest incident energy for which cross section was given, was also used at higher energies. By combining the contribution of all the reactions at a particular energy, the total neutron output at that energy, for each of the stable isotopes of Cu and Ta (only one) were calculated. The neutron yields from Cu-63 and Cu-65 were combined in ratio of their natural abundances (69.1% and 30.9% respectively) to obtain the neutron output from a natural Cu target at different bombarding energies.

In order to estimate the forward direction (0-degree) neutron yields, which are generally used in therapy neutron production, from the total 4 π neutron yields, isotropic angular distributions was assumed for all the reactions.

Results And Discussion

The results of our compilation and calculations, for protons and deuterons, are shown in tables I and II respectively. The tables are self explanatory and give the intensity of neutrons produced in the forward direction (zero-degree) by the bombardment of thick targets of Li-7, Be, Cu (natural abundance) and Ta, with protons and deuterons of different energies. The incident energy range considered, 10-30 MeV for deuterons and 20-60 MeV for protons, covers maximum energies provided by most of the commercially available cyclotrons used for neutron therapy.

The uncertainties in the neutron yields from Li and Be targets, as can be read from the published data (2), vary from 12% at lower energies to up to 25% at higher energies for both protons and deuterons. However, the uncertainties in the calculated yields from Cu and Ta are larger and could vary from as low as 20% to up to 50% (3,4).

To illustrate the use of the tables, let us suppose that we have a cyclotron capable of producing 30 MeV deuterons and 60 MeV protons. As can be seen from Table II, 30 MeV deuterons would produce 19 x 10^{10} and 18 x 10^{10} n/sr /sec/ uA from "infinitely" thick targets of Li-7 and Be respectively. In this case the backing material does not contribute any neutron to the total neutron output as the deuteron beam is completely stopped in the Li or Be target. However, for a moderately thick target which, let us suppose, reduces the deuteron energy from 30 to 20 MeV, the rest of the energy (20 MeV) is dumped onto the backing material of Cu or Ta. In such a case the neutron yields from Li-7 and Be targets respectively would be (19-6.2 = 12.8)x10^{10} and (18-6.3 = 11.7) x 10^{10} n /sr / sec /uA . The contributions of the backing material of Cu and Ta would be, as can be read from Table II also (for 20 MeV), 12.7 x 10^{8} and 7.8 x 10^{8}n/sr / sec / uA respectively. This means that for such moderately thick targets of Li-7 and Be, the contributions of the backing materials of Cu and Ta, to the total neutron yield, would respectively be only about 1% and 0.6% for Li-7 and 1.1% and .7% for Be. Therefore, the effect of the backing material on the neutron spectra from the moderately thick targets, would be insignificant and could be neglected.

At the same time however, as already mentioned in the introduction, the moderately thick target would produce higher mean energies of neutrons (1) and therefore, more penetrating neutron beams. Even the neutron intensity from such moderately thick targets of Li-7 and Be, 12.8 x 10^{10} and 11.7 x 10^{10}n/sr /sec / uA would be more than adequate for therapy requirement. Moreover, heat dissipation problems would be lesser, and the related target technology easier, for targets absorbing only 10 MeV rather than full 30 MeV deuterons. From even thinner neutron producing targets, the mean energy of neutrons might improve (5), but naturally, the intensity of the neutrons from Li and Be would also be lesser and the contribution of the backing neutrons greater.

Sometimes we may need to find out the thicknesses of neutron producing targets of Li-7 and Be for obtaining a certain neutron yield. This can also be easily achieved with the help of Tables I and II. Let us suppose again that we have a 60 MeV proton cyclotron and we need to know the thicknesses of Li-7 and Be targets for producing around 5 x 10^{10}n / sr/sec / uA . Referring to Table I, it can be seen that, to produce a similar intensity of neutrons, the Li-7 and Be targets must reduce the 60 MeV incident protons to about 45 MeV and 40 MeV respectively. The corresponding contributions of the backing materials can also be read from Table I (at 45 MeV for Li-7 and at 40 MeV for Be).

However, it must be pointed out that the figures obtained using tables I and II are to be taken as guide lines only, due to large errors involved in the neutron yields (12-25% for the experimental results on Li-7 and Be, and from 20% to as much as 50% for theoretical yields from Cu and Ta).

Summary

In this paper the yields of neutrons, by the bombardment of thick targets of Li-7, Be, and of backing materials of Cu and Ta, with deuterons of 10-30 MeV (in steps of 2.5 MeV) and protons from 20-60 MeV (in steps of 5 MeV)

are presented. From our data, the neutron yields from Li-7 and for Be targets, "infinitely" thick or of any known thickness, under bombardment with protons and deuterons of any energy in the aforementioned range, can be easily obtained. Furthermore, the contribution of the backing materials to the total neutron yields, in case of moderately thick or thin targets, can also be estimated. It is further shown that this information can also be used for selecting the optimum thickness of neutron producing targets of Li-7 and/or Be, for a required neutron intensity, under given bombarding conditions, and to estimate the contribution of the backing material of Cu and/or Ta. It is also pointed out that by careful selection of the target thickness, the contribution of the backing material can be minimized, and the neutron mean energy enhanced. All this information would help in the design of an optimum target of Li-7 and/or Be for therapy neutron production with any commercial cyclotron currently available.

TABLE 1

Forward direction (0-degree) neutron yields from thick targets of Li-7, Be, Cu and Ta at different energies of incident protons.

THICK TARGET				
Energy of protons (MeV)	^{7}Li	Be	Cu (Natural)	Ta
	Neutrons produced : n sr^{-1} sec^{-1} uA^{-1}			
	Measured		Calculated	
	$\times 10^{10}$	$\times 10^{10}$	$\times 10^{9}$	$\times 10^{9}$
15	0.1 (0.5)	0.2 (1.5)		
20	0.3 (1.1)	0.5 (2.3)	1.9	1.0
25	0.6 (1.9)	0.9 (3.7)	3.7	1.9
30	1.1	1.6	5.9	3.2
35	1.8	2.3	8.3	5.1
40	2.6	3.2	10.2	7.3
45	3.6	4.2	12.5	9.5
50	4.8	5.2	13.9	12.2
55	6.6	6.4	14.7	14.3
60	8.7	7.7	15.4	15.6

P.S. Figures without brackets = neutrons with En > 5 MeV
Figures with brackets = neutrons with En > 0.3 MeV

TABLE II

Forward direction (0-degree) neutron yields from thick targets of Li-7, Be, Cu & Ta at different energies of incident deuterons.

	THICK TARGET			
Energy of deuterons (MeV)	^{7}Li	Be	Cu (Natural)	Ta
	Neutrons produced : n sr^{-1} sec^{-1} uA^{-1}			
	Measured		Calculated	
	x 10^{10}	x 10^{10}	x 10^{8}	x 10^{8}
10.0		0.7	2.6	0.7
12.5	1.1	1.7	3.8	1.7
15.0	2.5	2.9	6.0	3.4
17.5	4.1	4.4	9.0	3.5
20.0	6.2	6.3	12.7	7.8
22.5	8.6	8.5	17.1	10.8
25.0	12.5	11.5	21.8	13.8
27.5	16.0	15.0	27.1	17.0
30.0	19.0	18.0	32.6	20.0

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