NEUTRON PRODUCTIONS FROM CARBON BY CHARGED PARTICLE BOMBARDMENT AT DIFFERENT ENERGIES

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ABSTRACT

By making use of the published cross section data and the range-energy tabulations, we have calculated neutron yields from carbon under bombardment with protons, deuterons and alphas of up to about 23 MeV. This data would help in estimating the neutron background/contamination when carbon is used as a backing/dumping material in cyclotrons while producing fast neutrons for therapy or other applications.

1. INTRODUCTION

Due to its extraordinary stability (temperature, nuclear, etc) carbon is an excellent material for "target-backings", "beam-dumps" and collimators for neutron producing reactions in cyclotrons at high beam intensities. However, for utilising the full potential of carbon in the aforementioned applications it is important to estimate the neutron productions from carbon under bombardment with charged particles of different energies. This information is not conveniently available from the literature.

In our programme on neutron production from different elements under charged particle bombardment we have already estimated the neutron output from all the elements with Z = 20 to Z = 92.[1] This data is now being extended to lower Z elements. In this paper we are presenting the neutron output from carbon under bombardment with protons, deuterons and alphas of up to 12, 20 and 23 MeV respectively.

2. THEORY AND METHOD

As shown by Chaudhri et al,[2] the neutron output from a thick target under bombardment with a beam of charged particles of atomic number z and energy E (MeV) is given by

$$A = f\ (N_A/W)\ .\ (6.25/z)\ 10^{12} I \quad \sigma_E(-dE/dx)^{-1} dE$$

where

f = the abundance of the isotope in the target which is undergoing nuclear transformation to produce neutrons

N_A = the Avagadro's number

W = the atomic weight of the target nuclide producing neutrons

E_i = the incident energy of the charged particle beam

E_O = the lowest energy for which any appreciable number of neutrons would be produced

I = the current in microamperes of the incident charged particles beam falling on the target.

σ_E = Cross sections of the neutron producing nuclear reaction at energy E.

$\frac{dE}{dx}$ = Stopping power of the target for the charged particle beam.

To evaluate the neutron yield equation the cross section and the stopping power data is required. The cross sections at different energies are obtained from the literature and the stopping powers for different elements from the tabulations of Williamson et al.[3] The cross sections for deuterons is taken from Brill and Sumin,[5] and for alphas from Black et al.[6] Due to non-availability of proton cross sections the neutron yields from Bair et al have been modified.[6]

3. RESULTS AND DISCUSSION

a) Protons on Carbon

Total neutron yield obtained by bombarding an "infinitely" thick target of high purity natural carbon, with protons from 4 - 12 MeV, is shown in Fig.1. This curve is produced by slightly modifying the neutron yield data of Bair et al, [6] as the c(ρ, n) cross section is not conveniently available. Since the $^{12}C(p, n)$ threshold is above 12 MeV, ^{12}C does not contribute to the neutron yield and most of the neutrons are produced by ^{13}C present in natural carbon. To estimate neutrons at o degree or in any given direction, on could assume an isotopic angular distribution, and calculate the desired yield as an approximation.

b) Deuterons on Carbon

Total numbers (4π) of neutrons produced from a "thick" ^{12}C-target under bombardment with deuterons of up to 20 MeV as shown in Fig.2. As mentioned already the cross section data for this curve has been taken from Brill et al,[5]. From this yield curve the total thick target neutron yield at any desired deuteron energy can be directly read. This curve can also be applied to estimate the neutron output from "semi-thick" targets of known thickness in the following way. The total neutron yield at the energies, at which the deuteron beam enters and leaves the "semi-thick" target are read from the yield curve. The difference between the two values is the neutron output from the "semi-thick" carbon target. Here again, if one wants to estimate the 0-degree yield, or yield at any other desired angle, one has to assume an isotropic distribution to get approximate estimates of neutrons in that direction. Please note that unlike the Carbon plus proton data, all the data in Fig.2 refers to ^{12}C and not a natural Carbon target. Moreover, the neutron yield is given for a 10μA deuteron beam. As is expected the deuteron beam produces many more neutrons from ^{12}C target than a proton beam of similar energy would produce even from a natural carbon target.

c) Alphas on Carbon

Total (4π) neutron yield produced from a "thick" target of 100% ^{12}C, under bombardment with alphas of up to 23 MeV are shown in Fig.3. The cross section for this yield curve has been taken from the data of Black et al.[6] The neutron yield is given for a 10μA alpha beam.

4. SUMMARY

Total neutron yields from thick Carbon targets (natural carbon for protons but 100% ^{12}C for deuterons and alphas) under bombardment with protons, deuterons and alphas of up to 12, 20 and 23 MeV respectively are presented. From these total yield curves neutron yield in any desired direction can be approximately estimated. Moreover, the thick target yield curves are also suitable for estimating yields from "semi-thick" targets. This information would be helpful when estimating the neutron background contamination from Carbon backings of neutron producing targets, Carbon collimators and Carbon beam dumps.

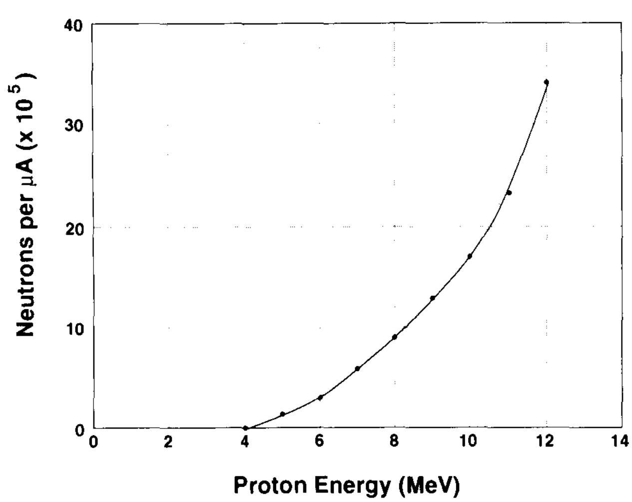

Fig. 1. Total neutron yield from the bombardment of a thick natural Carbon target with protons.

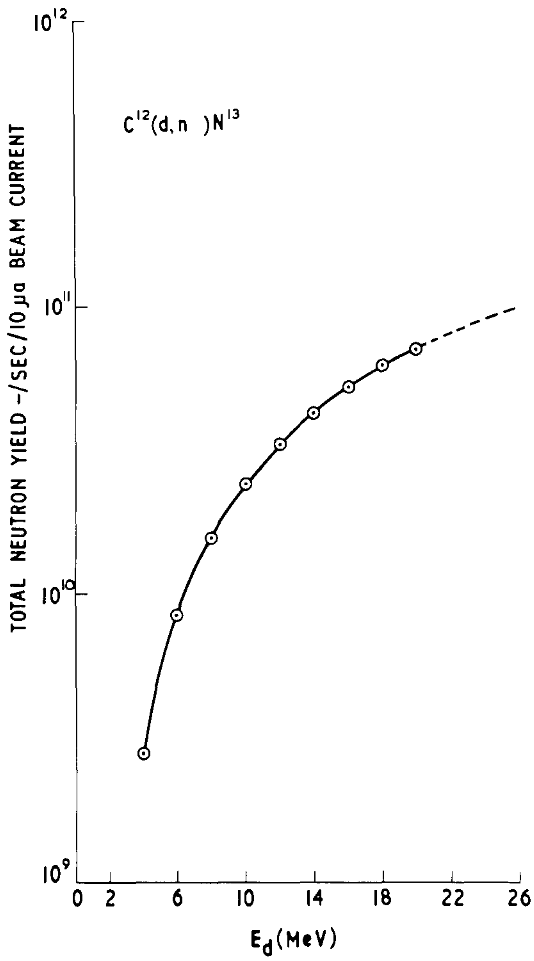

Fig.2. Total neutron yield from a C - 12 target under bombardment with deuterons of different energies

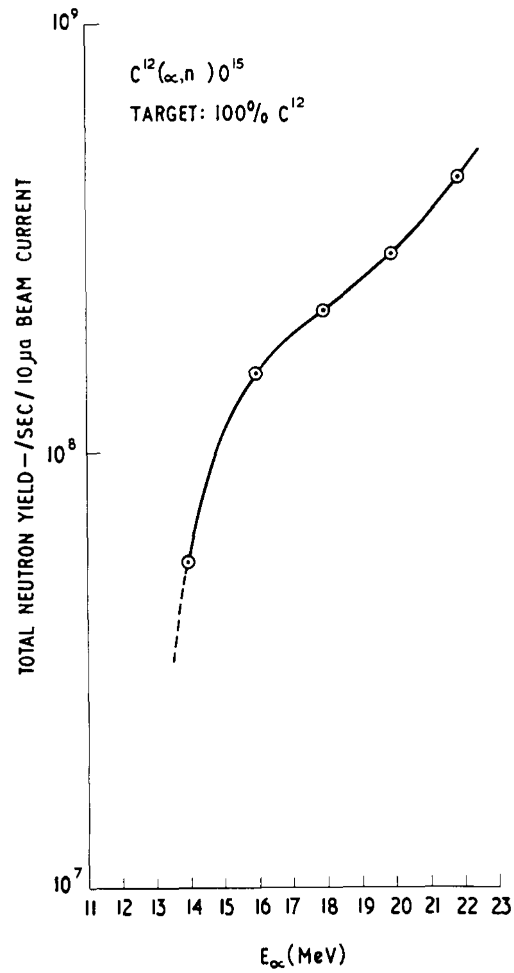

Fig.3. Total neutron yield from a "thick" C - 12 target under bombardment with alphas of different energies

5. REFERENCES

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