

A HEAVY WATER TARGET FOR FAST NEUTRON PRODUCTION BY CYCLOTRONS

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Abstract.- A simple and cheap design of a heavy water target for fast neutron production with cyclotrons is presented. It has been shown that this target will easily withstand deuteron beam intensities of at least 70 μA at 16 MeV, without any decrease in the neutron yield. The advantages of such a target for routine production of therapy neutrons, even with smaller compact cyclotrons (deuteron energy of around 10 MeV), are highlighted.

1. **Introduction.**- From theoretical calculations it was demonstrated by Chaudhri and Batra,¹⁾ that a heavy water target would produce neutrons with a higher mean energy than a Be target, at similar deuteron bombarding energies. This was later verified experimentally by measuring the neutron spectra and depth-dose characteristics from the two types of targets at different incident energies.²⁾ It was also shown that 10 MeV deuterons would produce a neutron beam from a heavy water target which has similar penetration as that produced by 16 MeV deuterons on a Be-target (The Hammersmith set-up).²⁾

Moreover, the neutron dose rate of about 13 rads/min, at 100 cm source to skin distance from such a target, was estimated, which is quite acceptable from a therapeutical point of view. Therefore, it was pointed out by us that even the smaller compact cyclotrons, with maximum deuteron energies of only around 10 MeV, could also produce clinically acceptable fast neutron beams, by using a suitable heavy water target, and a neutron therapy programme similar to that of Hammersmith Hospital could be conducted.

In this paper we are presenting the design, technical details and operational characteristics of a simple heavy-water-target.

2. **Design and method.**- An exploded view of the target is shown in Fig. 1. The heavy-water is supported in a 4 mm deep depression in the aluminum plate (3) by a 0.0025 cm thick titanium foil (2). This foil is held in position with the help of the mounting plate (1) and the O-ring in (3), and thus forms an air-tight joint on the front face of the heavy water compartment. The back of the aluminum plate (3) also has a recess for water cooling, which is applied via the back-plate (4) and carries away the heat generated by the stoppage of the incoming beam of charged particles. The heavy water can be introduced into the target assembly, or taken away from it using a syringe through a side hole, which is vacuum sealed with a screw cap during irradiation. About 20 ml of heavy water is injected into the target, which forms a layer of about 4 mm thickness underneath the Ti foil, and is capable of completely stopping at least 16.7 MeV deuterons, the maximum energy used in these investigations.

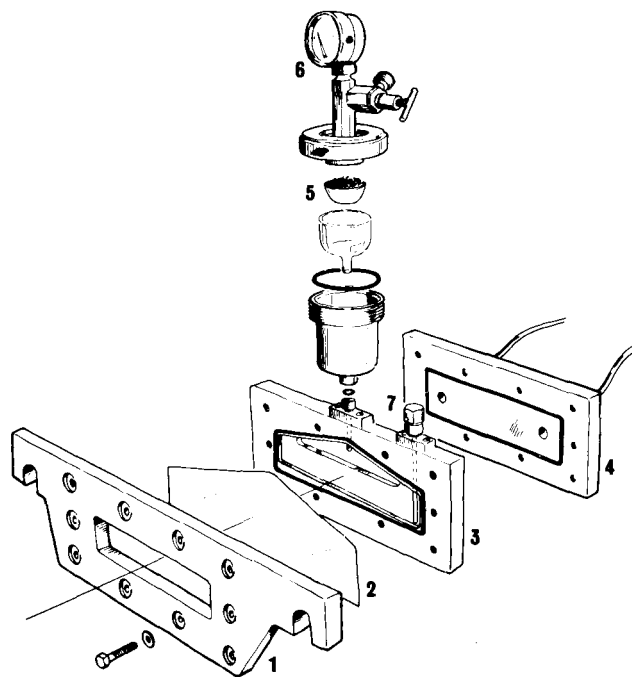


Fig. 1. Exploded view of the heavy water target

The high intensity deuterons incident upon the target would cause partial decomposition of the heavy-water, liberating hydrogen and oxygen, which would accumulate in the dead space above the liquid. These radioanalytic gases are continuously being recombined within the sealed target system, by the catalyst (Deoxo Catalyst, Model D, supplied by Engelhard Industries Ltd., Baker Platinum Division) contained in the crucible (5).

During irradiation, the pressure inside the target assembly is continuously monitored by a gauge (6) on top of the catalyst vessel and viewed with a close-circuit television. This is to ensure that the target pressure does not rise to unacceptable limits during bombardment and thus threaten to rupture the thin Ti-window. It was observed that as soon as the beam was brought on, the pressure inside the target rose by

10-15 lbs/in² and then remained constant during the course of bombardment. It fluctuated with the beam intensity, and fell down to 2-3 lbs/in² over the starting pressure inside the target, which was atmospheric. This excess pressure had to be released through the side valve before the target could be opened up.

In order to check the functioning of this target as a reliable neutron source, its neutron out-put was measured at 16 MeV deuterons, with beam currents varying from 10-70μA, using a modified version of the gamma-compensated ionization chamber. ³⁾

After testing the target for a few hours, the beam was switched off and the target dismantled. The Ti foil had become radioactive due to the bombardment by deuterons. It was placed in contact with an x-ray film in order to take an autoradiograph of the irradiated portion, and hence determine the beam size. With a micro densitometer this intensity distribution within the beam spot was also determined.

3. Results and discussion.-

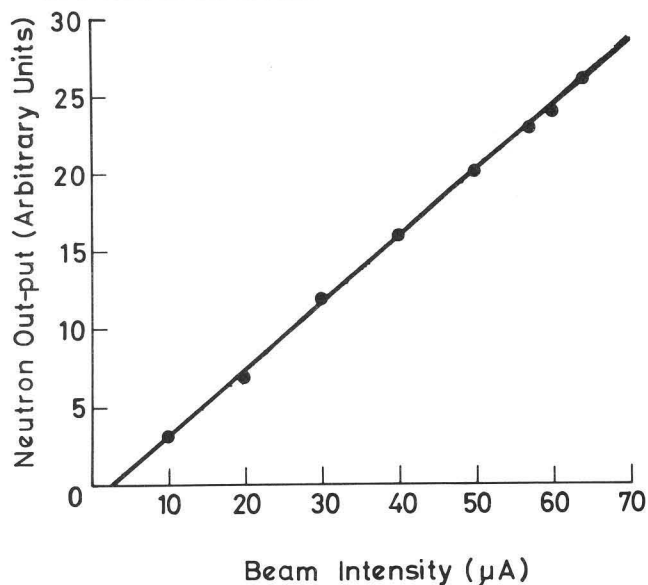


Fig. 2. Neutron intensity in the forward direction from the heavy water target bombardment with 16 MeV deuterons at different beam currents

The Fig. 2 shows the neutron out-put from the heavy water target for different values of the deuteron beam current, ranging from 10-70 μA. As can be clearly seen from the figure, all experimental points lie on a straight line, meaning that the neutron out-put is directly proportional to the beam intensity of up to 70 μA. This perfect linear relationship between the neutron output and the beam intensity confirmed two main features of the target design. Firstly it proved that the target was capable of dissipating the amount of thermal energy generated by completely stopping 16 MeV deuterons, of up to 70 μA intensity, which is equivalent to about 1.1 kW. Secondly, it showed that, even at the maximum beam intensity, the target did not deteriorate, and any radiolytic gases formed were quickly recombined with the help of the catalyst and returned to the target, thus ensuring that there was no depletion in the thickness of the

heavy water layer in the beam path. It is possible that the target could have withstood even higher beam power, but we could not check it as beam intensities greater than 70 μA were not available from the Hammersmith Cyclotron.

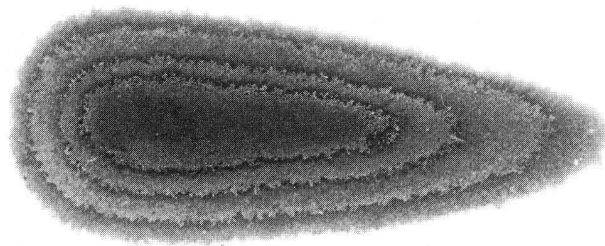


Fig. 3. Autoradiograph of the irradiated Ti-foil, showing the deuteron beam profile

An autoradiograph of the irradiated Ti foil is shown in fig. 3, which gives the size of the beam spot at the entrance of the target. The width of the beam spot is measured to be about 35 mm, its maximum height about 15 mm and the area about 3.5 cm². Different shades/zones in the autoradiograph correspond to different deuteron densities within the incoming beam. The innermost zone, measuring 2 mm x 4 mm, is not visible in the reproduction. Regarding the intensity of the charged particle beam to be 1 in this zone, the intensities corresponding to other zones (starting from the outermost zone) are 0.42, 0.51, 0.66 and 0.78. This means that most of the deuteron intensity was concentrated in an area of about 1 cm² (this area corresponding to the visible innermost region in the autoradiograph), and that the Ti foil used in this design was capable of handling this much power density without any apparent signs of deterioration.

The power dissipation capability of the target corresponds to a 100 μA beam at 10-11 MeV deuteron energy, which is available in modern small compact cyclotrons. Therefore, using such a target, even the small cyclotrons could easily produce neutrons which would deliver about 13 rads/min. at a source to surface distance of 100 cm, and have the same penetration characteristics as those produced by 16 MeV deuterons on thick Be (the Hammersmith set-up), and thus be useful for neutron therapy.

The target described here was designed for use with the deuteron beam from the Hammersmith (maximum energy 16.7 MeV) or from any other smaller cyclotron. However, the design features could be easily incorporated into constructing a target for use with bigger machines or particles other than deuterons. One would only have to make the depression in target plate (3) fig. 1 deep enough and, therefore, the thickness of the heavy water layer large enough, to completely stop the incoming beam.

All the components of the target are cheap, easily available and can be assembled without any problems. The present target showed no sign of deterioration whatsoever, even after hours of operation and testing.

The only possible weakness could be the danger of accidental foil rupture during irradiation. This risk could, however, be minimized by applying air cooling to the surface of the foil with gentle jets. This simple target must be compared with Be targets, which are not only expensive and relatively dangerous to handle and manipulate, but also extremely difficult to solder to a copper backing for the purpose of producing a therapy target.

The present target is not only suitable for therapy applications, but also for other types of applications requiring intense neutron beams with higher mean energies, such as fast neutron activation, radiation damage studies in materials, etc.

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References.-

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