ROTATING TARGET FOR INTENSE 14-MeV NEUTRON SOURCE*

Rex Booth, H. H. Barschall, and E. Goldberg
Lawrence Livermore Laboratory
Livermore, California 94550

Summary

The previously described intense source of 14-MeV neutrons has been observed to produce a source strength of 3×10^{12} s^{-1}, and a flux density of 7×10^{11} cm^{-2} s^{-1} on a small sample. Development work is in progress to increase the intensity further.

Introduction

The 14-MeV neutron source at Livermore has been described previously.[1,2] An intense beam of atomic deuterium ions is stopped in a target consisting of a layer of Ti in which tritium is absorbed. The Ti layer has a diameter of 14 cm. The target rotates at 1100 rpm, and its outer surface is water cooled. We wish to report some more recent studies and developments on this source, as well as some applications.

Applications

A high-intensity 14-MeV source is useful in biomedical work and in testing of materials for applications for controlled thermonuclear reactions. For most biomedical applications, some shielding is required. To accomodate the shielding, the object to be irradiated is placed far enough from the source that only the total number of neutrons emitted by the source matters. For materials testing applications, however, the sample is usually small and can be placed next to the source so that the usefulness of the source is determined by the attainable flux density which depends on the diameter and the accessibility of the source. Our neutron source is designed to optimize its usefulness for both types of experiments.

Source Strength

We previously reported a source strength of 2×10^{12} neutrons/s when a good fresh target is bombarded with 8 mA of 400-keV deuterons. The source strength decreases with a half life of about 700 mAh if all target areas receive equal charges of deuteron beam. The inner portion deteriorates, however, appreciably faster that the outer portion. We have been able to increase the beam current to 12 mA and to obtain a source strength of 3×10^{12} neutrons/s, but this operation strains the high voltage supply and reduces target life time. In order to make higher source strengths available the following changes are under way: A new high-voltage power supply rated at 60 mA instead of the present 20 mA has been ordered. A new ion source has been constructed that produces 40 mA of deuteron current, and a larger rotating target has been built.

Larger Target

Fig. 1 shows a drawing of the larger rotating target and Fig. 2 shows a photograph. The rotating seal is the same as that used on the smaller target. The new target has a diameter of 22 cm instead of 15 cm. A conical section permits the 22-cm target to be used with the 15-cm diameter rotating seal. The target backing is a 1-mm thick sheet of Cu-Zr alloy (Amzirc) that is hydroformed to have a radius of curvature of 23 cm. The targets are coated with Ti and loaded with tritium at the Isotopes Division of Oak Ridge National Laboratory. Since this target has twice the area of the previously used target we expect it to have a substantially longer life time than the smaller

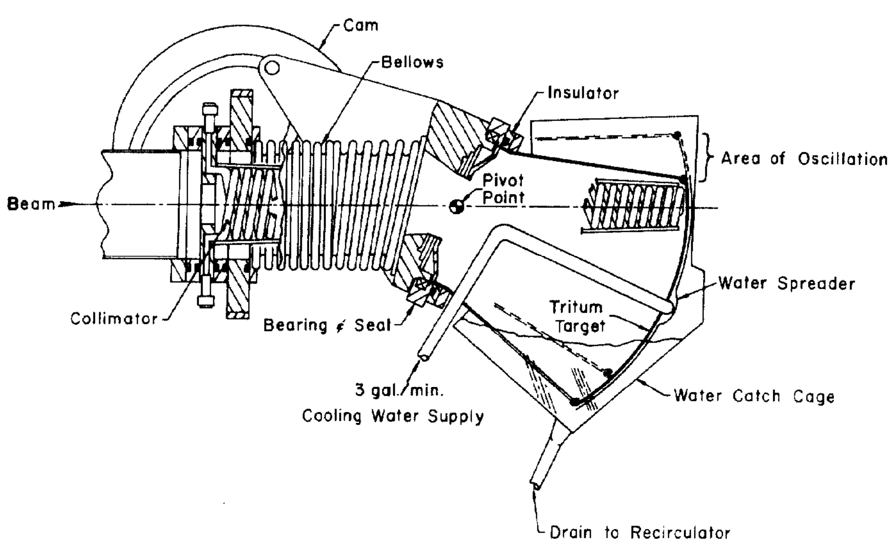

Fig. 1 Rotating target. The section to the right of the bearing and seal rotates at 1100 rpm. The 22-cm diameter tritium-loaded target is held with an O-ring seal at the end of the accelerator vacuum system. The section to the right of the bellows is slowly moved up and down so that all parts of the target can be used.

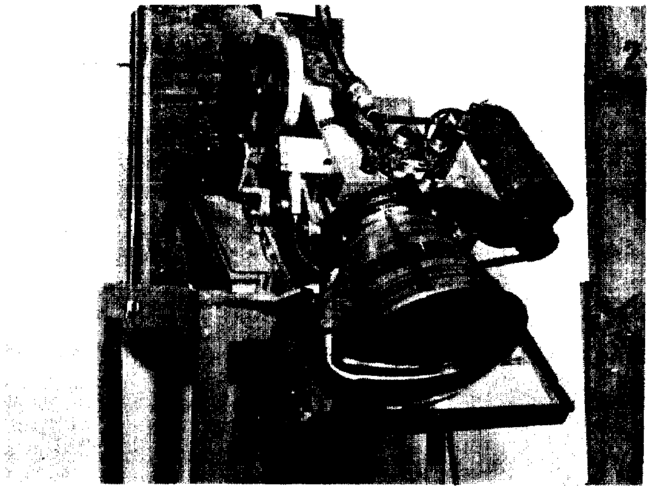

Fig. 2 Photograph of the large rotating target shown schematically in Fig. 1. The upper part of the water catcher has been removed to show the target itself.

targets, but we received the larger targets only recently and have not yet had enough operating experience with them.

Effect of Beam Spot Size on Target Life

For most uses, the deuteron beam passes through a 1.6 cm diameter collimator in front of the target. There is qualitative evidence that focussing the beam too sharply within this area results in rapid target deterioration. We have observed, for example, that when a target had been bombarded at a fixed radius of rotation with a sharp beam, reduction of beam current by defocussing increases neutron yield.

Effect of Target Thickness on Target Life

We have attempted to study the effect of the thickness of the Ti-T layer on target life and neutron yield. It is desirable to make this layer as thin as possible to minimize the tritium requirement both to reduce the hazard and the cost. In addition, a thinner layer should reduce the resistance to heat flow through the layer. The range of 400-keV deuterons is about 1.6 mg/cm^2 in Ti. Since the neutron production cross section remains large down to about 50 keV deuteron energy, layers less than 1.4 mg/cm^2 thick would be expected to produce lower yields. Whether increasing the thickness above 1.6 mg/cm^2 results in longer target lifetimes depends on whether tritium diffuses from the deeper layers to replenish released or displaced tritium at the depth at which neutrons are produced. In order to be able to make reliable comparisons between targets of different thickness we obtained from the Oak Ridge Laboratory three targets each of which consisted of four sectors of thicknesses between 1.5 and 6 mg/cm^2. During each revolution of the target the beam sweeps over all four sectors, so that all sectors received the same bombardment. The neutron yield is monitored with a plastic scintillator and displayed on an oscilloscope whose sweep is synchronized with the target rotation. Initially all four sectors of a given target produced approximately the same yield, but one of the three targets gave a 20% lower yield than the other two. In this low yield target the yield dropped at about the same rate for all four sectors. For the other two targets the yield decreased most rapidly for the thinnest layer and most slowly for layers of thickness between 3.5 and 4.5 mg/cm^2. While there appear to be variations in the performance of different targets, our experience indicates that the optimum thickness is between 2 and 2-1/2 times the deuteron range.

Available Neutron Flux Density

The highest available flux density for irradiation of small samples is determined by the average distance to the point at which the neutrons are produced. This average distance depends on the size of the target spot and the spacing between the Ti-T layer and the sample. The latter spacing is limited by the thickness of the target backing (1 mm), of the layer of cooling water (∿1 mm), and of the stainless steel water spreader and water catcher cover (0.3 mm). The normal distance between the neutron source and the sample can therefore be a little less than 4 mm, but the size of the beam spot cannot be measured directly. In order to measure the available flux density, we activated small samples of Zr and S close to the source and observed the 3.2-day activity from $^{90}Zr(n,2n)$ reaction and the 14-day activity from the $^{32}S(n,p)$ reaction. The first reaction has an effective threshold of 12 MeV, the latter of 2 MeV. The cross section of the $^{90}Zr(n,2n)$ reaction increases with neutron energy, while that of the S(n,p) reaction decreases with neutron energy between 14 and 15.6 MeV which is the range of energies of neutrons emitted in the forward hemisphere. The samples are discs about 1 cm in diameter; the Zr discs are about 0.5 mm thick, the S discs were 2 mm thick. Eight discs of the same element were irradiated simultaneously at various distances up to 5 cm from the target. The closest disc touched the outside of the water catcher. The discs were arranged parallel to each other with their common axis parallel to the deuteron beam and pointing at the center of the beam spot. The center of the beam spot had been determined by placing a Kodak Pathe No. LR115 film on the cover of the water catcher. This film was developed in a Na OH solution and clearly showed the location of the center of the neutron source. For the activation about 3×10^{13} neutrons/sr were produced in the forward direction.

If one assumes that at 5 cm from the target the effect of finite target size can be neglected, the source strength as measured by a proton recoil counter and by the two activation detectors agreed to 12% which is consistent with the accuracy to which the activation cross sections are known. By comparing the activities of the farthest and closest discs we obtain an equivalent ($1/R^2$) distance from the source to the center of the disc of 5.5 mm.

A simple mathematical model,[4] assuming a circular disc radiating uniformly and isotropically, was examined. Within a small sample positioned on the axis of the disc of radius (R_S) and a distance (Z) from the disc, the reaction rate will be:

$$\frac{S_o}{2\lambda} \ln (\sec \theta_{Max}),$$

where S_o = source surface density

λ = reaction mean-free-path

$$\sec \theta_{Max} = (Z^2 + R_S^2)^{1/2}/Z$$

Displacement of the sample normal to the disc axis by an increment, ε, leads to the more elaborate expression for the reaction rate:

$$(S_o/4\lambda)\ \ln\ (Z^2+R_s^2-\varepsilon^2+[(Z^2+R_s^2-\varepsilon^2)^2+4\varepsilon^2Z^2]^{1/2})/2Z^2$$

For a finite sample disc, numerical integration over the disc using the latter expression yields the quantity which may be compared directly to experimental data.

An attempt was made to fit the variation of activity with distance to calculations using the above model based on various assumed sizes of neutron source and minimum spacing between source and detector. Fig. 3 shows a plot of the observed Zr activity as a function of distance from the source for an assumed radius of the neutron source of 3 mm and minimum spacing of 4 mm. Account was taken of the rapidly rising $^{90}Zr(n,2n)$ cross section in the E_n = 15 MeV range through Monte Carlo calculations. This correction, shown in Fig. 3, arises because of the variation of source neutron energy with emission angle. The closer discs, which see more of the oblique neutrons, require the largest adjustment. The good fit indicates that the assumed radius is consistent with the observations.

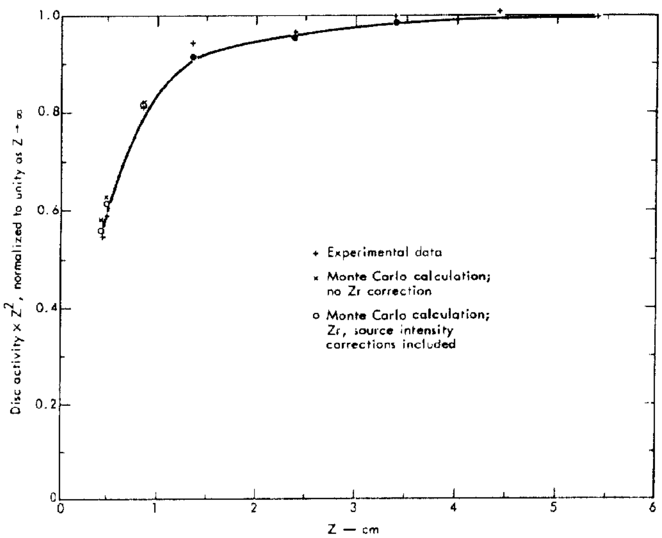

Fig. 3 Zr activity times distance squared as a function of distance from the neutron source. The calculation is based on the assumption of a disc source of 3 mm radius and of a distance between the source and the inner face of the first sample of 4 mm.

Available Flux Density for Materials Testing

If a small sample (i.e. < 3 mm diameter) can be placed 4 mm from a source of $2 \times 10^{12}\ s^{-1}$, a flux density of about $6\text{-}7 \times 10^{11}\ cm^{-2}\ s^{-1}$ is available. This can be raised to $9 \times 10^{11}\ cm^{-2}\ s^{-1}$ if the spacing is reduced to an allowable 3 mm. The source strength decreases, however, with time because of target deterioration with a ∿100 hour half life. We have exposed small Nb samples to fluences of $10^{17}\ cm^{-2}$ by runs which have lasted 60 hours.

*Work performed under the auspices of the U.S. Atomic Energy Commission.

References

1. Rex Booth, IEEE Trans. Nucl. Sci. NS-14, 943 (1967)

2. R. Booth and H. H. Barschall, Nucl. Instr. and Meth. 99, 1 (1972)

3. R. Booth, Nucl. Instr. and Meth. 59, 131 (1968)

4. E. Goldberg, R. Griffith, and C. Logan, LLL Report UCRL-51317 (1972)