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TRITIUM-TARGET PERFORMANCE AT RTNS-II*

D. W. Heikkinen and C. M. Logan
Lawrence Livermore National Laboratory
Livermore, California 94550

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Summary

The Rotating Target Neutron Source (RTNS-II) uses a 360-keV deuterium beam and the $^3\text{H}(d,n)^4\text{He}$ reaction to generate 14-MeV neutrons. The neutrons are used for fusion materials damage studies. The tritium target consists of a band of titanium tritide on copper alloy substrates of 23- or 50-cm diameter. During operation, the substrates are internally cooled and rotated at ~ 4000 rpm to withstand beam intensities in excess of 100 mA. Neutron production data have been accumulated for fifty-eight 23-cm and five 50-cm targets. From these data, using a non-linear least-squares fitting procedure, target performance parameters have been obtained which permit a quantitative comparison of individual targets. Average parameters are obtained for the 23- and 50-cm targets.

Introduction

Since early 1979, the RTNS-II facility at Lawrence Livermore National Laboratory has operated one of two identical accelerator-based 14-MeV neutron sources for fusion materials damage studies. At present, the RTNS-II facility is jointly supported and utilized by Japan (Mombusho) and the U.S. (DOE). Detailed characteristics of the neutron sources have been given elsewhere.^{1,2}

Briefly, an RTNS-II neutron source consists of a 400-keV Cockcroft-Walton high voltage terminal (with associated ion source), a 10-m beam transport system and

the rotating target assembly containing the titanium-tritide target. A schematic diagram of a neutron source is given in Fig. 1.

Neutron production obviously depends on the performance of the tritium targets. In this paper we will discuss the performance of a large subset of tritium targets used at RTNS-II for the production of 14-MeV neutrons.

Target Substrates

Because of the high power density in the beam (approaching 40 kW in a beam spot size of 1 cm FWHM), the target substrates are rotated at ~ 4000 rpm and internally cooled by water to avoid excessive heating of the target. This requires the substrate material to have high thermal conductivity. In addition, the substrates, which are formed to a spherical segment shape, are subjected to high temperatures and mechanical stresses at times during the target production process and during operation. This leads to the requirement of maintaining good strength and ductility after high temperature exposure. Three Cu alloys which satisfy these requirements have been used for the substrates. Two of these are precipitation-hardened alloys, Amzire (Cu with .15% Zr by weight), and MZC (Cu with .03% Mg, .1% Zr and .1% Cr by weight), both made by Amax Copper, Inc. In addition, a dispersion-hardened alloy, Glidcop (Cu with .2% Al_2O_3 by weight), made by Glidden Metals has been used.

Figure 1. A schematic diagram of a RTNS-II neutron source illustrating the basic components of the system.

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To achieve internal cooling, the substrates are made with two layers by one of two methods: electroforming or diffusion bonding. In each of the methods, a flat plate of Cu alloy is photo-chemically etched with radial supply and return water channels. These channels are 0.5 mm in depth and range in width from 0.5 to 2.0 mm depending on position on the substrate and substrate diameter. The water passages are also convoluted to provide turbulent flow for enhanced heat transfer. In the diffusion bonding method, the etched layer is gold-plated (6.4 μm) and a matching unetched plate (0.5 mm and 1.0 mm thick for 23- and 50-cm substrates) is bonded to the etched plate at high temperature and pressure. The temperatures and pressures used are 400-500°C and 20-35 MPa.

The electroformed method uses electroplating techniques to deposit a 0.5 mm layer of copper over the etched plate which has had the water channels filled with a removable conducting wax. The details of the two methods for producing substrates are described elsewhere.^{3,4} The substrates are hydroformed to the spherical segment shape, finish machined and pressure tested to 8.3 and 17.5 MPa for 23- and 50-cm substrates, respectively. Typical target cooling water flows during operation are 15 L/min and 40 L/min for 23- and 50-cm targets using 4°C and 2.4 MPa water.

Titanium-Tritide Layer

After further testing, the substrates are sent to Oak Ridge National Laboratory for titanium coating and tritium loading. The titanium vacuum evaporation is done with a substrate temperature of 400°C. The titanium is evaporated in bands of 5.9 and 14.6 cm width and areas of 300 and 1545 cm^2 for the 23- and 50-cm targets. The nominal thickness is 10 μm (or 3.5 to 4.5 mg/cm^2).

Tritium loading is done at a substrate temperature of $\sim 400^\circ\text{C}$ and a tritium pressure of 40-50 kPa. The tritium exposure time is ~ 1 hour. The nominal tritium content of the two different sized targets is 4.4×10^7 and 2.0×10^8 MBq. In addition, preliminary measurements have shown the titanium tritide is near the stoichiometric value TiT_2 .⁵

A more thorough discussion on preparation of the titanium-tritide layer is given in Refs. 6 and 7.

For completeness, a diagram of the complete rotating target assembly is shown in Fig. 2. The rotating assembly utilizes an air-levitated, differentially pumped vacuum seal and is driven by an air turbine. The target is oscillated, as indicated, to utilize the complete titanium tritide layer.

Target Performance

The neutron production from targets is measured using conventional ion chambers and proton recoil counters. Data are recorded by a small on-line computer. In addition to providing neutron production data, this also provides the time-history of the irradiation for dosimetry purposes. Standard beam integration techniques are used to measure the total number of incident deuterons. Figure 3 shows total neutron production vs total incident deuterons for representative 23- and 50-cm targets. Also shown in Fig. 3 are fitted values from a non-linear least squares fit to the data. The fit is to the equation

$$Y = A_1(1 - e^{-A_2 \cdot x})$$

where

$$Y = \text{total neutrons } (10^{18}n)$$

$$x = \text{total incident deuterons } (10^{23}d^+)$$

and A_1 and A_2 are constants determined by the fitting procedure. A_1 and A_2 have units of $10^{18}n$ and $10^{24}/d^+$, respectively. The agreement between data and the fitted values is quite good, generally being within 2%.

Having determined A_1 and A_2 from the fitting procedure, we note that

$$dy/dx = (A_1 - A_2) e^{-A_2 \cdot x}$$

From this we observe that at $x = 0$, $(dy/dx)_{x=0}$ gives the initial yield of the target (n/d^+) . On a semi-log plot, the

Figure 2. A schematic drawing of the rotating target assembly. The shaded parts rotate at ~ 4000 rpm during operation.

Figure 3. Total neutron production vs total incident deuterons for representative 23- and 50-cm targets including both the data and fitted points. The data points represent only a subset of the data used in the fitting procedure.

slope gives an indication of the tritium depletion rate of the target. This illustrates more clearly differences in neutron production rate. These are shown in Fig. 4 for the same targets as given in Fig. 3. Also shown in Fig. 4 are the results for a target which was inadvertently exposed to air after partial usage. This exhibits a very large depletion rate of tritium.

Table 1 gives the average values for A_1 , A_2 and $(dy/dx)_{x=0}$ for fifty-eight 23- and five 50-cm targets with the average deviation shown in parentheses. It does not include all targets used at RTNS-II but only those with total number of incident deuterons $> 2.7 \times 10^{22}$. In addition, for some of the first targets used, the data collection system was not in complete operation. Also given in Table 1 are "best" and "worst" values for A_2 and $(dy/dx)_{x=0}$. The difference in the average values for A_1 and A_2 for 23- and 50-cm targets is due in large part, but not totally, to the difference in surface area of the titanium tritide. Table 1 also gives the average total incident number of deuterons for each size target.

The range of a 360-keV deuteron in the titanium tritide layer is $\sim 2 \mu\text{m}$ as compared to the $10 \mu\text{m}$ thickness. The depth-profiling measurements⁵ show an expected large depletion of tritium in the deuteron range. However, there is much less depletion beyond the deuteron range. This is illustrated in Fig. 5. Figure 5a shows the tritium depth profile for a virtually unused portion of a RTNS-II target. This exhibits a characteristic flat top distribution. In Fig. 5b, the tritium distribution is given for a used portion of a target and shows the large depletion

Figure 4. Neutron production rates vs number of incident deuterons for the same targets as shown in Fig. 3. Also included is the neutron production rate for a target with a high depletion rate (see text). These curves are generated using the A_1 and A_2 values determined by the fitting procedure. The arrows indicate the total number of deuterons incident on each target.

TABLE 1: PARAMETERS FOR RTNS-II TARGETS

	50-cm	23-cm
Ave. A_1 (1)	28.0 (4.6)	3.7 (1.0)
Ave. A_2 (2)	1.5 (0.3)	10.0 (3.2)
Ave. $(dy/dx)_{x=0}$ (3)	3.9 (0.2)	3.3 (0.4)
Best A_2	1.0	4.4
Worst A_2	2.1	29.1
Best $(dy/dx)_{x=0}$	4.2	4.1
Worst $(dy/dx)_{x=0}$	3.7	1.6
Ave. total d^+ (4)	3.7	1.0

(1) Units (10^{18} n)

(2) Units ($10^{-24} / \text{d}^+$)

(3) Units (10^{-5} n/d^+)

(4) Units (10^{23} d^+)

Figure 5. The ratio of tritium to titanium atoms (n_T/n_{Ti}) vs depth in the titanium tritide layer. Data are taken from Ref. 5.

within the deuteron range. It also shows a reasonable amount of tritium beyond the deuteron range. Previous work⁸ has shown that tritium targets can be regenerated by heating at 200°C for 0.5 hr. Presumably this causes the tritium to diffuse to the reaction region. The possibility

exists, therefore, of increasing total neutron yield for RTNS-II targets by periodic heat treatment. The exact time-temperature cycles needed can be determined using the depth-profiling technique. This possibility is being investigated.

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