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ROTATING NEUTRON TARGET SYSTEM*

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Summary

A D-T neutron target system with a 30- to 40-hour half-life has been developed that yields 1 to 2 × 10^{12} neutrons per sec. This system uses a target that is rotating at 1100 rpm. The good success of this system indicates that this type of target system may be capable of being used at much higher beam power levels. Calculations indicate that a beam power of 100 kW and a beam density of 10 kW/cm^2 can be handled with a front target temperature of less than 250°C.

Introduction

A 6-inch rotating D-T neutron target system has been produced that yields initially 10^{12} neutrons per second, with a half-life of 30 to 40 hours. This target system has proved that high-speed rotating targets can take beam densities of (1 to 2 kW/cm^2) and still have long usable life. The success of this target system raised the question of how much beam a rotating target system can be designed for. With larger targets, higher rotational speed and better cooling, the target can be designed to take 5 to 10 kW/cm^2 beam density or higher. These high-beam densities can be used because the cooling mechanism is different from slow rotating target systems. The linear speed of the target at the beam spot is so high that all the beam energy is taken up by the heat capacity of the target backing. The heat is then transferred to cooling water as the target is rotating out of the beam spot. In effect, the beam power is spread over a large area; this area can then be cooled easily. D-T targets of this type can be designed to take 50-100 kW on a 2-in.-diam spot size.

Description of Present System

This Laboratory recently purchased a 500-keV accelerator to produce 9 mA of H^+, $_2H^+$, H^2 and $_2H^{2+}$ beam for various experimental purposes. Neutron production was one of the uses that this machine was to be used for. This meant that a D-T target system had to be built that would handle up to 10 mA of beam at 300-500 keV. Other desirable characteristics for a target system would be a small beam spot size, high neutron yield, long life, low neutron attenuating mass, and the ability to activate samples close to the beam spot. All of these characteristics have been achieved by the target system to be described.

The target system layout is shown in Fig. 1. (This is the second version of our target system. The first system was very similar except that a 1-inch collimator was used at "old collimator position" in Fig. 1 and no bias rings were used to improve target current measurements.)

The beam is collimated by a long tapered collimator to a size between 0.5- to 1-inch diameter, depending on experimental requirements. The beam bombards a 6-inch diameter Ti H^3 target turning at 1100 rpm. The radius of Ti H^3 on the target is between 1.25 to 2.75 inches; this allows two or three bands to use on the target before the target is used up. The target is cooled by water running or sprayed on the back of the target. The water is collected by a frame and sheet plastic water catch cage.

The neutron yield and usable life of the target on this system has been good. Because of running time limitations, only two Ti H^3 targets and one Ti H^2 target have been run.

Figure 2 shows the neutron flux versus the product of mA and running time for the second target that was run here. The average beam level was 6 mA; the maximum level used was 9 mA. The initial yield of the target was 2 × 10^{12} neutrons/sec for an 8-mA beam; the half-life of the target is 400 mA-hr. The neutron yield was measured to 10% by a neutron recoil telescope; the beam current was calorimetrically measured to 10% also.

The first Ti H^3 target ran gave an initial yield of 1.4 × 10^{12} neutrons/sec for an estimated beam of 6 mA. The beam current was taken off the target drum, and no biasing was used. The beam currents that were obtained were suspected of being low by as much as a factor of 2 some of the time. After an estimated beam-hour running time of 230 mA-hr, the beam current was measured calorimetrically. The target current measurements were found to be low by up to a factor of 3, depending on accelerator condition, vacuum conditions, etc. This target ran another 170 mA-hr after the beam current was correctly measured. The neutron flux that could be obtained after 400 mA-hr was 7.6 × 10^{11} neutrons/sec for a beam current measured calorimetrically of 8.25 mA at

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500 keV. This gives roughly a target half-life of 400 mA-hr for this target also.

The collimator used on the Ti H^3 runs was located 22 inches from the target. This collimator did not locate the beam position on the target as it was originally expected. It was discovered that the beam optics of the machine are such that any target radius from 1 inch to 2.5 inches could be hit; this covers all the Ti H^3 surface. Also, the machine is tuned on neutron yield that is given by a large plastic scintillator and photo multiplier that are dc-coupled to a microammeter. These two conditions insured, over a long period of use, that the entire target would be used up. This is the reason the neutron yield versus mA-hr plot for the second target applies to the whole target surface. This also applies to a lesser extent to the first target that was run.

Targets

Two targets have been designed for this system. One is a spherical target shown in Fig. 3. designed for activation work very close to the beam spot and experiments in the forward direction. The other one is a conical shaped one shown in Fig. 4, designed for experiments at side and back angles.

The targets fabricated at this laboratory are made on a backing of 0.010-inch Cu, plated on 0.032-inch mild steel; the Cu is needed on the front surface for its high heat conductivity and the steel is needed for its structural strength, particularly in the spherical targets. All-Cu targets could be used if the Cu would end up in a hardened condition after the targets were tritiated. In tritiating the targets, they are heated above the annealing temperature of Cu and become dead soft. The tritium is absorbed into Ti of 4 to 5 mg/cm^2 thickness, the Ti being vapor plated directly onto the Cu. This is a thick target for a 500-keV beam, thus the resulting neutron spectrum will be characteristic of a "thick target."

We have since learned that Cu alloyed with a small percentage of Zr has several properties that will eliminate the need for the steel backing. This Cu alloy has an annealing temperature of 500 to 600°C, which is above the temperature used in tritiating the targets. The heat conductivity is about 80% or higher of the heat conductivity of pure Cu, and the yield strength is about that of mild steel. In the future, our target will probably be made of this material.

Neutron Attenuation in Target System

The amount of mass that neutrons must go through to leave the target is from 50 to 100 mils of matter.

This material consists of the following:

1. 42 mils of target or 20 mils of the target drum.
2. Estimated water thickness of 32 mils, depending on direction.
3. 5 to 10 mils of Mylar of the water-catch cage.

Neutron Sample Distances from Target

The distance of neutron samples from the beam spot can be less than 100 mils; in the forward direction, with the spherical target, samples can be put almost against the target back. Figure 1 shows a high neutron sample holder that places sample within 100 mils of the beam spot. At other directions, samples can be placed within 1 to 5 inches of the beam spot. The water-catch cage can be modified so that samples can be placed inside its area.

High-Speed Rotating Seal

The rotating seal allows the target to be rotated at 1100 rpm; it has a 2.5-inch opening for the beam to pass through. The layout is shown in Fig. 5. The actual sealing is done by two Rulon (a loaded Teflon) sealing rings running against a steel insert. A vacuum pumpout is used to maintain less than 1000 microns pressure between the sealing surfaces. The pressure that holds the sealing surfaces together is the air atmospheric pressure; this provides a low 15 psi seal surface pressure loading. "O" rings in the sealing rings provides vacuum seals and allows the sealing rings to move to take up for wear. Two steel dowel pins prevent the sealing rings from turning at the "O" ring locations.

The leak rate of the seal is quite low; it is probably less than the outgassing of the remainder of the target system. On our present system, the rotating target is located 40 feet from the pumping station; the beam pipe is 4 inches in diameter. The pressure measured by an ion gauge at the seal is 5×10^{-5} mm of Hg with the beam off. The vacuum pressure is not sensitive to between-seal pressure until it rises above 1000 microns; the usual pressure is 100 to 200 microns. The between-seal vacuum pump is a Kinney KC 8 pump.

The sealing ring material is a commercially available, loaded Teflon called "Rulon A." Only one other type of sealing ring was tried, a 30% by weight bronze loaded Teflon; it had a high friction drag and failed within 16 hours. Rulon A sealing rings of somewhat different design has run for 1000 hours at 1100 rpm with 0.050-inch wear. It maintained a good vacuum during this test and had not failed when the test was terminated. Other running indicates that 500 to 1000 hours can be expected out of this seal. The design shown is expected to have a longer life than the seal tested because the seal surface pressure is lower.

The friction heating generated by the seal is estimated to be 50 to 100 watts; a water passage running next to the steel insert provides good seal cooling. It is believed that lower seal temperature will help increase seal life expectancy.

The bearing used in this seal assembly was commercially manufactured, and is ≈ 6.5 inches diameter by 0.375 inch square. The bearing life is good if it is properly lubricated.

Beam Collimation

The beam position in the new target system will be well-defined. A long tapered collimator has been designed that has low mass and good cooling, and it is easy to fabricate in various sizes. A tapered mandrel has been machined to shape the collimator; 0.25-inch Cu tubing is wound on this mandrel to form the collimator; then sheet stainless steel is hard-soldered to the outside to make a good stiff assembly. Different size collimators can be made by winding the tubing to a smaller size on the mandrel. The distance of the end of the collimator to the target can be adjusted to any desired distance.

Target Cooling

The target cooling at the beam spot of these high-speed rotating targets is entirely done by the heat capacity of the Cu backing. The heat is then conducted on back through the target backing to the water on the target. In the present system, 1.6 gal/min of water is sprayed by a lawn-type sprinkler head onto the back of the target; this has been adequate for our present operating condition, but it is far from the best. A better system would have a thin metal stationary shroud that formed a thin sheet of water at the back of the target. The moving target would create considerable shear in the water between the target and shroud, and thus greatly improve heat transfer.

The good success of this target system in taking 4 kW in a few Cm^2 and giving long target life raises the question of how much beam a rotating target system can handle. An attempt will be made to show that a target system of this type can handle much higher levels.

Calculations of the Temperature Rise for a 100-kW Target

The temperature rise in a hypothetical rotating target has been calculated; this calculation shows roughly what are the cooling limits of these systems. The temperature rise of this target system can be estimated by use of a simple numerical method; the problem has been treated conservatively. The peak temperatures were found according to the rate of power deposition appropriate to the region in question. Temperature drops were found for the Ti H^3, the Cu backing, and the target backing to the water coolant. The water temperature rise was also taken into account.

The hypothetical target system to be discussed has the following characteristics:

Beam spot diameter – 5 cm
Target beam spot radius – 15 cm
Target thickness – 0.150 cm
Target material – 0.050 cm H.C. Cu on 0.100-cm Z alloyed Cu
Ti H^3 thickness – 0.5×10^{-4} cm
Rotation speed – 35 rps

The beam to be considered has a total power of 100 kW, and is roughly 2 inches in diameter; the maximum power density to be considered is 10 kW/cm^2. Only the worst case for power loading will be considered; this will be a 1-cm-wide band going through the center of the beam spot. It will be assumed to intercept 10 kW for 4-cm distance or 40 kW; these conditions can probably be achieved by a reasonable machine.

The following facts should be pointed out about this hypothetical target system:

1. The linear speed of the target at the beam spot is 100 ft/sec.
2. A given spot on the target sees the beam for only 1.2×10^{-3} sec.
3. A 1-cm^2 area passing through the center of the beam spot sees only 12.1 W-sec per traversal.
4. This 12.1 W-sec is removed in 30×10^{-3} sec by the water. That is, the average power density for transferring the beam power to the cooling water is only 400 W/cm^2.
5. The high linear speed of the target facilitates heat transfer to the cooling water.

The thickness of Ti H^3 considered for these calculations is 5×10^{-4} cm. This is adequate to stop a 300- to 500-keV beam. The Ti H^3 should be just thick enough to stop the beam; this keeps the temperature drop across the Ti H^3 low. The temperature gradient solved for assumes a steady-state entry of 10 kW/cm^2 distributed uniformly through the Ti H^3. The Ti H^3 thermal conductivity used is 0.03 cal/cm °C sec.[1] The heat rise across Ti H^3 of 5×10^{-4}cm thickness is less than 20°C while traversing the beam spot.

The biggest heat rise in this system is the heating of the beam side of the copper backing. During the heating impulse, the copper is sufficiently thick to effectively store the heat pulse. With a 100°C heat rise of the front surface, the first two mils of copper contain 13% of the heat pulse immediately after beam spot traversal. The maximum rise across the copper backing is calculated to be approximately 115°C.

The high velocity of the target with respect to the cooling water shroud, 0.032 inch from the target, gives very high heat-transfer rates. The heat transfer rates for water moving at 50 ft/sec between surfaces 32 mils apart is roughly 50 W/°C-in^2.[2,3] This should be roughly comparable to this target system where the target-to-shroud velocity is 100 ft/sec. If the water shroud had radial grooves that increase the shear in the water, heat transfer would be greatly increased. Heat transfer rates of 100 to 150 W/in^2-°C are probably easily achievable. For these target calculations, 50 W/in^2-°C or 8 W/cm^2-°C were used. This coefficient of heat transfer results in an average temperature difference of 50°C between the copper backing and the cooling water.

The Maximum Target Temperature

The maximum target temperature is the sum of all of the temperature rises and gradients. These temperatures are:

40°C	Cooling output H_2O temp
50°C	Temp between H_2O and target back
20°C	Temp gradient across Ti H^3
115°C	Temp rise of front Cu surface
225°C	Maximum temp at front surface of target

This temperature at the front surface of the target should be quite reasonable, especially since the target surface is only near this temperature for roughly 2% of the time. The average surface temperature would be under 150 °C. It may be possible to use twice as high a beam level if an Er target is used, providing the conductivity of Er H^3_2 is as good as Ti H^3.

These low target temperatures indicate that beams of 100 kW and 2 inches in diameter can be handled by Ti H^3, and probably would have a life limited by the displacement of H^3 by H^2. The neutron yield per mA of this target should be that of smaller targets.

Structural fatigue of the Ti H^3 due to the temperature cycling may be a problem with these targets. In our present system, no sign of this problem has developed, but our running time has been limited. No consideration has been given to this problem, if it is a problem.

A possible target design to handle these beam levels is shown in Fig. 6. It is to be noted that this design uses a rotating seal of the same size as has been run at this Laboratory. The minimum diameter through the seal operating at the angle shown in Fig. 6 is about 2.12 inches.

References

[1] Dr. Henry Otsuki, private communication.
[2] Clyde E. Taylor and James F. Steinhaus, "High Flux Boiling Heat Transfer From a Flat Plate," UCRL-5415.
[3] Private communication.

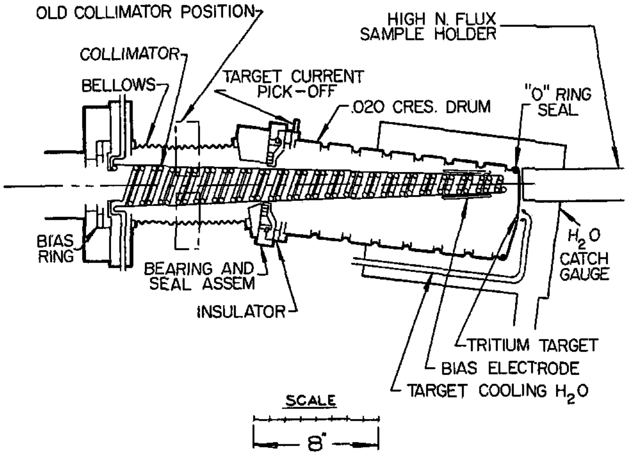

Fig. 1. Target System Layout.

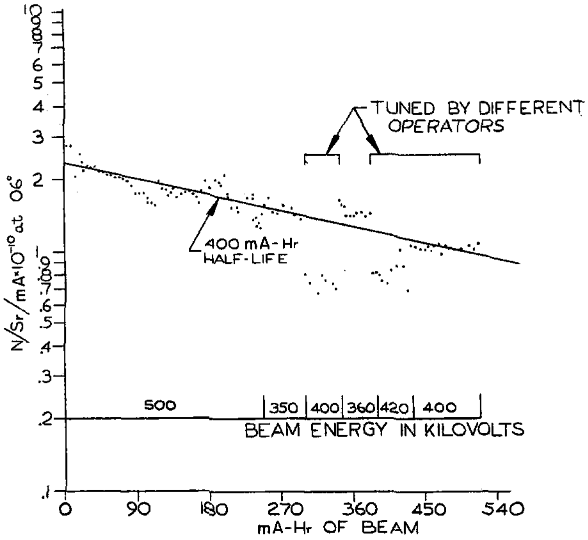

Fig. 2. Neutron yield versus mA-hr of beam.

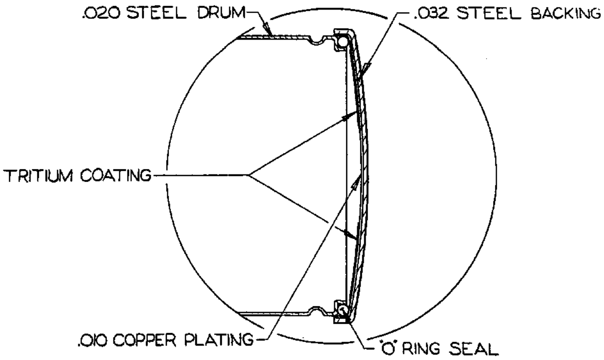

Fig. 3. Spherical target.

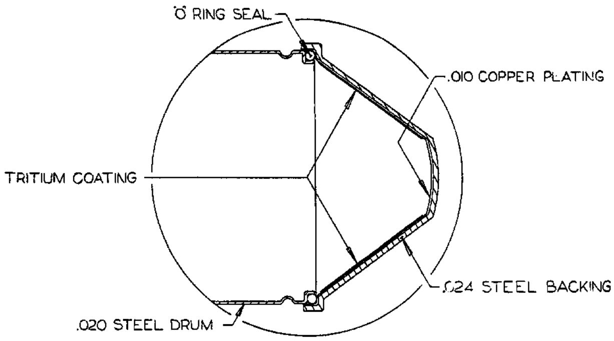

Fig. 4. Conical target.

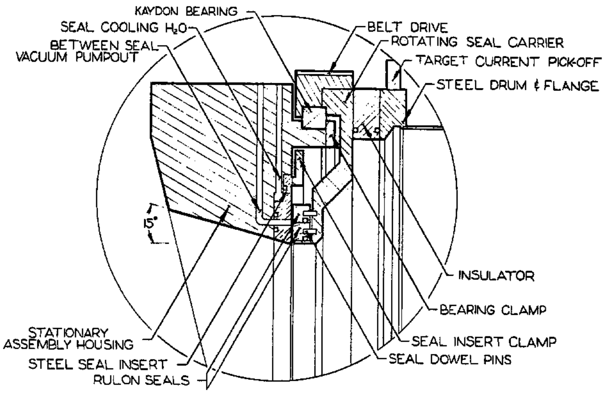

Fig. 5. Seal layout.

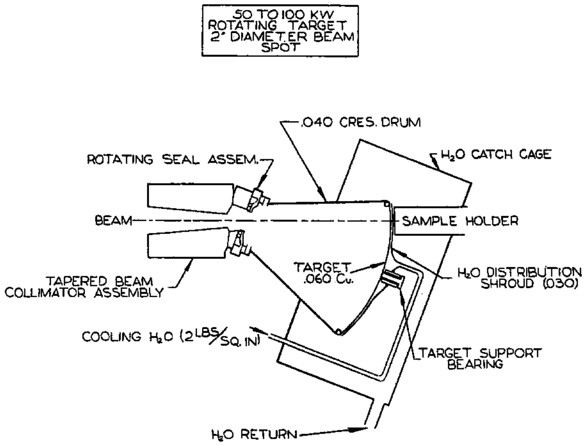

Fig. 6. 50- to 100-kW target layout.