Design and Use of 14-MeV Neutron Sources

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Abstract: The rotating target neutron sources at Lawrence Livermore National Laboratory are effectively intense point sources of 14-MeV neutrons. So far the highest source strength that has been achieved is 2.2×10^{13} neutrons/sec. The sources are used primarily for radiation damage studies, but other types of neutron physics experiments have also been performed.

1. Introduction

For research in pure and applied nuclear physics very intense point sources of monoenergetic fast neutrons are important tools. The most suitable source reaction is the interaction of deuterons with tritons. At the desired source strengths many kW of beam power have to be dissipated in the target so that target cooling becomes a major problem. At Lawrence Livermore National Laboratory intense 14-MeV neutron sources have been in operation since 1967. Deuteron beams of energy between 350 and 400 keV are incident on rotating targets coated with titanium tritide. These neutron sources have become known as RTNS for Rotating Target Neutron Sources.

2. RTNS I

The first source[1,2) that was constructed used originally 8 mA of 400-keV deuterons to bombard a target 14 cm o.d. rotating at 1100 rpm. A 4 mg/cm^2 Ti layer was vapor plated onto 1-mm thick Cu alloy backing. The target formed the end of the accelerator vacuum system. A stationary stainless steel sheet was placed parallel to the outside of the target with a 0.3-mm gap. Water was injected at the center of the steel sheet. The large velocity gradient between the rotating target and the stationary water spreader produced turbulent flow and effective cooling. With this system a source strength of 2×10^{12} neutrons/sec was achieved.

In order to permit operation at higher source strength the 14-cm target was replaced by a 22-cm target$^{3)}$. A new high-voltage power supply permitted the deuteron beam to be increased to 16 mA. In 1973 a source strength of 4×10^{12}/sec was achieved. The source strength decreased only 10-20% in 50 hours if the beam spot was kept above 1 cm diameter$^{4)}$.

3. RTNS II

In 1976 the decision was made to attempt to increase the neutron source strength by a factor of ten. Two new sources, RTNS II, were constructed. These facilities were designed to have 150 mA of deuteron beam, i.e., ten times that used in RTNS I. The instantaneous beam power deposited in the metal tritide target would be 250 MW/cm^3. Without thermal conduction the tritide would be heated at a rate of ~ 100 MK/s. In order to limit the temperature rise at the surface to 200K the target diameter had to be increased to 50 cm and the rotation speed to 5000 rpm. For these larger targets and higher speeds the viscous drag caused by external cooling would be excessive. Hence the cooling water is placed inside a sandwich target backing that contains convoluted channels to produce turbulent flow. Chilled cooling water enters and leaves the target through a rotating hub at the center of the target at a rate of about 10 L/min.

An air cushion prevents the rotating target from touching the stationary accelerator vacuum system. Leakage of air into the vacuum system is kept small by a differentially pumped seal. A matched pair of ball bearings holds the load of the rotating target. The rotor is driven by an air jet that hits the blades of a turbine wheel.

4. Present Status of RTNS II

The first unit of RTNS II began operation in November 1978. The second unit is scheduled to be in operation in the summer of 1983. So far deuteron beams have been limited to 80 mA because of limitations of the ion source power supplies and the deuteron energy has been limited to 370 keV by acceleration tube breakdown. The maximum source strength achieved so far has been

2.2×10^{13} neutrons/sec. During 1981 the time-averaged source strength was 1.1×10^{13}/sec, and the source was available 60 hours/week (out of a scheduled 80 hours). After a week's operation which ends Friday night, the target is changed on Monday morning. Personnel participating in a target change typically receive a body dose of 0.2 mGy.

5. Radiation Damage Experiments

Because of the concern about radiation damage caused by fusion neutrons to the structural materials of a fusion reactor, especially to the first wall, an experimental program to study fusion materials began on RTNS I in 1972^7). Since the completion of RTNS II most of the operation of the facility has been devoted to irradiations in support of the U.S. fusion reactor materials program. Recently an increasing fraction of the work is being carried out by Japanese scientists under the auspices of the Japanese Ministry of Education. When the second unit of RTNS begins operations, it is expected to be devoted entirely to experiments performed under Japanese auspices.

So far most measurements have attempted to gain an understanding of defect production and of microstructure damage. The effects of the neutron irradiations have been studied by measuring resistivity at low temperature, by transmission electron microscopy, or by observing changes in mechanical properties. In most experiments the radiation-induced effects were studied after irradiation. However, a few experiments have involved measurements during irradiation, for example creep measurements.

6. Nuclear Physics Experiments

RTNS I has been used extensively to study the interaction of 14-MeV neutrons with nuclei. In some of the experiments the neutron source was pulsed. In a series of experiments with a pulsed source, known as the "Pulsed Sphere" experiments^8), a 1.5-ns burst of neutrons was produced at the center of a sphere of the material to be studied. The spectrum of neutrons emanating from the sphere was measured by observing the arrival times of the neutrons at a detector 10 m from the neutron source. These experiments were important because they showed that the secondary neutrons could not be described in terms of an evaporation spectrum, but clearly showed the contributions of reactions in which the neutrons did not form a compound system.

The high intensity of the source permits the measurement of small cross sections of reactions which are of particular importance in producing radiation damage in fusion reactor materials, especially cross sections for helium production. Two approaches have been used for measuring the cross sections for helium production: the collection of the He gas that is produced in a solid sample$^{9)}$ and the observation of charged particles emitted from a thin foil. For the latter experiments a magnetic lens system$^{10)}$ focused the charged particles onto a thin Si detector in coincidence with a thick Si detector so that the charged particles could be identified and their energy could be measured. At each reaction angle the energy distributions were determined at nine different magnet settings to cover the entire charged-particle energy spectrum. Measurements at several angles were combined to yield energy distributions from which reaction cross sections could be deduced. Absolute cross sections were obtained by normalization to the neutron-proton or neutron-deuteron scattering cross section$^{11)}$.

Table I summarizes the data on nuclides of A between 27 and 96, and compares the results of charged-particle production measurements with helium production measurements.

Additional measurements have been performed on Be, C, N, and O, but the data analysis is incomplete.

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TABLE I

Cross Sections for 15-MeV Neutrons (mb)

Target	Proton Emission	Deuteron Emission	Alpha Emission	Helium Production
^{27}Al	400±60	19±8	121±25	144±7
^{46}Ti	670±90	9±4	98±18	
^{48}Ti	85±16	7±3	28±6	
^{51}V	91±14	7±3	17±3	18.6±1.3
^{50}Cr	830±100	13±4	94±15	
^{52}Cr	182±25	8±3	38±6	
^{54}Fe	900±110	10±4	80±13	91±7
^{56}Fe	190±20	8±3	41±7	46±3
^{58}Ni	1000±120	14±6	106±17	121±8
^{60}Ni	330±40	11±4	76±12	80±6
^{63}Cu	320±50	9±4	56±10	65±5
^{65}Cu	44±5	10±4	14±3	17±1
^{89}Y	98±12	10±3	8±2	
^{90}Zr	166±20	10±3	15±3	
^{93}Nb	51±8	8±3	14±3	14±1
^{92}Mo	967±116	22±7	36±7	31±2
^{94}Mo	124±15	9±3	28±6	22±2
^{95}Mo	84±10	8±3	24±5	17±1
^{96}Mo	64±8	6±2	18±4	12±1