3

CONF-781113--20

MASTER

PREPRINT UCRL- 81531

# Lawrence Livermore Laboratory

# Research Applications of the Livermore RTNS-II Neutron Sources

Jay C. Davis

November 1, 1978

This paper was prepared for submission to
Small Accelerator Conference, Denton, Texas Nov. 6,7,8, 1978

# RESEARCH APPLICATIONS OF THE LIVERMORE RTNS-II NEUTRON SOURCES[*]

J. C. Davis

University of California, Lawrence Livermore Laboratory
Livermore, California 94550

## Introduction

The Lawrence Livermore Laboratory has completed construction of the Rotating Target Neutron Source -II (RTNS-II) Facility. These sources, built and operated for the Office of Fusion Energy of the Department of Energy, will be operated by LLL as a national facility for the study of materials damage processes induced by 14-MeV neutrons. Design strength of the sources is $4 \times 10^{13}$ n/s with a maximum flux of $1 \times 10^{13}$ n/cm$^2$s. The 400 keV, 150 mA $D^+$ accelerators and 5000 rpm titanium-tritide target assemblies were built using experience gained with LLL's RTNS-I neutron source[1]. The RTNS-I source, producing $6 \times 10^{12}$ n/s, is currently the most intense 14-MeV source available. RTNS-I has been used for fusion reactor materials studies for the past six years. The experimental program for the new sources will be oriented toward fundamental measurements of high energy neutron-induced effects. The data produced will be used to develop models of damage processes to help guide materials selection for future fusion reactors.

## Fusion Reactor Materials Problems

For any of the presently proposed fusion reactor concepts (either magnetic or inertial confinement), the 14-MeV neutron flux incident upon the inner wall of the reactor vessel will be of the order of $10^{14}$ n/cm$^2$s. Although this flux is much lower than that typical of fission power reactors ($1\text{-}3 \times 10^{15}$ n/cm$^2$s), the average energy of fission reactor neutrons is so much lower (<1 MeV even for fast breeders) that the damage resulting from 14-MeV neutron-induced events may be significantly greater. This possibility results from the greater energy of nuclear recoils from collisions with 14-MeV neutrons and from the difference in ratio of nuclear transmutations to nuclear recoils in the two cases. For these reasons, the prediction of materials performance in fusion reactors from the large amount of data available from fission reactors cannot be confidently made.

Confidence in the lifetime of the first wall of the reactor is of both engineering and economic importance because of the amount of material required. The power density of a magnetically confined plasma is so low that the wall nearest the plasma must have an area of 1000's of square meters for a reactor of output in the 500 MWe to 1 GWe range. The initial capital cost of this wall and the difficulty of replacement of it once activated make the economic penalty for short lifetimes prohibitive. Conceptual designs of reactors done to date suggest that the wall should last for at least two years (equivalent to a fluence of $10^{22}$ n/cm$^2$) if fusion is to be economically competitive.

In addition to the first wall, components somewhat shielded from the primary neutron flux may suffer neutron damage. Superconducting magnets, neutral beam injectors or rf heating ports, insulators on divertors, and diagnostic and control devices are all examples of reactor systems which might suffer unacceptable damage at neutron fluences below those experienced by the reactor first wall. Damage to the final optics of laser drivers for inertial confinement fusion is also of concern.

Neutrons produce damage in materials in several different ways. The energetic atoms recoiling from collisions with neutrons produce interstitials and vacancies in material lattices. The hydrogen and helium produced by (n,p) and (n,α) reactions on latticd material can interact with other crystal defects and may even collect in gas bubbles. Rates of gas production and configuration of defects in the damage cascade depend on incident neutron energy. Subsequent thermal diffusion of gas atoms and point defects may result in aggregation, annihilation or migration to defect sinks. The microstructural changes resulting from these processes can cause unacceptable changes in the gross properties of materials. Bulk properties such as ductility, yield strength, fracture modes, or conductivity may change. Near surfaces, energetic recoil atoms may escape completely (sputtering) or gas bubbles may grow so large that their lids break off (exfoliation). Release of sufficient high-Z impurities into the plasma volume by these processes could cool the plasma enough to quench the thermonuclear burn. Other surface properties such as electrical breakdown strength and gas absorption or release rates could be similarly modified. Investigation of these problems was begun with the RTNS-I source in 1972.

At flux levels below those expected for reactors, neutron damage can pose other problems for the fusion program. In near-term confinement experiments such as the Tokamak Fusion Test Reactor (TFTR) at Princeton and the Mirror Fusion Test Facility (MFTF) at Livermore, the neutron fluxes produced by the T(d,n) and D(d,n) reactions respectively will be sufficiently high that damage to plasma diagnostic devices is likely. As these diagnostic devices must eventually develop into the control circuitry for fusion reactors, they must survive neutron doses typical of reactor conditions.

## RTNS-II Sources

The designs of several neutron sources proposed for fusion materials research and cancer therapy applications have been discussed previously[2]. Details of the design considerations for the RTNS-II sources have also been published[3]. Each RTNS-II source has a 4m x 4m high voltage terminal containing a multi-aperature reflex arc ion source operated at ∿ 20kV above terminal potential and a 90° double focussing magnet to separate the $D^+$ beam from $D_2^+$ and $D_3^+$ components. A solenoid lens is used to focus the 20 keV $D^+$ beam at the entrance to a 25 cm long uniform gradient acceleration column. The high voltage supply for each accelerator is a motor-generator driven 400 kV, 300 mA Cockcroft-Walton. A high voltage terminal and power supply rectifier stack are shown in Figure 1.

After acceleration, the deuteron beam is transported from the accelerator through a 1.25m thick shield wall with a short beam transport system using two quadrupole triplet lenses to the rotating target. The rotating target is contained in a room with concrete walls

2.5m thick. All components within the target room are designed to be withdrawn from the room for service if necessary. The target room beam line is shown in Figure 2; the quad triplet, turbomolecular pumps, and all other components are mounted on a cart which may be removed from the room after breaking quick disconnect vacuum, water and electrical fittings.

The 5000 rpm target and the experimental package for irradiation are placed on a separate cart that can be placed in the target room by a remote handling system. Connections are made automatically to join the target assembly vacuum system to the beam transport cart and to provide utility, signal, and control service to the experiment mounted behind the target. A prototype of the target cart with a 50 cm diameter 5000 rpm target mounted is shown in Figure 3. The carts now in use at RTNS-II can support an experimental package 2m long by 1.5m wide by 2m high with a mass of 2000kg. Up to 30 kW of controllable single phase and three phase power can be delivered to the experiment on the cart.

To achieve the design source strength of $4 \times 10^{13}$ n/s the tritium target must be bombarded by a 150 mA beam of deuterons. For a beam diameter of 1 cm (fwhm of a gaussian distribution), the flux contours in the near field of the source are shown in Figure 4. The highest flux accessible is $\sim 10^{13}$ n/cm$^2$s over a test volume about 1 cm in diameter by 1 mm in depth. This peak flux is a factor of ten below the primary flux at reactor first walls. At the design beam current the target is expected to have a usefull lifetime of $\sim$ 100 hours, limited by thermally driven outgassing of tritium. Over that lifetime the yield drops by $\sim$ 30%.

At present, one of the deuteron accelerators is operational and the second one is nearing completion. Building systems necessary for operation with tritium targets such as tritium scrubbers and closed loop water cooling for targets are operational. The first accelerator has delivered $D^+$ beams of 25-30 mA to targets at energies between 350 keV and 400 keV. It is expected that six months will be necessary to reach the design goal of 150 mA on target.

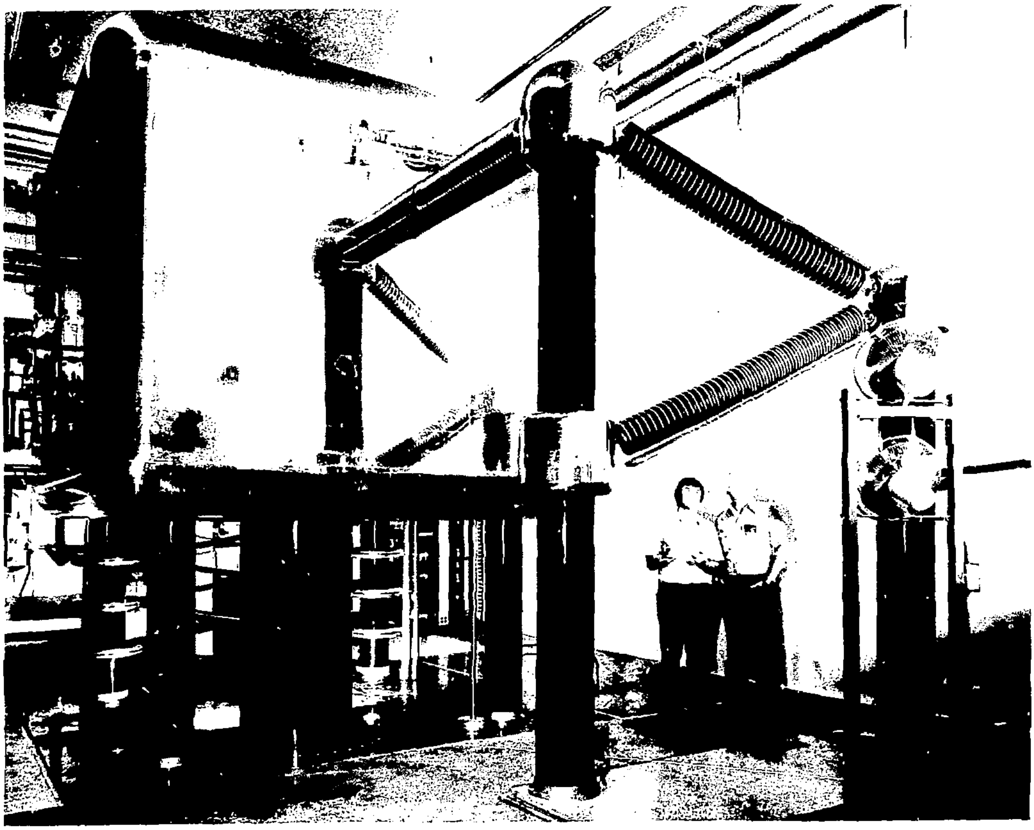

Figure 1 - Main high voltage components of the deuteron accelerator of one of the RTNS-II sources are shown in this photograph. The Cockcroft-Walton rectifier stack is in the right foreground with the high voltage terminal behind it. The large cylinder under the high voltage terminal is the top half of the 75 kW isolation transformer.

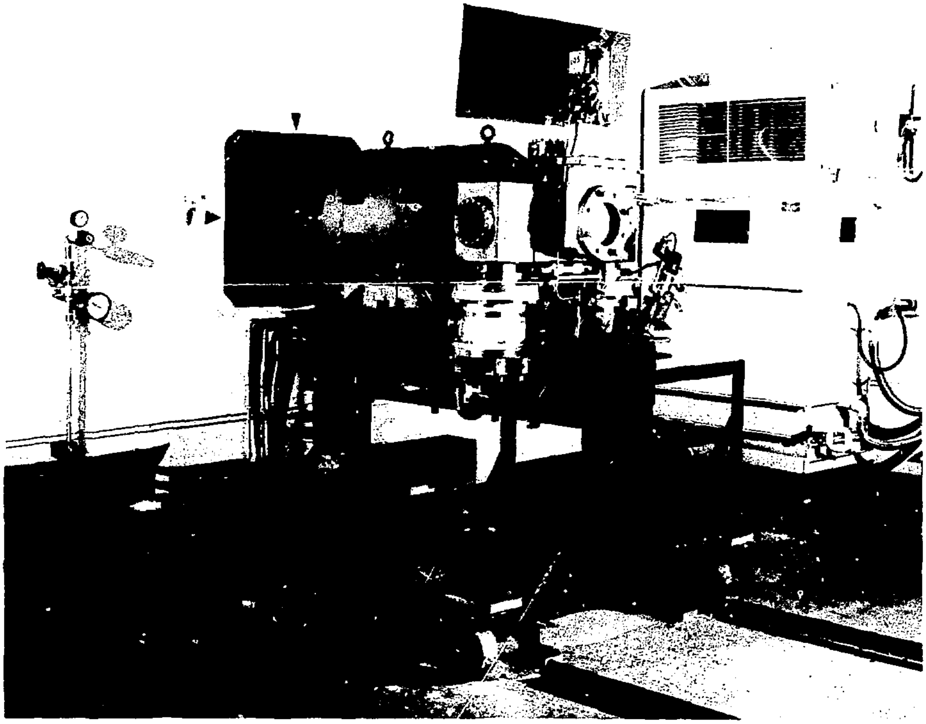

Figure 2 - Beam transport cart in the target room. The rotating target and experiment are mounted on a separate cart that is placed on the rails at lower right and coupled to the end of the beam line.

## Experimental Program

Experiments to be done at the RTNS-II facility fall into three catagories: those which are part of the program of the Materials and Radiation Effects Branch of the Office of Fusion Energy[4] (the funding agency for RTNS-II), experiments which are fusion-related but not part of the above program, and possible experiments not related to the fusion program directly. Examples of each of these will be given. The steps through which a prospective experimenter should go to field an irradiation experiment at RTNS-II are described in the Experimenters' Guide for the facility[5].

## Materials and Radiation Effects Program

The Materials and Radiation Effects Branch of the Office of Fusion Energy is responsible for providing the data base necessary to select materials for demonstration fusion power reactors. Much of the program is directed toward problems of the first wall, where the environment is most severe and fission reactor experience is of least help. Of particular concern is the aggravation of materials problems by the thermal cycling expected in tokamak reactors. A detailed program for use of the RTNS-II facility by this program has been prepared. This program is organized into four areas: alloy development, damage analysis and fundamental studies, plasma-materials interaction, and special purpose materials. The alloy development work is oriented primarily toward development of improved materials for first walls; engineering test for this effort require fluences greater than RTNS-II can deliver. The damage models produced from fundamental studies done with RTNS-II will be used to guide extrapolation to fusion reactor of alloy development results obtained in fission reactors.

Fundamental experiments will examine the temperature dependence of damage processes, irradiating specimens at cryogenic temperatures, room temperature, and elevated temperatures (up to 0.6 of the melting temperature). Damage will be measured by in situ measurements of creep, stress relaxation and resistivity in addition to post-irradiation measurements of mechanical properties, and microscopic examinations such as transmission electron microscopy. Post-irradiation annealing cycles to study defeat stability will also be performed. These experiments require that irradiations be performed at controlled temperatures and that the damage rate, hence neutron flux, be constant.

An experiment which bridges the gap between fundamental studies and special purpose materials is the irradiation of superconductors. Irradiation of NbTi samples[6] at liquid He temperature on the RTNS-I source has shown a decrease in critical current of the superconductor which is consistent with that predicted from fission reactor experiments. With RTNS-II these measurements can be extended to the fluence which the superconductor will get at end of lifetime in a fusion reactor. These measurements are done in situ; the crit-

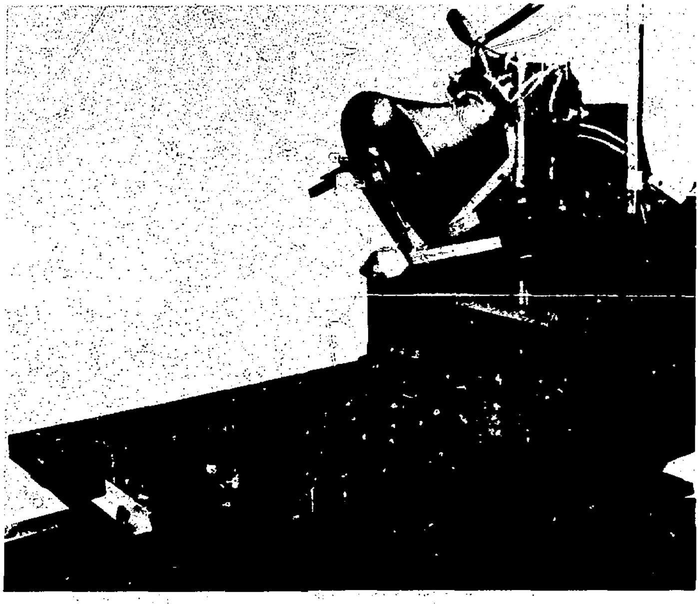

Figure 3 - Target cart containing a prototype of the 50 cm diameter, 5000 rpm target.

ical current of the superconductor is measured repeatedly in place on the neutron source as fluence is accumulated.

Several experiments were done on RTNS-I to measure neutron-induced sputtering from material surfaces[7]. At present, it is thought that ion bombardment of inner surfaces will dominate any neutron-driven processes. However, other neutron effects on surfaces may require investigation. An experiment has been proposed[8] in which samples of the vacuum wall of the TFTR experiment (304 stainless steel) will be irradiated to lifetime fluence ($10^{17}$-$10^{18}$n/cm$^2$) with 14-MeV neutrons and then examined by techniques such as hydrogen isotope profiling to determine whether the gas retention coefficient of the surface has been changed. Gas retention and release from inner surfaces are important to the fusion program both from the standpoint of total tritium inventory on the walls of experiments and reactors and outgassing which could affect neutral beam transport and exchange of cold gas with the hot plasma.

## Fusion-related Experiments

Measurements not funded by the OFE materials program but related to the fusion effort will also be carried out at RTNS-II. The first experiment to be done when neutrons are produced will be the irradiation to end of life fluence of samples of silica[9] of the type selected for optical diagnostic ports on the TFTR experiment at the Princeton Plasma Physics Laboratory. Post-irradiation analysis will determine the modification of refractive index resulting from neutron exposure.

Nuclear cross sections for (n,p) and (n,$\alpha$) reactions have been measured down to charged particle energies of $\sim$1MeV at RTNS-I using a magnetic quadrupole spectrometer and charged particle time-of-flight[10]. These measurements have produced total gas production cross sections where little data was previously available. Funding has been provided by the Division of Basic Energy Sciences to support creation of a nuclear data base for fusion materials work. These experiments will move to RTNS-II

Neutron spectrometers for magnetic fusion experiments are difficult to construct because the long pulse lengths of magnetic devices do not allow one to use time-of-flight techniques to separate neutron energies. Experiments to investigate the spatial and energy resolution possible with small scintillator-collimator combination have been done at RTNS-II. Futher developmental work on neutron diagnostics is planned at RTNS-II.

Fusion experiments which may use the ion beams from the RTNS-II accelerators include tests of direct converters to recover energy from plasma leaking from reactors and from charged particle beams magnetically swept out of neutral injector beam lines. Ion currents are large enough to allow measurement of erosion yields by mass removal techniques. Over the 100 keV to 400 keV range ion currents of 10-100 mA of H$^+$, H$_2^+$, D$^+$, and D$_2^+$ can be delivered to a target. Operation with He$^+$ beams is also possible but has not been investigated.

## Non-fusion Experiments

As the irradiation schedule permits, the neutron sources can be used for work unrelated to the fusion program. Likely experiments are dosimetry development, tissue and small animal irradiations, and collimator studies for neutron cancer therapy. Although the RTNS-II facility was not designed to be suitable for human cancer therapy studies, the equipment built for the project could be adapted for that purpose. Based on experience gained with RTNS-II, a neutron source capable of producing 80 rads/min at a source-to-skin-distance of 125 cm could be built for approximately a million doll-

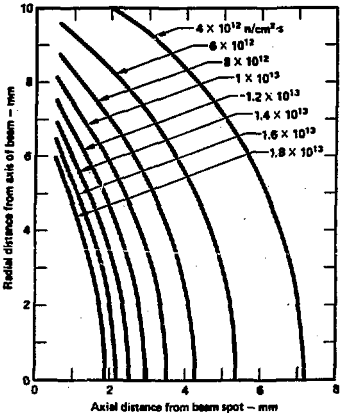

Figure 4 - Flux plot for the region near the target when operating at 4 x $10^{13}$ n/s.

ars exclusive of shielding.

Although the facility is not equipped for nuclear physics research at present, control room space and trunk lines for nuclear electronics have been provided and penetrations for radiochemistry rabit systems are in place.

## Conclusion

The RTNS-II Facility at Livermore is now complete and in final debug operation before production of neutrons begins. The research program of the facility is presently strongly oriented toward providing fundamental information to guide materials selection for fusion reactors. As the schedule and needs of the fusion program change, this emphasis can be expected to change. A variety of applied and basic investigations in radiation damage and effects are possible in addition to the base program.

## References

1. R. A. Van Konynenburg, H. H. Barschall, R. Booth and C. Wong, *Proc. of the Inter. Conf. on Radiation Test Facilities for the CTR Surface and Materials Program*, Argonne, Illinois, ANL/CTR-75-4, 171 (1975)
2. J. C. Davis, *Proc. of the Fourth Conf. on Scientific and Industrial Applications of Small Accelerators*, Denton, Texas, 76CH 1175-9 NPS 454 (1976).
3. R. Booth, et. al., *Nucl. Instr. Meth. 145*, 25 (1977).
4. *RTNS-II Utilization Plan*, Department of Energy Publication DOE/ET-0066, 1978.
5. *Experimenters' Guide: Rotating Target Neutron Source II Facility*, Lawrence Livermore Laboratory Manual M-094, 1978.
6. R. M. Scanlan, "Low Temperature Irradiations of Niobium-Tritanium with 14-MeV Neutrons", UCRL-79418, May 1977.
7. R. Behrisch, et. al., *J. Appl. Physics 218*, 3914 (1978).
8. K. J. Wilson, private communication.
9. W. L. Primak, private communication.
10. R. C. Haight, S. M. Grimes, K. R. Alvar and H. H. Barschall, "Production of Hydrogen, Deuterium and Helium by 15 MeV Neutrons", *Trans. Am. Nucl. Soc.*, Nov. 1978, to be published.

### NOTICE

* "Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore Laboratory under contract number W-7405-ENG-48."