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Materials Testing Capabilities

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Office of Fusion Energy

Westinghouse Hanford Company Richland, Washington

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IFMIF, AN ACCELERATOR-BASED NEUTRON SOURCE FOR FUSION COMPONENTS IRRADIATION TESTING MATERIALS TESTING CAPABILITIES

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ABSTRACT

The International Fusion Materials Irradiation Facility (IFMIF) is proposed as an advanced accelerator-based neutron source for high-flux irradiation testing of large-sized fusion reactor components. The facility would require only small extensions to existing accelerator and target technology originally developed for the Fusion Materials Irradiation Test (FMIT) facility. At the extended facility, neutrons would be produced by a 0.1-A beam of 35-MeV deuterons incident upon a liquid lithium target. The volume available for high-flux ($>10^{15}$ n/cm^2-s) testing in IFMITF would be over a liter, a factor of about three larger than in the FMIT facility. This is because the effective beam current of 35-MeV deuterons on target can be increased by a factor of ten to 1A or more. Such an increase can be accomplished by funnelling beams of deuterium ions from the radio-frequency quadruple into a linear accelerator and by taking advantage of recent developments in accelerator technology. Multiple beams and large total current allow great variety in available testing. For example, multiple simultaneous experiments, and great flexibility in tailoring spatial distributions of flux and spectra can be achieved.

INTRODUCTION

The practicality of fusion power is strongly dependent upon the development of materials and components that have acceptable properties in the severe radiation environments of fusion reactors. Materials research for the fusion program is being conducted at a number of neutron irradiation facilities.[1] All but one of these facilities are fission reactors that have neutron spectra much softer than in fusion reactors. The Rotating Target Neutron Source (RTNS-II) is the major U.S. facility[2] with 14-MeV neutrons from the d,t fusion reaction. However, the volume and fluxes available for testing are quite low (a few cm^3 with less than 10^{13} n/cm^2-s). Currently there is no facility in which high-dose radiation effects produced by fusion neutrons can be studied.

The FMIT facility[3] was designed to provide high fluxes of fusion-like neutrons ($>10^{15}$ n/cm^2-s) with much larger testing volumes and smaller gradients than in RTNS-II. The neutrons would be produced by a 0.17-A beam of 35-MeV deuterons incident upon a liquid lithium target. The neutron spectrum peaks at 14 MeV in the forward direction but is much broader than the d,t spectrum. The average neutron energy varies from about 8 to 12 MeV, depending upon location. It was shown by Doran[4] that interpretation and application of FMIT data would not be compromised by differences between the initial FMIT and d,t spectra.

Because of the advances in accelerator technology and the changing needs of the fusion materials testing program, a study was done to see if the FMIT concept could be extended. The new concept, called IFMIF (International Fusion Materials Irradiation Facility), is briefly described along with its possible applications.

ACCELERATOR CONSIDERATIONS

A detailed description of the accelerator is given in the companion paper.[5] The key feature allowing a large increase in beam current is the acceleration of multiple parallel beams in a common accelerator structure.

The overall layout of the concept of the IFMIF accelerator is shown in Figure 1 for the reference case of two beams. It consists of: 1) two independent ion sources and d.c. accelerators, each of which injects D^+ ions of about 125 KeV into 2) two radio frequency quadruples (RFQ) that focus, bunch, and accelerate each of the beams and injects them into 3) an Alvarez-type drift tube linear accelerator that brings the combined beam to 35 MeV, and finally 4) a system of multiple, quadruple, and bending magnets for directing the beams to one or more target areas.

TARGET AND NEUTRON FIELD CONSIDERATIONS

In the FMIT facility, the single 0.1-A beam would be focused on a liquid lithium target

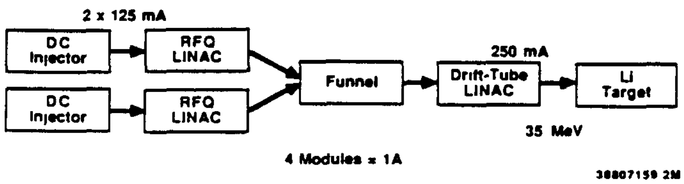

Figure 1. Overall schematic of the reference IFMIT concept.

whose front surface was exposed to accelerator vacuum. The lithium would be a jet, nominally 1.9 cm thick, backed by a 0.16-cm thick steel plate through which the neutrons pass into the irradiation test cell. The backwall was slightly curved so that centrifugal forces would be induced in the flowing lithium. This would pressurize the lithium to prevent boiling when the 3.5 MW of heat is deposited. Limited studies have shown that this concept can be modified for use in IFMIF by changing the width, flow rate, and curvature of the lithium as necessary to carry away additional heat.

In the case of IFMIF, the higher beam current and hence the possible use of multiple beams provide added benefits and flexibility. One can choose to emphasize any one of the following objectives.

First, one could choose to use different beams for simultaneous but separate irradiations in different target areas. This would enhance availability to a number of users.

Second, one could choose to emphasize obtaining the highest peak fluxes and largest testing volumes. The shape of the FMIT beam spot was to be biGaussian with full widths at half maxima of 3 x 1 cm. With an effective 1.0-A beam shaped like the FMIT beam incident upon the FMIT target with higher lithium flow, the volumes would be as shown in Table 1 for IFMIF. There, one sees that there is a significant volume (1000 cm^3) for testing with neutron fluxes greater than 10^{15} n/cm^2-s. This flux corresponds to a wall loading in a fusion reactor of at least 13 MW/m^2. Furthermore, the volume available for testing in fluxes greater than 10^{16} n/cm^2-s is 7.6 cm^3.

Third, one could choose to emphasize obtaining a nearly uniform distribution of flux on the front surface of a large flat component. This situation might correspond to a first wall backed by a blanket or shield in a fusion reactor. To do this, one can aim the multiple beams at different parts of a large lithium target. The magnitude of the highest flux is then reduced, but the gradients on the surface are less. Calculations show that a flux greater

Table 1. Volumes available for testing as a function of minimum neutron flux.

Minimum Flux (n/cm^2s)	Volume Available (cm^3) RTNS-II	FMIT	SUPER-FMIT
10^{16}	--	--	7.6
10^{15}	--	7.6	1.4×10^2
10^{14}	--	4.8×10^2	1.4×10^4
10^{13}	0.01	1.4×10^4	4.5×10^5

than 10^{14} n/cm^2-s can be made uniform to within 20% across the front surface of a flat square that is 30 cm (1 ft) on each side. This was done by aiming four beams at the corners of a 20-cm square on the surface of the lithium target. Each beam has a Gaussian shape with 3 cm full width at half maximum. In the forward direction, the flux decreased by a factor of about 3 in 30 cm. Such a gradient is probably comparable to the radial variation one might expect outward from the first wall in a fusion reactor.

Fourth, one could choose to emphasize obtaining a nearly uniform flux and spectrum throughout a large volume. To do this, it is necessary to use multiple beams that converge on multiple targets. An example was calculated for two beams, each with an effective current of 0.5-A uniformly distributed over a 6-cm diameter and 90° apart. Figure 2 shows the spatial distribution of the neutron flux in the plane of the beam centroids in terms of wall loading. There, 20 MW/m^2 corresponds to about 1.5×10^{15} n/cm^2-s. A cubic object about 12 cm on each side, placed in the region between the targets, would experience a nearly uniform flux and spectrum throughout its volume at a level of about 10 MW/m^2.

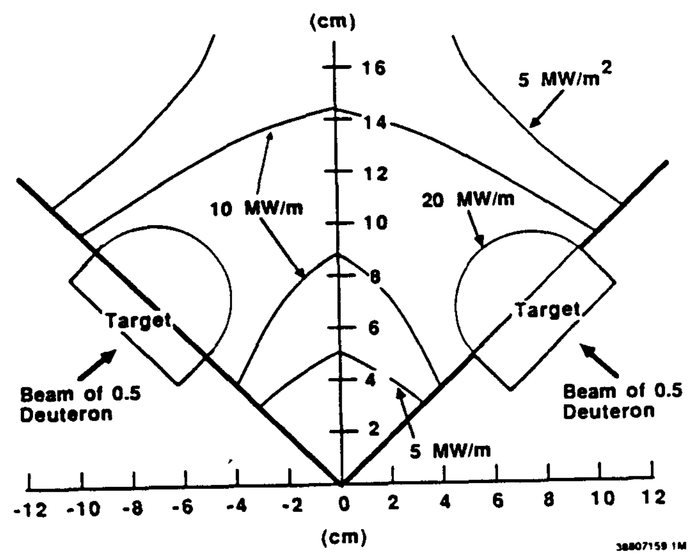

Figure 2. Neutron flux contours in the plane between the converging beams, each with effective currents of 0.1 A.

Fifth, one could choose to emphasize tailoring the spatial distribution of the flux and spectra for a special case. To do this, independently focused multiple beams can be directed to one or more targets, at different angles. The presence of moderators, reflectors, and fission multipliers could also be used to produce a wide variety of neutron environments.

SUMMARY AND CONCLUSIONS

It has been shown that the concept of the IFMIF is a major advance over the FMIT concept that it could be accomplished with only small extensions in technology. By acceleration of multiple beams of deuterium ions (D^+), the effective beam current of 35 MeV deuterons on target can be increased by at least a factor of 5 to 1.0 A, and irradiation volumes increased by a factor of 30. Furthermore, the extension it can be done without a corresponding increase in cost over that of the FMIT facility. This is because newer technology allows a shorter accelerator and multiples of the large, expensive accelerator are not required.

The multiple beams with higher total effective current allow much greater variety in the kinds of testing that can be done than in FMIT. One could choose to 1) use each beam for simultaneous irradiations in different target areas, or 2) emphasize maximal fluxes (greater than 10^{16} n/cm^2-s) and the largest volume with fluxes greater than 10^{15} n/cm^2-s, or 3) emphasize a nearly uniform flux across the front surface of a large flat component, or 4) emphasize a nearly uniform flux and spectrum throughout a large volume, or 5) emphasize tailoring the spatial distribution of flux and spectra for a special case.

Thus, although IFMIF was originally conceived as a facility to allow testing of larger components, it is clear that it could be more of a multi-purpose facility. These would include the needs of basic materials science as well as those of fusion engineering.

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