MULTIPLE USES OF AN UPGRADED FMIT FACILITY

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Abstract

The Fusion Materials Irradiation Test (FMIT) facility was designed to test small samples in fluxes greater than 1 × 10^12 n/cm^2-s of fusion-like neutrons. The source of neutrons would be a 0.1 A beam of 35 MeV deuterons stopped in a liquid lithium jet target. During the present construction deferral, pending an international agreement, an expanded mission is being explored. Multiple CW beams in a common accelerator structure could be used to obtain a total steady-state beam current of about 1 A. This could provide for simultaneous multiple uses in up to four or more target areas as described below. For fusion materials, individual CW beams could be simultaneously directed to two or more FMIT targets, greatly improving availability. Alternately, the multiple beams could be combined for testing of large, multi-liter sized components of fusion reactors. At the same time, research in condensed matter could be pursued using both a steady-state and pulsed source of thermal neutrons in separate target areas. A steady-state flux that is an order of magnitude improvement over current reactor sources can be obtained. Moreover, a pulsed source that is comparable to the most intense pulsed sources nearing completion can also be achieved.

Introduction

Construction of the FMIT facility [1] was postponed by the US-DOE Office of Fusion Energy, however, international support has also been proposed. Progress in this direction awaits the results of an international review, now underway, of the needs for radiation damage studies in fusion materials. In the interim, ways are being explored for upgrading the facility with relatively small technological extrapolations that would greatly expand its usefulness. Multiple uses, where costs can be shared, are desirable.

Facility for Irradiation of Fusion Components

A study is underway in the U.S. fusion program to determine the issues, experiments, and facilities needed for research and development in fusion power technology. One of the needs will be for irradiation testing of fusion reactor components such as sections of a first wall and blanket. These would have much larger volumes than could be accommodated in the original FMIT facility. A recent study [2] showed that the FMIT concept could be extended for such large components by using multiple CW beams in a common accelerator.

The general layout of the concept for a multiple-beam, multiple-use accelerator facility is shown in Figure 1. The fusion part of the facility will be discussed in the following paragraphs. Additions for neutron scattering research are also shown in Figure 1 but will be described later.

In the previous study [2], 0.125 A of 70 MeV D^+ ions was assumed for each of four beams, leading to an effective current of 1.0 A of 35 MeV D^+ ions in the lithium target. The beam from the original 0.1 A FMIT beam to one of the multiple beams would, for the most part, require relatively small changes in the parameters of the injector (e.g., d.c. column voltage), RFQ (e.g., length), and linac (e.g., quadrupole magnet strengths). However, with 70 MeV D^+ ions, the length of the linac would double. Even these changes would be unnecessary by simply using about twice as many beams (e.g., eight) and 35 MeV D^+ ions with 0.125 A per beam.

There is no obvious way to accommodate multiple beams in a vane-type RFQ such as developed for the FMIT. The "zero-mode" concept developed and tested at Frankfurt University [3] is suitable for multiple beams as shown in Figure 2.

To accelerate multiple beams in an Alvarez linear accelerator requires multiple drift tubes and focusing elements within each drift tube shell. Rare-earth permanent magnet quadrupoles are proposed for the multiple beam accelerator, because they are smaller than corresponding electromagnets. Figure 1 shows that four permanent magnet quadrupoles can be accommodated in a drift tube shell smaller than the original FMIT design, and that nine would be reasonable.

Targets and Neutron Fields for Fusion

The use of multiple beams and targets provides added benefits and flexibility. First, one could use each beam for simultaneous irradiations in different target areas to enhance availability. Second, one could tailor the spatial distribution of the flux and spectra for a special case. Specific examples are given in the following paragraphs.

To obtain the highest peak flux and largest testing volumes, the beams could be combined into a single beam spot having about the same size as in the original FMIT facility but 10 times the current. Table 1 shows that increases of a factor of 30 or more can be expected in the volumes available for testing as a function of the minimum flux. Data are also shown for RMTS-II, the only other facility in the U.S. having a fusion neutron spectrum. Note that an FMIT flux of 10^10 n/cm^2-s corresponds to a wall loading in a fusion reactor of 130 MW/m^2.

Alternately, one could obtain a nearly uniform distribution of flux on the front surface of a large flat component. Such a situation might correspond to the first wall of a fusion reactor backed by a blanket or shield. Calculations have shown that a flux greater than 10^14 n/cm^2-s can be made uniform within 20% across the front surface of a flat square, 30 cm 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 had an effective current of 0.25 A and a Gaussian shape with 3 cm full width at half maximum.

Finally, a nearly uniform flux and spectrum throughout a large volume could be obtained. An example was calculated for two beams, each with an effective current of 0.5 A, uniformly distributed over a 6 cm diameter and with directions that are 90° apart. Figure 3 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 1.5×10^12 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.

Upgrade of Facility for Neutron Scattering

One of the strong potential uses of an upgraded FMIT facility is basic and applied research in condensed...
matter using neutron scattering. In a recent review by the U.S. National Research Council, there were high priorities for new facilities to provide a very high flux, steady-state source of thermal neutrons and also an upgraded source of pulsed neutrons. For the steady-state source, an initial flux of \(10^{16} \text{n/cm}^2\text{-s}\) is the goal. That is an order of magnitude greater than in current research reactors. For the pulsed source, a peak thermal flux of \(10^{17} \text{n/cm}^2\text{-s}\) is desired. The current maximum peak flux of about \(4 \times 10^{14} \text{n/cm}^2\text{-s}\) is available at a rate of 30 Hz in the IPNS facility at Argonne National Laboratory. However, a peak flux of \(8 \times 10^{15} \text{n/cm}^2\text{-s}\) at a rate of 50 Hz is expected soon at the SNS facility in the U.K., and a peak flux of \(1.6 \times 10^{16} \text{n/cm}^2\text{-s}\) at a rate of 12 Hz is expected at the WNR/PSR facility at Los Alamos National Laboratory.

Calculations showed that thermalizing the fusion-like neutrons from the PMIT \(\text{Li}(d,xn)\) reaction was not a practical way to obtain a steady-state flux of \(10^{16} \text{n/cm}^2\text{-s}\), even with a fission multiplying booster.

Table 1

<table>
<thead>
<tr>
<th>Minimum Flux (n/cm²-s)</th>
<th>RTNS-II</th>
<th>PMIT</th>
<th>Upgraded PMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>(10^{16})</td>
<td>--</td>
<td>7.6</td>
<td>4.8\times10^2</td>
</tr>
<tr>
<td>(10^{15})</td>
<td>--</td>
<td>4.8\times10^2</td>
<td>1.6\times10^2</td>
</tr>
<tr>
<td>(10^{14})</td>
<td>0.01</td>
<td>1.4\times10^4</td>
<td>4.5\times10^5</td>
</tr>
<tr>
<td>(10^{13})</td>
<td>8.0</td>
<td>4.5\times10^5</td>
<td>1.4\times10^7</td>
</tr>
</tbody>
</table>

It was concluded that the best way to obtain a thermal flux of \(10^{15} \text{n/cm}^2\text{-s}\) is to raise the energy of the beam to the spallation region, exploiting the dramatic increase in the yield of fast neutrons with energy. More electrical power would be required to accelerate protons or deuterons to 300 MeV. However, the efficiency or neutron production per unit power is much greater than if one increased the beam current without a significant change in the beam energy.

Initial calculations showed a maximum flux of \(8.0 \times 10^{15} \text{n/cm}^2\text{-s}\) from thermalizing the fast neutrons produced by protons of only 300 MeV incident upon a Pb-Bi target. The beam current was 0.1 A. It is believed that deuterons of the same energy would produce a thermal flux that is 10 to 20% larger, however calculations are not readily obtainable. The target was 12 cm thick to stop the protons, and surrounded by a beryllium moderator. Improvement to \(10^{16} \text{n/cm}^2\text{-s}\)
would be accomplished by a combination of the following: 1) small increases in the beam energy or current, 2) using deuterons, or 3) using a better moderator. Cooling of the target and moderator and safety issues are much easier for such an accelerator driven source compared to a fission reactor having the same thermal flux.

Figure 4 shows the calculated thermal neutron spectrum compared to what is available in the world's premier neutron scattering reactor at the Institut Laue-Langevin (ILL) in Grenoble, France. It has a maximum thermal flux of about $1.2 \times 10^{15}$ n/cm²-s. The comparisons for a room temperature moderator and a hot moderator show that the upgraded FMIT's steady-state spectrum is 1) about an order of magnitude larger than the ILL room temperature spectrum and 2) enhanced in the epithermal range (>1 eV) compared to the ILL hot source. Epithermal neutrons are particularly useful for types of measurements that are attracting increasing interest.

A pulsed neutron source could also be used in a separate target area. The dashed curve in Figure 4 shows an estimate of the spectrum of the peak flux for the pulsed source of an upgraded FMIT facility. One can see about an order of magnitude increase in the epithermal neutrons compared to the steady-state spectrum from the upgraded FMIT. This enhancement allows measurements that cannot be done with a steady-state source, either from a reactor or an accelerator target.

The pulsed source could be obtained simultaneously with the steady-state source of thermal neutrons in the following manner. A quasi-continuous beam of D₂ ions with 0.1 A average current could be accelerated to 35 MeV in the multiple beam linac. It would then be accelerated to 300 MeV in a booster linac. The beam would have a macrostructure, created in the ion source, with pulses of about 300 ns separated by gaps of about 100 ns. A portion of the main beam, about 150 ns long, could be deflected and sent to a storage ring for compression. This would be done with a kicker magnet at a rate of 60 Hz. The main 300 MeV beam would be relatively undiminished and could be simultaneously used for producing the steady-state source of thermal neutrons.

The deflected portion would be compressed by a factor of about 533 into a pulse with a current of 53.3 A and a width of 300 ns. This is well within the space charge limit of about 1.5 $\times 10^{10}$ deuterons for such a storage ring. The output of the storage ring would go to a Pb-Bi target in the pulsed source area where a peak thermal flux of about $2.4 \times 10^{15}$ n/cm²-s would be produced. The product of the pulse rate times the peak flux is a measure of the data collection rate. On this basis, the pulsed facility proposed here would be quite comparable to those nearing completion at SNS and WNR/PDR.

**Discussion**

For the facility described above, there could be four or more target areas used at the same time. These would include two or more for fusion materials, and two for condensed matter research. There would be great economic benefit from a facility such as described. The total cost of the upgraded facility would, of course, be larger than for the original FMIT facility. However, costs for construction of the multiple beam accelerator could be divided among those who would use it. The fusion materials part could be shared among three or more international partners, thus reducing the U.S. contribution. The capital costs of a steady-state and pulsed source of thermal neutrons could be added incrementally. However, the costs would be much less than if a facility for each had to be entirely financed. Operating crews and other expenses, such as electrical power, could be pro-rated according to the fraction used for each portion of the facility.

The breadth of the scientific missions is one of the most compelling reasons for such a multiple use facility. One could study fusion radiation effects in small specimens or very large components to extremely high fluences. No comparable fusion irradiation facility is likely to come about for some time. The steady-state source of thermal neutrons would exceed current reactor fluxes by an order of magnitude but without the considerable problems of cooling and safety in reactors. Furthermore, the pulsed source would exceed the most intense pulsed source by about an order of magnitude in the peak flux and would be comparable to pulsed sources that are now nearing completion in terms of the pulse rate times the peak flux. These features could help make the upgraded FMIT facility the world's leading facility for research in neutron scattering as well as fusion materials. A project that would combine all the above in the same facility would be truly remarkable.

**References**

