Irradiating Fusion Materials in the Proposed LANL Materials Test Station

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The proposed Materials Test Station [1] at Los Alamos National Laboratory will be used to irradiate fast reactor fuels and materials being developed under the Department of Energy's Advanced Fuel Cycle Initiative. It has sufficient volume to irradiate over four linear meters of test fuel in a neutron flux of up to 1.6×10^{15} n/cm^2/s. A spallation source produces the neutrons that irradiate the fuels and materials. A 1-MW proton beam delivered by the Los Alamos Neutron Science Center's (LANSCE) linear accelerator will drive the spallation source. The neutron energy spectrum is similar to that found in a fast reactor, with the addition of a high-energy tail that extends to 800 MeV. This high-energy tail produces helium in iron through (n,α) reactions, yielding a helium-to-dpa ratio near 10, which matches the ratio expected in a fusion reactor first wall. This fact, combined with other conditions found in the MTS, makes this facility well suited for fusion materials testing.

This white paper outlines the fusion-relevant irradiation capabilities of the MTS, which directly addresses Initiative 7 (I-7), "Materials qualification facility," noted in Section 5.b of the Greenwald report [2]. The Greenwald report states

> "Considering the long time that will be required to complete the detailed engineering design and to construct IFMIF, the question has arisen whether accelerator-based spallation neutron sources can provide insight on the microstructural evolution of materials at fusion-relevant He/dpa levels… Utilization of such a spallation neutron facility might accelerate the development of fusion materials and could reduce or potentially eliminate the need for US participation as a full partner in IFMIF."

The MTS project received Critical Decision 0 (CD-0, Approval of Mission Need) from the DOE Office of Nuclear Energy in November 2007. Critical Decision 1 (Approval of Conceptual Design) is anticipated this year. The Preliminary and Final Design phases are scheduled for completion by 2011, followed by a three-year construction phase. The MTS is expected to start operation in 2014. Total Project Cost (with contingency) is estimated at $79M in 2008 dollars.

Irradiation Environment

Radiation damage parameters such as atomic displacement rates, H and He production rates, primary knock-on (PKA) spectra, and reaction products depend on the energy spectrum of the neutrons inducing damage. Figure 1 shows the neutron spectra for three facilities: the ITER first wall, the International Fusion Materials Irradiation Facility (IFMIF) High Flux Test Module (HFTM), and the MTS fuel irradiation region. For the ITER first wall, 20% of the flux falls between 13 and 15 MeV, whereas for IFMIF and MTS, the fractions are 4% and 0.4%, respectively. Radiation damage parameters are spectrum-integrated quantities, $\langle \phi\sigma \rangle$. Even though there are significant differences in the three spectra, when integrating over neutron energy, radiation damage parameters are nearly the same for all three.

The MTS design allows the insertion of 18 materials test specimen sample cans, each capable of holding hundreds of samples. Irradiation temperature of the sample cans is actively controlled by adjusting the relative concentrations of Ar and He in gas gaps surrounding the cans.

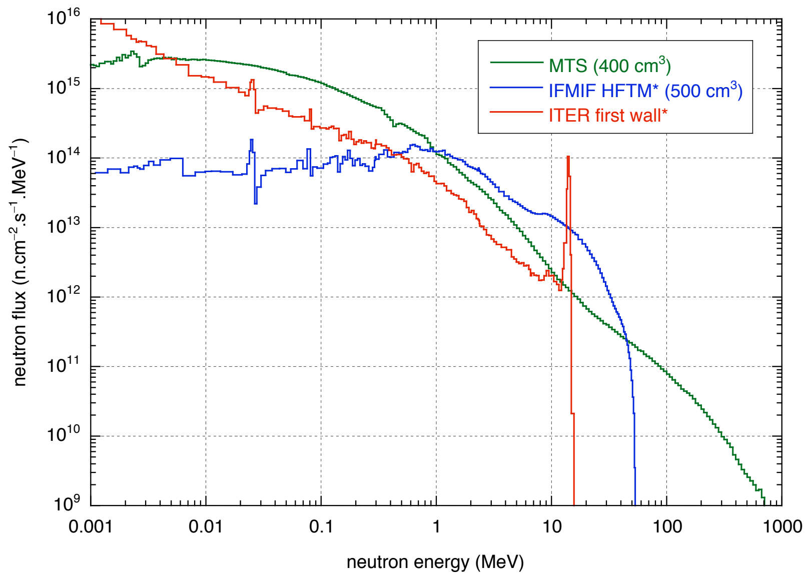

*Figure 1. Neutron spectra for MTS, IFMIF, and ITER [*data courtesy of Dr. U. Fischer et al., Fusion Engineering and Design 63-64 (2002) 493-500]. The 400-cc MTS volume is in the fuel irradiation region.*

Table 1 provides summary damage parameters for IFMIF and for the MTS at three beam power levels. The 1-MW option is the current baseline. Two LANSCE beam power upgrade options are possible that will increase the dose rate of the MTS. Table 1 is a variation of Table 3.d.8-1 in the Greenwald Report. Note the IFMIF doses in Table 1 account for the facility's anticipated 70% availability; the MTS availability of 50% is also taken into account. For the MTS, the irradiation volume (both fuels and materials irradiation regions) is limited to that for which the He-to-dpa ratio ranges from 8 to 13. At 1-MW beam power, the MTS provides a peak dose that is about half of IFMIF. At 1.8-MW beam power, the MTS peak dose is 80% of IFMIF. At 3.6 MW, the MTS peak dose exceeds that of IFMIF by 10%. A broader range of He-to-dpa ratios is accessible in MTS, as shown in Figure 2. This broad range allows researchers the ability to assess the impact of He concentration on materials performance.

Table 1. Summary of proposed IFMIF and MTS (at 3 beam power levels) parameters assuming a 4-year irradiation period (after Table 3.d.8-1 of the Greenwald Report).

Facility	Irrad. Temp. (K)	Max dose (dpa)	appm He/dpa ratio	Irradiation volume (cm^3)
IFMIF HFTM	520-1300	100-140 56-100	10-12	200 cm^3 300 cm^3
MTS @ 1 MW	400-1200	30-70 10-30	8-13	200 cm^3 450 cm^3
MTS @ 1.8 MW	400-1200	50-110 10-50	8-13	200 cm^3 450 cm^3
MTS @ 3.6 MW	400-1200	80-160 20-80	8-13	200 cm^3 450 cm^3

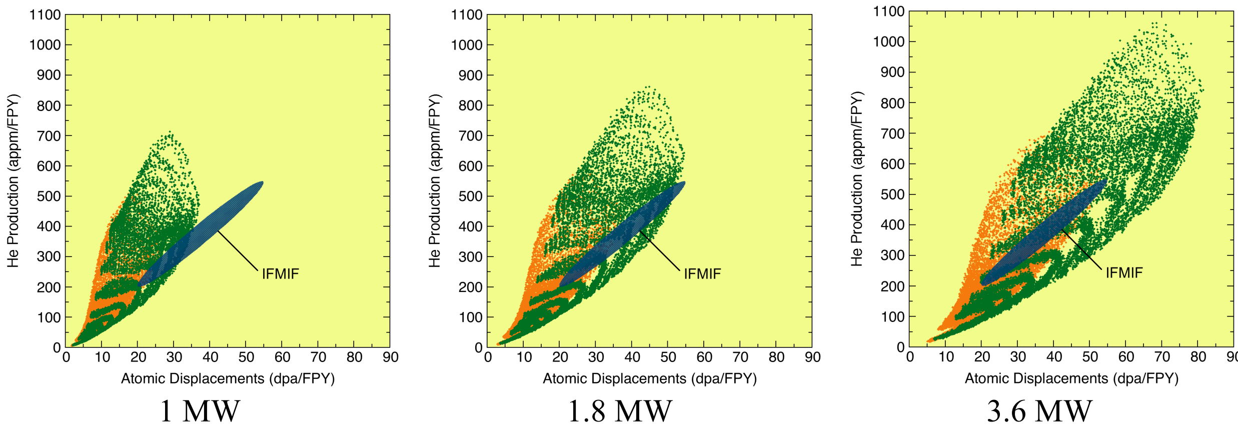

Figure 2. Helium production rate vs. atomic displacement rate for iron in the MTS at three beam powers. Each green (orange) dot represents a 0.04-cc volume element in the fuels (materials) irradiation region. The blue ellipse represents the He and dpa production rates in the 500-cc IFMIF HFTM.

<u>Costs</u>

Chapter 6 of the IFMIF Comprehensive Design Report [3] provides estimated project costs in 2003 US dollars. The EVEDA, Construction, Installation & Checkout, and Startup & Commissioning phases are comparable to the Critical Decision phases CD-1 through CD-4 as defined in DOE Order 413.3A, which are used by DOE to establish Total Project Cost (TPC). Estimated costs for each of these IFMIF stages are reproduced in the second column of Table 2. The third column removes contingency from the cost estimate. The last column escalates costs to 2009, assuming an annual inflation rate of 2.7% per year. This yields an IFMIF estimated TPC, in 2009 dollars without contingency, of $900M. The MTS estimated TPC, in 2006 dollars without contingency, is $58M [4]. Escalating by 2.7% for three years raises this to $63M in 2009 dollars. The MTS estimated TPC is a small fraction (7%) of the IFMIF estimated TPC.

Table 2. IFMIF project costs.

Phase	From Table 6.1-1 of the IFMIF CDP (M$)	Without Contingency (M$)	Escalated to 2009 (2.7% per year) (M$)
EVEDA	88.4	88.4	103.7
Construction	539.2	458.2	537.6
Installation & Checkout	116.7	106.7	125.2
Startup & Commissioning	115.4	115.4	135.4
Total	859.7	768.7	901.9

Two options exist for upgrading the LANSCE accelerator beam power that can be delivered to MTS. The first consists of replacing old-style klystrons that power the coupled cavity linac (CCL) section of the accelerator with higher power high-efficiency klystrons. If done in close coordination with the LANSCE Refurbishment project, this has an estimated cost of about $105M. In addition, the H^+ injector would need to be replaced with a radiofrequency quadrupole for a cost of $15M, for a total of $120M. The second option involves the same replacement of the H^+ injector and replacement of the existing drift tube linac and existing CCL with a superconducting cavity structure ($230M). The $120M option would raise the beam power delivered to MTS to 1.8 MW, while the $230M option would provide 3.6-MW beam power delivery to MTS. The 3.6-MW option does not require the $105M replacement of the old-style klystrons. The cost estimates for both linac upgrade options include contingency, and both are predicated on the successful completion of the LANSCE Refurbishment project. The costs associated with upgrading the MTS to allow higher beam power operation have not been estimated, but are probably in the range of $10M to $20M.

During operation the IFMIF facility draws 37 MW of AC power [3], consuming 230 million kW-h of electricity annually. By contrast, the incremental AC power needed to deliver 1 MW of beam power to MTS is at most 8.7 MW, or 38 million kW-h annually (note IFMIF has 70% availability, MTS has 50%). Because the proposed MTS upgrade to 1.8 MW employs higher efficiency klystrons, the electricity usage is not appreciably higher (40 million kW-h) than for the 1-MW option. The same is true for the 3.6-MW upgrade, which uses superconducting cavities. Assuming an electricity cost of 10¢ per kW-h, the IFMIF annual electricity cost is at least $19M higher than that for any of the three MTS options. In contrast to IFMIF, LANSCE is a multi-user facility where operating costs are shared by the programs served by the linac. As such, MTS accelerator operating costs should be less than those for IFMIF.

Summary

The Greenwald Report identifies a "materials qualification facility" as one of nine initiatives that will make a major contribution to three identified gaps (plasma facing components, low activation materials, and safety). An upgraded MTS can fully satisfy this initiative. It can provide a fusion-relevant irradiation environment with irradiation volume on par with IFMIF, at a fraction of the capital and operating costs of IFMIF, and on a time scale 5 to 10 years earlier.

References

1. E.J. Pitcher, "The materials test station: a fast-spectrum irradiation facility," J. Nucl. Mater. 377 (2008) 17; E. Pitcher, "The Materials Test Station: a Fast Spectrum Irradiation Facility," Proceedings of GLOBAL 2007, Sept. 9-13, 2007, Boise, USA, p. 1703; E. Pitcher, et al., "Progress on the Materials Test Station," Proceedings of the International Conference on the Physics of Reactors (PHYSOR08), log 274.
2. M. Greenwald, et al., "Priorities, Gaps and Opportunities: Towards A Long-Range Strategic Plan For Magnetic Fusion Energy," A Report to the Fusion Energy Sciences Advisory Committee, October 2007.
3. IFMIF Comprehensive Design Report, International Energy Agency, January 2004.
4. E. Pitcher and P. Sanchez, "LANSCE Materials Test Station Preliminary Cost Estimate and Schedule," LA-UR-06-0197.