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# A Potential Capability for Initial Testing of Fusion Materials based on the LANL Low Energy Demonstration Accelerator (LEDA) Facility

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## Abstract

A source of 14 MeV neutrons with fusion reactor level neutron fluxes and fluences is essential for the development of fusion reactor materials. The International Fusion Materials Irradiation Facility (IFMIF) team [1] has developed a well-advanced design to provide this source for $800M (1996$). However, the IFMIF is regrettably facing delays partially due to funding issues. We propose using the Low Energy Demonstration Accelerator (LEDA) facility at the Los Alamos National Laboratory (LANL) to build and operate a smaller scale international fusion testing facility sooner and cheaper than the full IFMIF. Such a facility could fill the gap between the present fusion materials program and the full IFMIF, and thus facilitate continued progress in the development of fusion reactor materials. It would also provide an early systems test-bed for accelerator and target development to reduce cost and schedule uncertainties for the full IFMIF or other subsequent fusion materials testing facilities.

**Keywords:**
F0400—First Wall Materials; F0800—Fusion Reactor Materials; N0100—Neutron Irradiation; R0300—Radiation Effects: Mechanical Properties; R0400—Radiation Effects: Physical Properties

## Introduction and Needs

Low-activation materials that can withstand a flux of $10^{18}$ 14 MeV neutrons/m$^2$-s[2] are required for fusion reactors. This necessitates the development of an adequate materials science and metallurgical basis for the selection and qualification of materials for fusion reactors. Fusion reactor materials must withstand 100 to 150 displacements/atom (dpa) and He production of 1000 to 1500 He atoms parts per million (~ 10 He appm/dpa). The present international fusion materials program consists of theory and computer simulations together with appropriate small-scale experiments. Fission reactors produce adequate fluxes to study displacement damage. But 2 MeV fission neutrons are too low in energy to provide sufficient transmutation rates for the required level of He production. Neutrons with energies much greater than 14 MeV produce too many He atoms for each displacement. A 14 MeV neutron facility with adequate fluxes is thus essential.

The international community has converged on the concept of an accelerator-based facility that directs a 40 MeV deuterium beam onto a target to produce 14 MeV neutrons by stripping reactions [3]. The accelerator-based Fusion Materials Irradiation Test (FMIT) project was initiated in 1975 to provide such a fusion materials test facility[4], but was terminated in 1984 due to budget shortfalls. Proposals for other projects[5] were not successful. Recognizing the continued need for such a facility, the international fusion community launched a program in the early 1990's to design, construct and operate a fusion materials testing facility. The conceptual design of the International Fusion Materials Irradiation Facility (IFMIF) was completed in 1996[1]. The IFMIF design was based on a 40 MeV deuterium beam system with a total current of 250 mA. The IFMIF estimated cost in 1996 was $800M with testing to begin approximately 10 years after project start. Due to the competition for funds with the International Thermonuclear Experimental Reactor (ITER) [6] and other national and international fusion projects and activities, it appears likely that the start of IFMIF will continue to be delayed until ITER has been launched and is well into construction, or possibly even later.

We have investigated utilizing the existing Low Energy Demonstration Accelerator (LEDA) facility[7] at the Los Alamos National Laboratory (LANL) to construct an initial fusion materials testing facility. The facility could bridge the gap between the full IFMIF and the present fusion materials testing program based irradiations in fission reactors and small scale experimental testing, theory and computer simulation[8]. This facility would allow the International Fusion Program to begin critical materials testing with fusion energies, fluxes and fluences much earlier and cheaper than the full IFMIF. It would also provide an early systems test-bed for accelerator and target development to reduce uncertainties in cost and schedule for subsequent fusion materials testing facilities such as the proposed full-scale IFMIF.

Our preliminary study indicates that a LEDA-based fusion materials testing facility could be constructed for roughly 20 to 30% of the full IFMIF costs with tests beginning 4.5 to 6.25 years after start of project. The facility would irradiate samples with the same flux and fluence as IFMIF, but fewer samples could be simultaneously irradiated. The lower cost (~15-20% of IFMIF) option would allow simultaneous tests of about 120 samples about 4.5 years after project start (Table 1). The more expensive facility (30% of IFMIF) would allow simultaneous tests of about 520 samples about 6.25 years after project start.

## LEDA Facility

In the late 1990s, the Low Energy Demonstration Accelerator (LEDA) was built and tested as a major element of the Accelerator Production of Tritium (APT) project engineering and development activities[7]. LEDA used existing accelerator building and support facilities constructed in the late 1980's. The original facility was designed to house a 100 MeV accelerator with associated facilities such as a control room, klystron gallery, shop, cranes, high-bay, support laboratories and office space. LEDA was built at a cost of about $170M to demonstrate the design, construction and operation of a 6.7 MeV, 100-mA, continuous wave (cw), proton accelerator as the front end of a proposed 1000-MeV, 100-mA, cw, proton accelerator for the APT program. The LEDA facility includes the proton ion-source, injector, low energy beam transport system, radiofrequency quadrapole (RFQ) high energy beam transport system, six 350-MHz klystrons (power generators), cooling systems, adequate ac power, and a water beam stop. The designs for superconducting cavities to raise the proton beam energy to 40 MeV are available and their use is included in our cost and schedule estimates. LEDA was operated successfully from 1999-2001 and was the world's only functional, high-current continuous proton linear accelerator. LEDA has provided useful R&D information for the IFMIF accelerator design[1]. Having successfully completed the APT mission, the DOE-owned LEDA facility is now available to address the needs of other programs.

The LEDA facility (Figure 1) includes a well-shielded 150-m long beam tunnel, with personnel access control, six 1-MW RF power generators, 13 MW of input ac power (easily expandable to 25 MW), 15 to 20 MW of cooling capability, 12 separate cooling systems (including 10°C ( 50° F) chilled water), high-power experimental and test areas, an equipped control room, instrumentation areas, and power supplies, integral machine shop and storage areas, cranes, a high-bay facility, small labs, more than 30 office spaces, meeting rooms, and a computer vault that are available for use for a fusion materials testing facility. The accelerator division staff at LANL are very experienced in accelerator design, construction and operation. This staff, together with industrial, laboratory and university (both national and international) participants, could readily carry out the LEDA conversion. The LANL staff would be available to support operation of the facility while the international fusion testing community designed and performed experiments.

Figure 1 LEDA building at Los Alamos from the back showing the high bay areas, offices, and other facilities.

LANL also has extensive experience with and facilities for handling and testing radioactive materials. These facilities would be available for post irradiation examination (PIE), although it is envisioned that most irradiated samples would be shipped to other national and international sites for PIE.

**Proposed Facility Upgrades**

An attractive, cost-effective option for fusion-relevant, neutron irradiation of materials can be realized by upgrading the Low Energy Demonstration Accelerator LEDA at Los Alamos. We investigated two options (Table 1) that provide testing capability for progressively greater number of samples. The first option provides a final energy of 40 MeV for a deuterium beam current of about 50 mA by changing the vanes in the RFQ to support deuteron acceleration and utilizing the existing 350 MHz klystrons. The accelerator upgrade would cost would about $95M. Both upgrades require design, fabrication and installation of a stripping target and a test chamber. We have not carried out detailed cost estimates for these latter capabilities, but for the 50 mA option rough estimates of these balance of plant costs vary between $55M and $100M. The power loading for a 50 mA beam might allow the use of a rotating Be disk like the one used in RTNS[9]. That could lower the target costs to about $20M giving the lowest cost.

Table 1 Two proposed LEDA-based facility options for superconducting 40 MeV deuterium beams.

| | Beam properties | | High-Flux Test Chamber | | Estimated costs and schedule* | | | |
|---|---|---|---|---|---|---|---|---|
| Option | Current (mA) | Beam Spot Size on Li target (cm$^2$) | Estimated volume (cm$^3$) in the 20 dpa/fpy region | Number of samples in volume | Estimate of accelerator costs ($M) | Estimate of balance of plant costs ($M) | Total Facility costs ($M) | Time from start to testing (years) |
| 1. Convert LEDA to D$^+$ at 350 MHz | 50 | 7x3 | 33 | 120 | 95 | 55—100 | 150—195 | 4.5 |
| 2. Convert LEDA to D$^+$ at 175 MHz | 125 | 12x4 | 172 | 520 | 130 | 100—170 | 230—300 | 6.25 |
| 3. Full IFMIF | 250 | 20x5 | 600 | 1800 | 500 | 300 | 800 | 10 |

*Costs for target and test sample facilities are only approximate and depend on the choice of the target technology. The estimated costs for the LEDA-based facility are in 2003$ and the costs for IFMIF are in 1996$. The balance of plant costs include the stripper target, the test sample chamber, etc.

The second option is based on generating a higher-current 125 mA 40 MeV deuteron beam. The higher current would require building a new RFQ that operates at 175 Mhz and a resulting conversion to 175-MHz klystrons. The estimated cost would be about $130M. Rough estimates for the balance of plant (stripping target, etc.) costs are between $100 and $170M (Table 1). The accelerator sections after the RFQ would be superconducting for both cases thereby reducing the operating costs by roughly a factor of two compared to a non-superconducting accelerator.

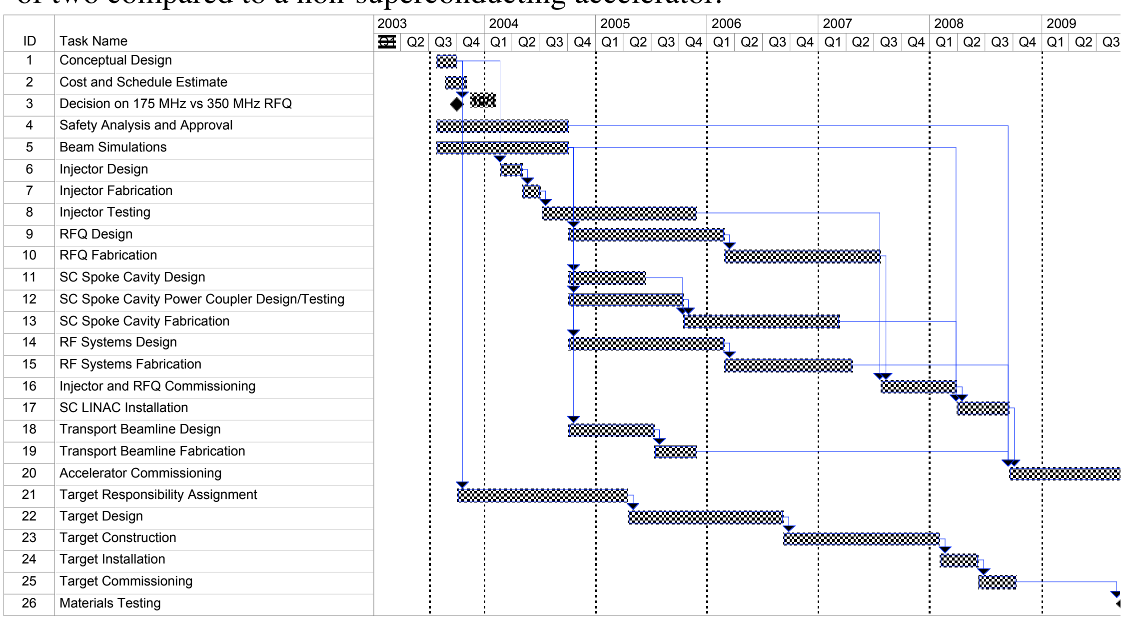

Figure 2 Work Breakdown Structure and schedule for conversion of the LEDA facility to a fusion materials testing facility based on a 125 mA 40 MeV deuterium beam.

These options would be available for fusion materials testing operation about 4.5

and 6.25 years, respectively, after project start (Figure 2).

These costs ($150 to $300M in 2003$) are substantially less than those estimated for a full-scale IFMIF accelerator and facility ($800M in 1996$)[1]. Recently a reduced cost option has been proposed[10] with staged delivery of a 125mA accelerator in 14 years and a 250mA accelerator in 17 years.

The DOE has provided funds to decommission and decontaminate the LEDA facility. While this work has started, it is being done in a manner that leaves IFMIF relevant components and facility infrastructure intact for use on other programs.

We envision that a LEDA-based facility would be built and operated as an international facility with full international participation. One possible plan would be for the US to build the accelerator upgrade, and for other international participants to build the target and test chamber facilities. Other plans are also possible. While the terms of any international participation have not been defined, we would expect that the envisioned facility would have international governance from the beginning. The Los Alamos National Laboratory general infrastructure would be available to support the project. The LEDA facility is located in an area of Los Alamos that is completely accessible to international participants.

**Potential Benefits of a LEDA-based fusion materials testing facility**

A reduced scale testing facility available before construction and operation of the full IFMIF could accelerate the fusion program and the design and construction of a demonstration fusion reactor. Assuming a 2005 start date for LEDA conversion, a 4.5 to 6 year conversion period for LEDA, and a 2007 start date for IFMIF construction, a LEDA-based facility could provide six to eight years (or more if IFMIF is delayed further than 2007) of fusion materials testing prior to full IFMIF operation. One possible plan is for the LEDA-based facility to carry out a testing program that concentrates on screening tests of potential first wall materials to identify and select the most promising candidate (Figure 3). IFMIF could then emphasize characterization and certification of the selected material, thus providing more timely data for the design of a demonstration reactor. This would reduce the design options that the demonstration reactor project would need to consider during initial design, and provide better data for use in the initial design. Other testing plans and schedules would also be possible.

In addition to the study of the nominal leading candidates, martensitic steel, SiC and Vanadium alloys, the study of other new, innovative materials would not have to wait until the full IFMIF becomes available. Finally, a LEDA-based facility would provide relevant data to help develop and validate materials simulations and theory.

**Summary**

While IFMIF[1, 11] is the planned international facility for fusion materials testing, the projected cost of up to $800M (1996$) may result in significant delays in the project. A testing facility based on the existing LEDA facility at Los Alamos could provide the international fusion community an initial fusion materials testing facility for between roughly 20 and 30% of the cost of the full IFMIF [1]and could begin operation and materials testing 4.5 to 6 years after the start of the project. Such a facility could help fill the gap between the present program and the start of operation of the full IFMIF, provide data to aid the development of simulations and theory, and speed the selection of candidate materials, thus allowing more efficient use of the full IFMIF when it begins operation. A LEDA-based facility would also provide design and operational experience that would improve the design and reduce the construction risks of the full IFMIF.

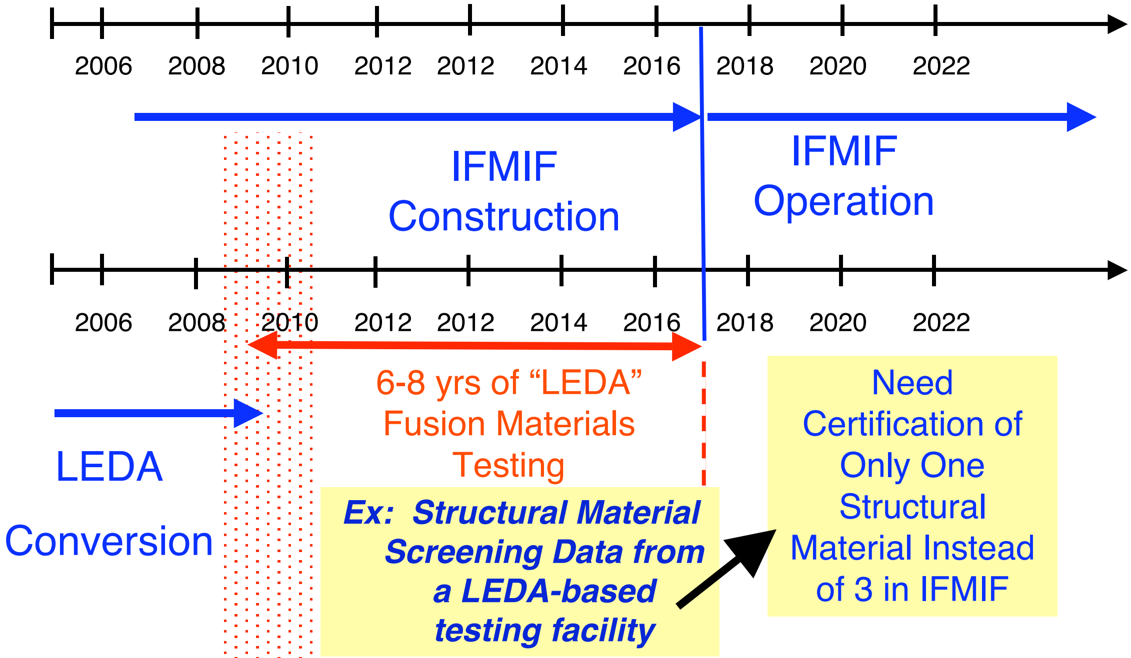


Figure 3. Schedule illustrating use of a LEDA-based fusion materials testing facility to conduct fusion materials tests prior to full testing in IFMIF.

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