LEDA - High Power Accelerator Facility for Target Development and Materials Testing

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High-Power Targetry for Future Accelerators

Outline

Introduction

IFMIF target design

The LEDA facility

The fusion materials program

Possible LEDA accelerator upgrades and targets

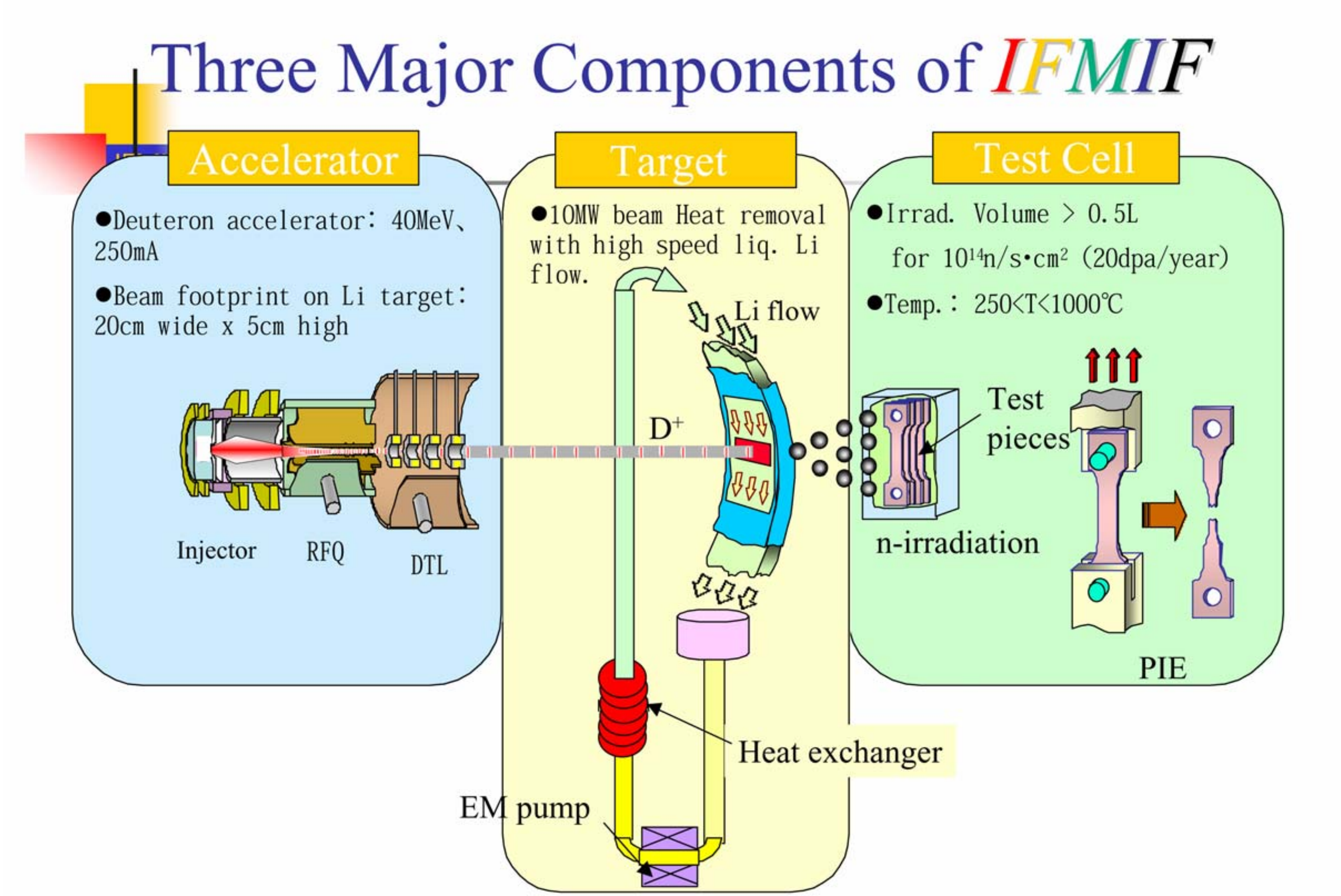
LANL material testing capabilities

Summary

There is an opportunity to begin fusion materials and target testing at reasonable cost using LEDA

- Use the existing Low Energy Demonstration Accelerator (LEDA) facility for an initial fusion materials test facility.
  - Provide the US Fusion Program with critical fusion materials development and testing much earlier and at lower cost than other proposed facilities.
  - Provide an early systems test-bed for accelerator and target development to reduce uncertainty in cost and schedule
- Develop a national/international fusion materials community program in fusion materials and target research and testing.

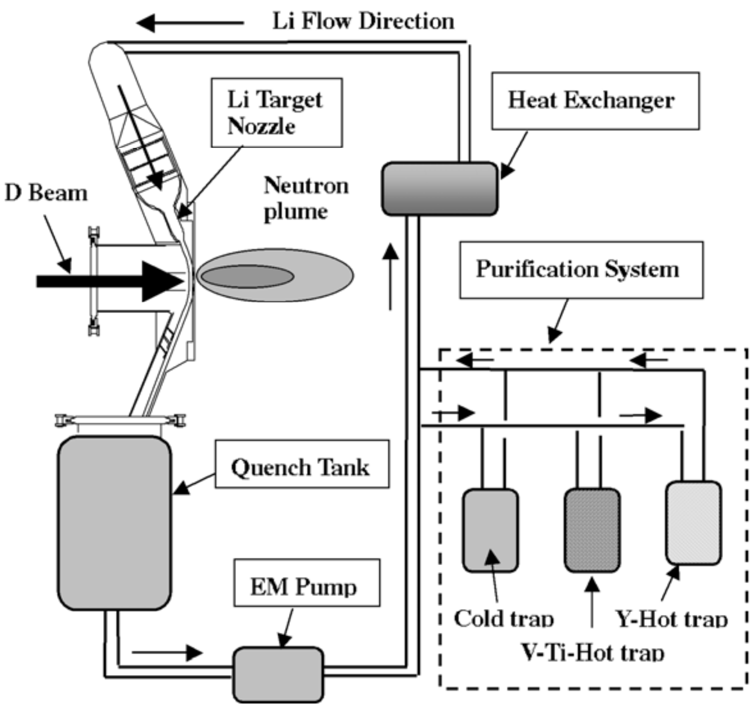
IFMIF pushes state-of-art in target design



Progress in *IFMIF* Project, Hideki Matsuia et. al., 6th International Symposium on Fusion Nuclear Technology, 7-12 April 2002, San Diego, California, USA

IFMIF target is a stable Li jet for production of intense neutrons with an averaged flux of 20 dpa/year

Items	Parameters
Deuterium Beam energy/current	40 MeV / 125 mA (nominal) x 2 accelerators
Averaged heat flux	100kW/cm^2
Beam Deposition Area on Li Jet	20 cm^W x 5 cm^H
Jet Width / Thickness	26 cm / 2.5 cm
Jet Velocity	15 (range 10 ~ 20) m/s
Flow Rate of Li	133 l/s (at target section)
Inlet Temperature of Li	250℃ (nominal)
Vacuum Pressure	10^{-3} Pa at Li free surface 10^{-1} Pa in target/test cell room
Materials (back wall) (Other components)	RAF steel or 304 stainless steel 304 stainless steel
Availability	> 95 %



Summary of Li target studies

- Flow stability validation of liquid Li
  - Simulated water jet tests for liquid Li
    - » Comprehensive data set has been obtained for a wide range of parameter space.
- Liquid Li loop experiment
  - Validation of water jet simulation data
  - Utilizing an existing Li loop (Osaka University) by incorporating free surface flow test section.
  - Experiment is planned to start in July, 2002.
- Measurement and control of impurities in liquid Li
  - Reduction of nitrogen in Li by hot trapping
    - » V-10Ti alloy is found better, while Cr performance is superior for when nitrogen concentration is high.

Cf. (MAT.POS.29) T. Sakurai, et al. Control of Nitrogen in Liquid Lithium by Hot Trapping.

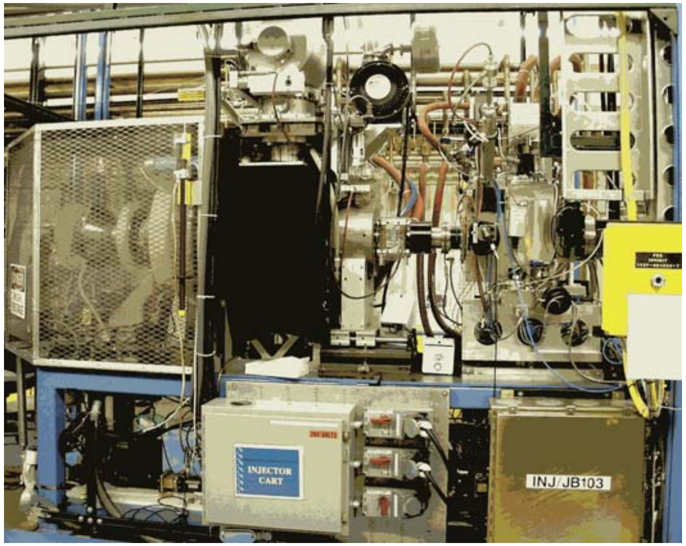
The LEDA facility can give relevant materials data and begin system component testing – reducing cost and risk.

- The original materials testing program doesn't seem to be affordable.
  - US and international fusion programs cannot find the $1B for the originally proposed full IFMIF in the next 5 to 10 years.
- Progress in modeling and simulation of radiation damage has reduced the machine requirements for initial studies.
  - Small part testing and benchmarking of damage calculations is now being considered the most cost-effective approach.
- Target power fluence can be same as IFMIF target design
  - Beam area scales with current, tests of beam striking an area of 1/5 IFMIF area and larger are possible
- Many of the accelerator and target systems are identical to that used in LEDA
- The LEDA facility is available because it is no longer needed by NNSA—site credits and redesign allow a significantly cheaper materials testing facility that can come on-line much earlier than the proposed IFMIF.

LEDA has a state-of-art facility for accelerator development

- Well-shielded 150-m long beam tunnel, with personnel access control
- Six 1-MW RF power generators
- 13 MVA of input ac power (easily expandable to 25 MW)
- 15--20 MW of cooling capability
- 12 separate cooling systems (including 50°F chilled water)
- High-power experimental and test areas
- Equipped control room, instrumentation area, power supplies
- Integral machine shop, storage areas, cranes, high-bay, small labs, >30 office spaces, meeting rooms, & computer vault.
- $150M has been invested in the LEDA facility

LEDA has produced a 670 kW CW proton beam



LEDA H^+ injector including Low Energy Beam Transport (LEBT)

LEDA Radio-Frequency Quadrupole (RFQ) accelerator with injector rolled back

NNSA

Los Alamos

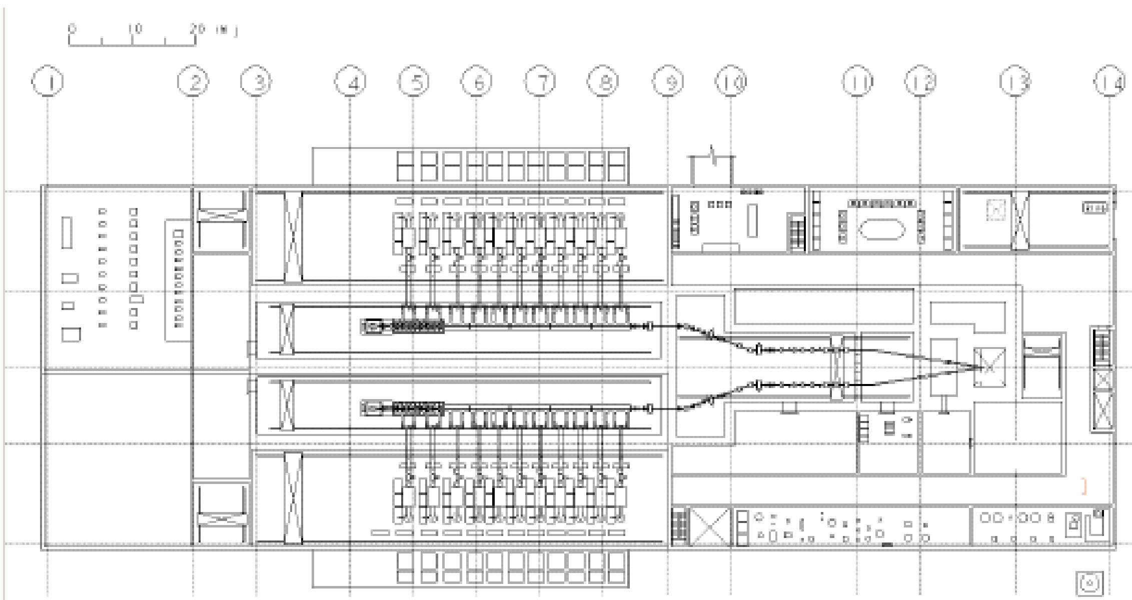
A large investment has been made in the LEDA facility and its associated infrastructure

- LEDA History
  - Built by NNSA for APT program to demonstrate front end of a 1000-MeV, 100-mA proton accelerator
  - Invested cost was $150M
  - 6.7 MeV, 100-mA CW proton beam (100x state-of-the-art beam current)
  - Operated successfully from 1999-2001
  - World’s only functional high-current, CW proton linear accelerator
- LEDA Status
  - APT mission complete
  - Partial D&D funding allocated early in ’03
  - Remaining D&D funding, $5.3M, allocated in final ’03 budget
    - » Partial D&D leaves IFMIF relevant components and facility infrastructure intact
  - Facility available for other programs

LEDA is a valuable facility for the fusion materials program

Scaled comparison of LEDA and IFMIF

LEDA



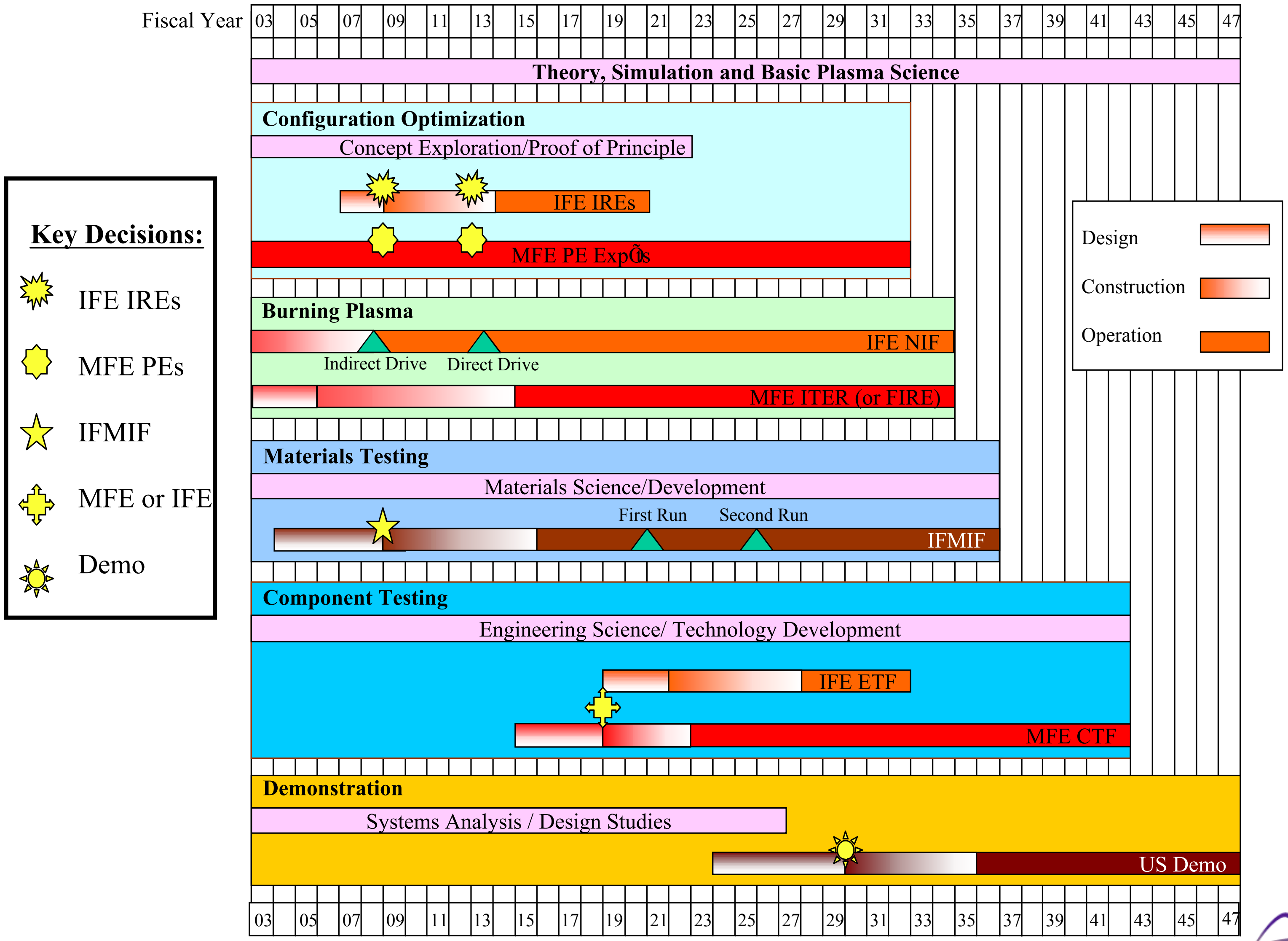
IFMIF

-J. Rathke, Adv. Energy Systems, 1/14/03 Development Paths Review

Fusion materials program goals and strategy

- Goals:
  - Develop materials science and metallurgical base for fusion materials that can withstand 10^{18} 14-MeV neutrons/m^2-s,
  - Select, understand and qualify materials for use in fusion reactors
- Strategy:
  - Utilize theory and simulation and small scale experiments as much as possible
  - Test materials in fission in nuclear reactors, adequate flux but only 2 MeV instead of 14 MeV neutrons (i.e. insufficient H and He production by transmutation)
  - Construct and operate a 14 MeV neutron facility with adequate flux (2MW/m^2-s of 14 MeV neutrons)
- Fusion neutron testing to be accomplished utilizing a 40 MeV D beam striking a ^{7}Li target to produce 14 MeV neutrons by stripping reactions
- Present international plan
  - International Fusion Materials Irradiation Facility (IFMIF, two 125 mA 40 MeV deuterium beams, 0.5 *l* target volume, \$800M in 1996 \$, ~ \$1B in 2003 \$)
- Part of 35 year plan developed by the US fusion program

US fusion energy program calls for fusion materials development through a proposed *35-year plan*

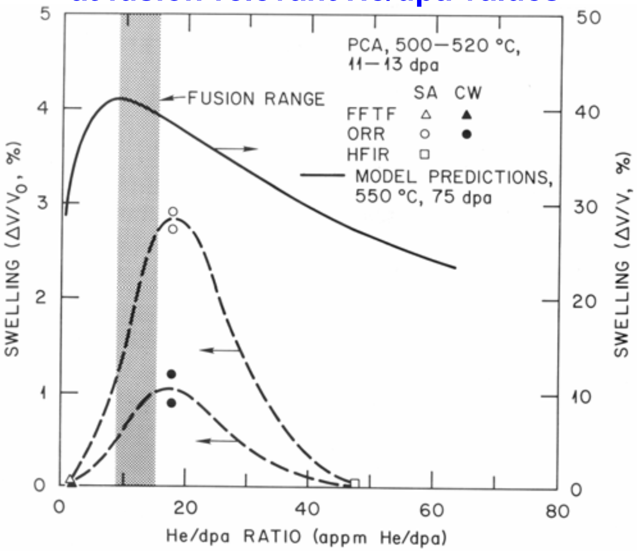


Materials requirements for fusion

- Radiation damage resistant materials are required for fusion to be successful.
- Requirements for fusion materials:
  - Low activation: shallow burial after 100 years desired, limits candidate elements
  - Withstand fusion fluxes: maintain strength, ductility, structural integrity for 2 MW/m^2-s (10^{18} neutrons/m^2-s)
  - Long lifetime: 5-10 years for full power operation with wall load of 2 MW/m^2; 1.5—3 x 10^{26} n/m^2
- Radiation damage issues:
  - Dislocation damage: 100—150 dpa
  - Transmutation to He, H with associated degradation of material properties: 1000—1500 He appm (~10,000 appm for SiC)
    - » He/dpa ratio ~ 10
  - Material conditions: material temperatures of 600° to 1000° C and fusion neutron spectrum of 14 MeV (σ ~ 1 MeV)

He bubbles on grain boundaries can cause severe embrittlement at high temperatures

Swelling in stainless steel is maximized at fusion-relevant He/dpa values



S. Zinkel, ORNL

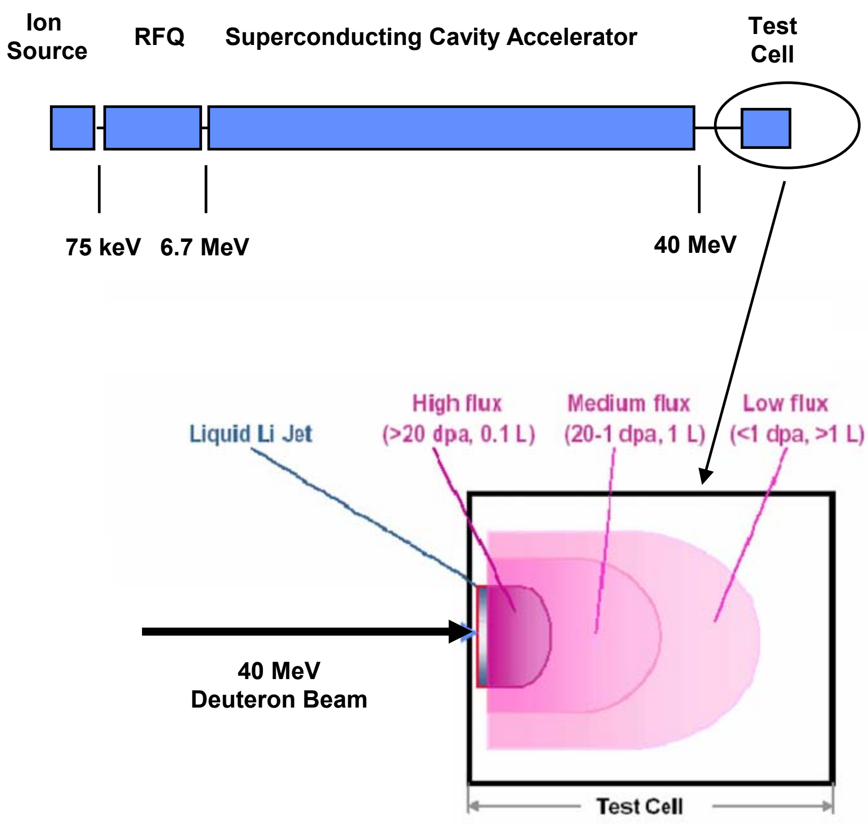
Need to sustain progress in materials science with a lower cost fusion materials testing program

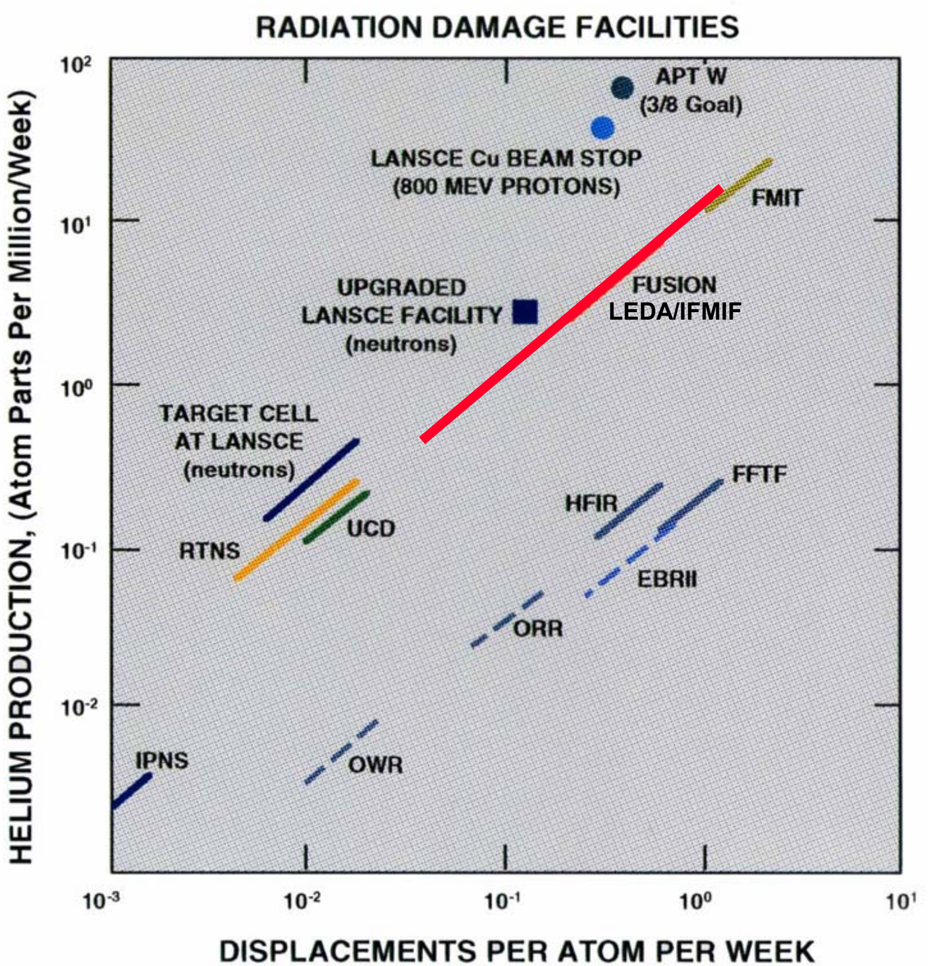
- Fusion Materials Science has made progress
  - Better understanding of materials science, simulation + experiments (small scale and fission neutron data and limited, but important, 14 MeV data from RTNS,…
  - Now we can make better extrapolations of dislocation damage (dpa) from fission data (based on 2 MeV neutrons), simulations have better accuracy and predictive capability
  - Need a facility to continue and build on progress
- A less expensive, near-term facility would sustain progress in fusion materials science while we wait for the full capability IFMIF
- Starting a testing program sooner results allows more time for iterations, for analysis and for making focused decisions on what to test; makes better and more efficient use of testing facility, reduces need for broad-scale testing; prepares us for full capability IFMIF

A LEDA-based program can be started earlier and with a smaller initial investment

- Program using a 50-mA, 40-MeV D beam can be launched for ~ $250 M internationally instead of ~ $800 M (in 1996 $, ~ $1 B in 2003 $).
- Full program capital costs are ~ $350 M (2003 $) instead of ~ $800M (1996 $) for one 125 mA beam.
- Materials and component testing can start 5 to 10 years sooner
- Reduced operation costs of a factor of two or more compared to IFMIF CDA design due to a reduction in operating cost by using superconducting accelerator structures

LEDA-based machine could provide helium production and dpa information needed to accurately predict damage





The 50 mA case may be compatible with rotating disk technology that is expected to be much less expensive than a liquid lithium system

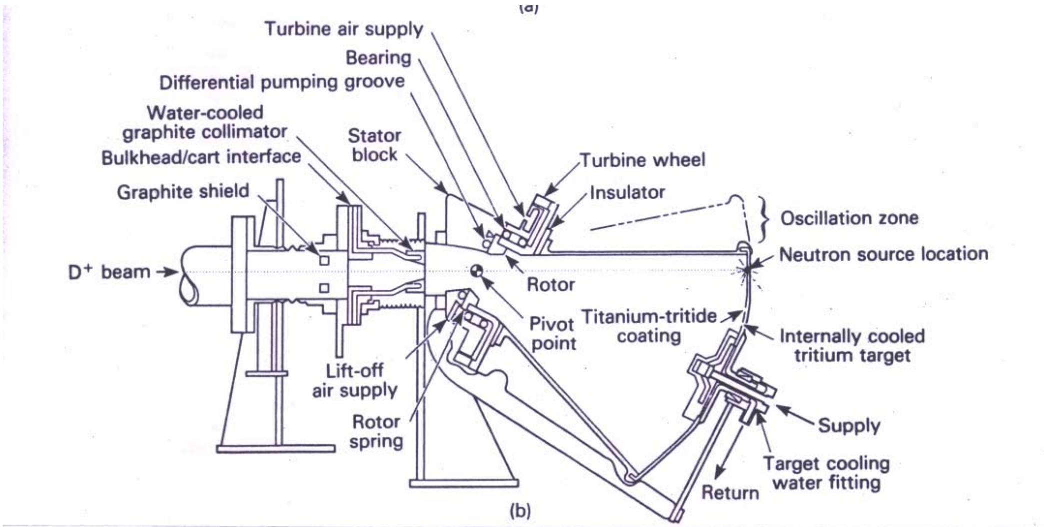


Fig. 3. (a) The externally cooled rotating target system used at RTNS-I, and (b) the internally cooled target assembly at RTNS-II.

NUCLEAR SCIENCE AND ENGINEERING VOL. 106 OCT. 1990

D. W. Heikkinen, et. al.

Shown above is the RTNS-II D-T source designed for 370 KeV and 150 mA (52 kW) in a 1 cm^2 spot that was expected to be compatible with 100 kW/cm^2

Our low power case is a 50 mA beam at 40 MeV (2 MW) in a 21 cm^2 spot – Main challenge is extracting the 2 MW of CW power from target area

Neutron Spectra from Deuteron Bombardment of ', Li, Be, and C by K. A. Weaver et. al., Nucl. Sci. and Eng., **52**, 35-45 (1973)

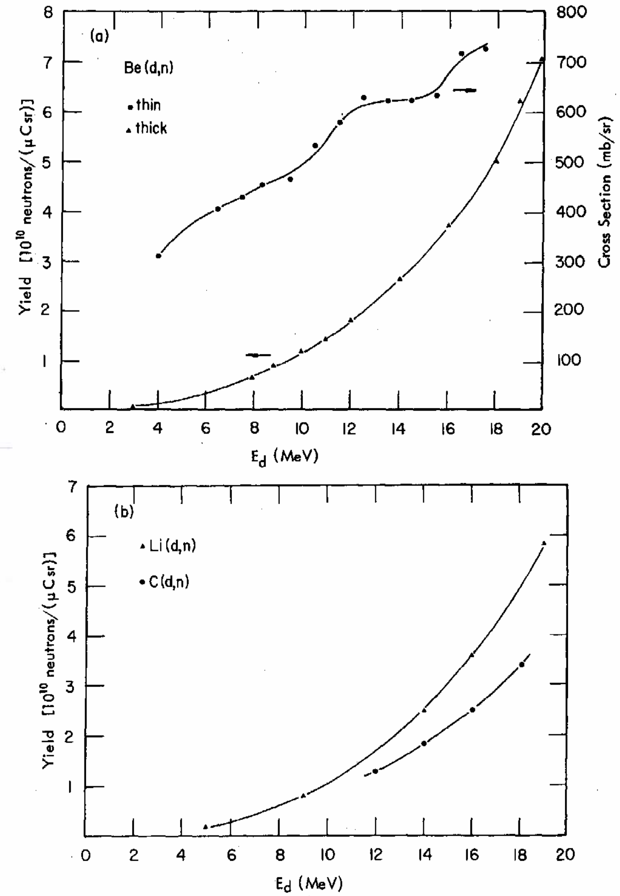


Fig. 5. Neutron production integrated over neutron energy for an emission angle of 3.5 deg as a function of deuteron energy: (a) yield for thick beryllium target and cross section for thin beryllium target and (b) yield for thick targets of lithium and carbon.

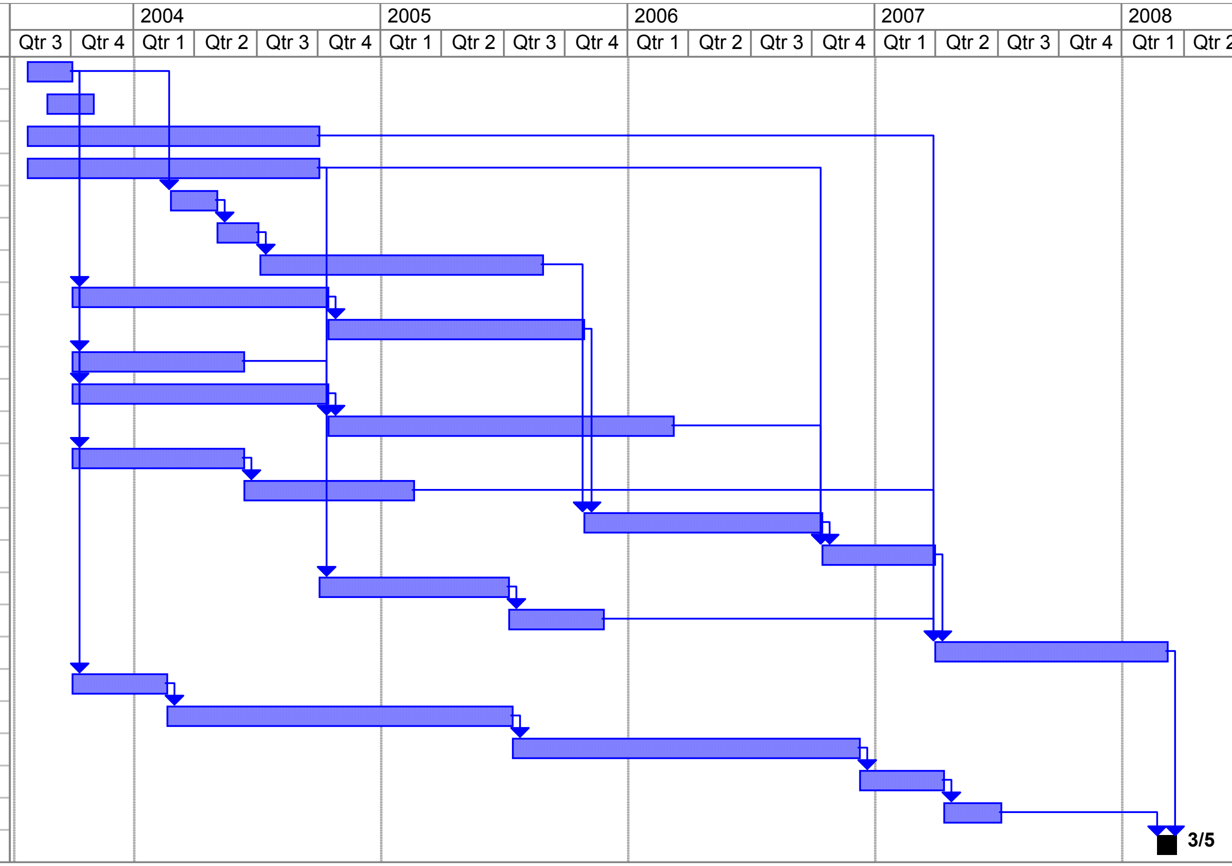
LEDA Upgrade Options for Fusion Irradiation Facility

	Beam Properties				High-Flux Test Chamber				
Case	Particle	Current (mA)	Energy (MeV)	Beam Spot Size on Li target (cm^2)	Average Neutron Energy (MeV)	Estimated volume (cm^3) in the 20 dpa/fpy region**	Estimated number of samples in volume***	Damage Rate (He/dpa ratio)	Rough Estimate of Accelerator and Facility Capital Cost ($M)*
1. Convert LEDA to D^+ at 350 MHz	D^+	50	40	7 x 3	14	33	120	11	95
2. Convert LEDA to D^+ at 175 MHz	D^+	125	40	12 x 4	14	172	520	11	130
3. Full IFMIF	D^+	250	40	20 x 5	14	600	1800	11	500

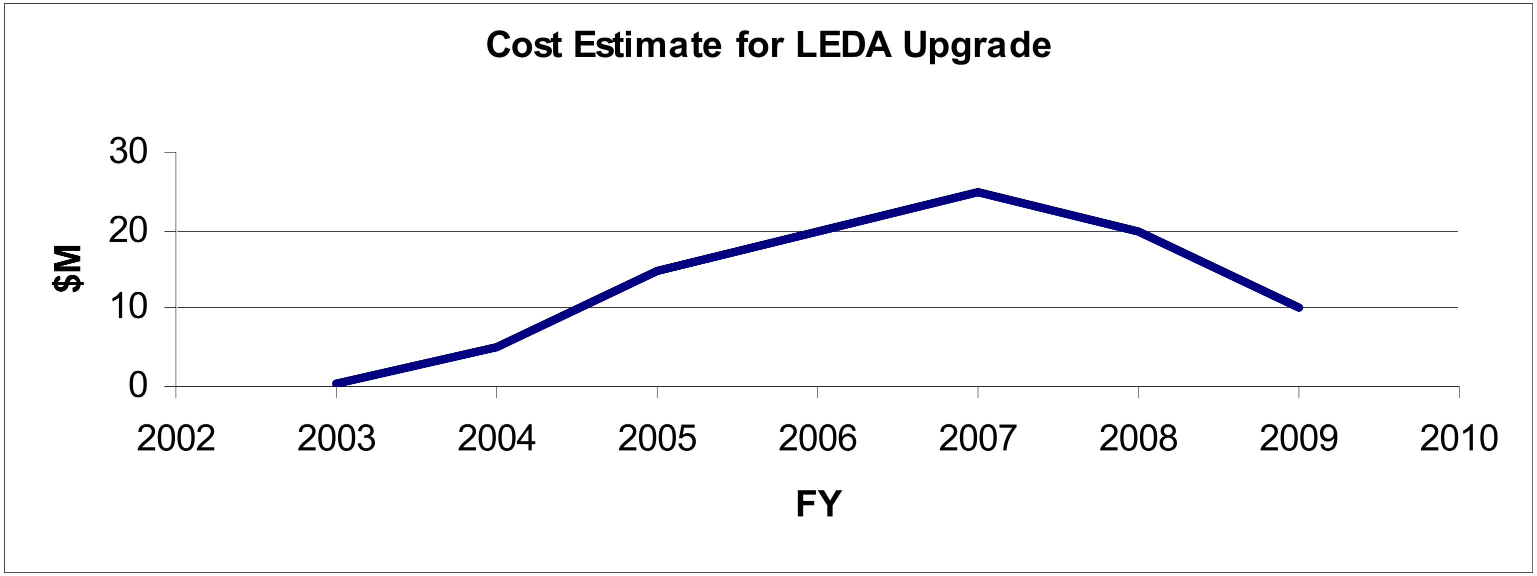
*Accelerator costs only, Li target and sample handling omitted.

A reduced power LEDA can begin operation for materials data 6½ years earlier than the present IFMIF plan

ID	Task Name
1	Conceptual Design
2	Cost and Schedule Estimate
3	Safety Analysis and Approval
4	Beam Simulations
5	Injector Design
6	Injector Fabrication
7	Injector Testing
8	RFQ Design
9	RFQ Fabrication
10	SC Spoke Cavity Design
11	SC Spoke Cavity Power Coupler Design/Testing
12	SC Spoke Cavity Fabrication
13	RF Systems Design
14	RF Systems Fabrication
15	Injector and RFQ Commissioning
16	SC LINAC Installation
17	Transport Beamline Design
18	Transport Beamline Fabrication
19	Accelerator Commissioning
20	Target Responsibility Assignment
21	Target Design
22	Target Construction
23	Target Installation
24	Target Commissioning
25	Materials Testing

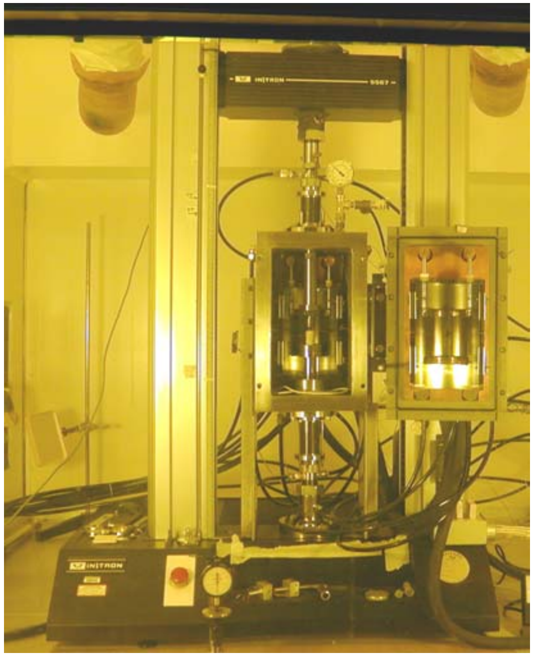


LEDA-based concept would achieve 1/4 the full scale IFMIF design power at 1/5 the cost



Spend plan does not include target or materials handling costs

LANL has continued to improve capabilities for radioactive material testing



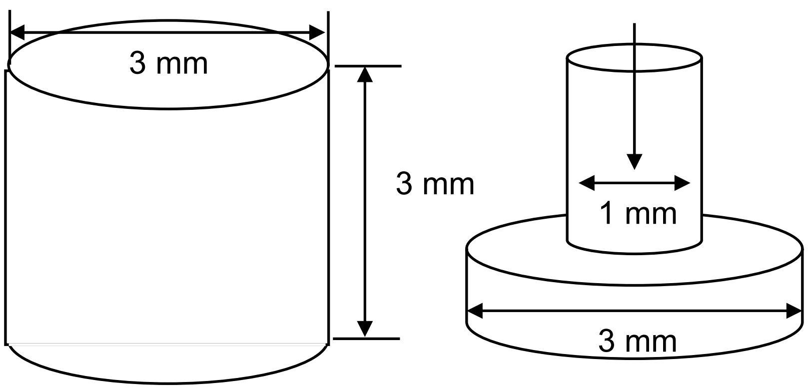
Instron 5567 testing machine in recently installed Hot Cell:

Temperature capabilities- RT to 700ºC in argon (**upgradable to 1200C with minor changes**)

Strain Rate - 10^{-3}/s

Mechanical tests - 3 pt. bend, tensile, shear punch and compression

Material tested - Tungsten

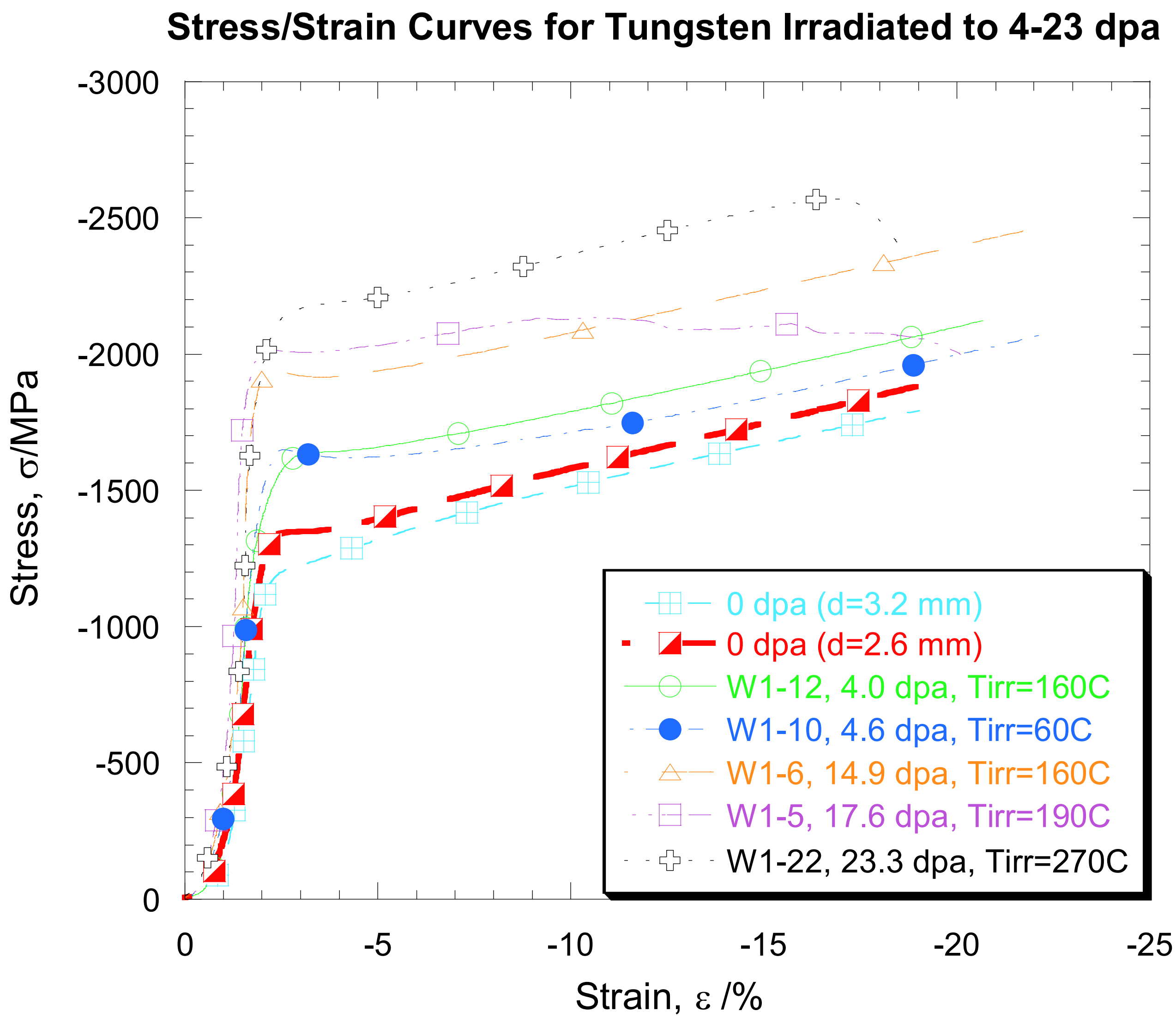


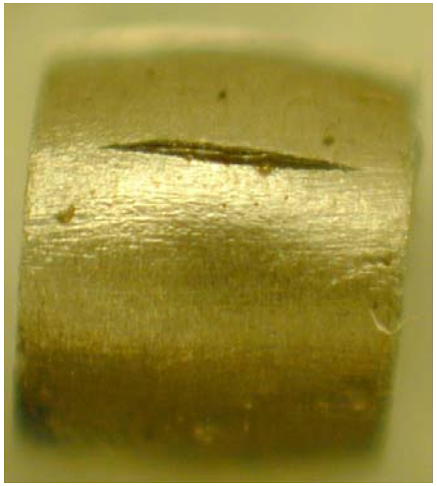
Hardness Testing

Leitz Metallograph in hot cell

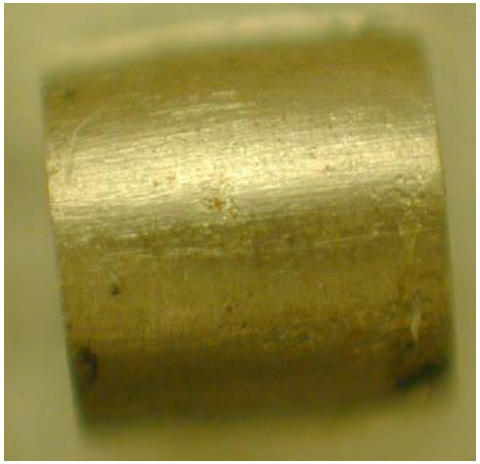
Vickers indentor 50-400g load

Compression stress/strain results for irradiated tungsten show increase in yield stress with dose above 4 dpa





3.2 dpa



0 dpa

Summary - Use of the LEDA facility could make a positive impression on the U.S. and international fusion communities

- This effort is a lower cost option and could “kick-start” materials testing.
- This offers a means to begin testing IFMIF scale accelerator systems and targets – reducing risk.
- It is recognized that this is addressing the long-standing fusion issue of materials testing.
- This addresses a major component identified by FESAC in their report “A Plan for the Development of Fusion Energy.”
- The larger international community will react positively to the US addressing an important fusion issue.