LA-UR 09-06728

MW Spallation Neutron Sources for Fusion Materials Testing

Princeton Plasma Physics Laboratory Colloquium

October 29, 2009

Don Rej

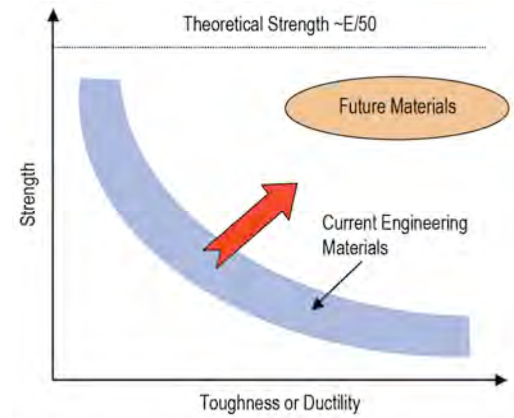
Los Alamos National Laboratory
Science Program Office

Outline

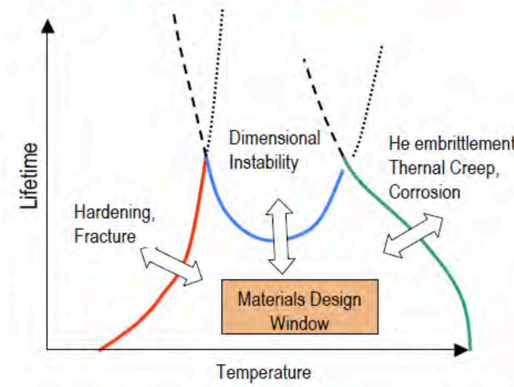
- Fusion Materials Issues, Needs, & Performance Gaps
- Neutron Irradiation Requirements & Options
- High-Power Spallation Neutron Source Applicability for Fusion Materials Testing
- LANSCE Facility
- Materials Test Station Project at LANSCE
- Transition from “observation & validation” to “prediction & control” - the MaRIE Facility Concept

Fusion reactor materials must function in a uniquely hostile radiation, thermal, & chemical environment

- There are no known materials for the first wall & blanket structural materials of a fusion system that can withstand the 10-15 MW-year/m2 high neutron & heat fluences in the extreme environments of a fusion reactor.
  - Existing structural materials are not ideal for advanced nuclear energy systems due to limited operating temperature windows
    - May produce technically viable design, but not with desired optimal economic attractiveness
- High heat, neutron fluxes and mechanical stresses result in microstructure & bulk property changes over long time.
  - Voids, bubbles, dislocations and phase instabilities
  - Dimensional instabilities (swelling & irradiation-thermal creep)
  - Loss of strain hardening capability
  - He embrittlement
  - Fatigue, creep-fatigue, crack growth
  - Corrosion, oxidation and impurity embrittlement (refractories)
  - Transient & permanent changes in electrical & thermal properties



High He may narrow or even close the window

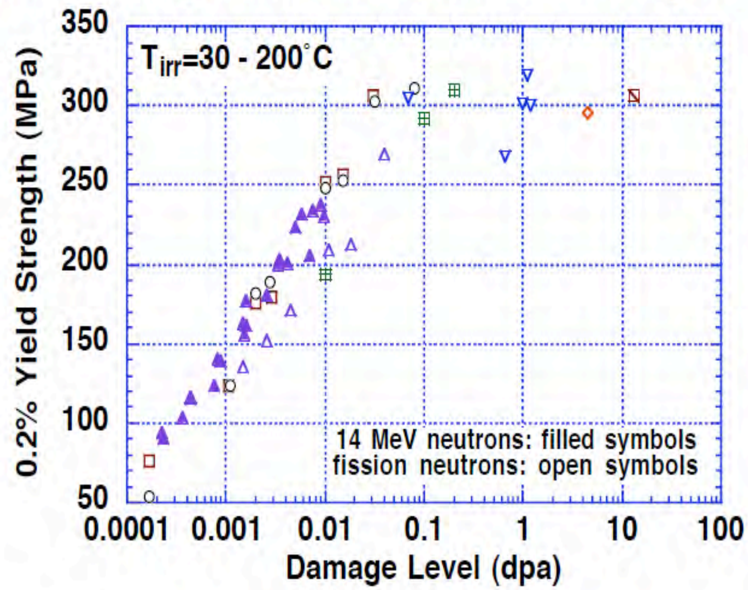


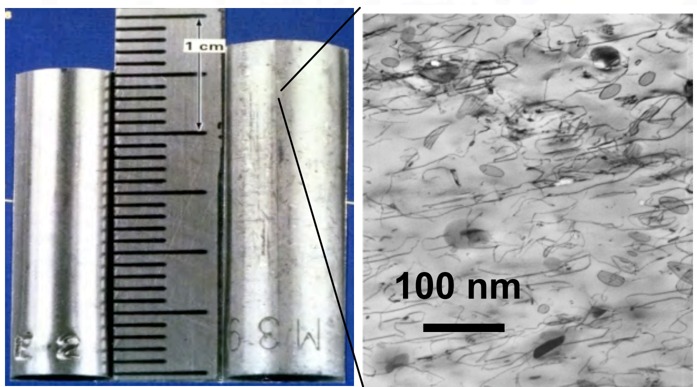
N. Ghoniem & B.D. Wirth, 2002

Radiation Damage can Produce Large Changes in Structural Materials

- Radiation hardening and embrittlement (<0.4 T_M, >0.1 displacements per atom (dpa))
- Phase instabilities from radiation-induced precipitation (0.3-0.6 T_M, >10 dpa)
- Irradiation creep (<0.45 T_M, >10 dpa)
- Volumetric swelling from void formation (0.3-0.6 T_M, >10 dpa)
- High temperature He embrittlement (>0.5 T_M, >10 dpa)

Source: S. Zinkle, *23rd SOFE* (San Diego, 2009)

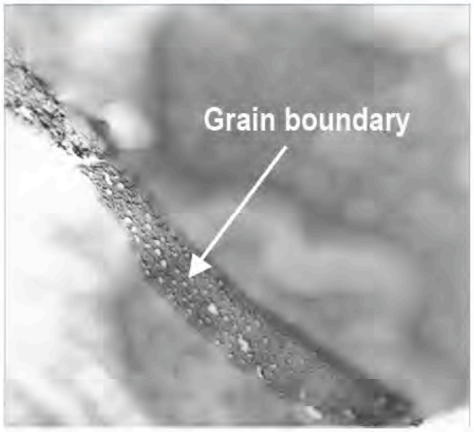




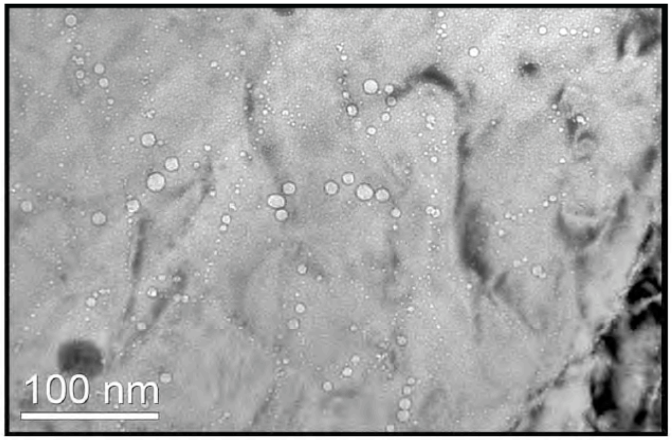
Dynamic, stochastic processes in extreme environments dominate phenomena, such as swelling, that we do not understand

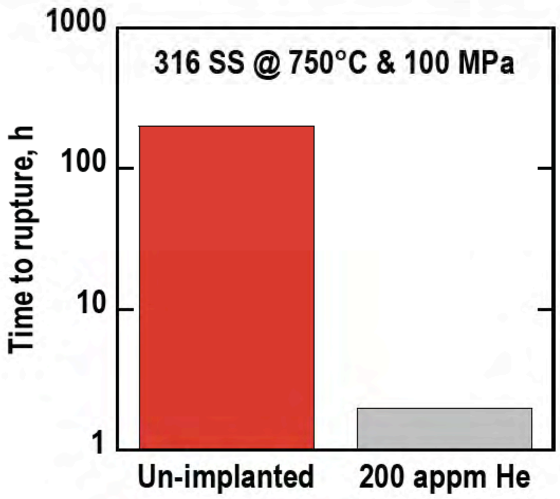
Critical unanswered question is the Impact of H- and He-Rich Environment on Neutron Irradiated Materials

- A unique aspect of the DT fusion environment is substantial production of gaseous transmutants such as He and H.
- Accumulation of He can have major implications for the integrity of fusion components & structures such as:
  - Loss of high-temperature creep strength.
  - Increased swelling and irradiation creep at intermediate temperatures.
  - Potential for loss of ductility and fracture toughness at low temperatures.



Voids in F82H at 500°C, 9dpa, 380 appm He



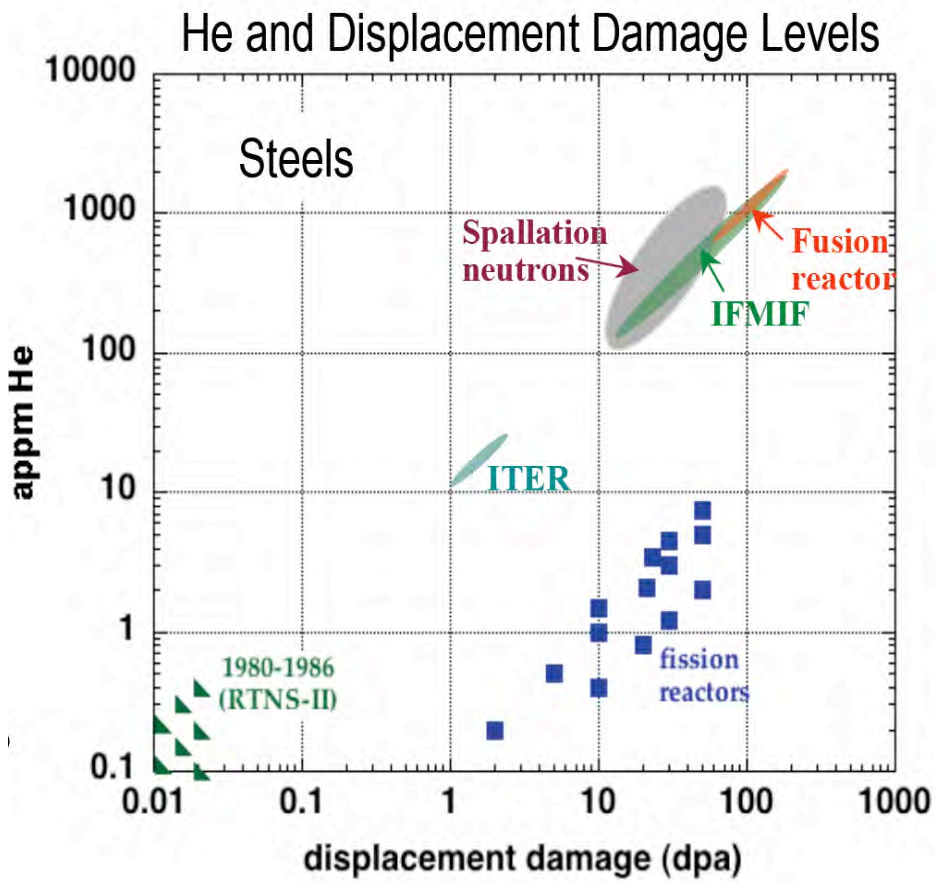


Source: R. Kurtz, M. Mauel, M.Nastasi, R. Odette, S. Sharafat, R. Stoller, S. Zinkle, MFES Research Needs Workshop (Bethesda, 2009)

Needs & Materiel Performance Gaps

- Finding & validating materials & blanket concepts in a fusion relevant environment is a necessary step for the design, construction, licensing, & safe operation of DEMO, *and* intermediate facilities to be built between the ITER and the DEMO.

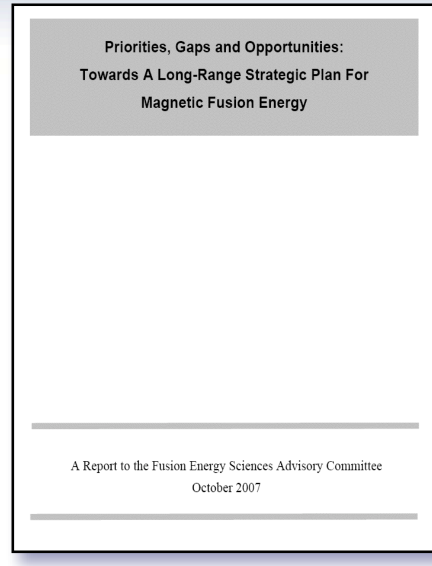
- To test & fully qualify candidate materials for high-fluence service in DEMO, a high-flux source of high energy neutrons needs to be built and operated that simulates service up to the full lifetime anticipated for DEMO and it's prerequisite facilities (*e.g.,* CTF).



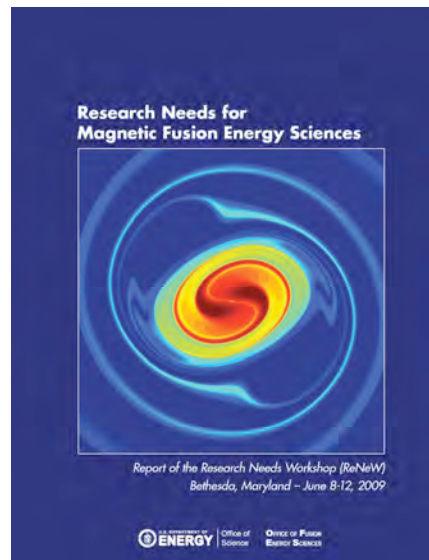
Sources: *IFMIF Comprehensive Design Report* (IEA, Jan 2004).
R. Kurtz *et al., ReNeW* (Bethesda, 2009).

The need for a neutron irradiation source has been articulated by the U.S. fusion community

- 2007 FESAC Panel recommended 9 initiatives, including:
  - A materials qualification facility that "would involve testing & qualification of low-activation materials by intense neutron bombardment. The facility generally associated with this mission is the IFMIF. The potential for alternative irradiation facilities to reduce or possibly eliminate the need for the US to participate as a full partner in IFMIF needs to be assessed."
- 2009 ReNeW recommendations:
  - "An essential requirement to fulfill the mission of (the Materials) Thrust is the establishment of a fusion-relevant neutron source to perform accelerated characterization of the effects of radiation damage to materials."
    - Specific example options cited: (1) IFMF; (2) Materials Test Station (LANSCE); (3) Dynamic Trap Neutron Source.
  - Carefully evaluate options & select the most technically attractive and cost effective approach or combination of approaches.
  - Balance need to obtain relevant bulk material property information with cost, schedule & potential for international participation to leverage investments by the US.
  - Later possibility might be to include large-scale nuclear facility such as the proposed FNSF. However, it must be emphasized that bulk material property data from a fusion relevant n source would inform the design, construction and licensing of such facilities.


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



The need for a neutron irradiation source has been articulated by the International fusion community

- Materials test facility options considered over last 3 decades.
  - Community selected a neutron source based upon D-Li stripping reaction as the basic concept of the International Fusion Materials Irradiation Facility (IFMIF).
- 2008 EU Fusion Facility Review concluded that:
  - During ITER construction, key strategic R&D emphasis should be on “establishing experimental means for validation” of materials in preparation for DEMO design
  - “During the following decade focus must shift towards…. optimizing and validating suitable materials and components for DEMO. ….It is imperative to make IFMIF available for preparing the DEMO engineering design & construction.”

R&D Needs and Required Facilities for the Development of Fusion as an Energy Source

Report of the Fusion Facilities Review Panel
October 2008

Current High-Power Accelerators with Spallation Neutron Production Capability

SNS (Oak Ridge)

LANSCE (Los Alamos)

SINQ(Paul Scherrer Inst.)

J-PARC (JAEA & KEK)

ISIS (Rutherford Appleton Lab)

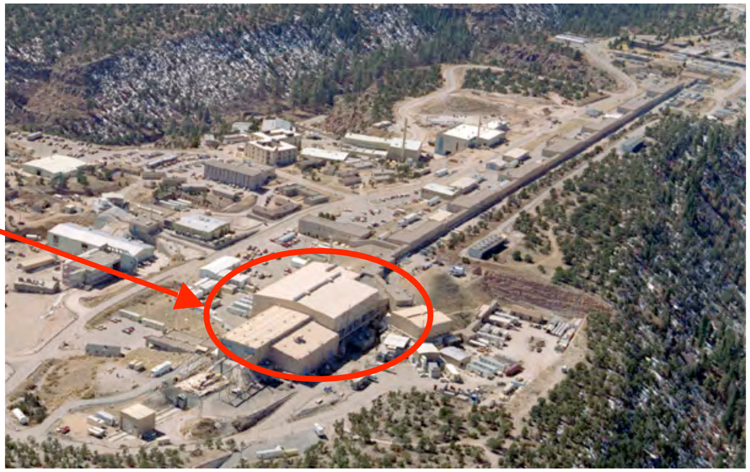
Using a spallation source for fusion materials testing is not a new idea

- Kley, Perlado, et al. (1984-89): EURAC proposal (600 MeV / 6 mA)
- Doran and Leiss (1989): IEA Evaluation Panel Report concluded that d-Li, spallation, and beam-plasma concepts all have the potential to meet flux, fluence, and test volume requirements
- Kondo, et al. (1992): concern over the neutron spectrum in spallation sources extending to several hundred MeV where "neutron data are poorly known, computational tools are inadequate, and radiation effects are poorly understood"
- IEA Evaluation Panel (Kondo 1992) concluded that "A spallation source is not generally favored by the materials community. It is a viable candidate only if it can be attained at much less expense than the alternatives."

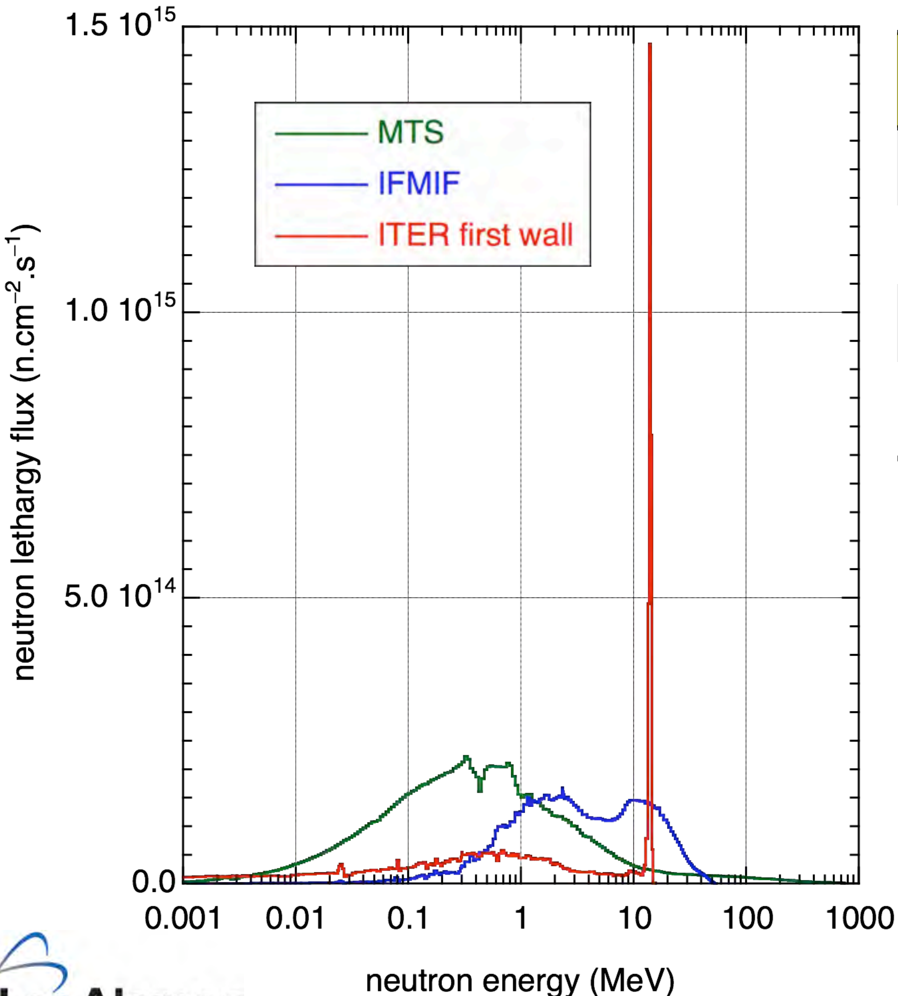
So what's different today?

- Nuclear data and simulation codes have made significant improvements
  - Nuclear data evaluations now extend to 150 MeV and include both He production and damage energy cross sections
  - Significant improvements in intranuclear cascade, high-energy fission, and evaporation models have been made, e.g.
    - New INCL / ABLA model
    - Improvements in evaporation models that now show better agreement with experimental data on He production
    - New experimental data against which to benchmark the codes

- The Materials Test Station:
  A cost effective spallation source building on existing infrastructure at LANSCE
  - Existing 1 MW proton linac with shared DOE sponsorship
  - Existing experimental hall with all needed utilities
  - Target designed specifically for high neutron flux irradiation



While a fusion reactor, a spallation source, and IFMIF have different spectra, materials damage is similar



	MTS	IFMIF	Fusion Reactor
dpa/fpy	**6-34**	**20-55**	**20-30**
appm He/dpa	**5-33**	**10-12**	**10-15**
appm H/dpa	**24-240**	**35-54**	**40-50**
transmutations in Fe appm Mn/dpa	**10**	**37**	**20-24**

- Major transmutants are similar for the three systems .
- Lack of neutrons below 100 keV in IFMIF HFTM yields a harder primary knock-on atom (PKA) spectrum than that for a fusion reactor 1st wall.

LANSCE presently provides the US & international research communities a diverse set of premier facilities

Unique, highly-flexible beam delivery to multiple facilities 6 mo/yr @ 24/7, > 80% reliability, with ~ 1200

Lujan Center

- *Materials science and condensed matter research*
- *Bio-science*
- *Nuclear physics*
- *A National BES user facility*

WNR

- *Nuclear physics*
- *Semiconductor irradiation*

Ultra-cold Neutron Facility

- *Fundamental nuclear physics*

Proton Radiography

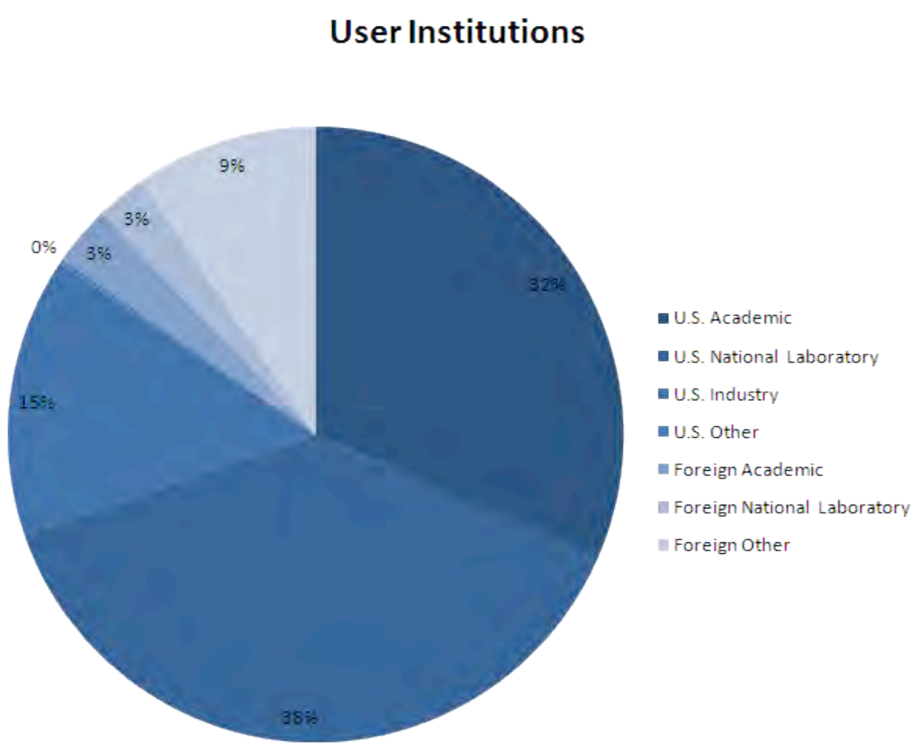
- *HE science, dynamic materials science, hydrodynamics*

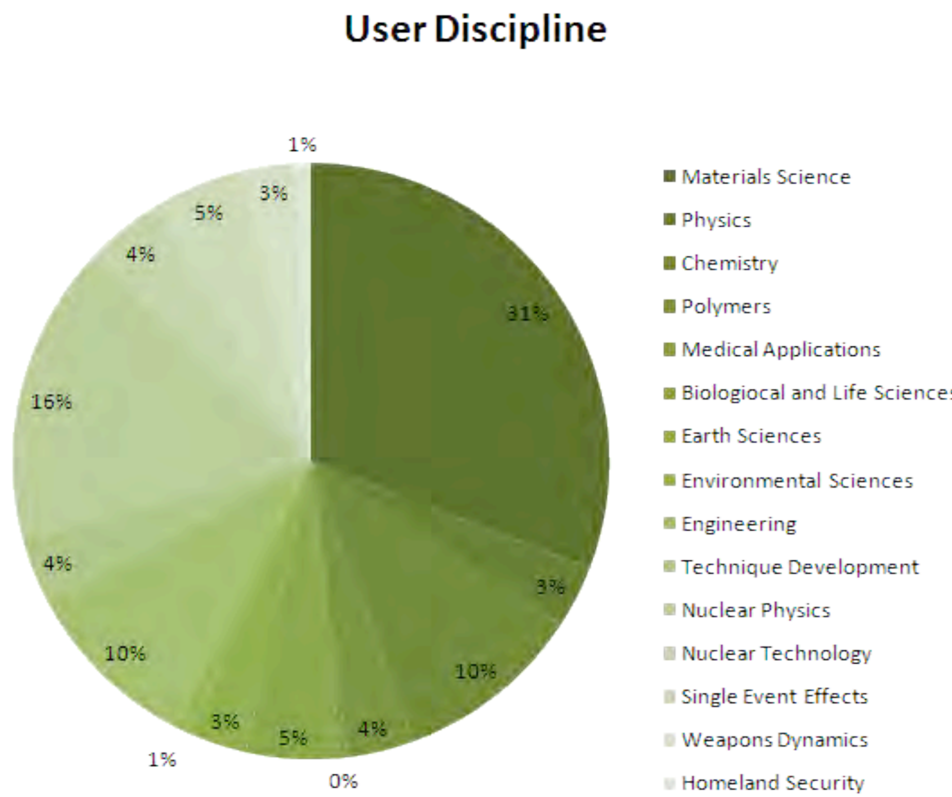
Isotope Production Facility

- *Nuclear medicine*
- *Research isotope production*

LANSCE serves a well-established and developing user community

Present LANSCE: 1200 User Visits Annually: 40 states, 15 foreign countries



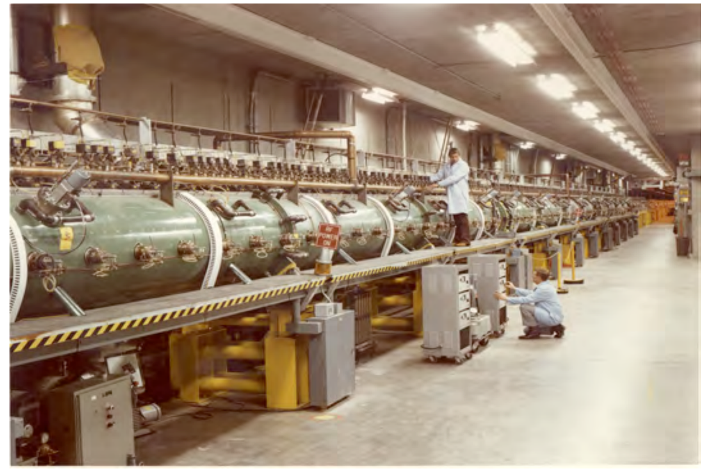


Year-to-date beam reliabilities exceeds 80% goals

CY2009 Year-to-Date			
Target	Hours Scheduled	Hours Delivered	Reliability
Lujan	1839.0	1502.8	81.7%
WNR Target 4	1716.5	1522.6	88.7%
pRad	508.3	448.8	88.3%
IPF	1869.4	1774.1	94.9%
UCN	746.0	611.8	82.0%
WNR Target 2	146.7	134.2	91.5%

Replacement value of LANSCE is ~$1.5B - with proper investment & maintenance, facility has no practical lifetime limit

The beam is produced by an injector and accelerated to 0.75 MeV



A Drift-Tube Linac Increases the Energy to 100 MeV

A Side-Coupled Linac Further Increases the Energy to 800 MeV

Control Room

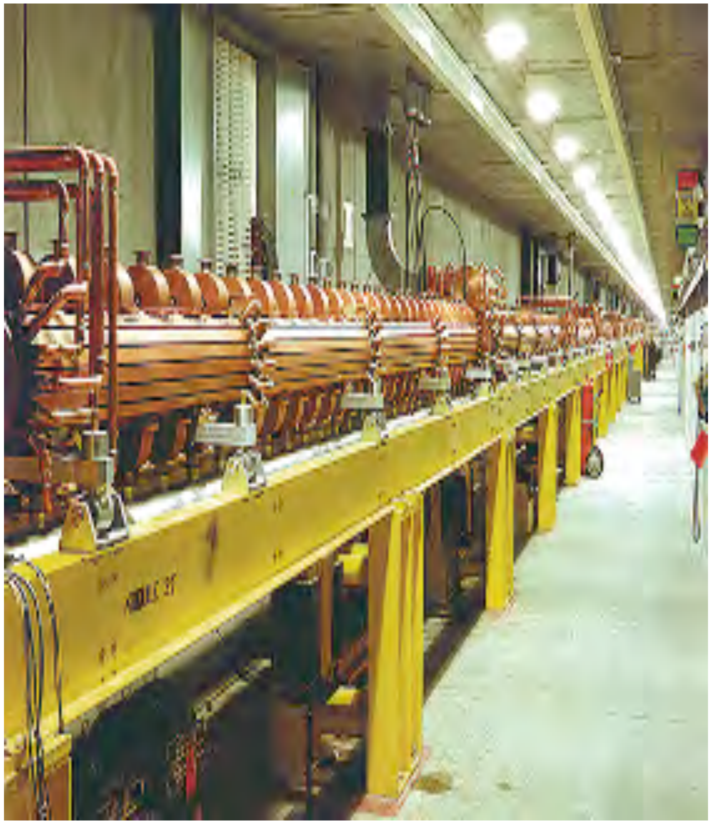
Substantial capital investments in the LANSCE Facility are underway to further improve reliability

- Facility Infrastructure & Revitalization Projects (FIRP, $25M, NNSA)
  - Radioactive liquid waste plant replacement
  - Cooling towers: 3 old units replaced with two modern units that provide greater efficiency and improved chemistry control
  - >30 year old chilled water plant replaced in FY04
  - Key sector water and power systems, Lujan spallation neutron target, and ventilation system all replaced in FY07
- LANSCE Refurbishment (LANSCE-R) Project ($149M, NNSA)
  - Scope includes replacement of RF Power System Components, Drift Tube Linac Subsystems, Facility Control Systems.
  - CD-0 granted in FY07
  - Working towards a 2015 completion schedule and expects CD-1 approval from NNSA in FY09
- Materials Test Station (MTS) Project ($58-90M, DOE-NE)
  - Provide irradiation capability for candidate fast-reactor fuels, targets and materials

Antiquated control system to be replaced by a modern EPICS system in LANSCE-R

LANSCE-R ensures reliable LANSCE operations to well into the 21st century

- **The LANSCE Refurbishment project is a 5 year, $149M line item construction project designed to:**
  - *Refurbish the 201MHz and 805 MHz RF systems to regain reliable RF power system operation.*
  - *Restore 120 MHz linac operation.*
  - *Implement a modern, maintainable EPICS-based control system.*
- **The project is integrated with operations to ensure continued programmatic research and a robust user program during project execution.**
- **CD-1 approved in late FY08**

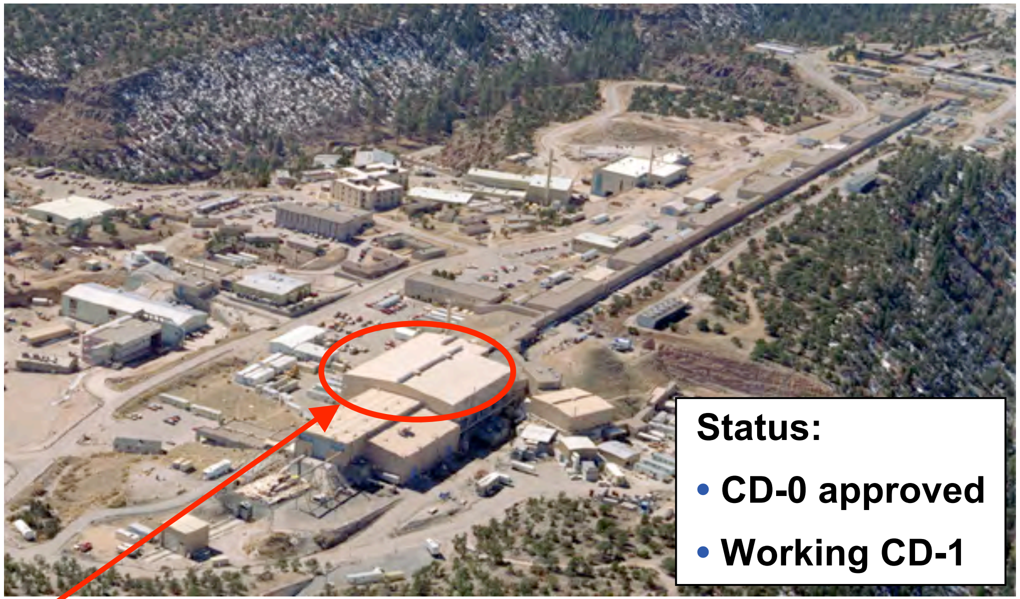


The LANSCE LINAC

LANSCE Materials Test Station to be 1st spallation source for high-flux neutron irradiation studies

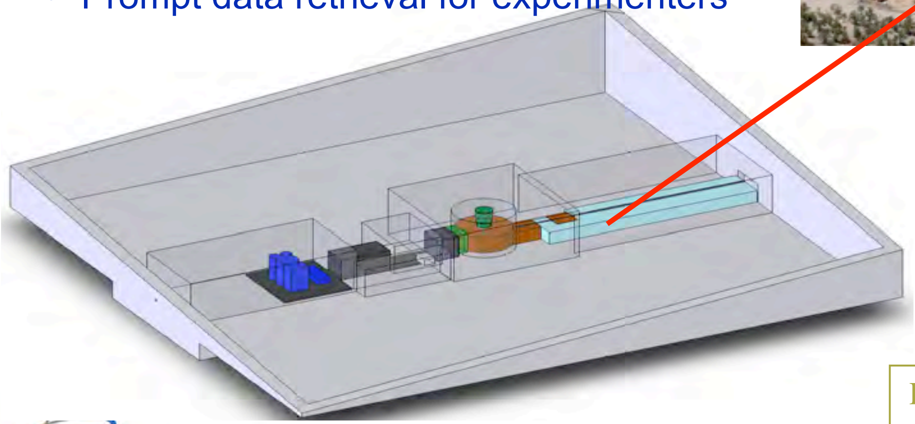
The quickest path to a fast-spectrum fission & fusion irradiation capability.

- Up to 2e15 n/cm^2/s (w/ beam upgrades), appropriate to prove transuranic fuel (*e.g.,* Np, Pu, Am, Cm) performance
- Spectrum relevant for fusion materials testing
- Controlled prototypic temperature, coolant environment
- Prompt data retrieval for experimenters



Status:

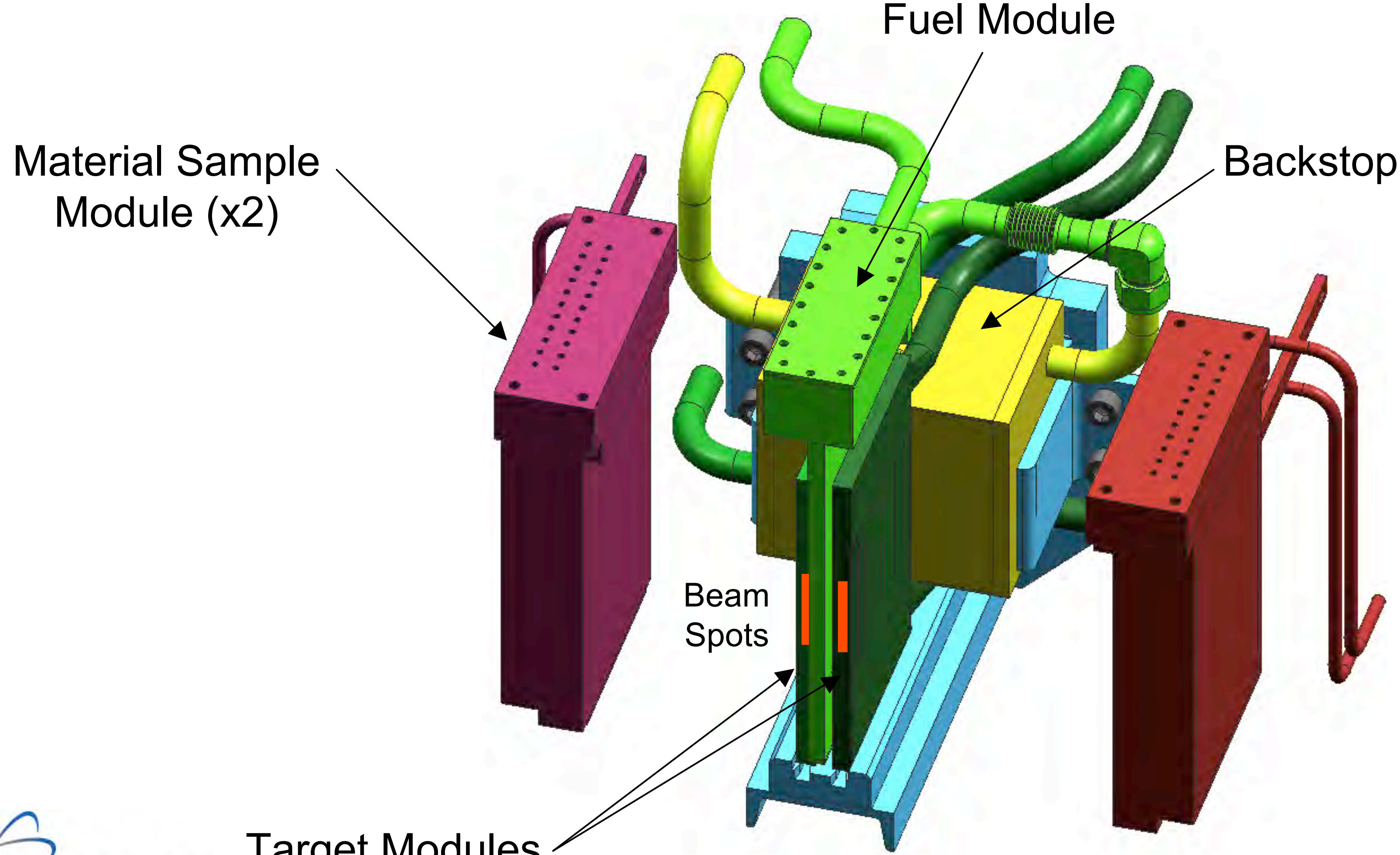
- **CD-0 approved**
- **Working CD-1**



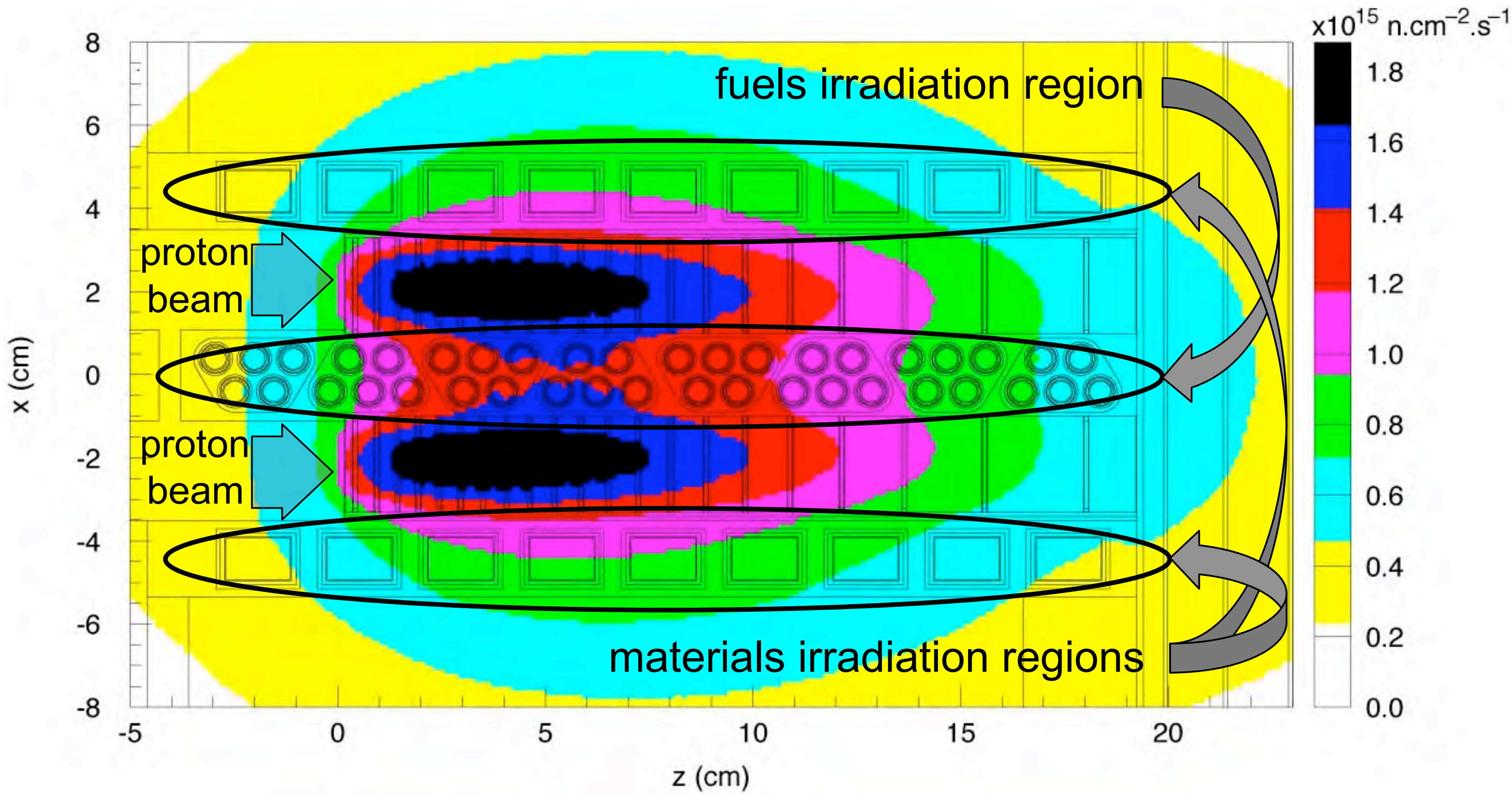
MTS is being built in an existing 3,000-m^2 experimental hall located at the end of the Los Alamos LANSCE linac ,which has successfully delivered 800-kW, 800-MeV beam to this area for a quarter century.

Ref: E.J. Pitcher, in *Utilization & Reliability of High Power Proton Accelerators* (OECD Publishing, 2008) pp. 427-433.

Target Assembly – Expanded View



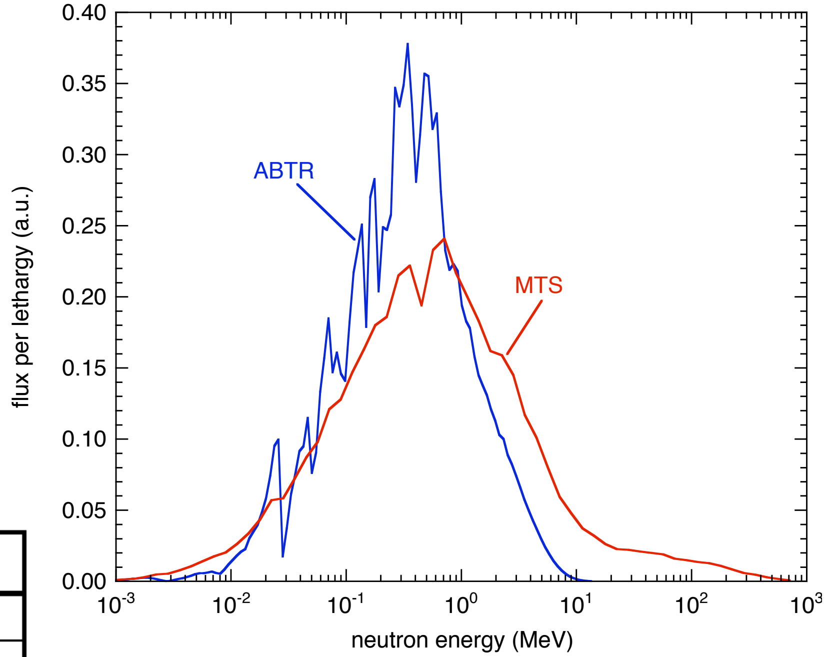
MTS produces an intense neutron flux for fast reactor fuels and materials irradiations



While designed for fission irradiations, the MTS environment is well suited for fusion materials testing, short-lived isotope production, transmutation studies, and cross section measurements.

MTS is the only viable option for near-term domestic fast-spectrum irradiations

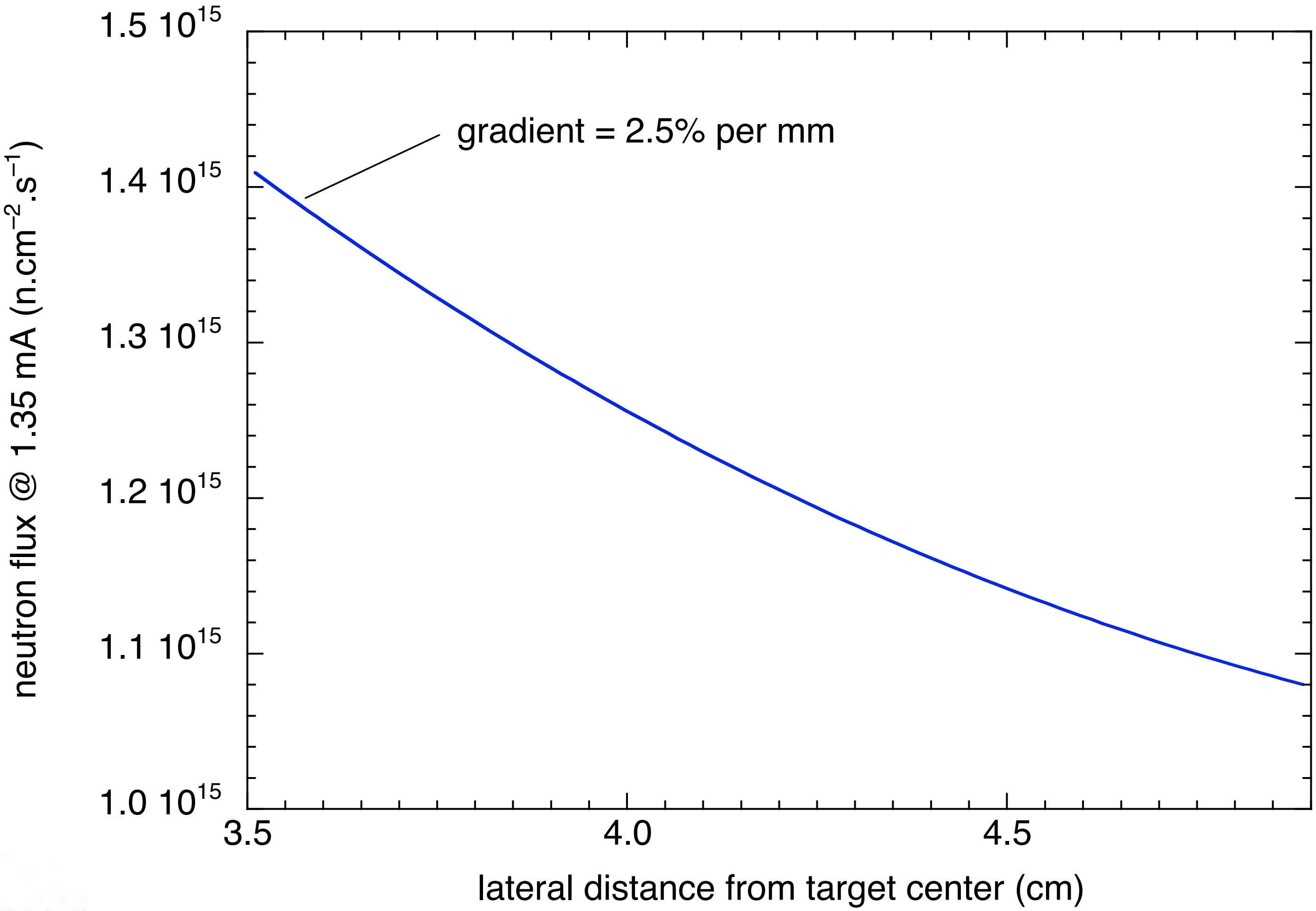
- No domestic facility today
- Limited facilities abroad
  - Phenix will close in 2009
  - JOYO operations plans under revision
  - BOR-60 access no longer viable
- A new domestic fast reactor will take at least a decade to build



Criterion	Design Requirement	Current Design
Neutron spectrum	Similar to that of a fast reactor	Meets requirement
Peak fast (>0.1 MeV) neutron flux	$\geq 1\times10^{15}$ n.cm^{-2}.s^{-1}	1.3×10^{15} n.cm^{-2}.s^{-1}
Irradiation volume	40 pellets in fast flux of at least 1×10^{15} n.cm^{-2}.s^{-1}	Exceeds requirement by factor of 5
Irradiation temperature	Up to 550 °C at clad surface	Meets requirement
Availability	$\geq$3%/y burnup and $\geq$10 dpa/y in Fe in the peak flux region	4%/y burnup and 18 dpa/y in Fe
Prototypic fast reactor environment	Ability to accommodate liquid metal coolants	Meets requirement

MTS neutron spectrum is similar to that of a fast reactor with the addition of a high-energy tail

MTS flux gradient in the lateral direction is sufficiently low for material sample irradiations



MTS radiation damage in Fe is predominantly from neutrons

Damage in Fe from neutrons and protons, dpa & He production in the peak damage position within the materials modules at 1 MW & 1.8 MW.

1 MW

	dpa/FPY	appm He/FPY	appm He/dpa
neutrons	24	257	
protons	1	81	
total	25	339	13.4

1.8 MW

	dpa/FPY	appm He/FPY	appm He/dpa
neutrons	44	463	
protons	2	147	
total	46	610	13.4

Energy deposition in the peak flux location is dominated by proton heating

Energy deposited in fusion candidate materials in W/cm^3 from neutrons, protons and photons at 1.25 mA and 2.25 mA.

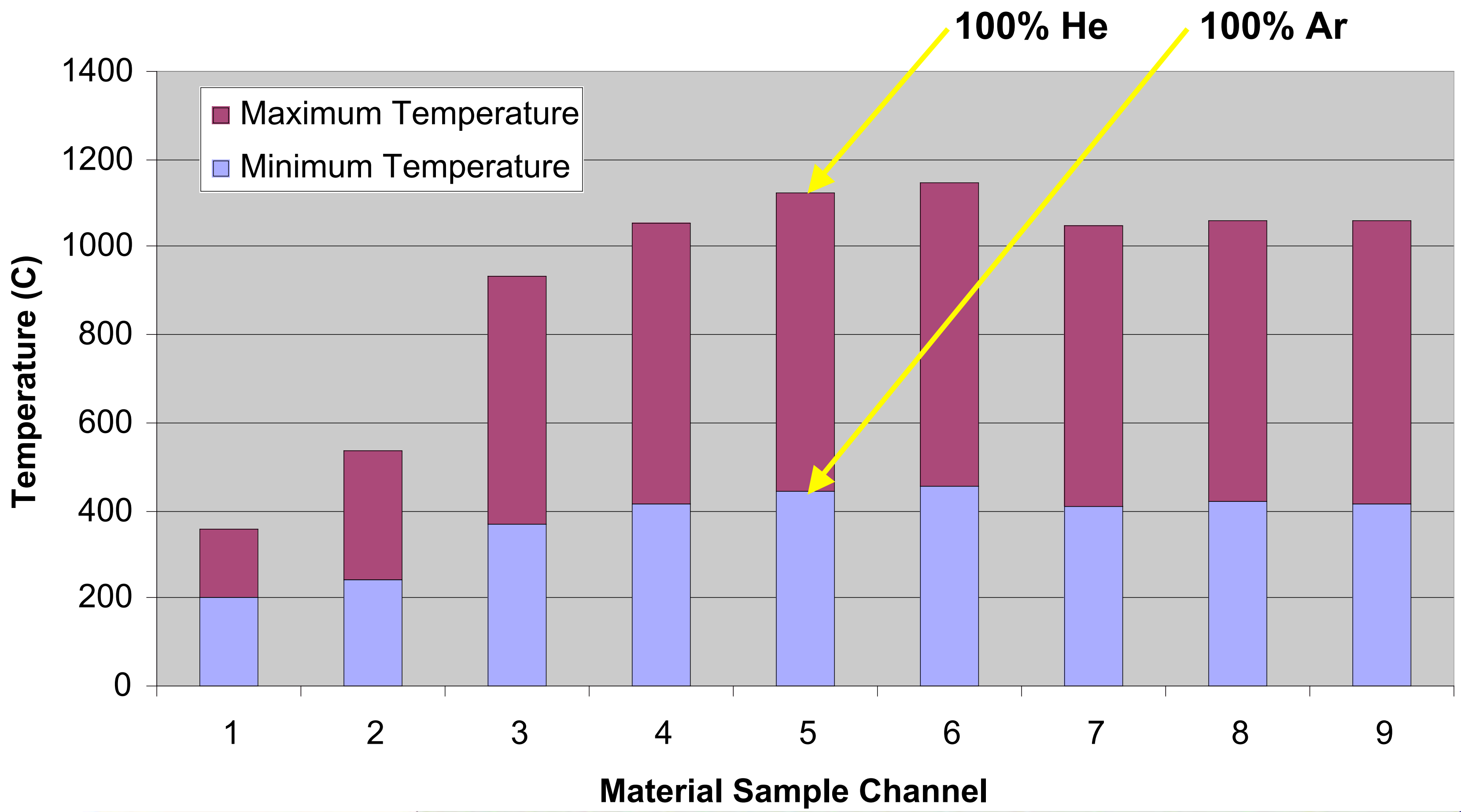
1 MW

Material	energy deposition by neutrons	photons	protons	total
V-4Cr-4Ti	2.3	9.8	54.3	66.4
T91	2.4	15.1	80.7	98.2
Nb-1Zr	1.9	23.0	81.3	106.1
SiC	6.9	5.1	41.8	53.7
316L	2.6	14.2	73.0	89.7

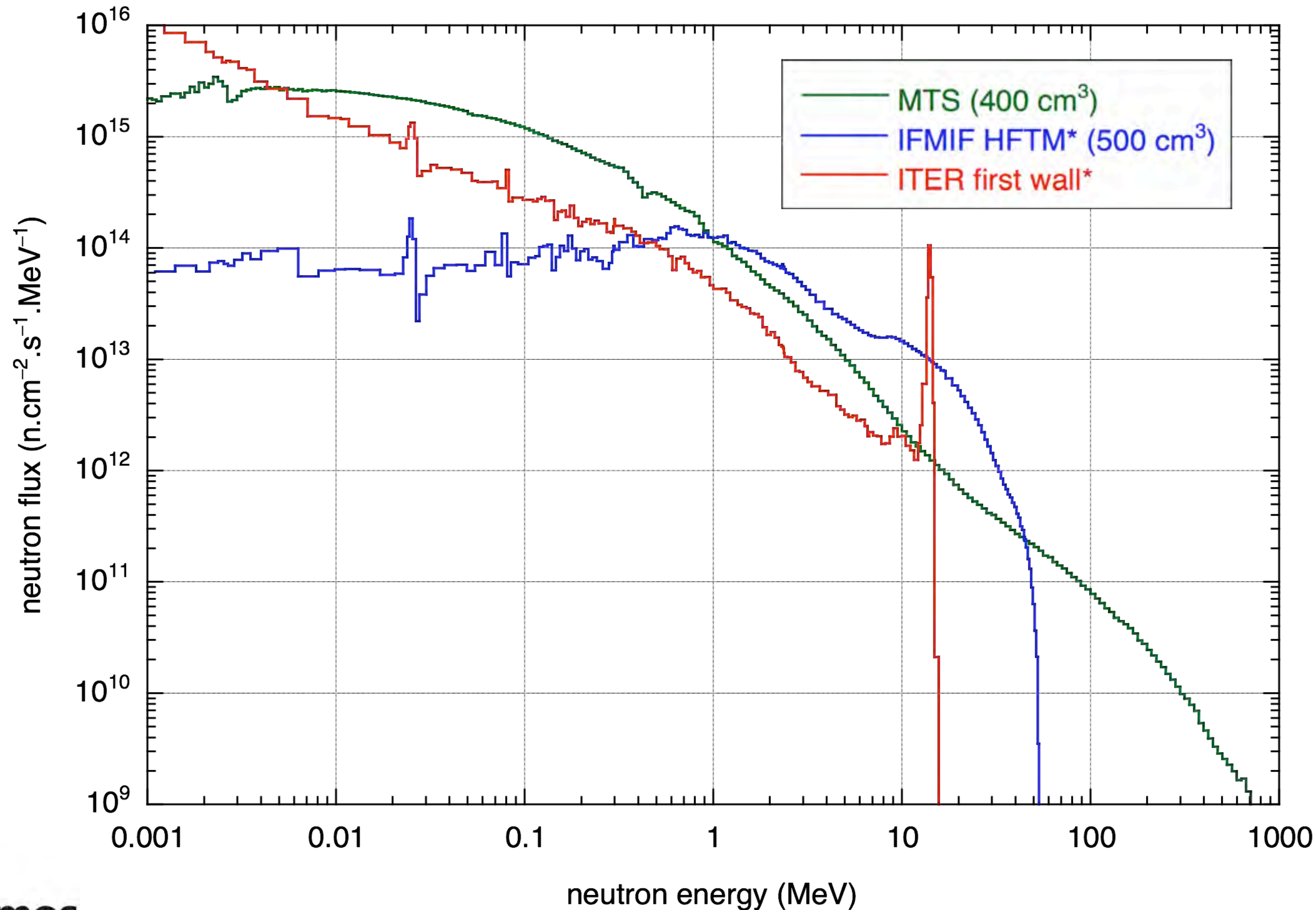
1.8 MW

Material	energy deposition by neutrons	photons	protons	total
V-4Cr-4Ti	4.2	17.7	97.7	119.5
T91	4.3	27.2	145.3	176.8
Nb-1Zr	3.3	41.3	146.3	191.0
SiC	12.3	9.2	75.2	96.7
316L	4.7	25.5	131.3	161.5

A broad range of sample irradiation temperatures are possible by adjusting gas gap composition

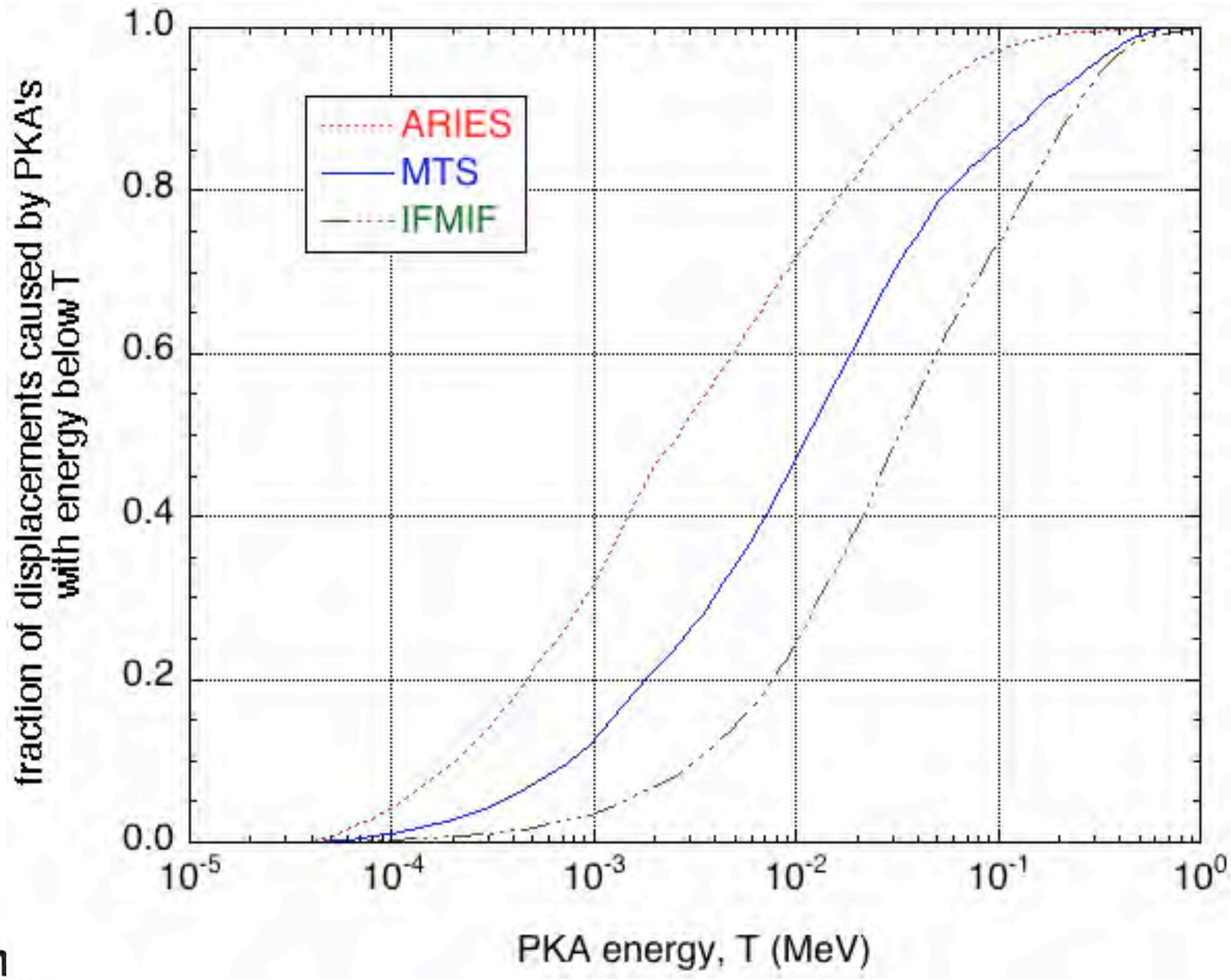


The MTS neutron spectrum has potential application for fusion materials research

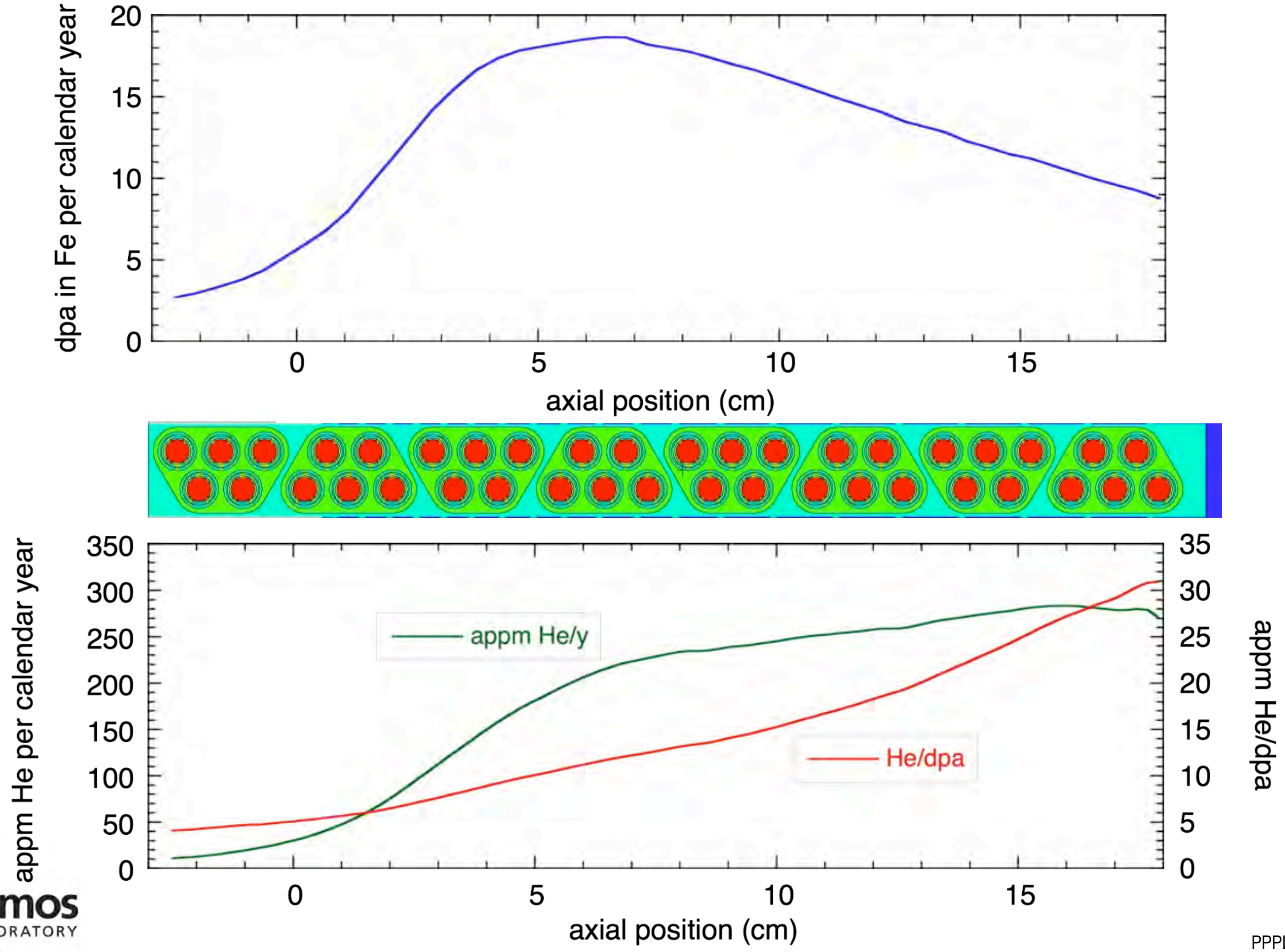


* Data from U. Fischer et al., Fusion Engineering and Design 63-64 (2002) 493-500.

Comparisons of primary knock-on atom (PKA) spectra of a fusion reactor 1st wall, IFMIF High-Flux Test Module, & MTS



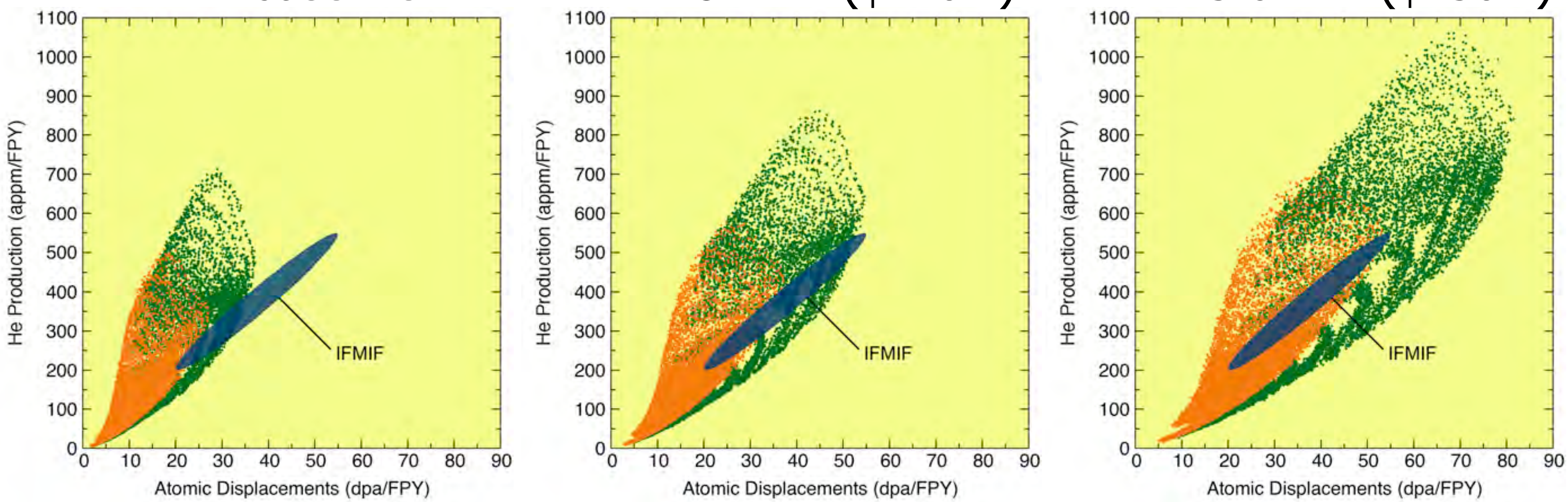
Within the fuel module, the peak damage rate is 17 dpa/calendar year, with He/dpa = 13 appm/dpa



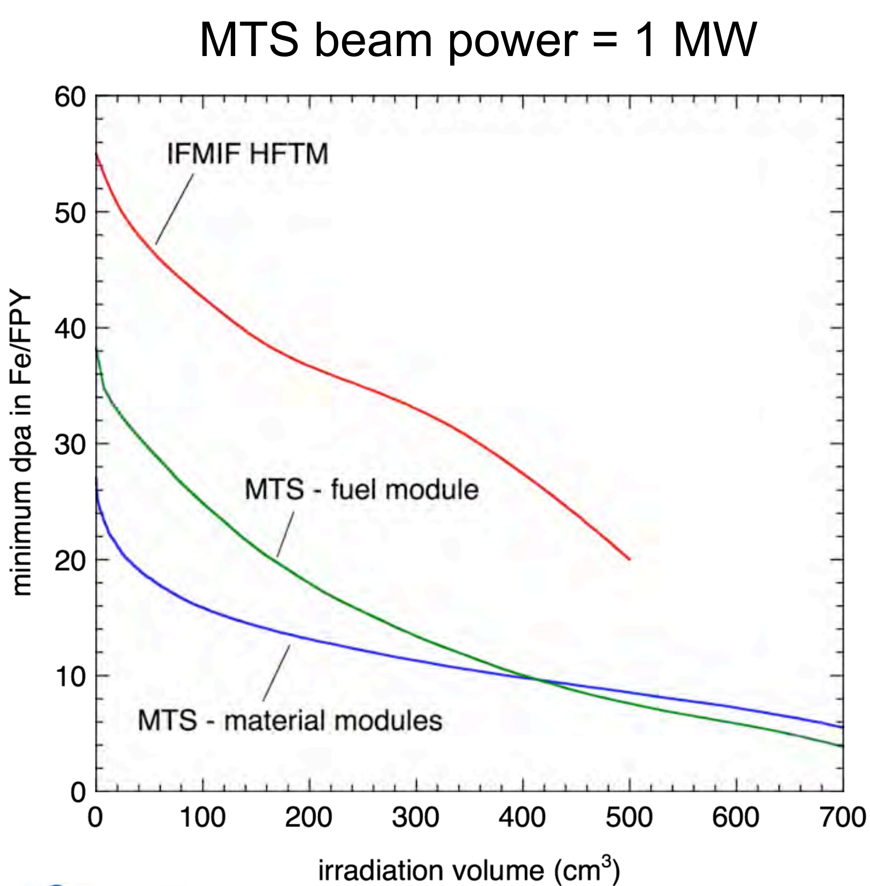
The MTS is a cost-effective alternative for a fusion materials irradiation facility

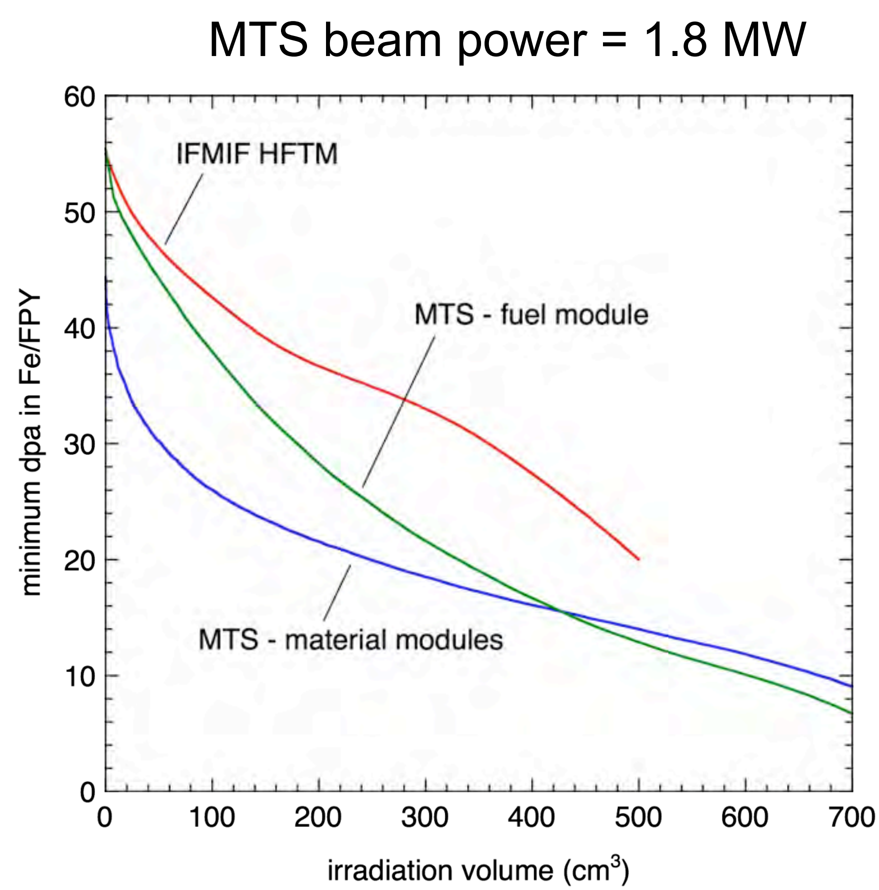
- MTS total project cost range is $63M to $81M (1 MW baseline, funded by DOE-NE)
- LANSCE beam power upgrade options:

1 MW baseline | 1.8 MW ($120M) | 3.6 MW ($230M)

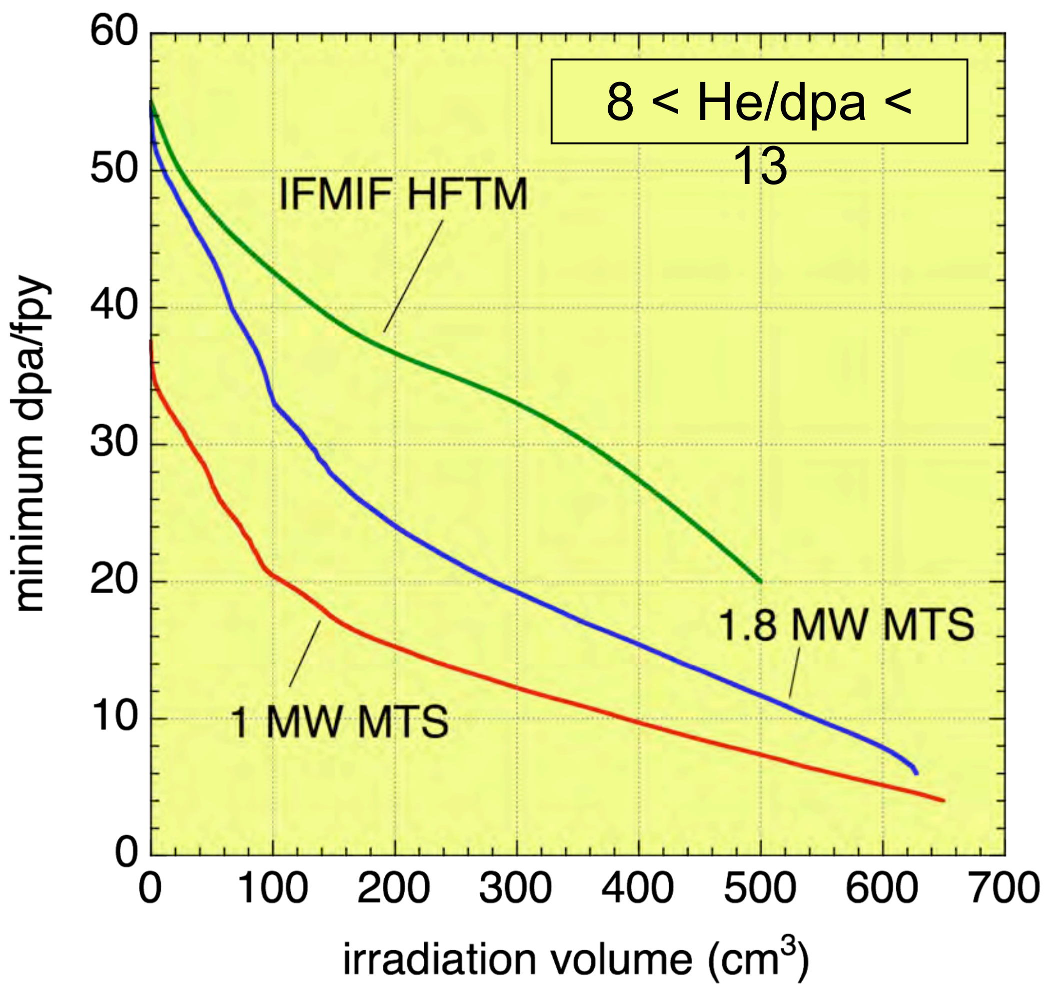


At 1.8 MW, MTS provides nearly the same dose and irradiation volume as IFMIF

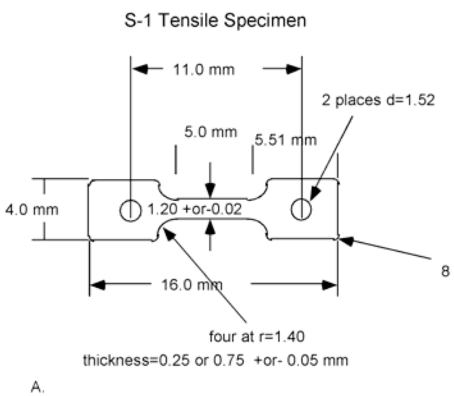


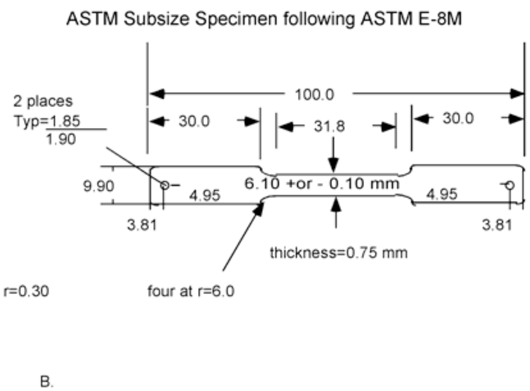


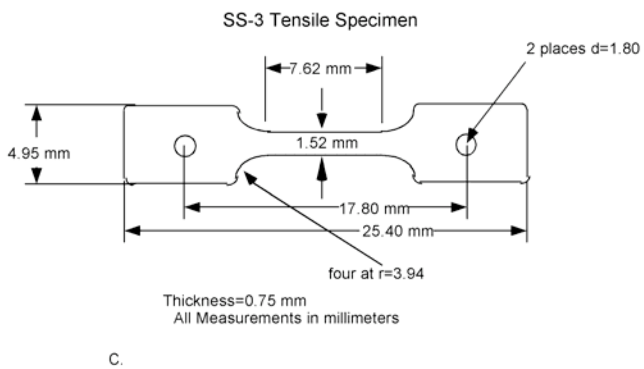
MTS irradiation volume is sufficient for conducting a vigorous fusion materials R&D program

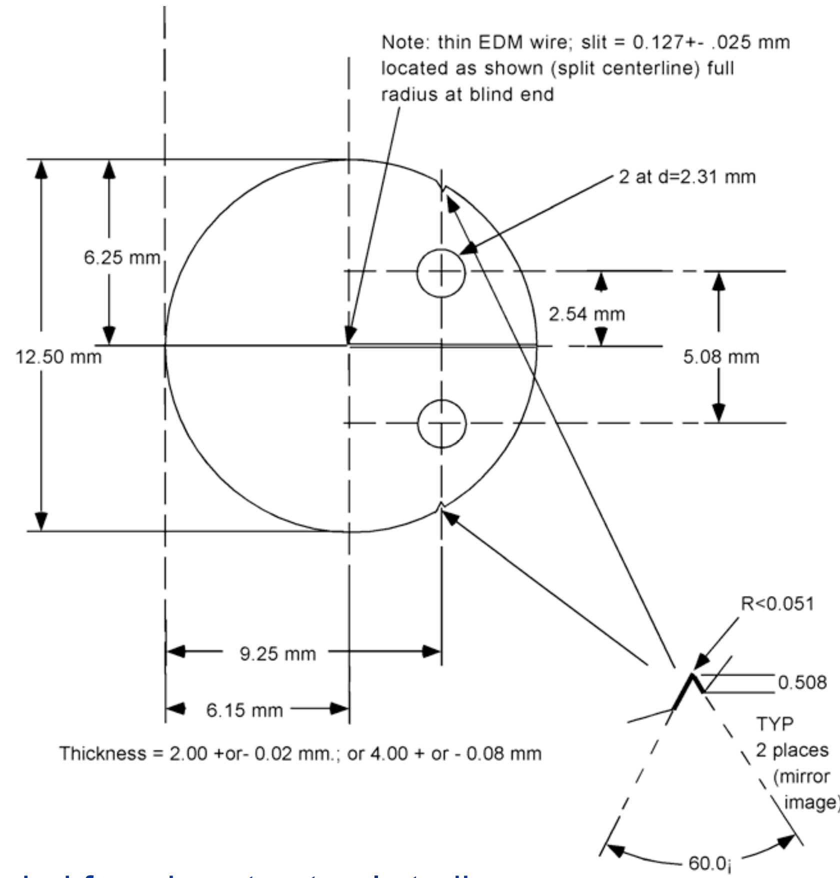


MTS irradiation locations can contain a range of different macroscopic specimens (tensile, compact tension, *etc*.)









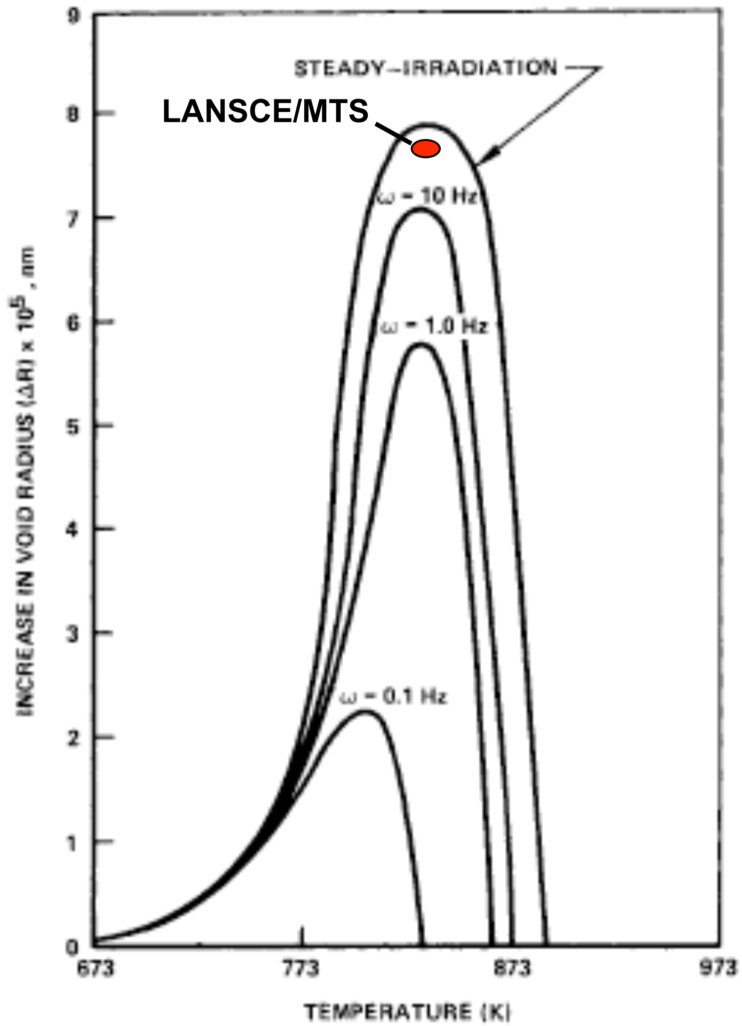
- TEM Specimens would be included for microstructural studies
- Each Tube needs to have at least two thermocouples for instrumentation

Operating a spallation source is cost effective

- Annual electricity usage comparison
  - IFMIF: 230 million kW-h
  - MTS (at 1 MW, 1.8 MW, or 3.6 MW): ~40 million kW-h *(800-MeV protons have 10 times greater neutron production per unit beam power than 40-MeV deuterons)*
- Other accelerator operating costs (*e.g.,* staff, spare parts)
  - IFMIF: accelerator is wholly dedicated to IFMIF target
  - MTS: LANSCE is a multi-target facility with shared accelerator operating costs
    - Shared accelerator beam does not preclude 1- to 3.6-MW beam delivery to MTS)

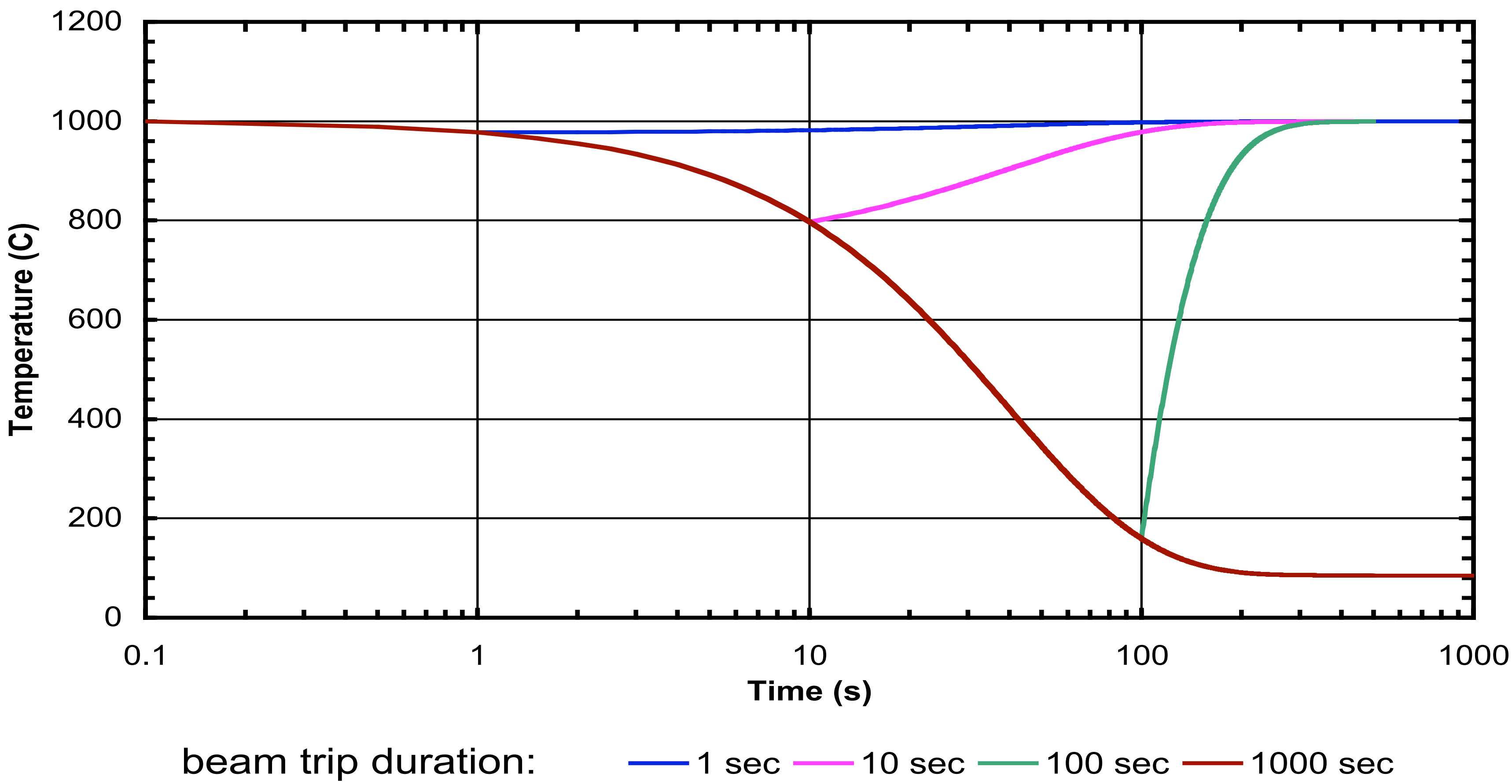
Pulsed nature of LANSCE proton beam being assessed relative to steady-state reactor conditions

- Studies indicate that the 100-Hz repetition rate of the LANSCE accelerator should exhibit radiation damage conditions close to that of steady-state
  - Graph shows calculated void growth vs. temperature for pulsing frequencies of 0.1, 1, and 10 Hz [Ghoniem & Gurol, Rad Effects 55 (1981) 209].
- Further work is needed to understand the effects of:
  - 7.5% beam duty factor
  - Beam rastering



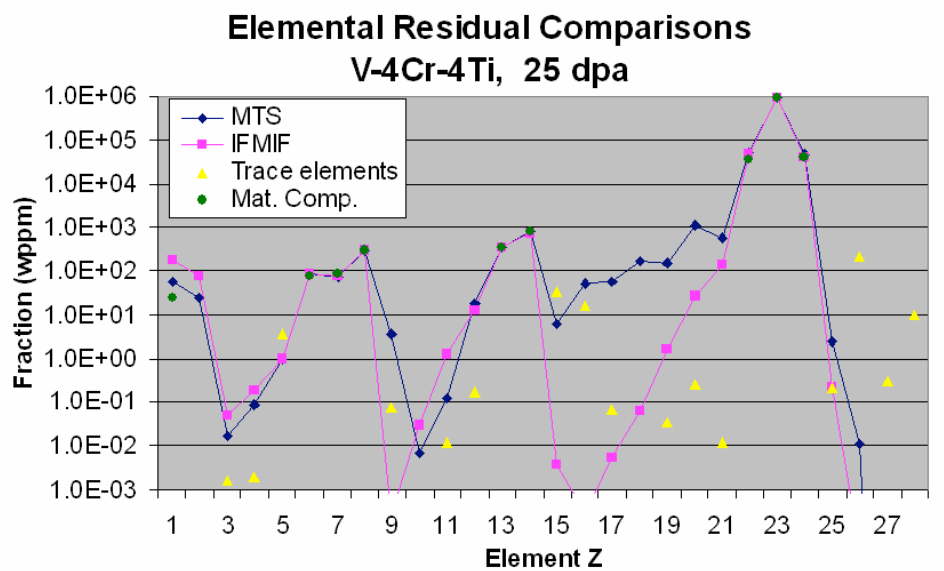
Los Alamos NATIONAL LABORATORY EST. 1943

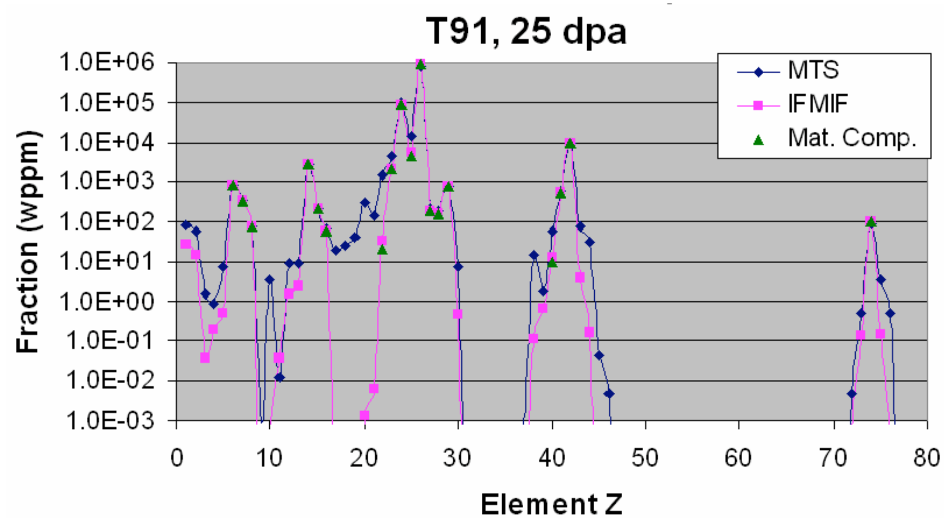
Material sample operating temperature recovers from beam trips within minutes



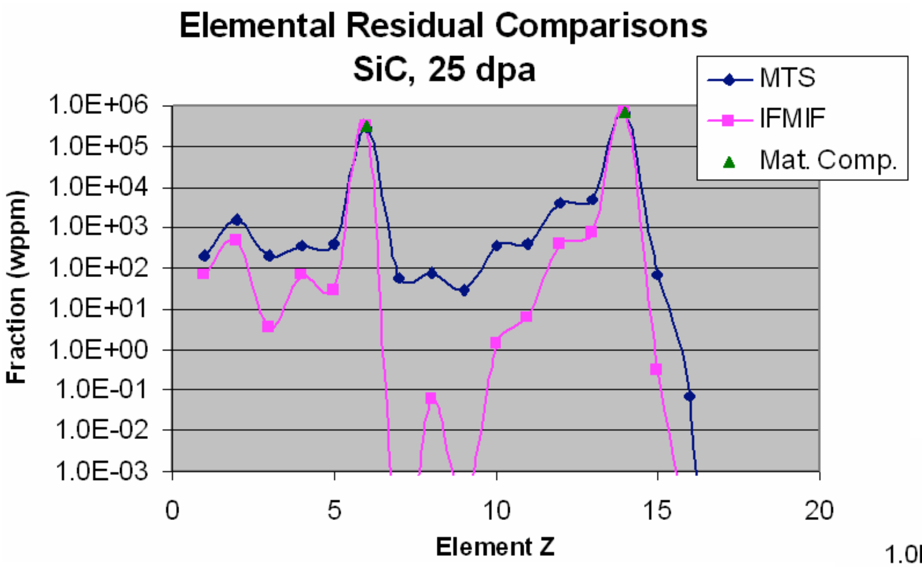
Impurity build-up during irradiation is small

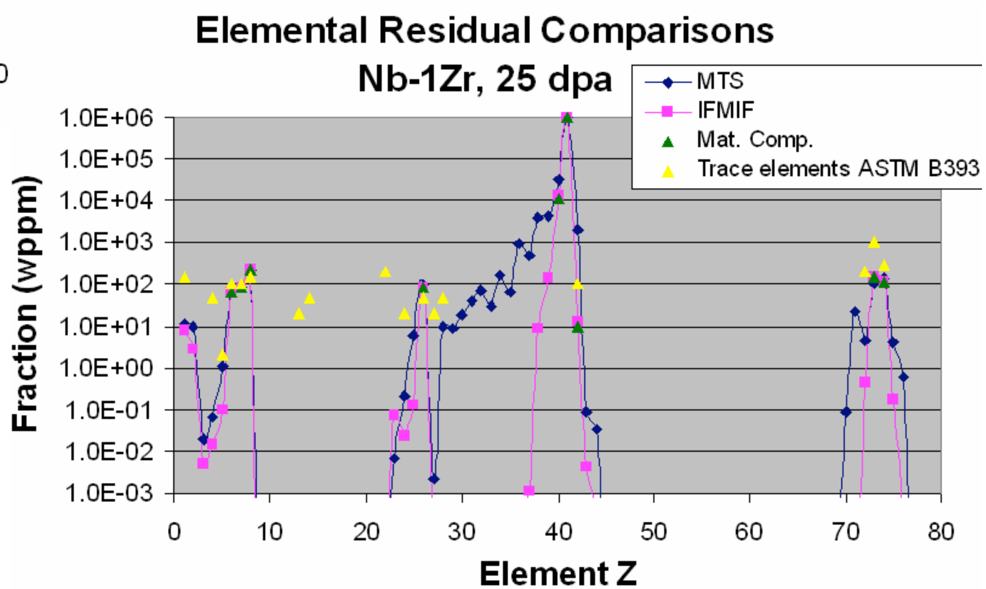
- Most prominent nuclide created by spallation has atomic number (Z-1), *e.g.,* for Fe-based alloys, Mn has the highest production rate
- The production rate of Mn from Fe at the peak flux position is about 10 appm/dpa
- For Fe samples taken to 50 dpa, this represents about a 0.05% "burn-in" of Mn
- Most Fe alloys have some Mn as an alloying agent, e.g., about 0.5% in T91





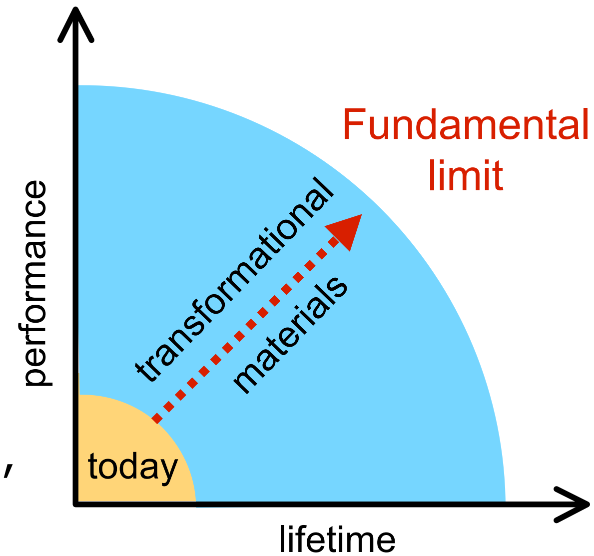
Similar results seen for impurity buildup in SiC and Nb-1Zr





Introduction to the MaRIE Facility Concept: A Transition from "observation & validation" to "prediction & control"

Achieve Transformational Materials Performance
- Solutions require unprecedented control of defects & interfaces



Through Predictive Multi-scale Understanding
- Perform experiments with unprecedented spectral, temporal, and spatial resolution in previously un-accessed extremes

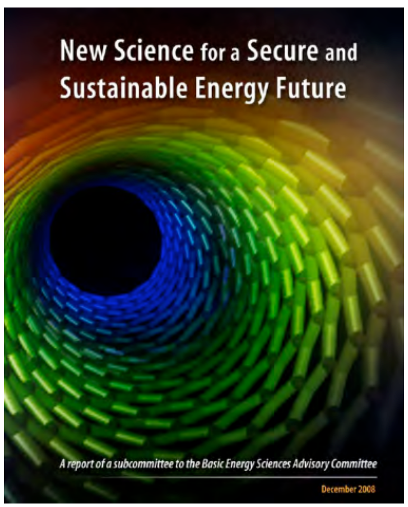
with an emphasis on Radiation-Matter Interactions
- Nuclear is special for LANL and for the world
  - LANSCE is key to our uniqueness in materials-centric national security science

MaRIE will be the first capability with unique co-located tools necessary to realize transformational advances in materials performance in extremes

Transition from “observation & validation” to “prediction & control” is the frontier of materials research

http://www.sc.doe.gov/bes/reports/list.html

By engaging thousands of scientists around the world in a series of workshops, BES has defined 5 key grand challenges for materials research



- Control the quantum behavior of electrons in materials
- Synthesize, atom by atom, new forms of matter with tailored properties
- Control emergent properties that arise from the complex correlations of atomic and electronic constituents
- Synthesize man-made nanoscale objects with capabilities rivaling those of living things
- Control matter very far away from equilibrium

“The intersection of control science with high-functioning materials creates a tipping point for sustainable energy”

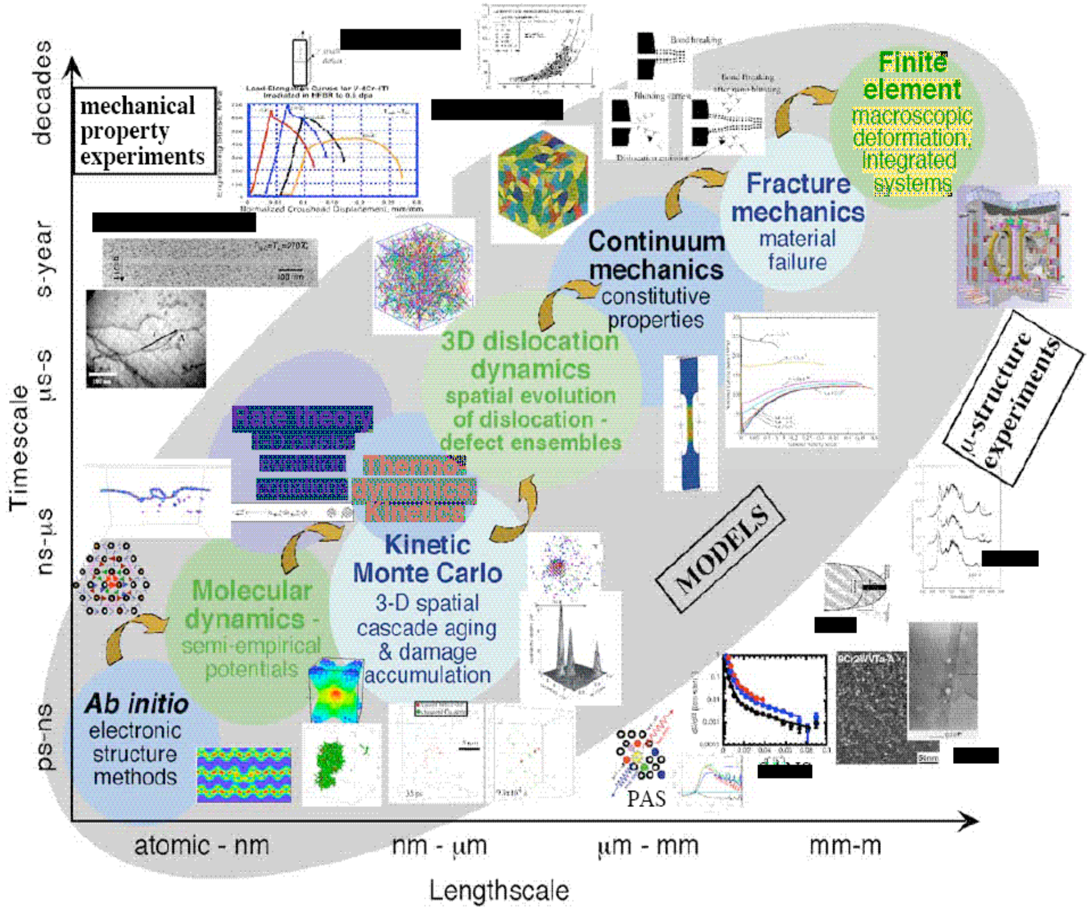
MaRIE provides to the user community the needed “beyond nano” tools for discovering and controlling complex materials

Experimental tools with unprecedented resolution are needed to validate & test the limits of modeling & simulation

Radiation damage is inherently multiscale with interacting phenomena ranging from ps to decades and nm to m

Anticipated advances in petaflop/s and exaflop/s computing – with advanced models - put us on the verge of accessing new phenomena on the micron scale

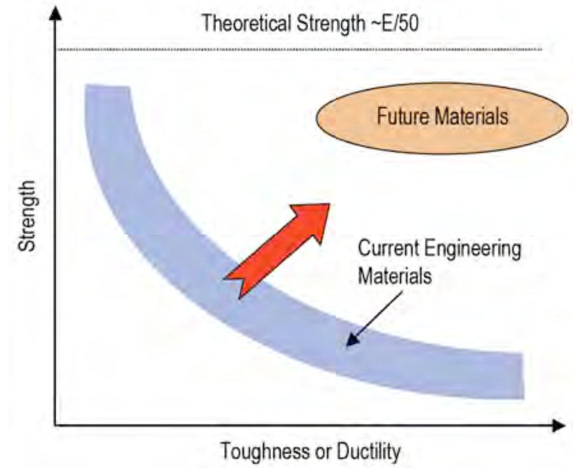
One of the greatest challenges in multi-scale modeling is the physically-based treatment of defects and interfaces

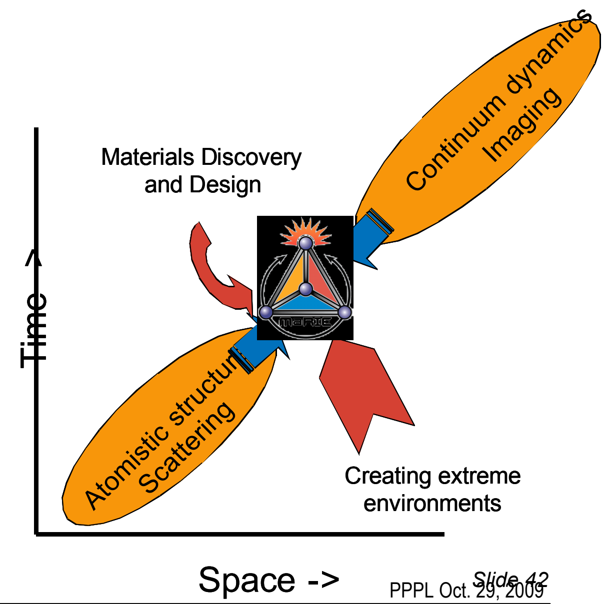


Source: R. Kurtz *et al.*, *ReNeW* (Bethesda, 2009).

Transition from "observation & validation" to "prediction & control" is a central mission challenge AND the frontier of materials research

- Conquering "the micron frontier" is essential for solving transformational materials grand challenges
- MaRIE will provide unique capabilities
  - Simultaneous *in situ* imaging and scattering measurements
  - Accessing materials irradiation/damage extremes
  - Incubating materials discovery and solutions through control of defects and interfaces
- LANSCE is essential for MaRIE's success
- Facility definition is being driven by community demand through validated performance gaps and functional requirements





MaRIE will be the first capability with unique co-located tools necessary to realize transformational advances in materials performance in extremes

MaRIE: A comprehensive set of co-located tools to realize transformational advances in materials performance in extremes

First x-ray scattering capability at high energy and high repetition frequency with simultaneous charged particle dynamic imaging

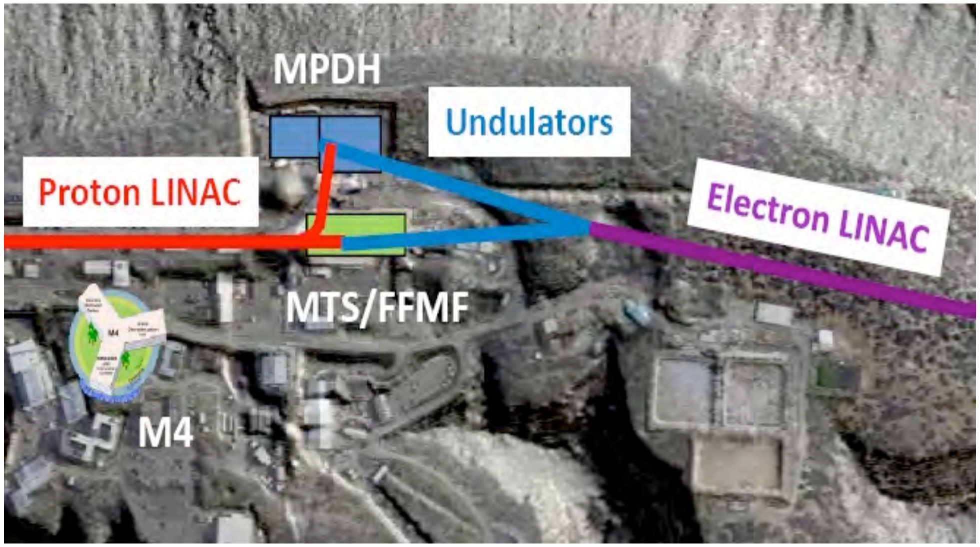
- Multi-Probe Diagnostic Hall (MPDH)

Unique in-situ diagnostics and irradiation environments beyond best planned facilities

- Fission - Fusion Material Facility

Comprehensive, integrated resource for materials synthesis and control, with national security infrastructure

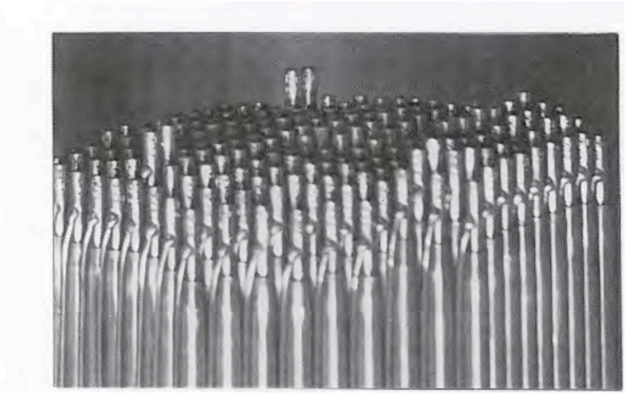
- Making, Measuring & Modeling Materials Facility (M4)



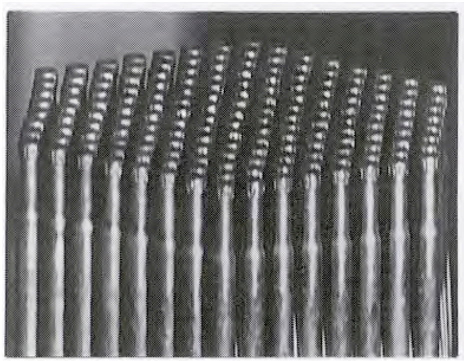
What does MaRIE success look like? Radiation-tolerant materials by design

- Developing radiation resistant structural materials by design

  e.g., Nanolayer architectures produce materials strength that exceeds theoretical "limits," and also produce extreme radiation resistance by actively eliminating point defects



D9 irradiated to 2.1 10^{23} (E>0.1MeV)*



HT9 irradiated to 1.9 10^{23} (E>0.1MeV)*

* Makenas et al 1990

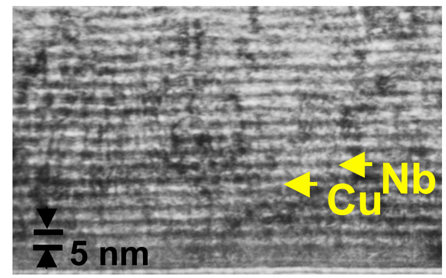
Ferritic/martensitic steels (e.g., HT9) are leading candidates for cladding, structural materials of fast breeder reactors and 1st walls & blankets in conceptual fusion reactor designs. They show resistance to void swelling and have adequate mechanical properties at elevated temperatures & expanded operating environments However, our understanding of the atomic-level processes that control bulk behavior is substantially incomplete

MaRIE Fission Fusion Materials Facility builds upon the LANSCE-R & MTS Projects

New capabilities from MaRIE:

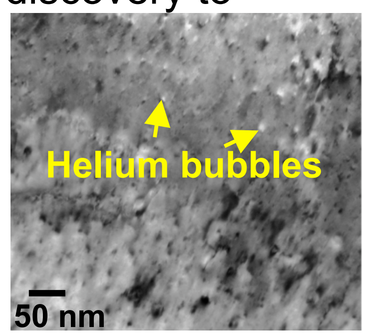
- Linac 2x power upgrade (to 1.8 MW) enables IFMIF-class irradiation capability
- Multiprobe Diagnostic Hall enables unsurpassed *in situ* and near-*in situ* sample measurements
  - *e.g.,* microstructure, voids, strain & swelling, corrosion layers, crack formation, creep & fatigue,
  - sample transport and hot cell infrastructure
- Near real-time materials characterization including post irradiation examination
- M4 Facility enables modeling, materials development, qualification, & characterization that translates discovery to solution

Frontiers of materials discovery: Interface/structure manipulation produces enhanced strength and radiation resistance:

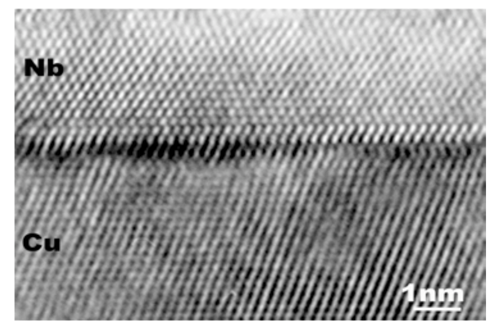


Nanolayer architectures produce materials strength that exceeds theoretical "limits"

Same structures produce extreme radiation resistance by actively eliminating point defects.

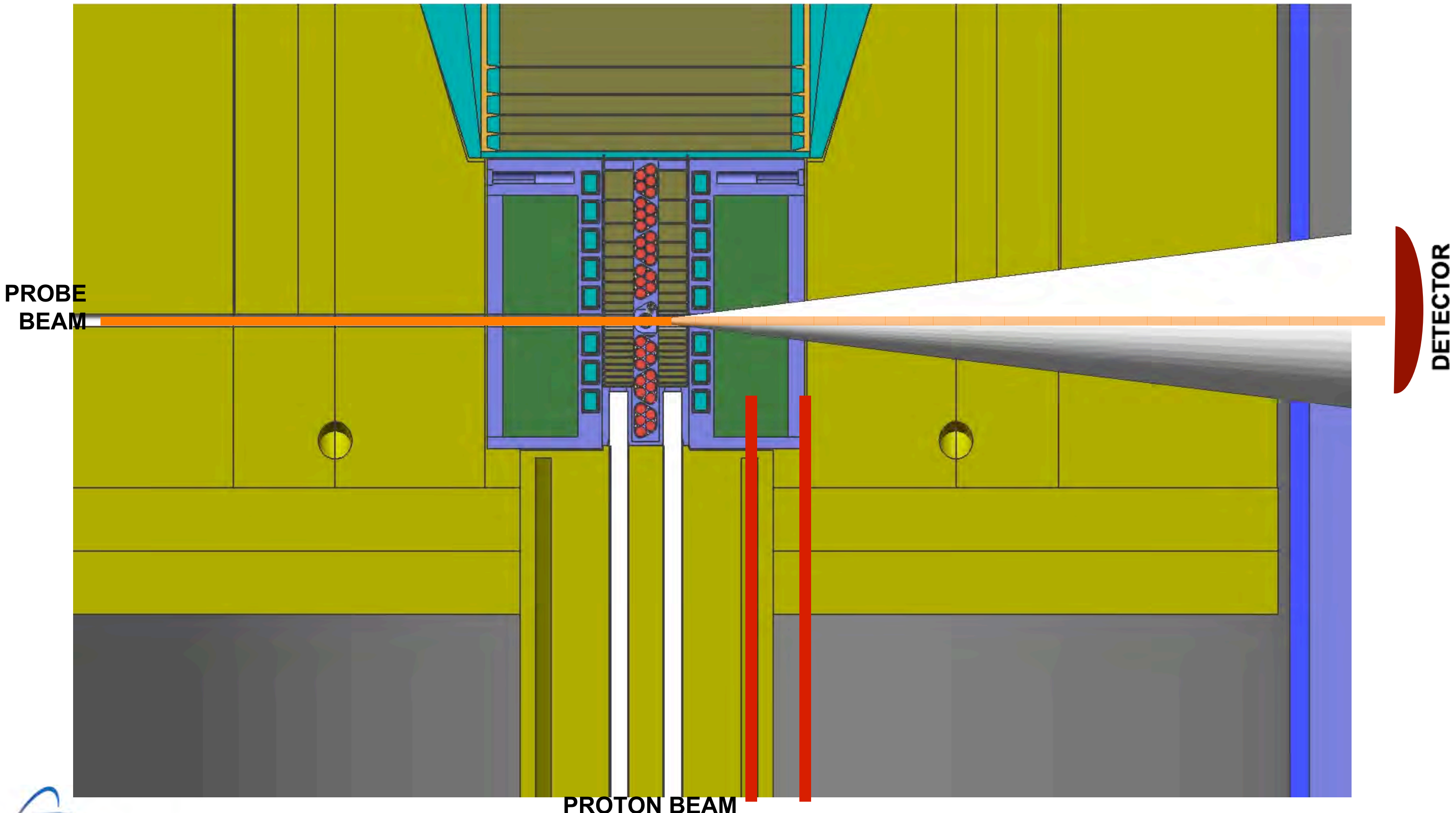


Pure Cu



5 nm layer thickness Cu-Nb multilayer

MaRIE: In-situ diagnostic capability would enhance our understanding of radiation damage processes



Frontier experiments in MaRIE to explore radiation-induced processes

To enable frontier experiments in …

Corrosion	Swelling	Structural integrity	Phase Stability	Thermal Transport

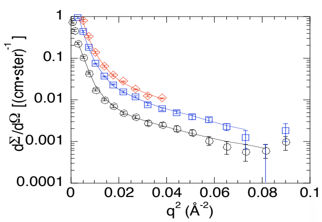
Requires *in-situ* measurement of e.g. …

Corrosion ***Growth rate*** ***Oxidation rate***	**Void / Bubble** ***Total volume*** ***Nucleation*** ***Growth rate & size*** ***Spatial distribution***	**Mech. properties** ***Creep strength*** ***Tensile strength*** ***Residual stress***	**Phase** ***Composition*** ***Microstructure*** **Grain** ***Growth rate & size***	**Thermo. properties** ***Heat capacity*** ***Conductivity*** ***Diffusivity***
layer ***Thickness*** ***Composition*****Fuel** **cladding** ***Interaction thickness***	**Defects** ***Number*** ***Type*** ***Volume***	**Cracks** ***Size*** ***Volume*** ***Shape***	**Fission Product** ***Distribution*** ***Segregation*** ***Accumulation***	**Temperature** ***Distributions***

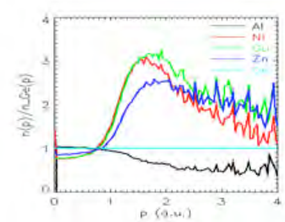
One can consider a very wide range of techniques …..

In the laboratory environment ….

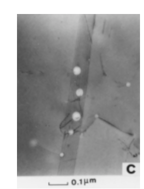
SANS / ASAXS



PAS



TEM

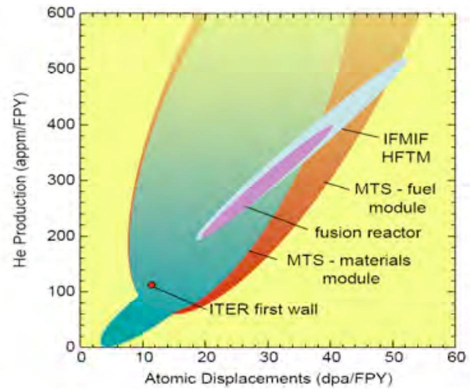


…. etc

Los Alamos NATIONAL LABORATORY EST.1943

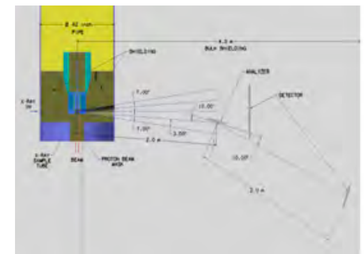
Conclusion: MaRIE can provide solutions to highest priority materials challenges for fusion energy

"Overcoming materials & structures challenges for first-wall, blanket & diverter systems is as difficult & important for fusion energy generation as achieving a burning plasma" - Kurtz & Odette (2009)



MaRIE provides an alternative to IFMIF with a US neutron irradiation facility, years earlier, with lower risk, at a fraction of the cost.

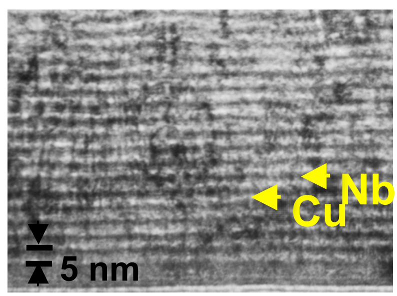
MaRIE enables transition from "observation" to "control," transforming the science of microstructure, interfaces, & defects, leading to a new class of materials



MaRIE surpasses conventional "cook & look" approaches by providing science-based certification, e.g., in-situ characterization in extreme radiation environments

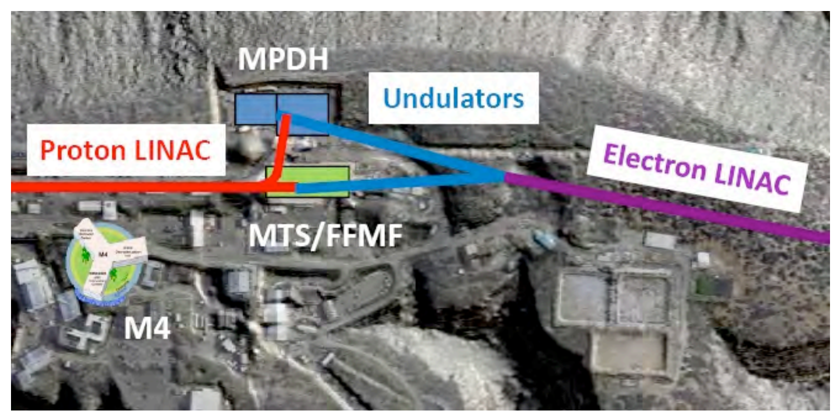
Users will design, synthesize, & qualify new radiation-resistant structural materials that avoid today's show-stoppers:

- embrittlement
- phase instabilities
- segregation & precipitation
- irradiation creep & volumetric swelling



Interface/structure manipulation produces enhanced strength & radiation resistance; e.g., nanolayer architectures actively eliminate point defects, producing materials strength that exceeds theoretical "limits" with extreme radiation resistance.

MaRIE provides tools for transformational materials performance in extremes



Acknowledgments

Mark Bourke, John Erickson, Turab Lookman, Stuart Maloy, Mike Nastasi, Eric Pitcher, Pete Prince, John Sarrao, Kurt Schoenberg, Rich Sheffield, Jack Shlachter, Marius Stan

Los Alamos National Laboratory

Charlie Baker, Mike Cappiello, John Hemminger, Thom Mason, Steve Zinkle

Members of the MaRIE Advisory Board

Supplemental Information

LANSCE facilities support many National missions and research needs

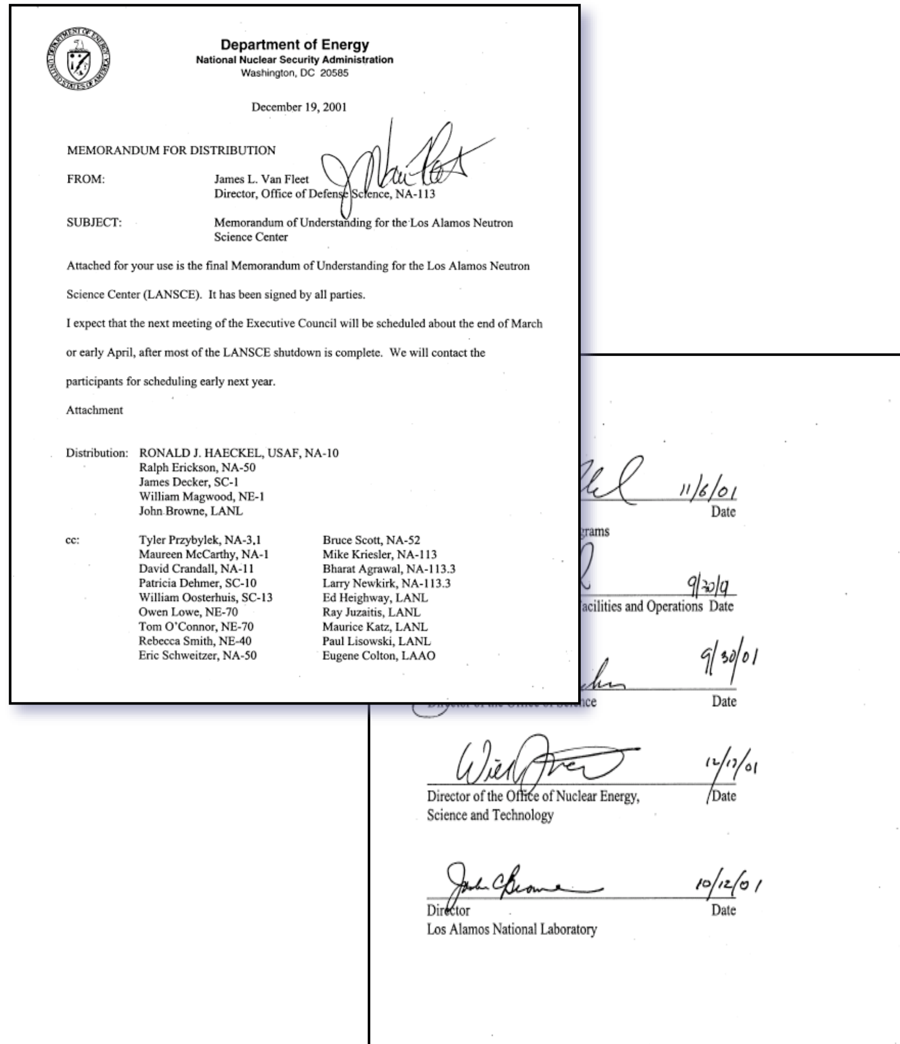
Research area	Needs/Drivers	Thrusts	Source
Materials and Bioscience	National Security Materials science Bioscience	Processing-structure-performance Fundamental properties Short/long range order Processing-structure-performance Superconductivity, Hydrogen storage…. Biotoxin mechanisms Protein function (location of Hydrogen) Self-assembly	Lujan
Nuclear Science	National Security Nuclear energy Astrophysics Other nuclear physics	Fission, capture: materials and diagnostics Fission, capture: advanced fuels Capture, nucleosynthesis processes Level densities	WNR Lujan
Materials Dynamics	National Security	High explosives, shock dynamics, material damage, implosion dynamics….RRW	pRad
Irradiation Response	National Security Advanced fuels Semiconductor upset	Sandia component qualification High power fuel irradiation testing Industry standard for testing, cosmic ray upset	WNR MTS WNR
Fundamental Science	Particle properties Beyond standard model	Ultracold neutron collaboration Neutron EDM…	UCN-b
Medical Isotopes	Medical therapy Medical, Physics research	Production for NE customers Short lived isotopes	IPF

Under update

The estimated total investment in LANSCE-based research exceeds $110M/yr

NNSA, DOE/SC, DOE/NE and LANL Memorandum Of Understanding codifies LANSCE governance plan

- Established LANSCE as a national user facility supporting NNSA/DP, DOE/SC, and DOE/NE programs
- Gave NNSA responsibility for LANSCE facility stewardship to support core NNSA science programs and partner (DOE/SC, and DOE/NE) activities
- Delegated to LANL responsibility for executing all aspects of the MOU
- Established Executive Council to carry out integration role given to DP by the Deputy Secretary and to resolve issues between the partners



Department of Energy
National Nuclear Security Administration
Washington, DC 20585

December 19, 2001

MEMORANDUM FOR DISTRIBUTION

FROM: James L. Van Fleet, Director, Office of Defense Science, NA-113

SUBJECT: Memorandum of Understanding for the Los Alamos Neutron Science Center

Attached for your use is the final Memorandum of Understanding for the Los Alamos Neutron Science Center (LANSCE). It has been signed by all parties.

I expect that the next meeting of the Executive Council will be scheduled about the end of March or early April, after most of the LANSCE shutdown is complete. We will contact the participants for scheduling early next year.

Attachment

Distribution: RONALD J. HAECKEL, USAF, NA-10
Ralph Erickson, NA-50
James Decker, SC-1
William Magwood, NE-1
John Browne, LANL

cc:

Tyler Przybylek, NA-3,1	Bruce Scott, NA-52
Maureen McCarthy, NA-1	Mike Kriesler, NA-113
David Crandall, NA-11	Bharat Agrawal, NA-113.3
Patricia Dehmer, SC-10	Larry Newkirk, NA-113.3
William Oosterhuis, SC-13	Ed Heighway, LANL
Owen Lowe, NE-70	Ray Juzaitis, LANL
Tom O'Connor, NE-70	Maurice Katz, LANL
Rebecca Smith, NE-40	Paul Lisowski, LANL
Eric Schweitzer, NA-50	Eugene Colton, LAAO

11/6/01 Date

...rams

...acilities and Operations 9/30/01 Date

9/30/01 Date

Director of the Office of Science

Director of the Office of Nuclear Energy, Science and Technology 12/17/01 Date

Director, Los Alamos National Laboratory 10/12/01 Date

Los Alamos NATIONAL LABORATORY EST.1943

LANSCE-R Project CD-1 approved in Sept 2009

NNSA

Department of Energy
National Nuclear Security Administration
Washington, DC 20585

September 28, 2009

MEMORANDUM FOR MANAGER, LOS ALAMOS SITE OFFICE

FROM: GARRETT HARENCAK, BRIG GEN, USAF
PRINCIPAL ASSISTANT DEPUTY ADMINISTRATOR
FOR MILITARY APPLICATION
OFFICE OF DEFENSE PRGRAMS

SUBJECT: Approval of Critical Decision-1 (CD-I), Approval of Cost Range, for the Los Alamos Neutron Science Center Refurbishment (LANSCE-R) Project at the Los Alamos National Laboratory

By this memorandum, I am approving Critical Decision-1 (CD-1) for the LANSCE-R Project with the Total Project Cost (TPC) range of $153 to $201 million and schedule range of the fourth quarter fiscal year (FY) 2016 to the third quarter of FY 2018. The Total Estimated Cost (TEC) portion of the project shall not exceed $149 million. The preliminary design activities will be executed with the FY 2009 appropriated project engineering design (PED) funds.

The LANSCE-R Project will refurbish, repair, replace, and modernize equipment and major components of the Linear Accelerator (LINAC) to meet Defense Programs operating requirements for the next two decades. The refurbishments of the major LINAC components under LANSCE-R include radio frequency power systems, integrated controls and diagnostics, and selected accelerator subsystems.

By this memorandum, I also approve Mr. Frank L. White as the Federal Project Director for the LANSCE-R Project. Approvals of the Preliminary Project Execution Plan, Acquisition Strategy, revised Program Requirements Document, and revised Mission Need Statement will be provided prior to October 24.

If you have any questions regarding this project, please call me or have your staff contact Sheila Feddis at 202-586-0823.

cc:
T. Konopnicki, NA-50
P. Bosco, NA-50

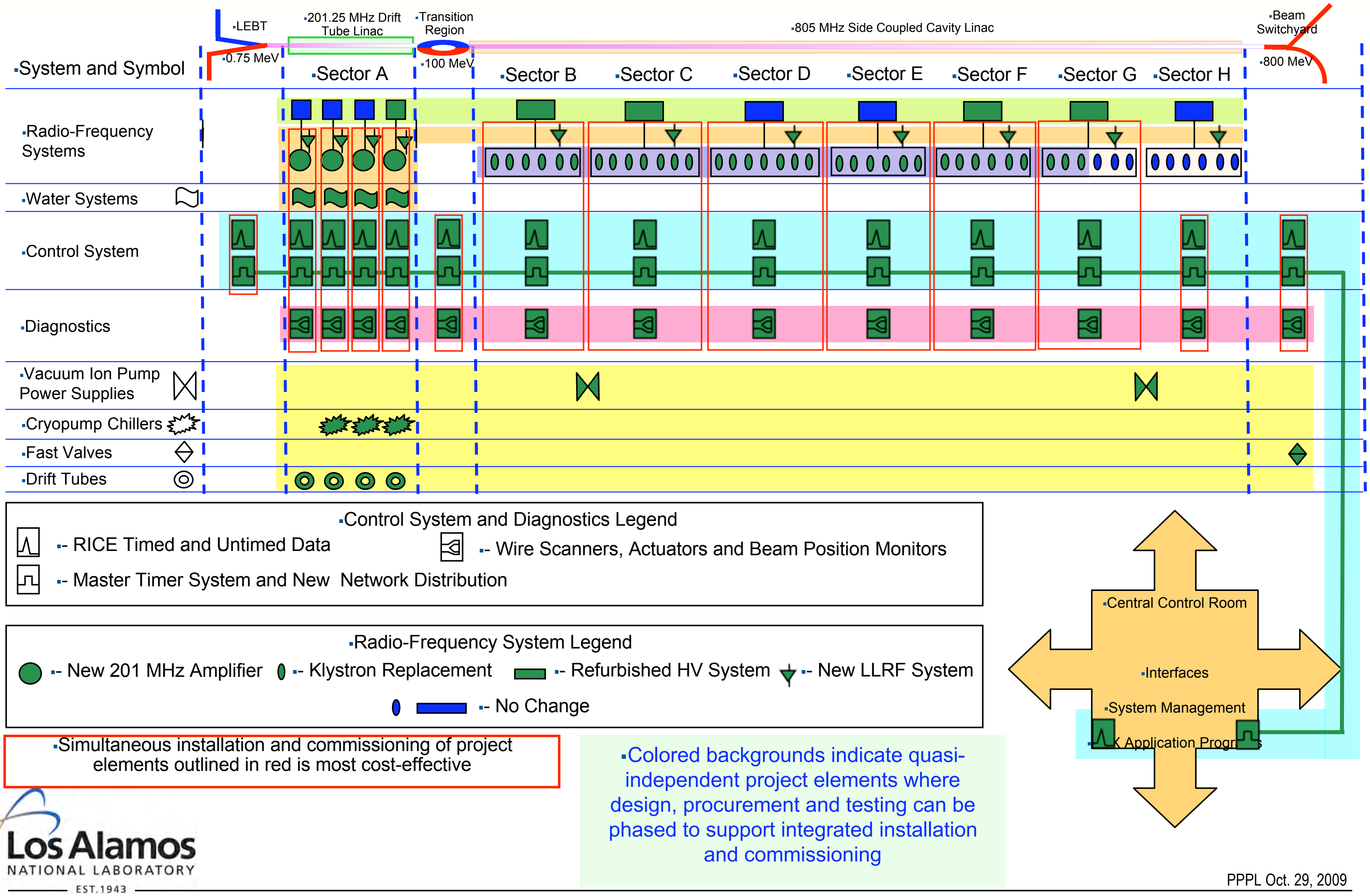
Printed with soy ink on recycled paper

"By this memorandum, I am approving Critical Decision 1 (CD-1) for the LANSCE-R project with the Total Project Cost range of $153M to $201M and schedule range of the fourth quarter of fiscal year 2016 to the third quarter of FY2018. "

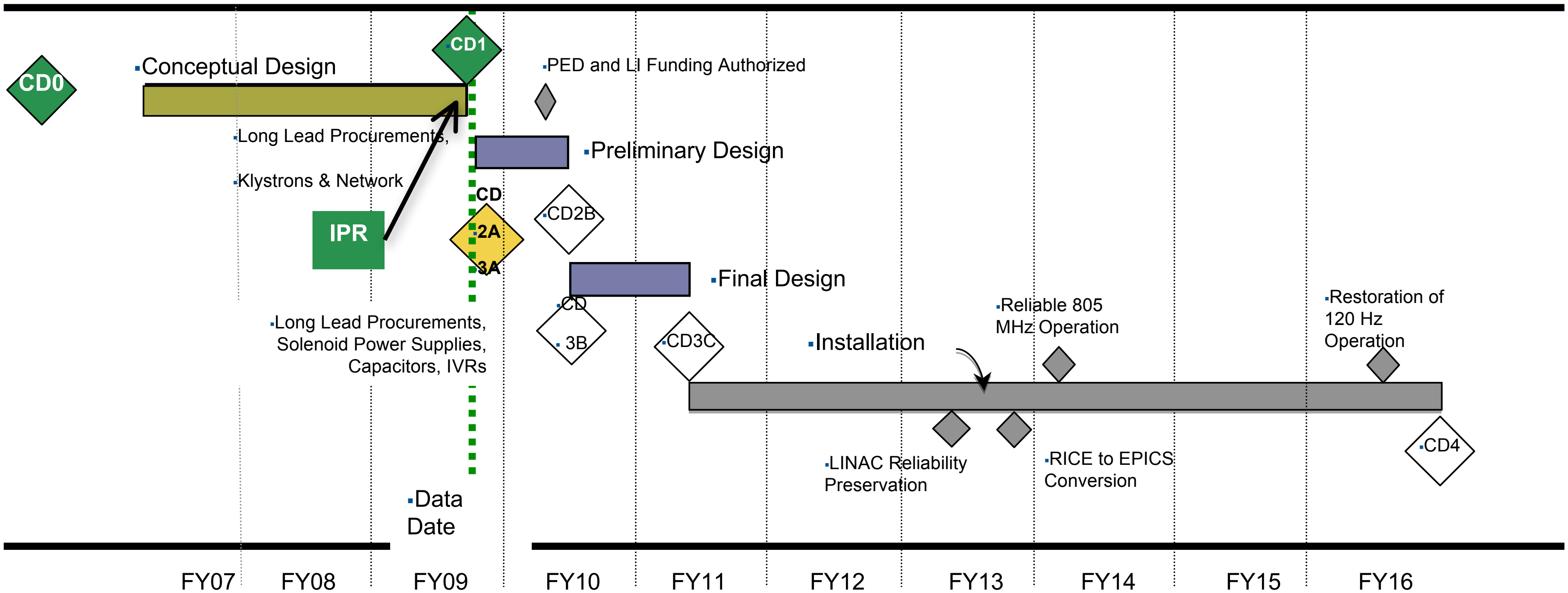
"The LANSCE-R project will refurbish, repair, replace, and modernize equipment and major components of the Linear Accelerator (LINAC) to meet Defense Programs operating requirements for the next two decades."

Approval of CD-1 allows the project to tap $19.3M of appropriated funds for further design activities

At CD-1 the LANSCE-R scope, as modified to fit within the specified total project cost, represents an integrated set of work



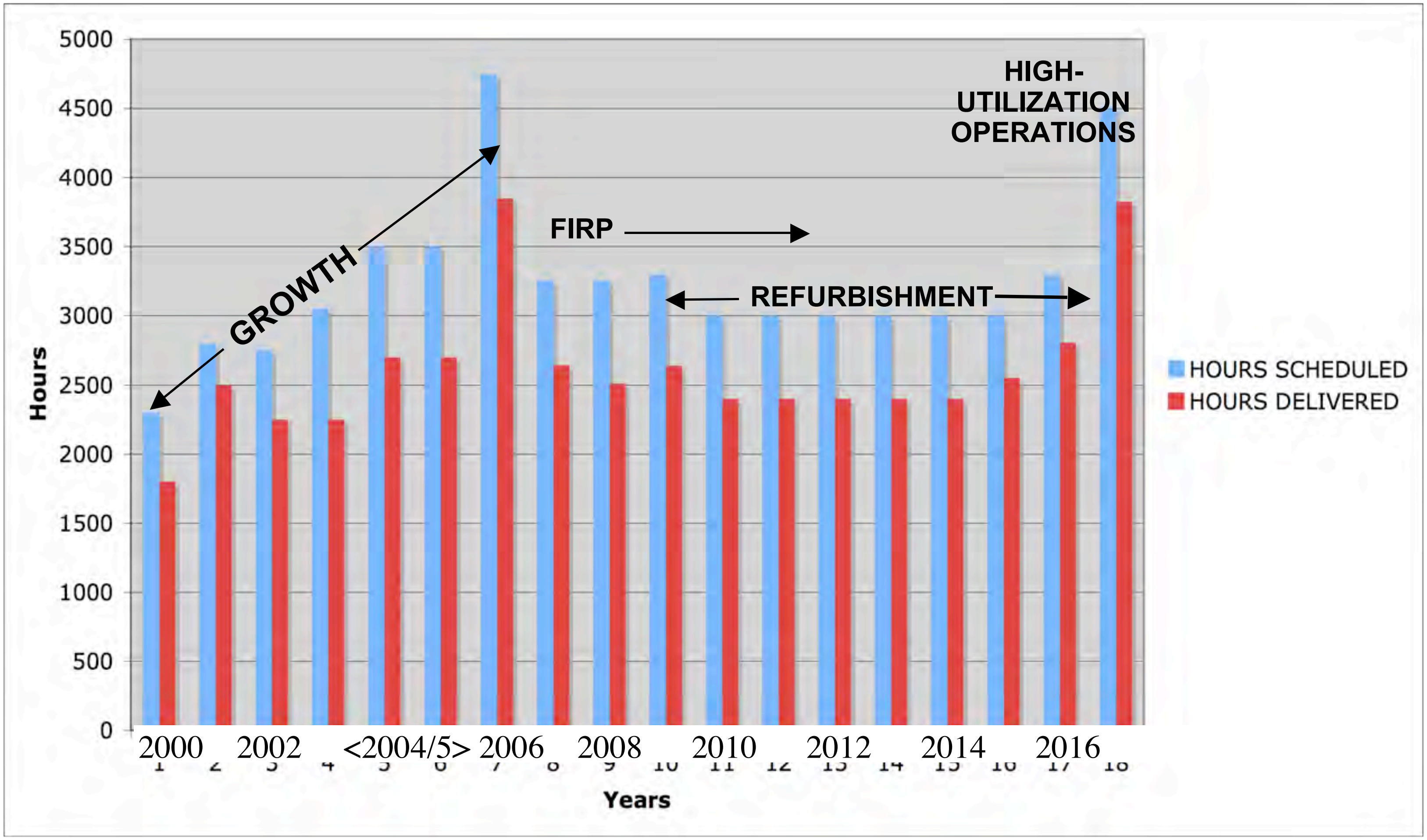
LANSCE-R Schedule



The project has worked planned for six annual outages, 2010 - 2015

Los Alamos NATIONAL LABORATORY EST.1943

The LANSCE facility has achieved good user program growth and will continuously operate during the LANSCE-R & FIRP projects



LANSCE is at the top of its scientific game, producing key basic and programmatic science

- Capabilities support, and are adapted to, US national security and science missions
  - *National security research environment*
  - *Leveraging basic research investments*
- Interplay of basic and national security missions is unique and provides unique opportunities for innovation in basic and applied science
- Support of the User Group is essential to achieve operational excellence and to achieve both our near and long term objectives.

June 3, 2009

The Honorable Jeff Bingaman
703 Hart Senate Office Bldg.
United States Senate
Washington, DC 20515

Dear Senator Bingaman:

As you work with Congress on the budget for the 2010 fiscal year, the Executive Committee of the Los Alamos Neutron Science Center (LANSCE) User Group strongly requests that you advocate for funding of the LANSCE Refurbishment Project. A healthy LANSCE is critical to research at Los Alamos National Laboratory and the country.

The Executive Committee of the LANSCE User Group is an elected body that represents scientists from academia, industry and national laboratories who use LANSCE facilities. We are concerned that the LANSCE Refurbishment Project has been targeted for termination in the President's 2010 Budget. The roughly $150 million, five-year refurbishment program is necessary to extend the useful life of LANSCE beyond the next decade. The budget language states, "LANSCE is a linear accelerator that was built 30 years ago and no longer plays a critical role in weapons research." We believe this position fails to recognize many current aspects of LANSCE and its full value to the country as a scientific research and development facility.

LANSCE is an internationally recognized and unique multidisciplinary accelerator facility that executes a broad range of defense and civilian research. Examples include classified measurements for the U.S. weapons and nuclear energy program; support for the semiconductor industry in testing devices for avionics, computing, and medical applications; investigation of CO_2 sequestration materials; exploration of new energy resources; the development of environmentally acceptable engineering materials; and the advancement of biomedical science, all issues with high national priorities. Many of the instruments at LANSCE are unique and not duplicated by other facilities in the United States. The value of LANSCE to science is without question: LANSCE has supported over 10,000 user visits in the last decade. Proposals submitted to LANSCE outnumber available instrument time by as much as 3:1. Over 200 publications result each year from research conducted at LANSCE.

LANSCE is crucial in ensuring U.S. competitiveness and educating our next generation of scientists. The LANSCE Refurbishment Project is an economically viable path for LANSCE to sustain its vigorous and diversified user program and to further advance American science and technology in the coming decade.

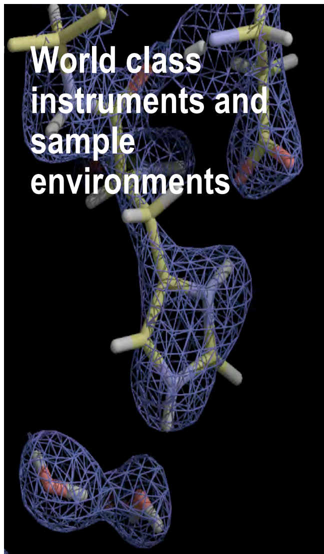
On behalf of the users of LANSCE, the Executive Committee urges you to help reverse the decision by the Administration. If more information is needed, please feel free to contact me at (813) 974-9164 or e-mail me at rtoomey@eng.usf.edu.

Thank you,

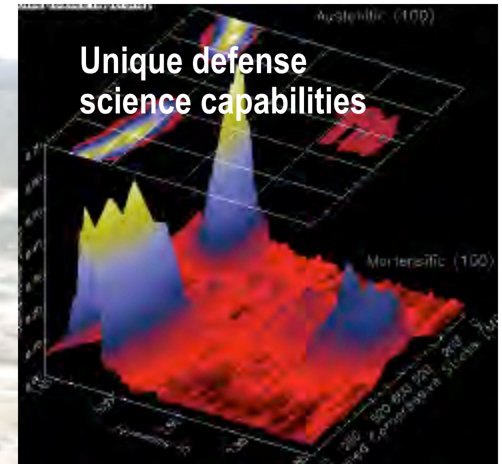
Ryan Toomey
Chair, Executive Committee LANSCE User Group
Assistant Professor of Chemical Engineering, University of South Florida
rtoomey@eng.usf.edu

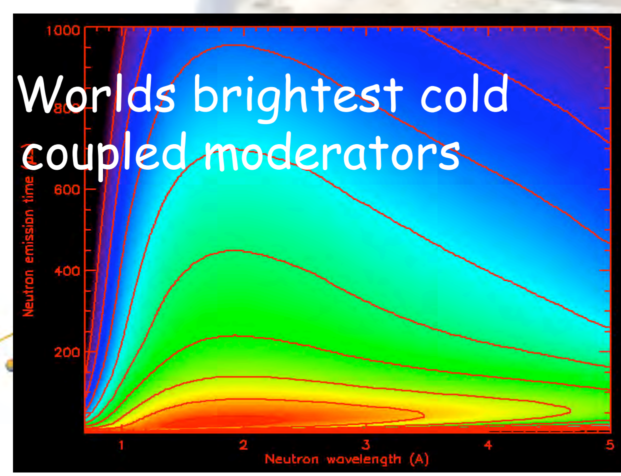
With LANSCE-R and other sponsor investments, LANSCE will continue to provide world-class scientific capabilities to address the complex challenges facing our Nation.

The Enhanced Lujan Center at LANSCE:
A premier neutron scattering facility for national security research



- Full utilization of all 16 Lujan Flightpaths- 1000 user visits per year
- All instruments built or upgraded to perform at world-class standards
- Superb sample environments commensurate with world-class instrument capabilities
- Accommodates classified national security research and materials
- Optimized cold-moderator performance, crucial for the study of
  - Polymeric materials (HE,stockpile materials)
  - Soft & magnetic metals (Pu)
  - Interfaces (corrosion)
  - Glasses and phase separated materials
- Upgraded power operation 120 kW @ 20Hz

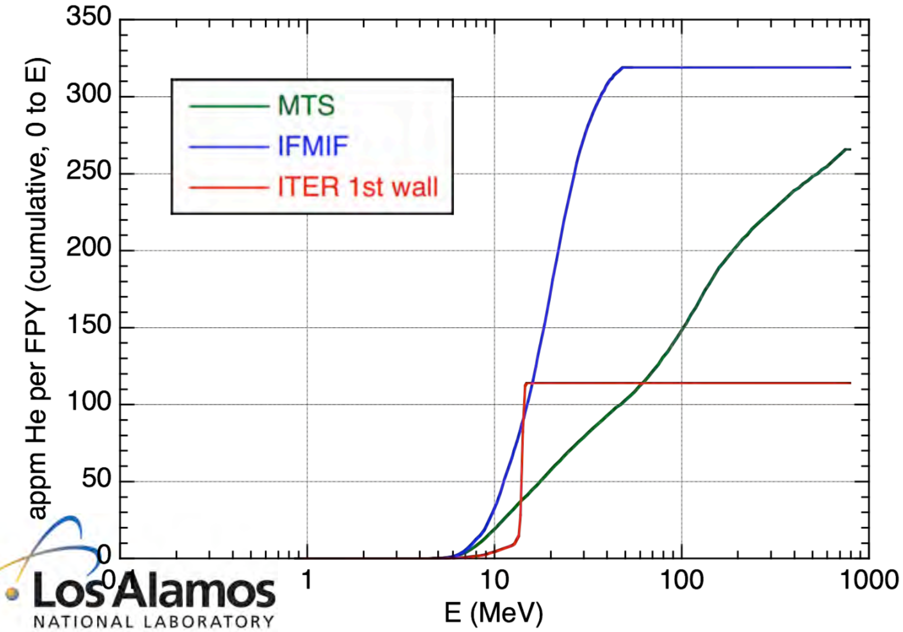


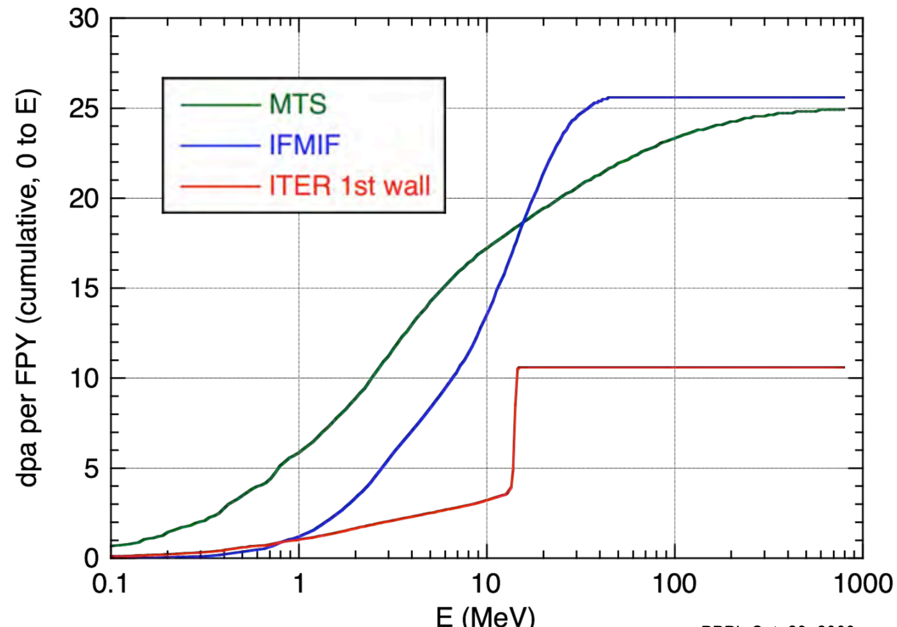


The damage rates for the MTS approach those observed in IFMIF and are 3 times ITER

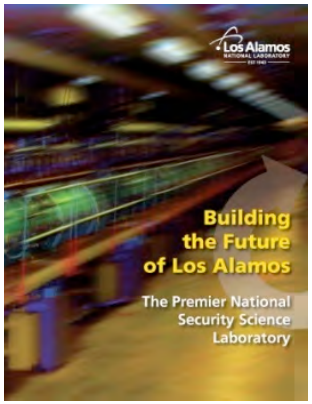
	appm He/FPY*	dpa/FPY*	He/dpa
ITER 1st wall	114	10.6	10.8
IFMIF HFTM (ave over 500 cc)	319	25.6	12.5
MTS (ave over 400 cc)	266	24.9	10.7
IFMIF Li back wall	619	65.8	9.4
MTS (peak, fuel module)	393	33.9	11.6

***FPY = full power year; MTS expected operation is 4400 hrs per year. Values for MTS assume 1 MW of beam power.**





LANL's materials strategy defines focus areas for materials-centric national security science consistent with these national drivers

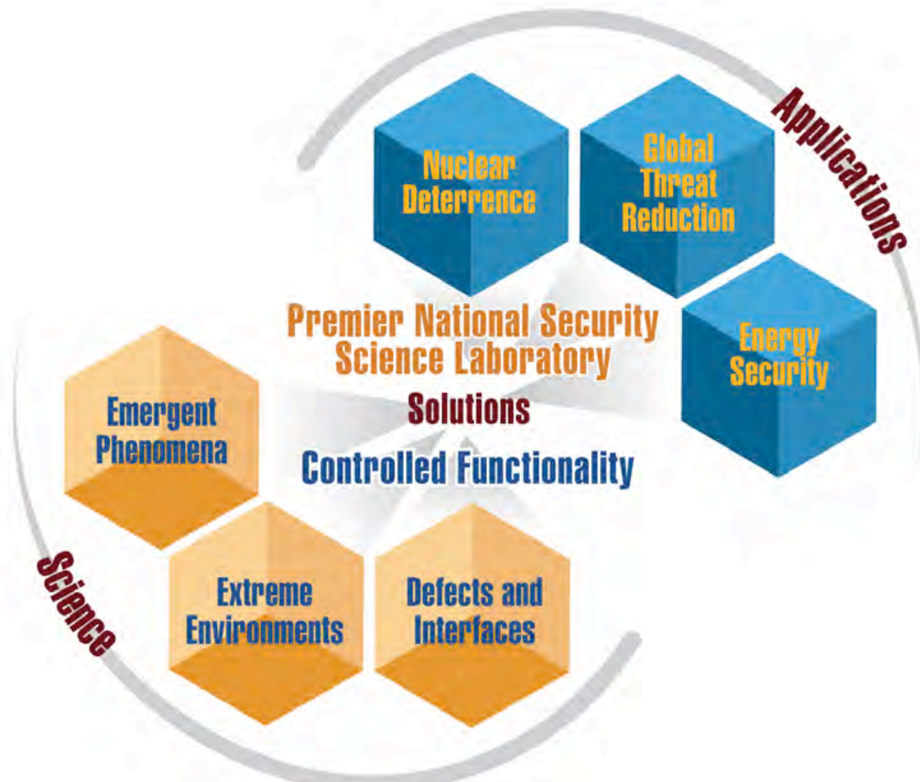


To achieve our vision of Los Alamos as the National Security Laboratory of choice, we have identified three strategic thrusts within "**Science that Matters**":

Information science and technology enabling predictive science,

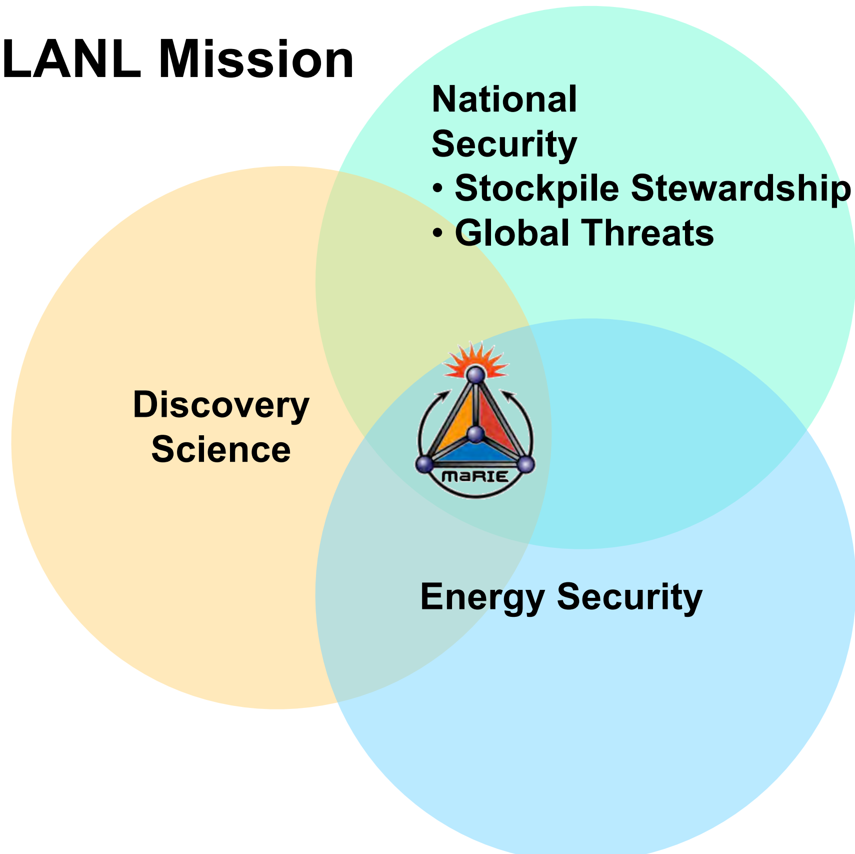
Experimental science focused on materials for the future, and

Fundamental forensic science for nuclear, biological, and chemical threats.



MaRIE addresses decadal research frontiers and challenges of critical importance to Los Alamos' national security missions

LANL Mission



National/Global Energy Challenge

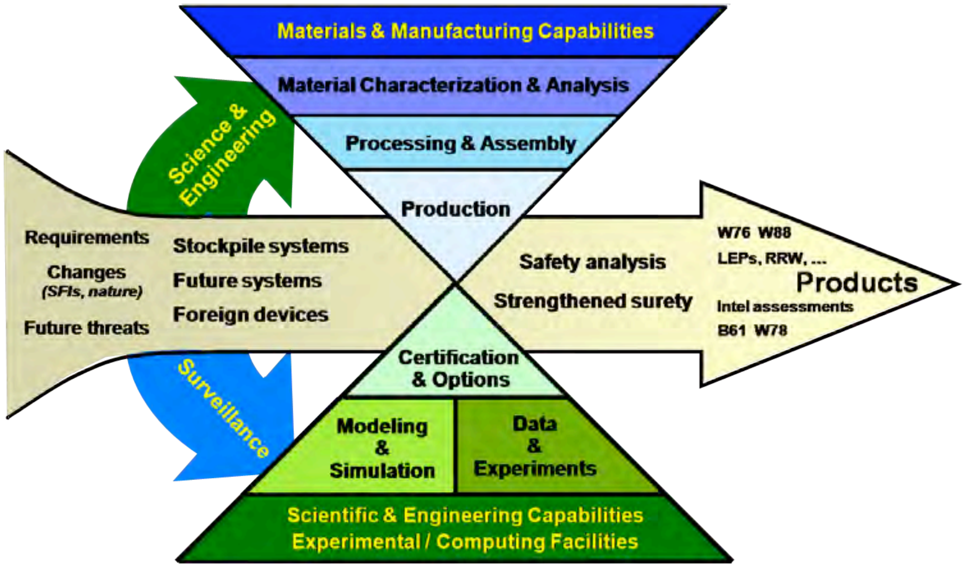
- **Close the 10 TW Gap between the energy we have and the energy we need: From fission & solar to fusion**

Materials Matter!
Material Requirements Central to National Grand Challenges

Materials Recognized as a Core LANL Capability

Enabling Materials-Centric National Security Science for the 21st Century

The transition from “observation & validation” to “prediction & control” is a central mission challenge *and* the frontier of materials research



Nuclear weapons program challenges

- Majority of stockpile issues have been and will likely continue to be materials based
  - Microstructure matters
  - cast/wrought, weld, special material
- Future stockpile manufacturing and certification requires a “process aware” understanding of materials
  - Materials compatibility/substitution
  - 9 of top 11 NM RRW technical risks materials-related

Dynamic processes dominate and are poorly understood today

Experimental capabilities to validate multi-scale models, especially on the meso-scale, are needed

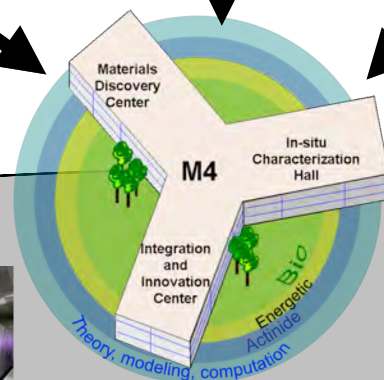
MaRIE will be the first capability with unique co-located tools necessary to realize transformational advances in materials performance in extremes

MaRIE: Integration is key – integrated facility capabilities and gateway to broader LANL

FFMF
- •Pre and post irradiation characterization
- •Radiation hard materials
- •Materials synthesis in a radiation environment

Portal to the External User Community

MPDH
- •Samples with controlled microstructure
- •Complimentary ultrafast characterization
- •In-situ characterization during synthesis




NHMFL


Roadrunner

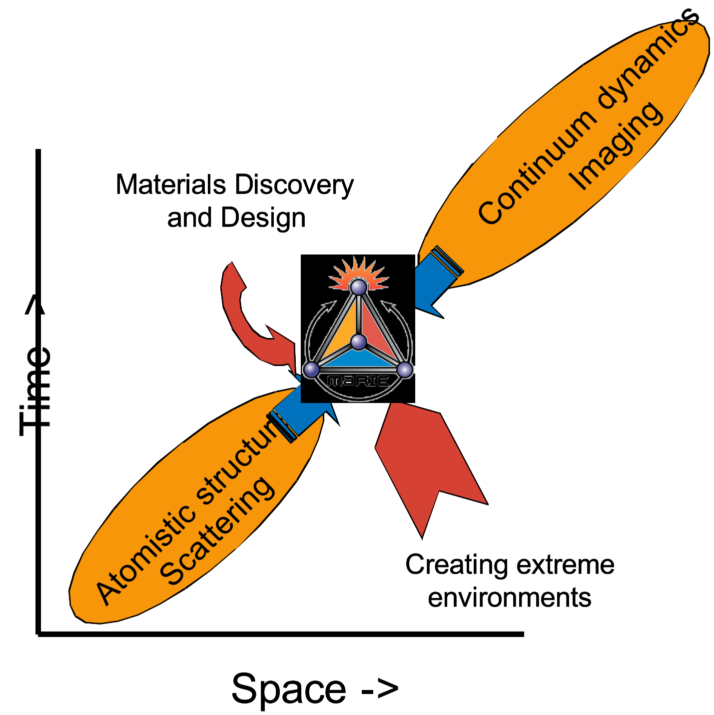

Enhanced Lujan


CINT

Integrated Solid State Solutions
- •Materials with process aware controlled microstructure
- •New radiation hard materials (self healing materials)
- •Next generation photovoltaics/Advanced radiation detectors

MaRIE bridges the “micron gap”

- **~ 1 μm scale represents an experimental and theoretical frontier**
  - Interface between scattering & imaging
  - Crossover from continuum to atomic scale models
  - Nexus of discovery science & predictive validation
- **Explicit focus on dynamic (~ ns/ps), stochastic processes requiring simultaneous measurements**
  - Translat emergent functionality to device realization / *interface phenomena*

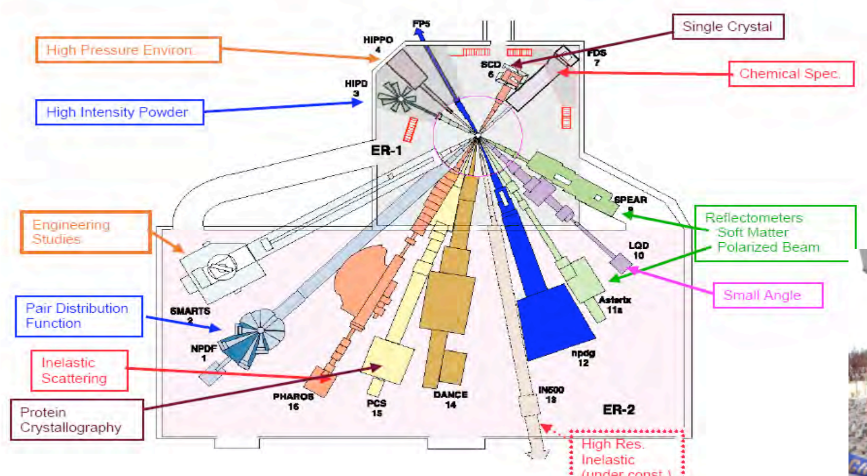


MaRIE provides unique capabilities for unraveling and controlling micron-scale interactions

MaRIE builds upon existing LANL strengths

- $1.5 B proton accelerator (1 MW, 800 MeV; with significant refurbishments) with unique proton radiography and irradiation capabilities
- Proven ability to operate materials-centric National User Facilities (Lujan, CINT, NHMFL)
- Legacy of leadership in materials discovery to component manufacturing
- Peta-scale simulations (Road Runner)

Los Alamos Neutron Science Center (LANSCE)



Lujan Neutron Scattering Center Experimental Room #2 Layout

Center for Integrated Nanotechnologies (CINT)

National High Magnetic Field Laboratory (NHMFL) 100-T Magnet Facility

Decadal Alternatives: MaRIE Fission-Fusion Materials Facility

- **High-Power (> 200-kW) Spallation Sources**
  - SINQ (Paul Scherrer Institute)
  - Spallation Neutron Source (ORNL)
  - Transmutation Experimental Facility (Japan Proton Accelerator Research Complex)
  - European Spallation Source (ESS)
- **Accelerator Sources**
  - IFMIF
  - MYRRHA or XT-ADS facility (SCK-CEN)
- **D-T Fusion Concepts**
  - Gas Dynamic Trap Mirror Neutron Source (Budker & LLNL)
  - Component Test Facility Concepts
    - Volume Neutron Source (ORNL)
    - Fusion Development Facility (GA)
  - Laser Inertial Fusion Engine (LLNL)
- **Fast Reactors**
  - Joyo (Japan)
  - Monj (Japan)
  - BOR-60 (Russia)
  - BN-600 (Russia)
  - CEFR (China)
- **Thermal Reactors with in-pile instrumentation**
  - ATR (INL)
  - HFIR (ORNL)
  - Halden Boiling Water Reactor (Norway)
  - Jules Horowitz reactor (France)
- **Triple Ion Beams**
  - ORNL EFRC (w/LCLS)
  - JANNuS (France)
  - LLNL

Decadal Alternatives:
MaRIE Fission-Fusion Materials Facility

	FACILITY	COUNTRY	INITIAL OPERATION	POWER
	SPALLATION			
Spallation Sources	SINQ	CH	1996	1.1 MW spallation source
	SNS	USA	2006	1.4 MW spallation source
	TEF @ J-PARC	JAPAN	~2015	200 kW spallation source with blanket
	ESS	SWEDEN	~2018	5 MW spallation source
	ADS			
Accelerator Sources	MYRRHA	BELGIUM	~2018	2.4 MW proton beam driving an 80-MW blanket
	LIGHT ION			
	IFMIF	TBD	~2019	40-MeV, 10-MW D beam on Li target
	FUSION			
D-T Fusion Facilities	ITER	FRANCE	2025	500 MW Tokamak
	FDF	TBD	TBD	150-250MW Tokamak
	VNS-CTF	TBD	TBD	75 MW Tokamak
	DTNS	TBD	TBD	Gas Dynamic Trap/Magnetic Mirror
	THERMAL REACTOR			
Reactors	Thermal Reactors	MANY	1957 – 1967	20 – 250 MW
	FAST REACTOR			
	Fast Reactors	SEVERAL	1968 – 2005	55 – 1470 MW
	ION BEAM			
Ion Beams	TRIPLE-BEAM			Triple ion beam with SEM at a light source
	SPALLATION			
MaRIE	MaRIE-FFF	USA		1.8 MW Spallation source

In-Situ Capability

Temperature	Macroscopic dimensions	Force (stress)	Displacement (strain)	Cracks in steels	Cracks in fuel	Bubbles / Voids	Phase	Defects

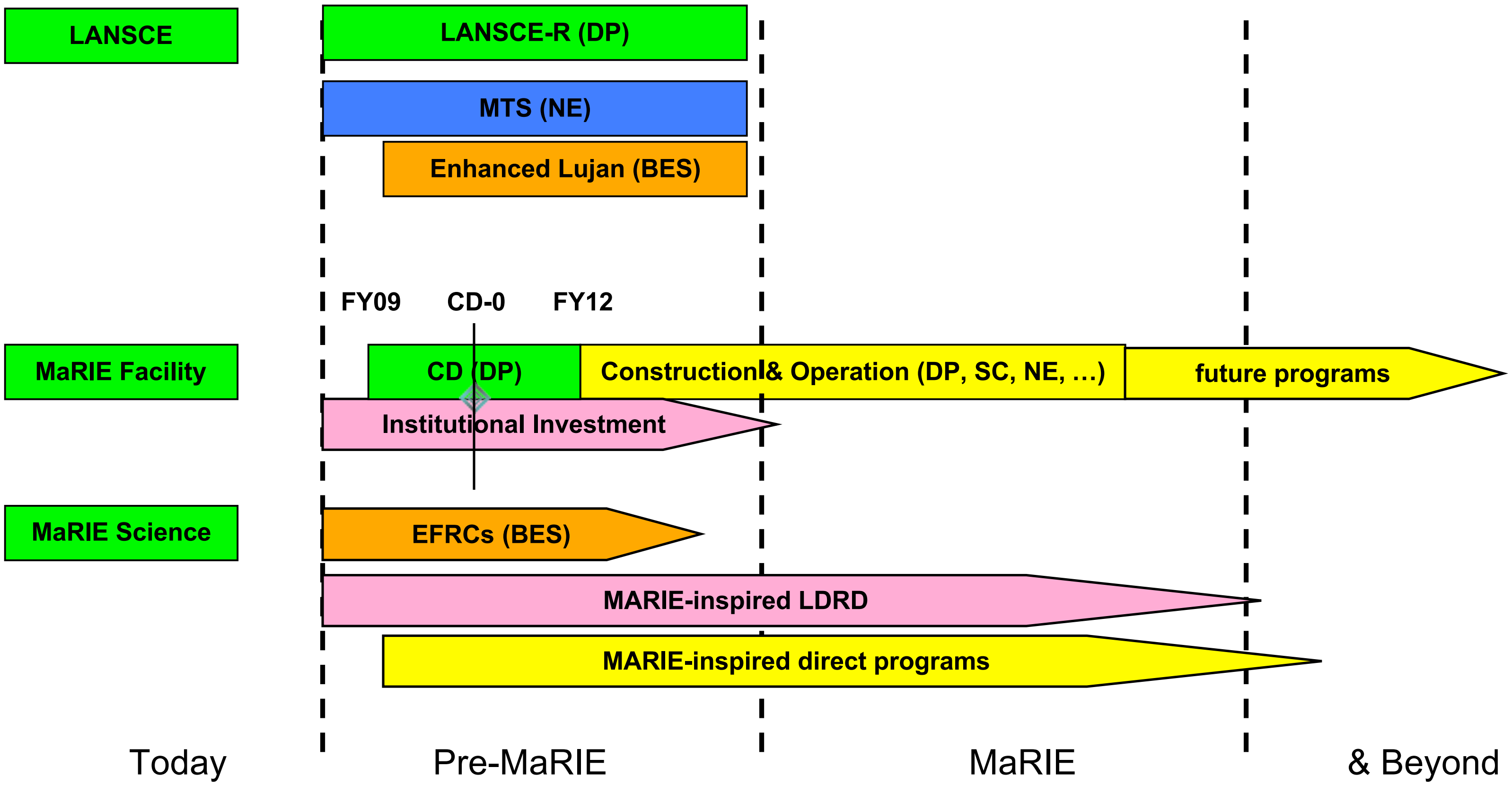
Irradiation Environment

Irrad. volume: 0.5 liter with >14 dpa/year	Flux gradient < 2% per mm	PKA spectrum like fusion first wall	Peak damage rate > 35 dpa/year	Fast / thermal neutron flux ratio > 10,000	Helium to dpa ratio ~ 0.2 (fast reactor)	Helium to dpa ratio ~ 10 (fusion first wall)	Facility available within 10 years

Preliminary

- Planned and achievable with present technology .
- Not planned, but achievable with modest cost facility improvements. .
- Not planned & not realizable with this facility without significant investment

MaRIE Acquisition Strategy Primary Planning Scenario: DP leadership is key



1) *Execute LANSCE-R + MTS + Enhanced Lujan Projects*
2) *Define Facility*
3) *Deliver MaRIE Science*