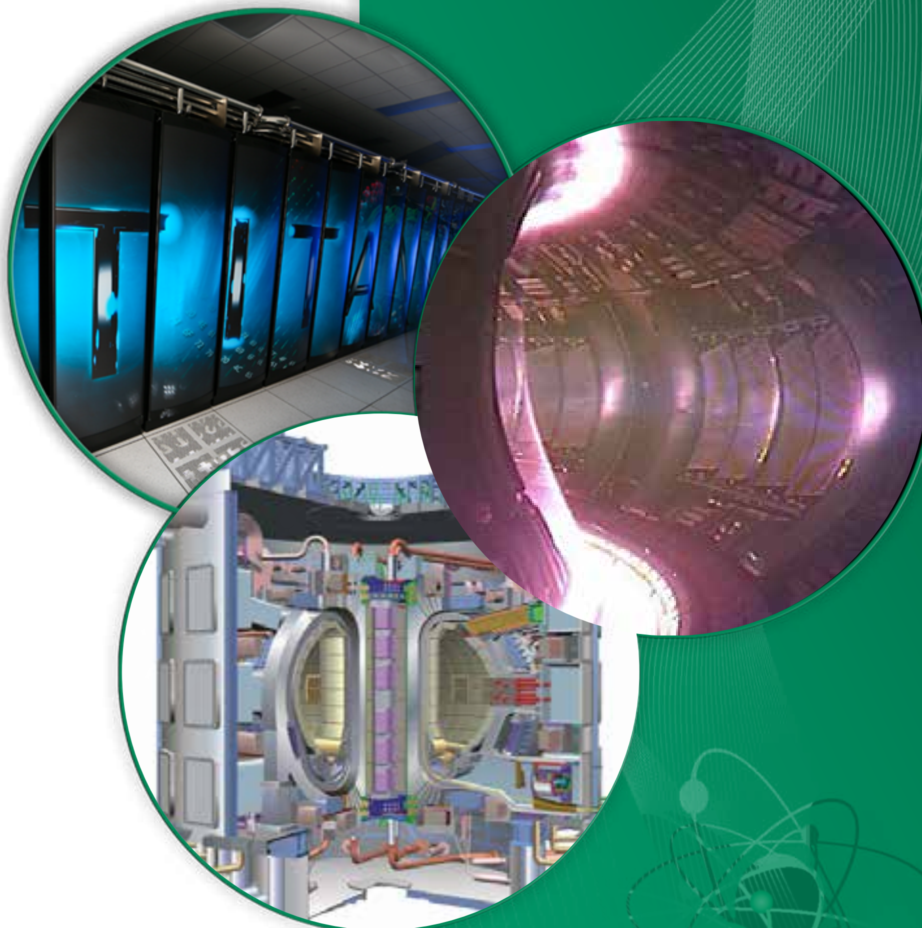
A Materials Facilities Initiative -

FMITS & MPEX



D.L. Hillis and ORNL Team

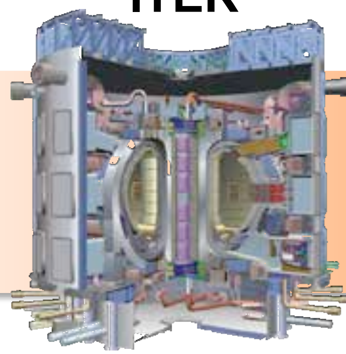
Fusion & Materials for Nuclear Systems Division

July 10, 2014

Challenges for materials: fluxes and fluence, temperatures

JET

ITER



FNSF

Fusion Reactor

50 x divertor ion fluxes

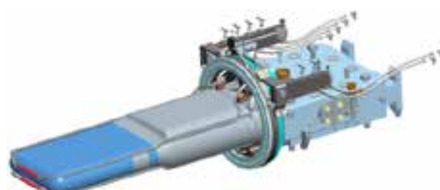
5000 x divertor ion fluence

10^6 x neutron fluence (1dpa)

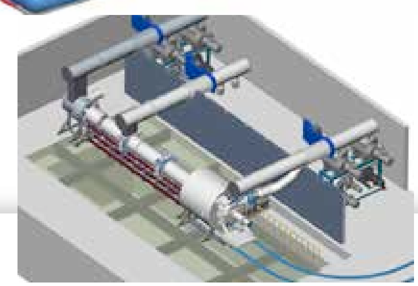
up to 5 x ion fluence

up to 100 x neutron fluence (150dpa)

Fusion Material Irradiation Test Station (**FMITS**) at SNS



Material Plasma Exposure eXperiment (**MPEX**)



Materials need to be developed and tested under fusion prototypic conditions

Material facilities initiative is a response to community requests:

Greenwald report identified several significant gaps related to PMI, high heat flux components, tritium retention and materials development: ***G7, G9, G10, G11, G12, G13***

Greenwald report identified area of ***Plasma-wall interactions***, where investments could sustain strength and where investments could provide new opportunities for U.S. leadership: ***Plasma facing components*** and ***Materials***

ReNeW theme 3 (Taming the Plasma-Material Interface), **Thrust 10** (Decode and advance the science and technology of plasma-material interactions) **identified the need for dedicated facilities**:

Upgrade existing laboratory facilities and test stands, and build new facilities capable of extending plasma-surface interaction parameters closer to conditions expected in fusion reactors, including the capability to handle tritium, liquid metals, and irradiated materials.

&

Build large-size test stands where full-scale internal component tests and design validations can occur.

FESAC panel report (*Zinkle*) on Materials Science and Technology Research Opportunities Now and in the ITER Era recently identified the need of an

Upgrade and/or New Build of linear plasma test stands with medium scale facilities

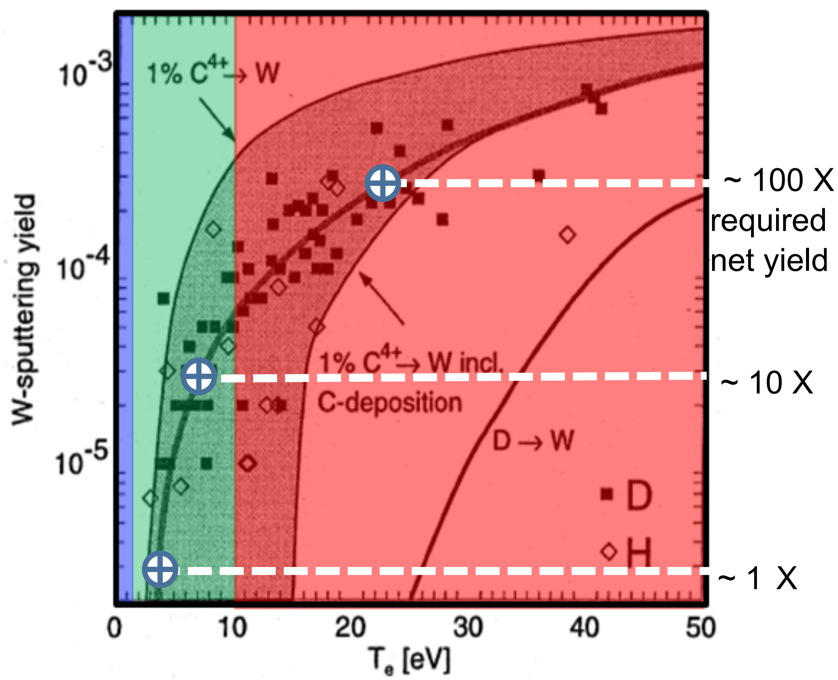
FESAC panel report (*Rosner*) on priorities for the fusion program ranks

Thrust 10 (Decode and advance the science and technology of plasma-surface interactions) among the 5 highest priority initiatives

Demand of high plasma performance and high PFC lifetime requires strong re-deposition to ensure low net erosion

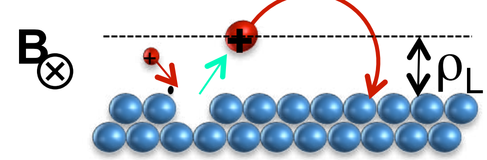
Divertor plasma temperature in the ~ 10 eV range where GROSS sputtering yield of tungsten is ~ 10 X greater than the required NET sputtering yield.

Reactor divertor lifetime ~10^8 s requires net erosion rate of 10^{-6}



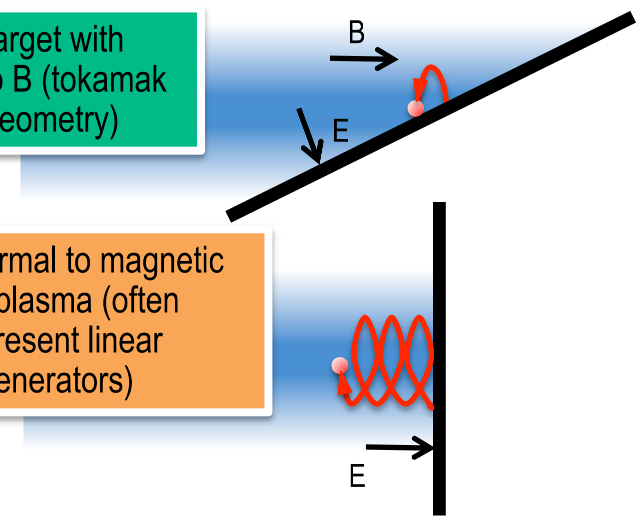
+ High divertor plasma density for prompt return of sputtered atoms to the surface.

⇒ Strongly coupled regime



Inclined target with respect to B (tokamak realistic geometry)

Target normal to magnetic field and plasma (often used in present linear plasma generators)

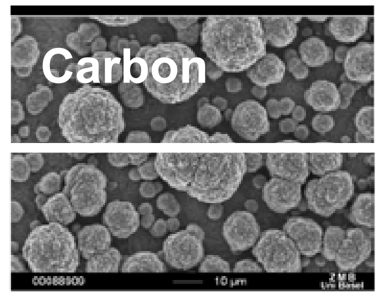


Accelerated lifetime tests need a device able to provide significant fluence (> 10^{30} m^{-2}) in realistic geometry

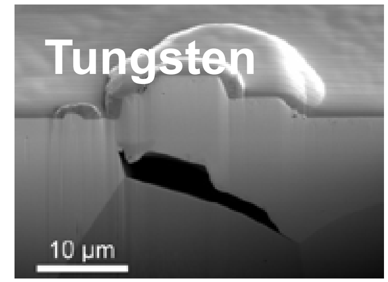
High fluence, long pulse plasmas will lead to surface morphology changes

Increase of density and energy to the surface leads to increased surface morphology changes and hence influences:

- Surface area; Surface roughness
- Surface potential (unipolar arcing may occur)
- Surface temperature (loosely bound layers)
- Surface chemical activity



K. Bystrov et al., J. Nucl. Mater. 415 (2011) S149



S. Lindig et al., T145 (2011) 014039

This all will have consequences for

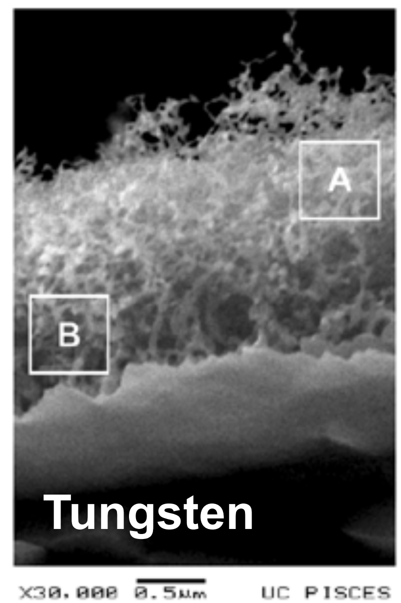
- Chemical and physical erosion yield
- Relation between gross erosion and net erosion
- Dust production might occur due to macroscopic erosion of surface structure

➢ Complexity will strongly change our understanding of erosion processes

➢ Need for long pulse PMI device, like MPEX

W nanostructure can delaminate (due to unipoloar arcing) and possibly create W dust of nm size

M. Tokitani et al., Nucl. Fusion 51 (2011) 102001



M.J. Baldwin et al., Nucl. Fusion 48 (2008) 035001

Fusion irradiation conditions include synergistic PMI and neutron irradiation

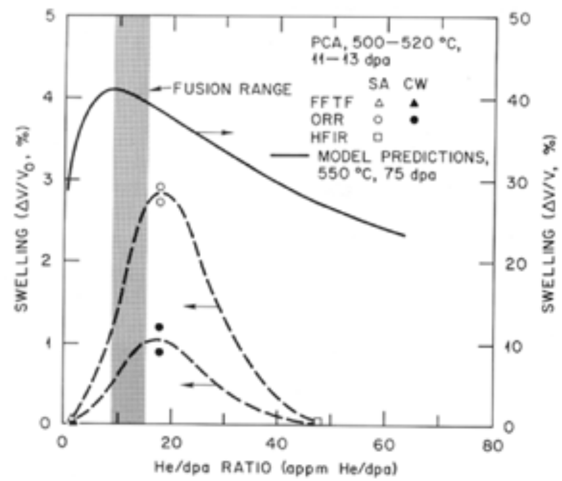
- 14 MeV neutrons, high He/dpa

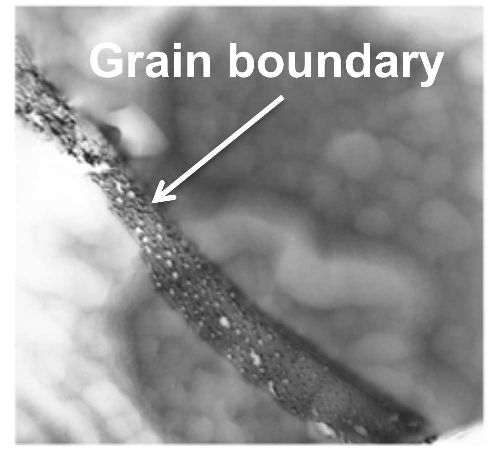
- up to 150 dpa for blankets

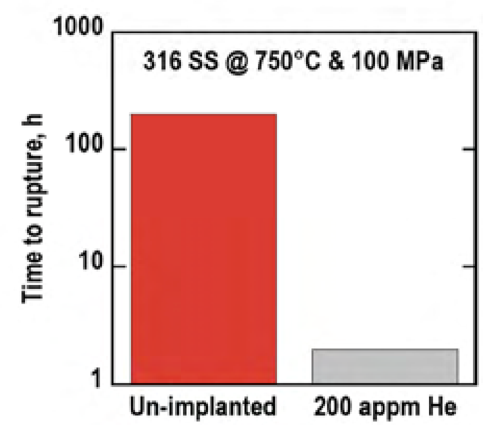
- up to 50 dpa for divertor

Neutron irradiation damage	Consequences on PMI
Thermal conductivity	Temperature operation window, less tolerance to transient heat loads, erosion yield
Chemical composition (transmutation)	Hydrogen retention, thermal conductivity indirectly
Interstitials, vacancies, dislocations, voids	Hydrogen retention
Swelling and irradiation creep at intermediate temperatures	Tolerance in PFC alignment will become larger, hence power handling capability lower
Loss of high-temperature creep strength	Reduced temperature operation window
Ductile to Brittle Transition Temperature	Reduced temperature operation window
He, H embrittlement	Erosion and dust production will be enhanced
Synergies of micro-structural changes between neutron and plasma irradiation	?????

Accumulation of He can have major implications for the integrity of plasma-facing- and structural-components



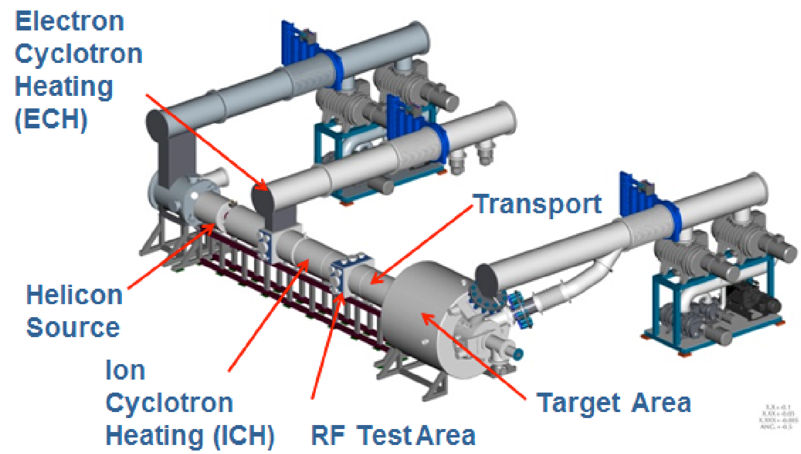




MPEX

- Direct response to thrust 10 in ReNeW
  - $\Gamma > 10^{23} m^{-2} s^{-1}$, P ~20MW/m^{-2}, inclined target
  - B > 1T
  - steady-state (up to 10^6 sec)
  - > 600^{o}C surface temperature
  - large plasma area ~100 cm^2
  - Liquid metal targets: Ga, Sn, Li
  - Neutron-irradiated material samples with significant dpa
  - Independent control of T and n at target
- Project cost: ~ $29M duration 5 years
- Upgrade (irradiated materials): ~ $5M
- Operation costs: $6 M / yr

Opportunity for world leadership

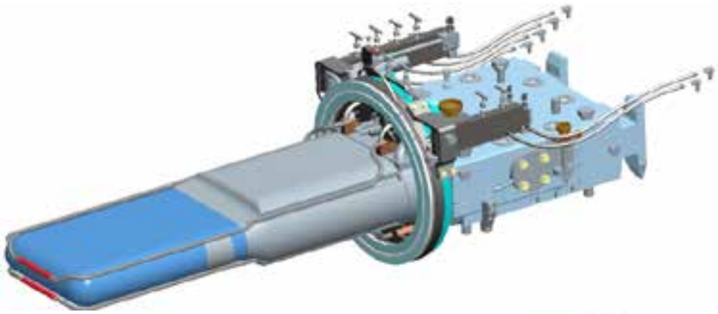


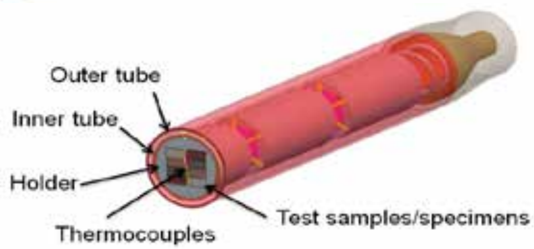
Unique due to RF heating approach
800 kW will make it most powerful steady state linear plasma device world wide

Proto-MPEX: first plasma May 28th
Installed RF power: 330 kW

FMITS

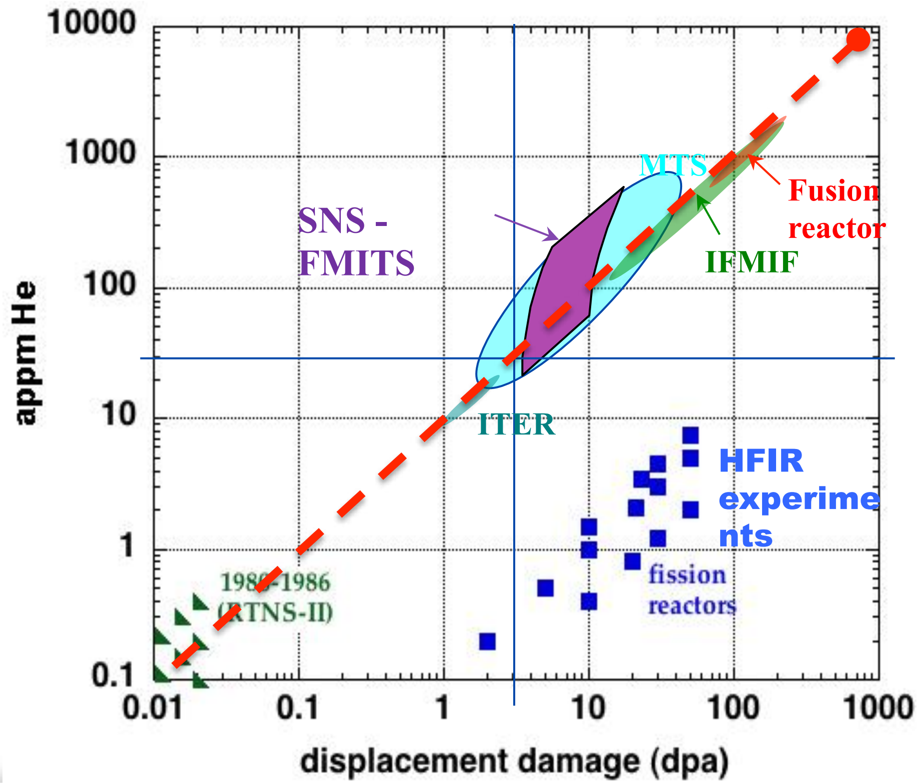
- SNS target station modification
  - Cost effective approach to study high He/dpa ratio
  - Simple modification to SNS target
  - Leverages on SNS B$ class facility
  - Project cost: ~ $14M, duration 3 years
  - Operation cost: ~ $1M / experiment





Active temperature control of material samples during irradiation

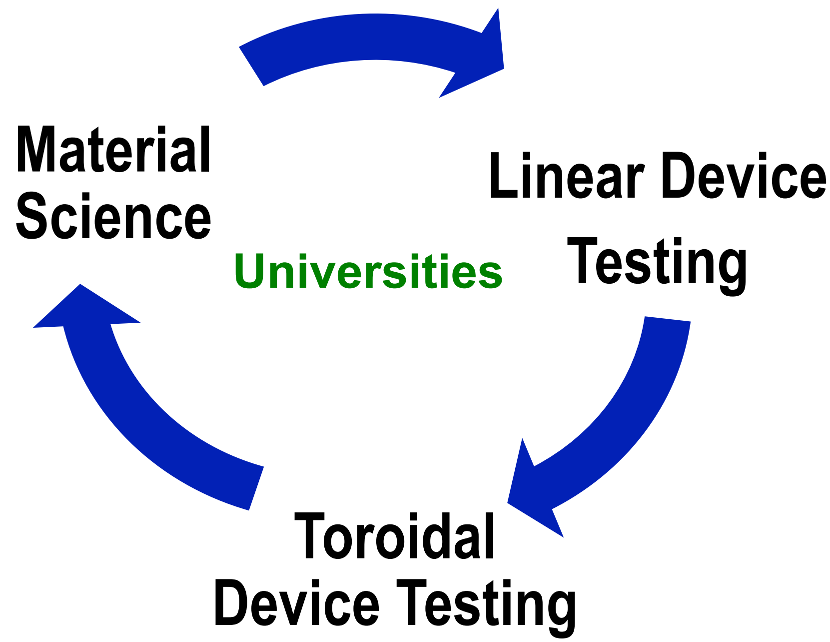
Summary of Helium and Displacement Damage Levels for Ferritic Steels



Fusion materials development is an opportunity for US leadership, including FMITS and MPEX as user facilities

- Initiative leverages on ORNL’s world leading capabilities

- **Declared interest from:**
  - University of Tennessee - Knoxville
  - Purdue University
  - University of Urbana-Champaign
  - West Virginia University
  - University of Wisconsin – Madison
  - University of California – San Diego
  - DIII-D and New B&PMI Center
  - PPPL
  - International (EAST, WEST)



MPEX and FMITS together with large scale testing in toroidal devices and an aggressive materials development program (PFCs) will pave the way for a next step Fusion Nuclear Science Facility.