Challenges for materials: fluxes and fluence, temperatures

- **JET**
  - 50 x divertor ion fluxes
  - 5000 x divertor ion fluence
  - $10^6$ x neutron fluence (1dpa)

- **ITER**
  - up to 5 x ion fluence

- **FNSF**
  - up to 100 x neutron fluence (150dpa)

- **Fusion Reactor**

**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.
  \[ \Rightarrow \text{Strongly coupled regime} \]

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

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


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

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

<table>
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<th>Consequences on PMI</th>
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<td>Thermal conductivity</td>
<td>Temperature operation window, less tolerance to transient heat loads, erosion yield</td>
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<td>He, H embrittlement</td>
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<td>Synergies of micro-structural changes between neutron and plasma irradiation</td>
<td>??????</td>
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</table>
MPEX

- Direct response to thrust 10 in ReNeW
  - $\Gamma > 10^{23}\text{m}^{-2}\text{s}^{-1}$, $P \sim 20\text{MW/m}^2$, inclined target
  - $B > 1\text{T}$
  - steady-state (up to $10^6$ sec)
  - $> 600^\circ\text{C}$ surface temperature
  - large plasma area $\sim 100 \text{cm}^2$
  - Liquid metal targets: Ga, Sn, Li
  - Neutron-irradiated material samples with significant dpa
  - Independent control of T and n at target

- Project cost: $\sim 29\text{M}$ duration 5 years
- Upgrade (irradiated materials): $\sim 5\text{M}$
- Operation costs: $6\text{ M / yr}$

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

Opportunity for world leadership
**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

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**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.