Synergistic Effects of Radiation Damage and Plasma Material Interactions

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Los Alamos NATIONAL LABORATORY

Main points of talk

- At DEMO fluences & timescales, radiation damage and PMI issues may be coupled → *needs assessment!*

- Facilities and modeling tools are available well ahead of NHTX/Vulcan/FDF/CTF to start assessing this issue

- Proposed research thrust includes:
  - Modeling
  - Material exposure and characterization (emphasizing near term)
  - Novel materials design, synthesis, testing (Demkowicz's talk)

- Emphasis on:
  - Turbulent sheath and material bulk modeling
  - Close collaboration between fusion/plasma & materials scientists/ engineers
  - Materials innovation based on first principles understanding
  - In situ material characterization

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Connections to Greenwald report gaps & initiatives

- High level Gaps 10 (PFC) and also 9 (PWI)
  - Effects of neutron irradiation on PFC materials properties that modify erosion/redeposition and tritium retention (p.161)
  - Characterization of processes that lead to T retention; synergistic effects of high plasma particle flux and neutron damage have never been studied (p.172)
  - Identification/qualification of materials which can take the heat loads and survive damage from neutron fluence; need to invent a new alloy (e.g., to improve ductility) (p.173)
  - Characterization of tritium effects (permeation, embrittlement, and retention), especially permeation effects in nuclear environment (p. 174)

- High level initiatives
  - I-6 Engineering and materials physics modeling and experimental validation
  - I-7 Materials qualification facility
  - I-8 Component development and testing program

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Coupled radiation damage and PMI phenomena

- Radiation damage issues:
  - Vacancies, defects, defect clusters
  - Helium production, bubble formation, embrittlement
  - Phase, dimensional, and structural stability

- PMI issues:
  - Erosion/redeposition
  - Tritium permeation, diffusion, and retention
  - Thermal shock resistance

- Coupling
  - Rad-damage affects thermal conductivity and material temperature → temperature dependent processes are affected
  - H/He retention/diffusion
  - Erosion and thermal shock resistance
  - ??

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Proposed research thrust (I): Modeling

- Assessing ion beam irradiation for simulating neutron damage
  - Irradiation depth
  - Ratio of electronic to nuclear stopping power
  - Similarity of damage cascades and final damaged states
- Turbulent sheath transport
  - Coupling between SOL and material surface
  - Electromagnetic PIC using parallel supercomputers
- Response of bulk material to radiation damage beyond μs time-scales
  - Accelerated MD using parallel supercomputers

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Proposed research thrust (II): Material exposure and characterization

- Serial exposure using ion beam irradiation to simulate neutron damage and then PMI (e.g., UCSD, MIT) *(ready)*

- Simultaneous exposure by co-locating PMI and multiple ion beam facilities *(available in near future, if necessary)*

- Serial exposure using accelerator-based neutron irradiation (e.g., LANL-MTS, IFMIF) and PMI facilities *(in ~5 years)* (white paper and presentation by Pitcher, Maloy)

- Simultaneous exposure by adding PMI capability to accelerator-based neutron facility *(in ~5 years)*

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Proposed research thrust (III): Material design, synthesis, testing

- White paper by Misra et al. (presented by Demkowicz)
- From “observation and validation” to “prediction and control”
- In situ characterization to provide the best data for materials model validation
- Leverage DOE/BES funded capabilities for material synthesis (e.g., LANL/SNL CINT)
- Test these materials in exposure environments

Summary

- At DEMO fluences & timescales, radiation damage and PMI issues may be coupled → *needs assessment!*

- Facilities and modeling tools are available ahead of NHTX/Vulcan/FDF/CTF to assess this issue

- Proposed research thrust includes:
  - Theory & modeling
  - Material exposure and characterization
  - Novel materials design, synthesis, testing

- Emphasis on:
  - Turbulent sheath and material bulk modeling
  - Close collaboration between fusion/plasma & materials scientists/engineers
  - Materials innovation based on first principles understanding
  - In situ material characterization

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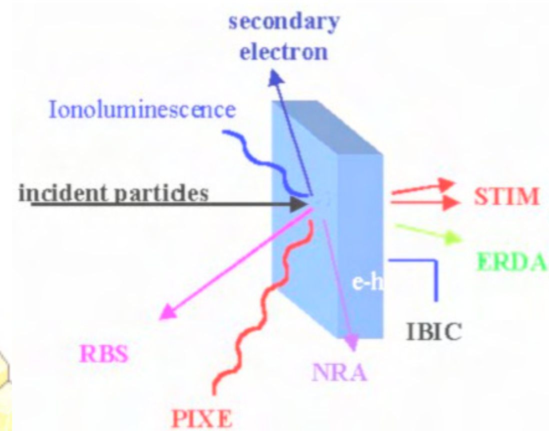
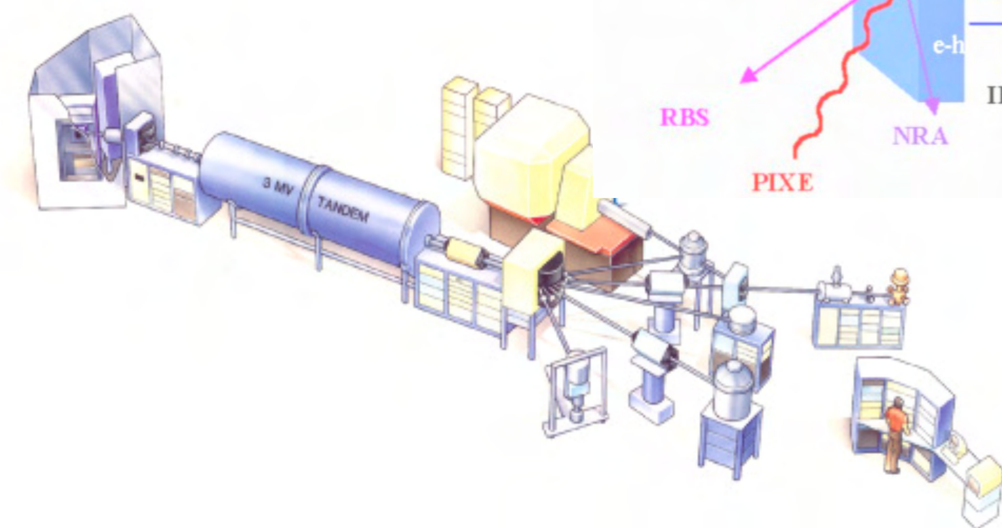
Backup slides

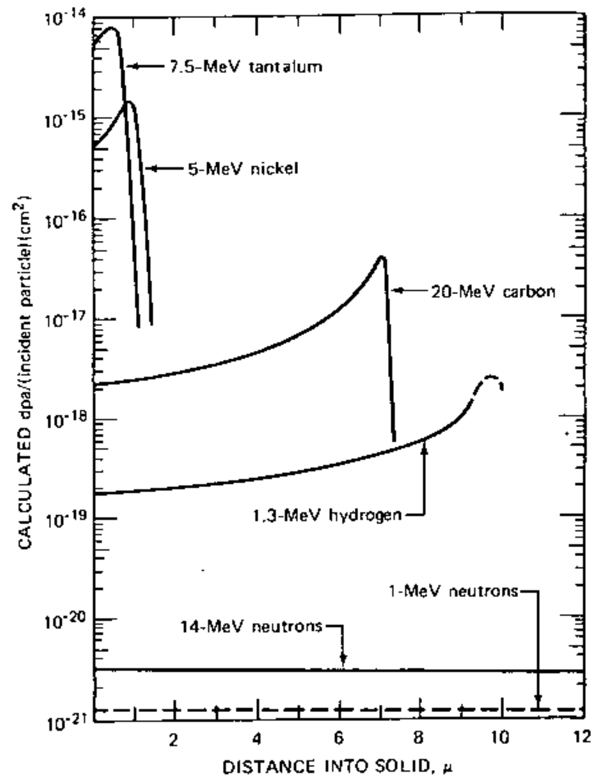
Material irradiation at a multiple ion beam facility

Ion beam analysis



LANL IBML





Why multiple ion beams?

1. dpa damage
2. in situ characterization/analysis
3. helium implantation to correct dpa/He ratios

Interfaces reduce radiation damage

by acting as sinks for radiation-induced point defects

Courtesy of Misra and Demkowicz etc.

Cu-Nb multilayer nanocomposites

- $10^{17}/cm^2$ 150keV He implantation
- No amorphization or defect clusters