U.S. DEPARTMENT OF ENERGY | Nuclear Energy

Nuclear Energy University Programs (NEUP) Fiscal Year (FY) 2013 Annual Planning Webinar

Simulation of Neutron Damage for High Dose Exposure of Advanced Reactor Materials (IRP-1)

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Grand Challenge

Structural Materials Are Critical for Advanced Nuclear Reactor Technologies

- **Development and qualification of advanced structural materials are critical to the design and deployment of the advanced nuclear reactor systems that DOE is developing**
  - High Temperature Gas Cooled Reactors (HTGRs)
  - Sodium Cooled Fast Reactors (SFRs)
  - Fluoride Salt Cooled High Temperature Reactors (FHRs)
  - Lead and Lead-Bismuth Cooled Fast Reactors (LFRs)
- **Structural materials must perform over design lifetimes for pressure boundaries, reactor internals, heat transfer components, etc.**
- **Performance of structural materials for high temperatures and radiation exposures associated with advanced reactor system development is supported by three separate reactor programs**

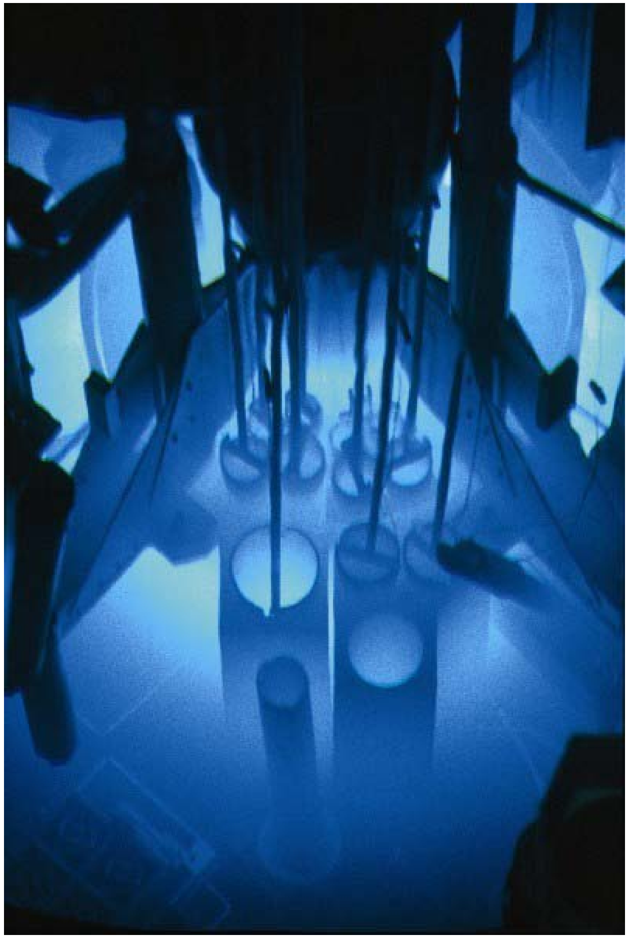
Program Overview and High Level Workscope

NGNP, ARC and SMR Programs Include Structural Materials R&D Activities

- **Next Generation Nuclear Plant (NGNP) performs fuels & materials qualification and reactor systems R&D for high-temperature gas cooled reactors**
  - Development and qualification of graphite, high temperature metals, and composite materials for pressure boundaries, internals, and heat transfer equipment
- **Advanced Reactor Concepts (ARC) performs R&D on fundamental nuclear technologies that enable new uses of nuclear energy**
  - Improvement of ferritic-martensitic and austenic alloys and materials compatibility for SFR, FHR, and LFR systems
- **Small Modular Reactor (SMR) supports smaller, advanced designs with longer-term licensing horizons through focused R&D**
  - High temp design methodology and ceramic composite codes & standards development and materials compatibility for LFR systems

A Capability for High Dose Exposure of Structural Materials Is Needed

- **Development and qualification of materials for components and structures in advanced, high temperature reactors will require neutron doses too high to be obtained in test reactors**
  - Fast reactors up to 200 dpa
  - Traveling wave up to 600 dpa
  - Even internals in existing reactors may exceed 40 dpa
- **Thermal and fast test reactors only produce max dose of ~ 5 to 20 dpa/yr**



MURR

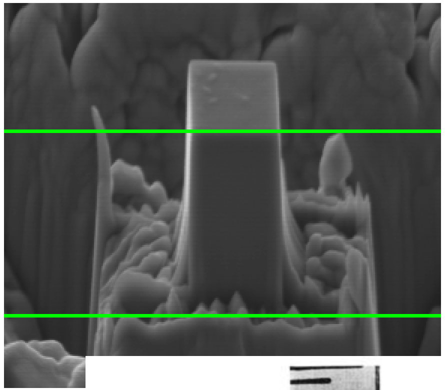
Technical Issue: An Alternate Approach for High Dose Irradiations Exposures Is Needed

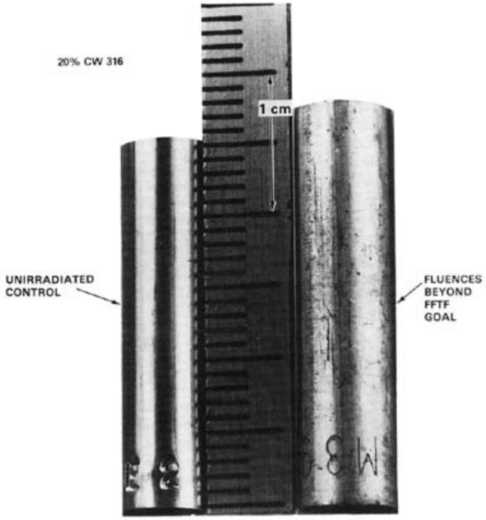
- **Test reactor exposures to reach multi-hundred dpa levels are impractical**
- **Test reactor space for materials irradiation is limited and fast spectrum space is <u>extremely</u> limited**
- **Alternate approaches, such as ion beam exposures, can reach the very high doses of interest but have many significant challenges**
  - Facilities for irradiations
  - Effects of dramatically accelerated flux
  - Spectral/particle effects
  - Atomic displacement damage vs He or H production
  - Irradiation volume/depth of penetration issues
  - PIE methods and correlation of results with macroscopic properties for structures and components

Highly Accelerated Irradiations Must Be Correlated with Reactor Conditions

- Effects from the nano-scale to macro-scale must be examined
- Effects of defect generation vs recombination rates for orders-of-magnitude variations in irradiation fluxes
- Simulation of transmutation-generated He and H
- Major variations in extended radiation-induced defects that affect microstructure and resultant materials properties
- Measurement techniques to relate changes in properties in damaged layers only a few microns thick to structural members

Micropillar technique.
Hoffelner, PSI





Swelling in CW 316 stainless steel

Evaluating Materials at Very High Irradiation Doses for Advanced Reactors Development Is Needed

- **Proposals are solicited to demonstrate the capability to predict the properties of structural materials after extremely high radiation doses**
- **Such a capability shall include the ability to expose materials via surrogate irradiations from sources other than test reactors to very high doses and interpret the results of those irradiations to the equivalent neutron exposure for reactor operation**
- **Major components of the demonstration will include:**
  - Irradiation source
  - Interpretive modeling
  - Post irradiation examination capacity for changes in properties and microstructures
  - Benchmarking of surrogate high-dose source irradiations with comparable neutron irradiations

The Capability to Evaluate Materials at Very High Irradiation Doses Shall Be Demonstrated

- **To demonstrate the capability to evaluate materials at high irradiation doses, benchmarking of the required experimental and analytical elements shall be performed via a focused study of comparative results of neutron vs surrogate irradiations under high-dose conditions specific enough to show the strengths and limitations of the capability**

- **Items that should be addressed in the benchmarking include:**
  - Irradiation rate and spectrum effects
  - Relative effects of displacement damage vs He or H production
  - Methods for PIE of microstructure and materials properties
  - Impacts of irradiation method on microstructure and materials properties
  - Strengths and limitations of the analytical methods used to relate the surrogate irradiations to comparable neutron irradiations