

# **Overview of the Fusion Materials Sciences Program**

**Presented by S.J. Zinkle,  
Oak Ridge National Lab**

**Fusion Energy Sciences  
Advisory Committee meeting**

**February 27, 2001**

**Gaithersburg, MD**

# OUTLINE

- Overview of Materials Sciences program: 1995-2001
  - Response to FESAC review (summer, 1998)
  - Summary of recent program restructuring (ongoing evolutionary process)
- Materials science highlights
  - Simultaneous scientific excellence: research directly relevant for fusion and of interest to the broader materials science community

## **Key findings from 1998 FESAC review**

- **Overall scientific quality of research is high**
- **R&D activities should be part of an integrated program in enabling technology**
- **Research focus should be expanded to include a wide variety of materials for MFE and IFE**
  - **Seek opportunities to interact & benefit from other government and industrial materials programs**
- **Budget should be increased by 1-2 M\$/yr to support new initiatives in modeling and exploratory concepts**

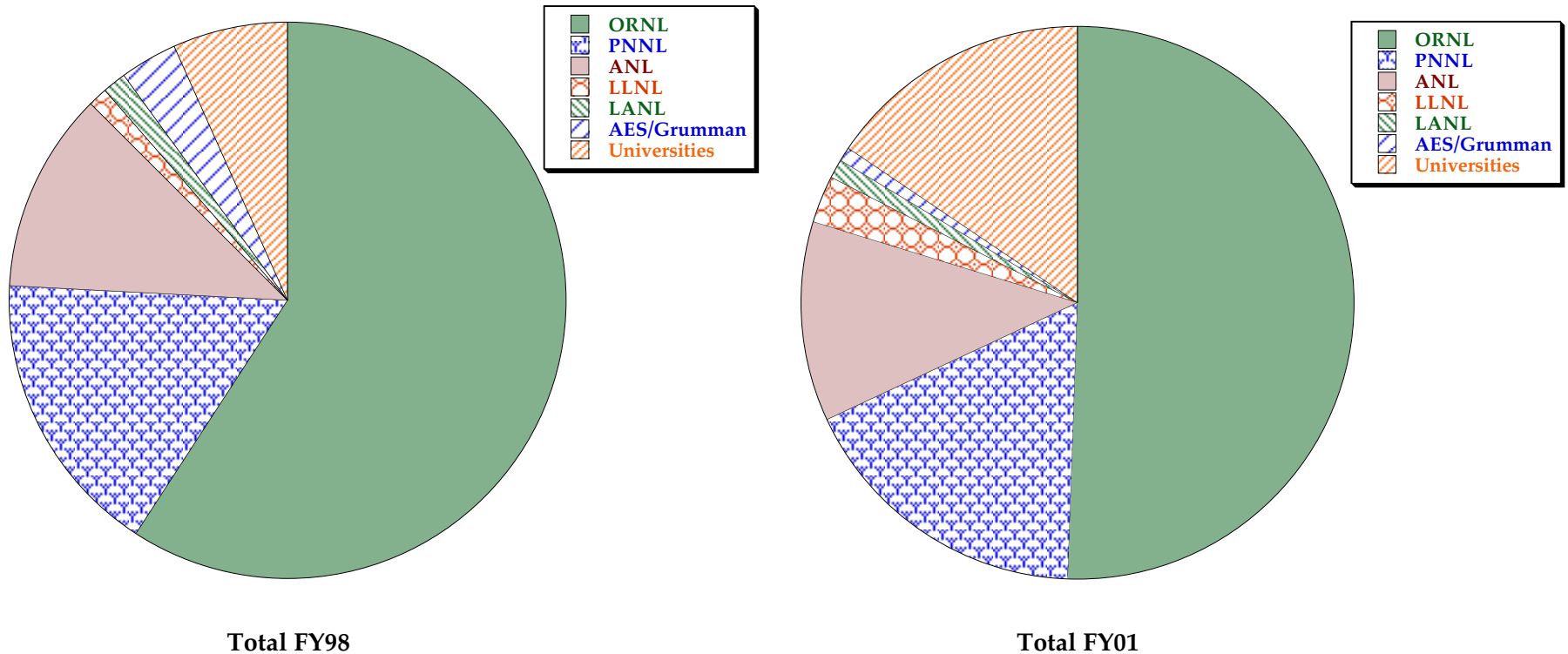
# Fusion Materials Restructuring

“As new discoveries are made, new truths discovered, and manners and opinions changed with the pace of circumstances, institutions must advance also to keep pace with the times”

Thomas Jefferson

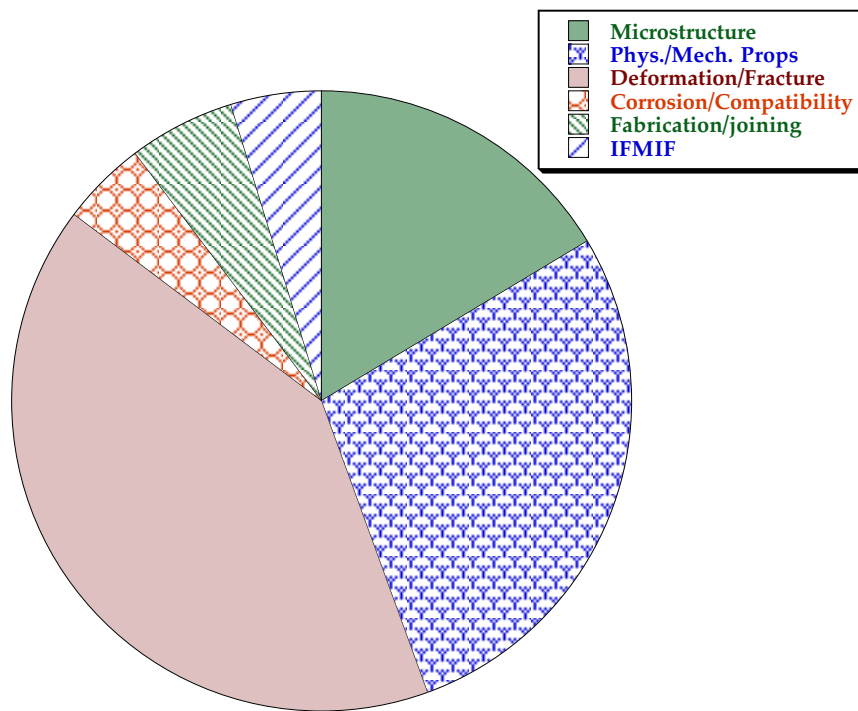


# Fusion Materials Sciences Institutional Budgets

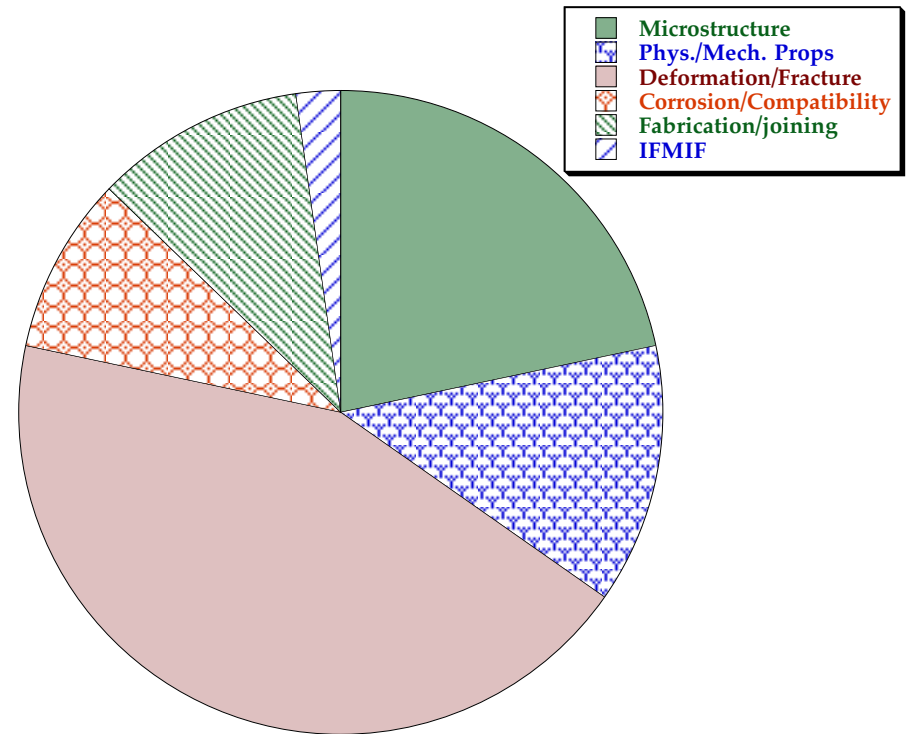


- University funding has tripled in the past 3 years
- Significant personnel changes have occurred at institutions
  - e.g., ORNL: 18 scientists with average support of 0.4 FTE/yr; 11 staff removed and 9 new researchers added since FY98

# Fusion Materials Sciences R&D Portfolio



FY98 funding



FY01 funding

- Continued emphasis on mechanical properties

# Materials Restructuring Process

	<u>Events</u>	<u>Comments</u>
1998 (external events, policy changes)	<ul style="list-style-type: none"><li>• End of U.S. participation in ITER activities</li><li>• FESAC panel review of Materials Program</li></ul>	<ul style="list-style-type: none"><li>• Beginning of technology program restructuring from energy development to science-oriented.</li><li>• Recommended increased effort on theory/modeling and road-mapping</li></ul>
1999	<ul style="list-style-type: none"><li>• Materials Program road-mapping</li><li>• White paper on theory/modeling initiative</li></ul>	<ul style="list-style-type: none"><li>• Identified key feasibility issues</li><li>• Modeling call for proposals released December 1999</li></ul>

# Materials Restructuring Process

	<u>Events</u>	<u>Comments</u>
2000 (restructuring implementation begins)	<ul style="list-style-type: none"><li>• Theory/modeling competitive solicitation (\$1M)</li><li>• Guidance from OFES to accelerate restructuring process</li><li>• Develop concept for reorganizing along cross-cutting technical issues</li></ul>	<ul style="list-style-type: none"><li>• outreach to broad materials community</li></ul>
2001	<ul style="list-style-type: none"><li>• Theory/modeling awards made</li><li>• Peer review to be conducted</li><li>• Initiate outreach to plasma research and IFE</li></ul>	<ul style="list-style-type: none"><li>• 3 new participating institutions</li></ul>

# Materials Science Restructuring Themes

	<b>Pre-Restructuring</b>	<b>Restructured</b>
<u>Orientation</u>	Fusion Materials <b><i>Development</i></b>	Fusion Materials <b><i>Science</i></b>
<u>Mission</u>	Schedule-driven development of materials for fusion power (ITER blanket test modules, DEMO, ...)	Fundamental understanding of scientific underpinnings of materials for fusion
<u>Organization</u>	Lead lab for each candidate structural materials class (V alloy, F/M, SiC/SiC)	Integrated national teams focused on key cross-cutting issues
<u>Approach</u>	Experiments for semi-empirical correlations	Experiments to guide/ validate theory and modeling

# Fusion Materials Science Mission Statement

- Advance the materials science base for the development of innovative materials and fabrication methods that will establish the technological viability of fusion energy and enable improved performance, enhanced safety, and reduced overall fusion system costs so as to permit fusion to reach its full potential
- Assess facility needs for this development, including opportunities for international collaboration
- Support materials research needs for existing and near-term devices

## Example of Change in Approach to Materials Research V alloy (a BCC metal)

<b>Old Approach (<i>Development</i>)</b>	<b>New Approach (<i>Science</i>)</b>
<ul style="list-style-type: none"> <li>• Select reference alloy (V-4Cr-4Ti)</li> </ul>	
<ul style="list-style-type: none"> <li>• Focus most research on this alloy (narrow scope)</li> </ul>	<ul style="list-style-type: none"> <li>• Focus research on fundamental understanding of BCC materials</li> </ul>
<ul style="list-style-type: none"> <li>• R&amp;D planning based on need to develop materials to meet device construction schedule</li> </ul>	<ul style="list-style-type: none"> <li>• Research planning based on theory and modeling requirements of BCC materials</li> </ul>
<ul style="list-style-type: none"> <li>• Experiment-based R&amp;D to build engineering data base</li> </ul>	<ul style="list-style-type: none"> <li>• Experiments used to guide and validate scientific theory and models</li> </ul>
	<ul style="list-style-type: none"> <li>• Study model BCC alloys/ surrogate materials encompassing V alloys</li> </ul>

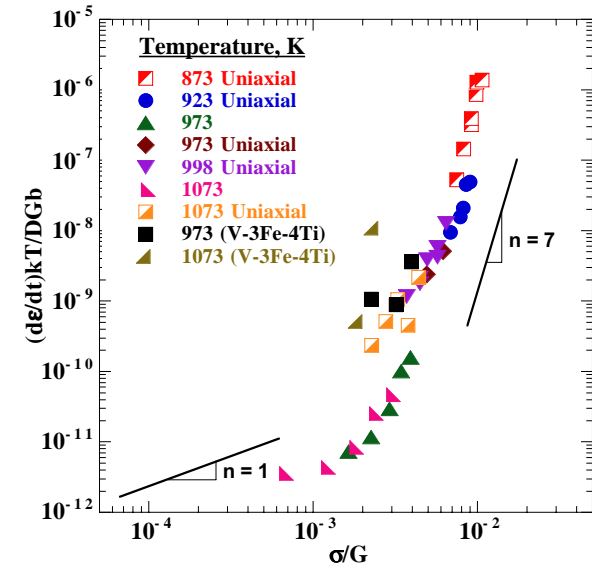
# Investigation of Thermal Creep Mechanisms in V-4Cr-4Ti

Diffusion-Controlled Creep Mechanisms

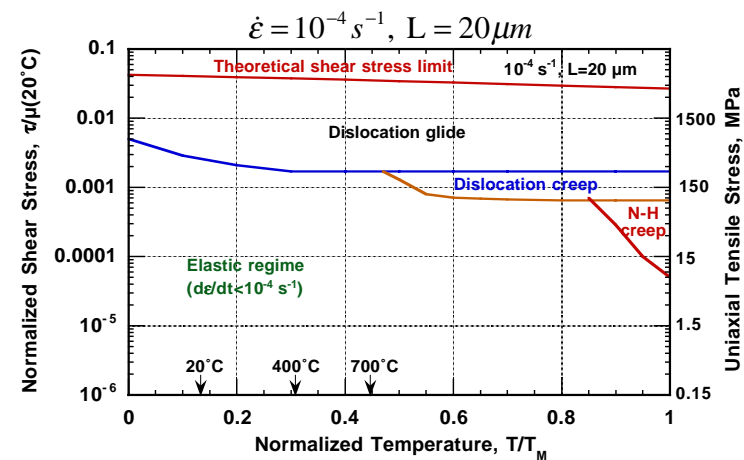
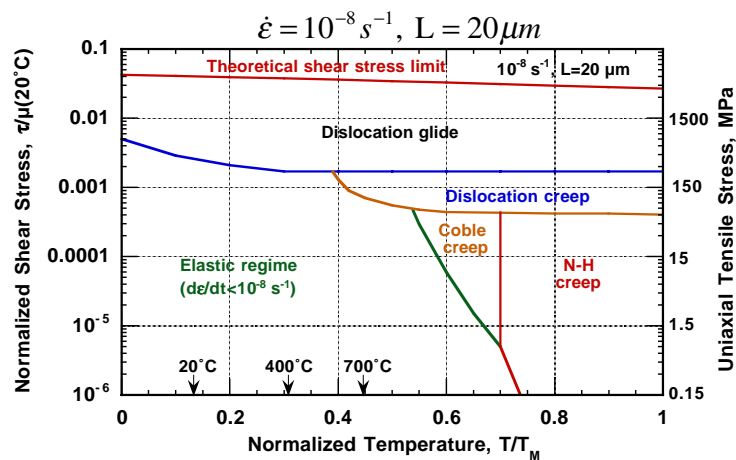
$$\frac{\dot{\epsilon}kT}{DGb} = A \left(\frac{b}{d}\right)^m \left(\frac{\sigma}{G}\right)^n$$

Mechanism	D	n	A	m
Climb of Edge Dislocations	D <sub>L</sub>	5	6x10 <sup>7</sup>	0
Viscous Glide (Microcreep)	D <sub>s</sub>	3	6	0
Low-Temperature Climb	D <sub>d</sub>	7	2x10 <sup>8</sup>	0
Harper-Dorn	D <sub>L</sub>	1	3x10 <sup>-10</sup>	0
Nabarro-Herring	D <sub>L</sub>	1	12	2
Coble	D <sub>b</sub>	1	100	3
GBS (Superplasticity)	D <sub>b</sub>	2	200	2
Nabarro-Subgrain	D <sub>L</sub>	1	12	2
Nabarro-Bardeen-Herring	D <sub>L</sub>	3	10	0

## Experimental Creep Data



## Deformation Mechanism Maps for V-4Cr-4Ti





# Features of Restructured Fusion Materials Science Program

- Science-based materials research
- Principal product is *basic knowledge, theory, and models* needed to resolve feasibility issues of fusion materials
- Primary role of experiments is to guide and validate theory and models
- Utilize, leverage, and expand on revolutionary advances in computational and experimental methods (e.g., nanoscience) for fusion materials design
- While focusing on long-term viability and attractiveness issues of fusion materials, apply expertise in near-term to current issues of plasma research and IFE studies

# Fusion Materials Science has Similarities with the Fusion Plasma Science Philosophy

	<b>Fusion Plasma Science</b>	<b>Fusion Materials Science</b>
<b><u>Basic Goal</u></b>	<b>Understand fourth state of matter as it relates to fusion</b>	<b>Understand first state of matter as it relates to fusion</b>
<b><u>Key Issues</u></b>		
<ul style="list-style-type: none"> <li>• Basic properties and microscopic phenomena</li> <li>• System properties and macroscopic phenomena</li> <li>• Creation and sustainment</li> <li>• Interactions with environment</li> </ul>	<ul style="list-style-type: none"> <li>– particle/energy confinement and transport</li> <li>– MHD stability</li> <li>– plasma-wave interactions</li> <li>– plasma-wall interactions</li> </ul>	<ul style="list-style-type: none"> <li>– dislocation propagation, phonon transport, ...</li> <li>– microstructural stability</li> <li>– fracture and deformation</li> <li>– physical metallurgy and thermodynamics</li> <li>– corrosion &amp; compatibility; radiation effects on materials</li> </ul>

## Fusion Materials Science Program

	Theory-Experiment Coordinating Group*				
	Microstructural Stability	Physical & Mechanical Properties	Fracture & Deformation Mechanisms	Corrosion and Compatibility Phenomena	Fabrication and Joining Science
<b>Materials for Attractive Fusion Energy</b>					
<ul style="list-style-type: none"> <li>• <b>Structural Alloys*</b> <ul style="list-style-type: none"> <li>- Vanadium Alloys</li> <li>- F/M and ODS Steels</li> <li>- High T Refractory Alloys</li> <li>- Exploratory Alloys</li> </ul> </li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Ceramic Composites*</b> <ul style="list-style-type: none"> <li>- SiC/SiC, other CFCs</li> </ul> </li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Coatings</b></li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Breeder/multiplier Materials</b></li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Neutron Source Facilities</b></li> </ul>					
<b>Materials for Near-Term Fusion Experiments</b>					
<ul style="list-style-type: none"> <li>• <b>PFMs (Refractory Alloys, etc.)</b></li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Copper Alloys</b></li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Ceramic Insulators</b></li> </ul>					
<ul style="list-style-type: none"> <li>• <b>Optical Materials</b></li> </ul>					

\*asterisk denotes Fusion Materials Task Group

# Simultaneous excellence is central to the R&D portfolio of the fusion materials science program

- Provide valuable product for fusion energy sciences (build knowledge base)
- Provide excellence in materials science
  - This also helps to build support for fusion energy within the broad materials science community

Scientific excellence	Nuclear physics	Semi-conductor R&D
		Cold fusion
	Interest outside subfield	

# Fusion Materials Science is the Vital Link Between the Fusion Energy Sciences and Materials Science Communities

- Researchers in the Fusion Materials Science program are housed in materials science departments at their institutions (provides access to the broader materials science community)
- Researchers in the Fusion Materials Science program are also actively involved in numerous non-fusion cutting-edge materials science endeavors (provides targeted leveraging)
- Fusion Materials research is contributing to several materials science “grand challenges”

## **Fusion Materials Science is Strongly Integrated with other Materials Science programs (research synergy)**

- No one engaged in fusion materials research is supported 100% by OFES funding; all fusion materials scientists actively interact with other research communities
- BES (ceramic composites, radiation effects in materials, electron microscopy, deformation physics, nanoscale materials)
- NERI (deformation mechanisms in irradiated materials, damage-resistant alloys)
- EMSP program (radiation effects in nuclear waste materials, including modeling relevant for SiC and other ceramics)
- Naval programs (radiation effects in SiC/SiC, refractory alloys, cladding materials)
- NRC (fracture mechanics and radiation effects in pressure vessel alloys)
- EPRI (stress corrosion cracking in alloys)
- APT, SNS (effects of He and radiation damage on structural integrity of materials)
- Defense programs (stockpile stewardship materials issues)

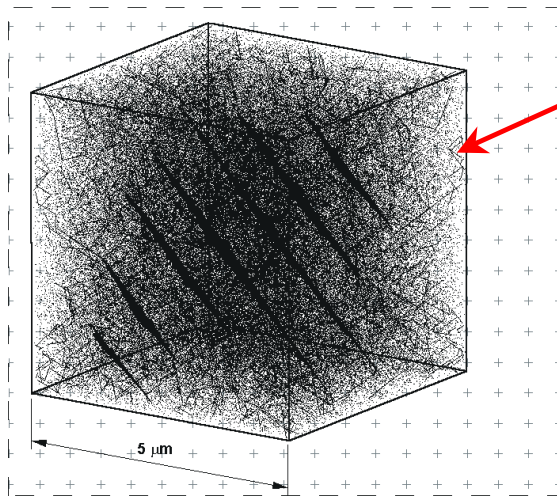
# **Fusion Materials Scientists are Contributing to the Resolution of Several Grand Challenges in the General Field of Materials Science**

- What are the maximum limits in strength and toughness for materials?
  - Dislocation propagation, interaction with matrix obstacles
- How are the “laws” of materials science altered under nanoscale and/or nonequilibrium conditions
  - Critical dimensions for dislocation multiplication
  - Nonequilibrium thermodynamics
- What is the correct physical description of electron and phonon transport and scattering in materials?
  - Thermal and electrical conductivity degradation due to point, line and planar defects
- What is the effect of crystal structure (or noncrystallinity) on the properties of matter?

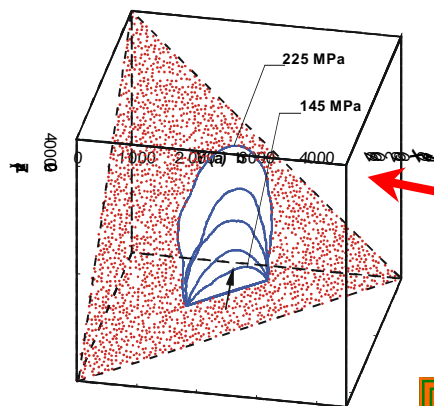
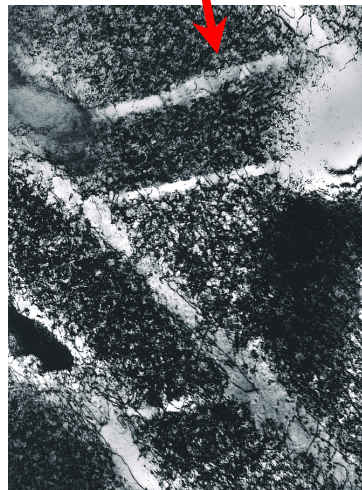




Dislocation Dynamics (DD) is a new computer simulation method developed at UCLA for modeling fundamental microscopic mechanical properties. Successful fusion applications: (1) Mechanisms of dislocation interaction with radiation defects; (2) Radiation hardening; (3) Localization of plastic flow.

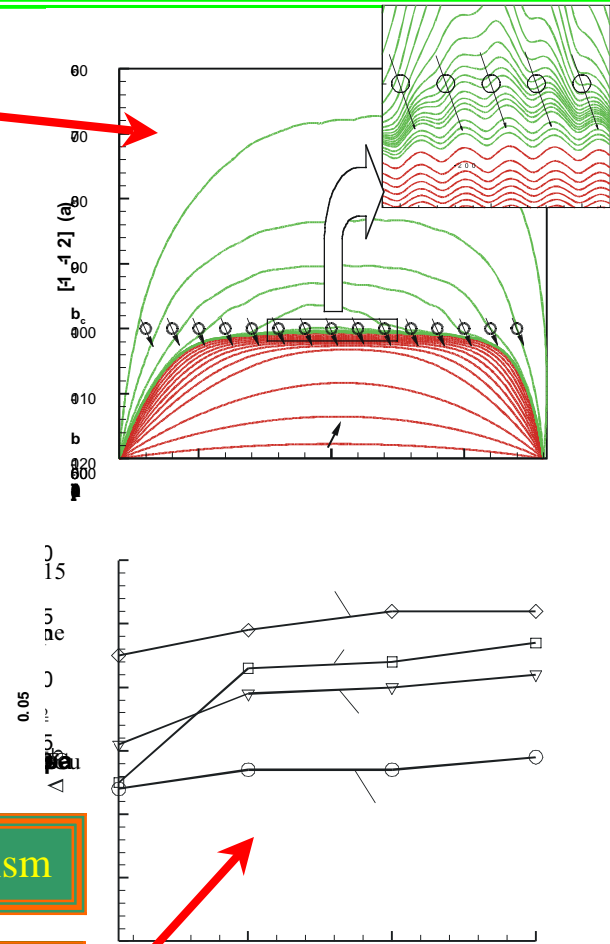


Simulations & experiments on flow localization

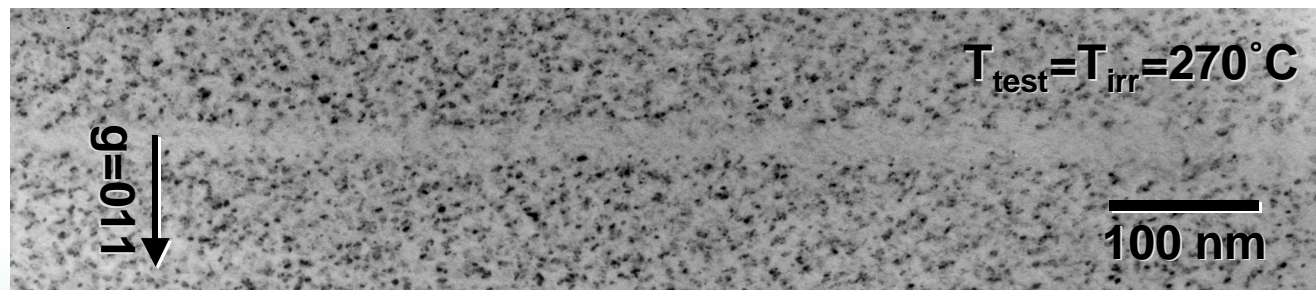
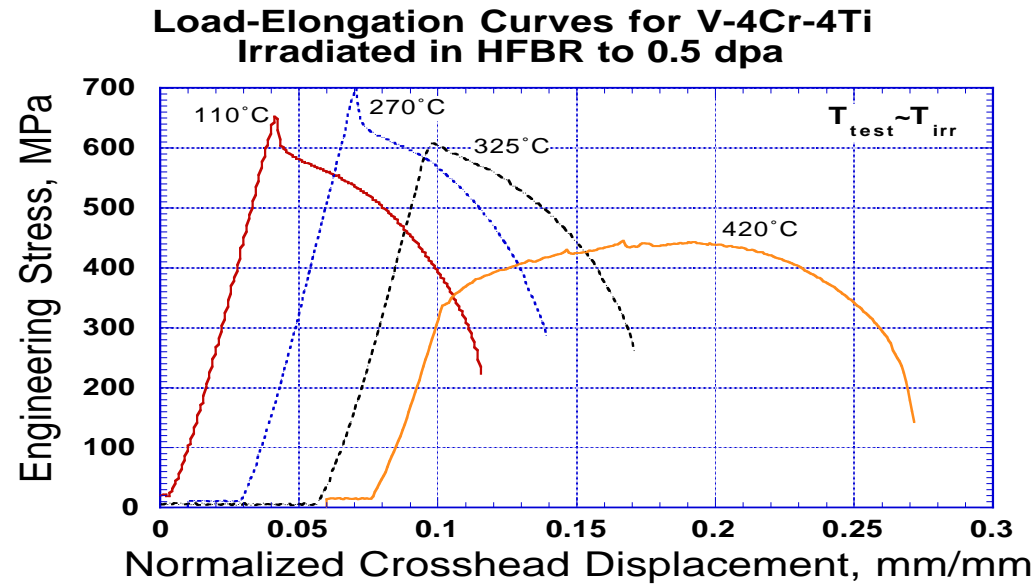


Flow Localization Mechanism

Comparison between simulations & radiation hardening experiments



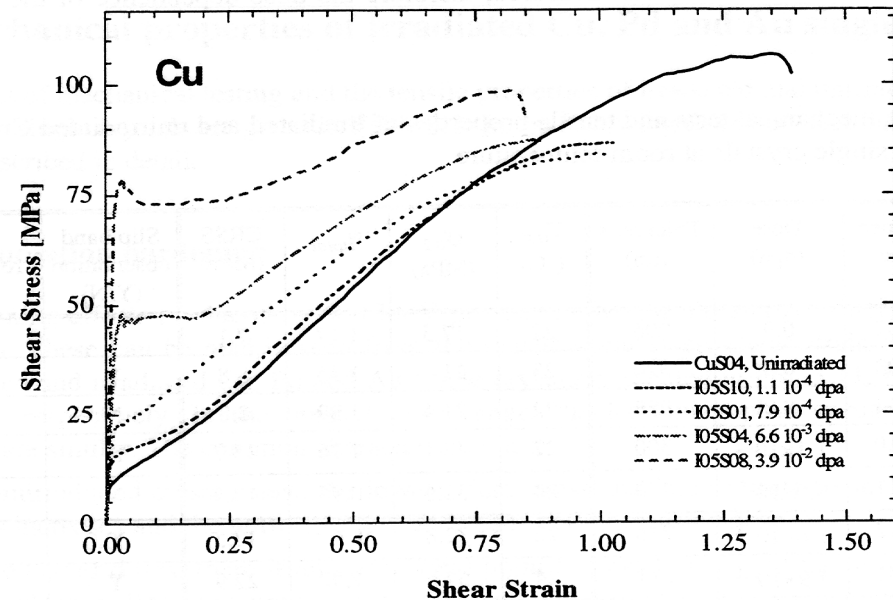
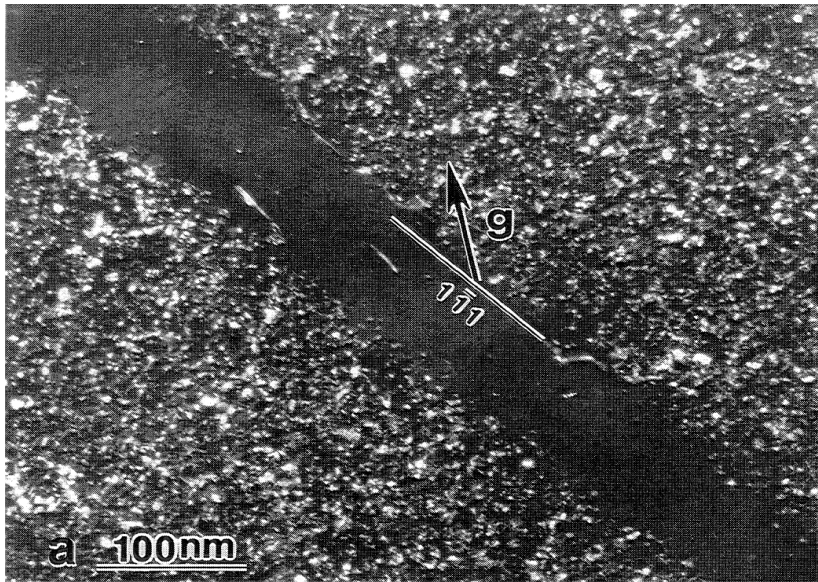
# Irradiated Materials Suffer Plastic Instability due to Dislocation Channeling



# Irradiated materials undergo plastic instability and failure due to dislocation channel formation



Plastic flow localization in irradiated metals - An unresolved issue for >30 yrs



## Outstanding questions:

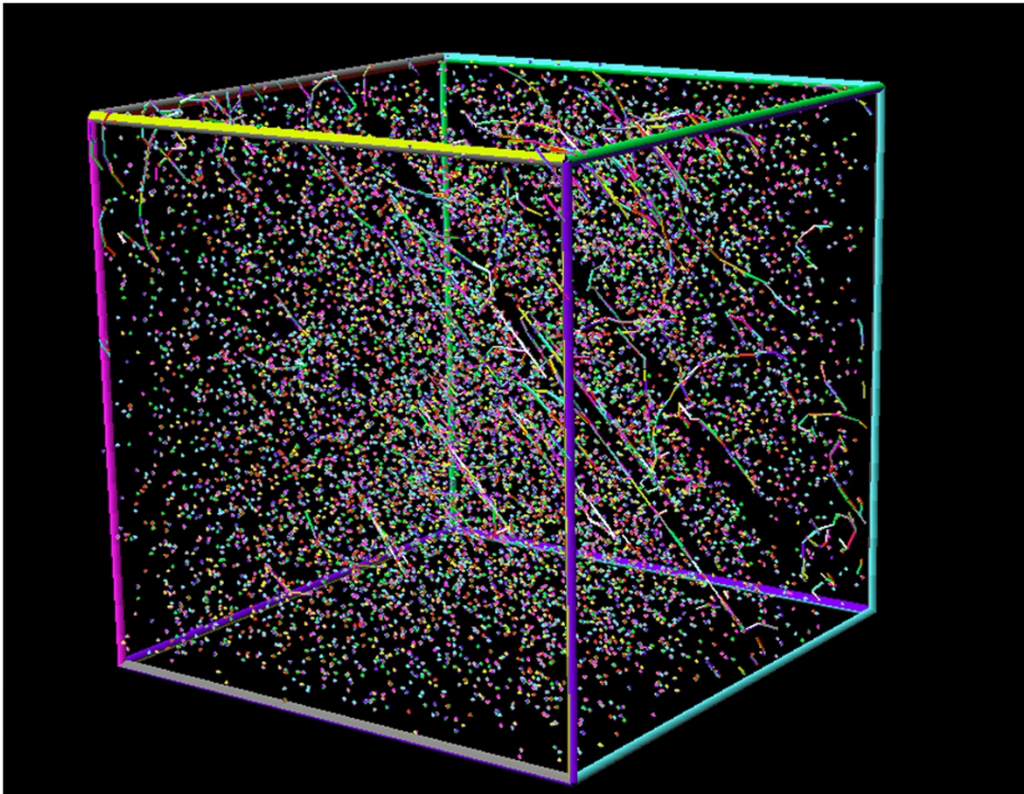
- What governs the appearance of a yield point?
- What governs the dose dependence of yield point onset?
- What governs dislocation channel initiation?
- What governs dislocation channel growth? (cross-slip in fcc metals is not well understood)
- What controls channel width?



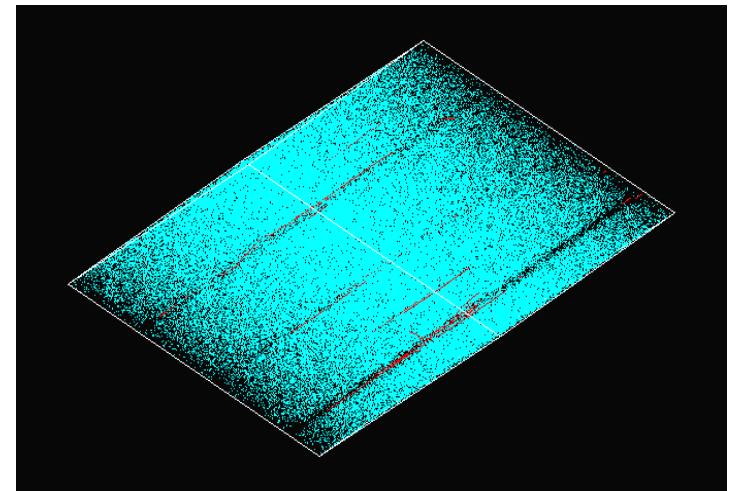
## Plastic flow localization in defect free bands appears in the Dislocation Dynamics (DD) simulations



The implementation of cross-slip into DD gives rise to the formation of defect free bands (channels) with a width of 200-300 nm

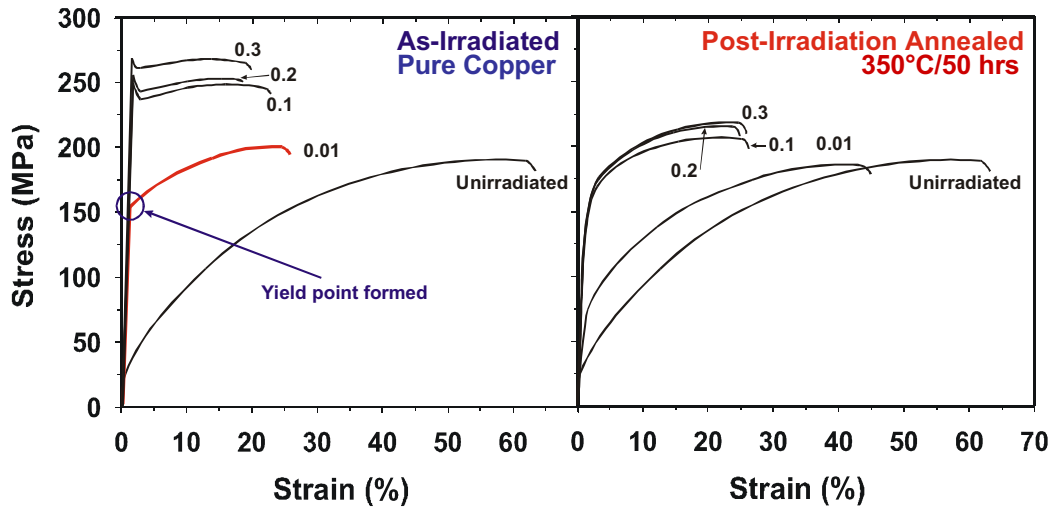


Spreading of the channels is restrained by the formation of dipole segments and the remaining radiation induced defect distribution



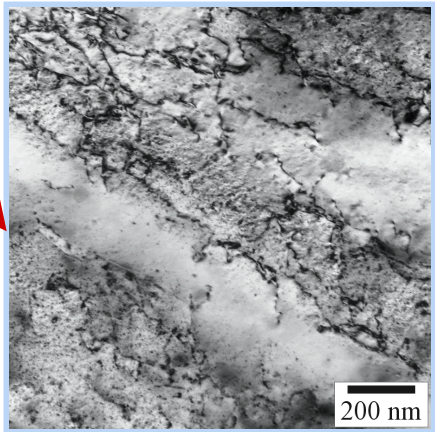
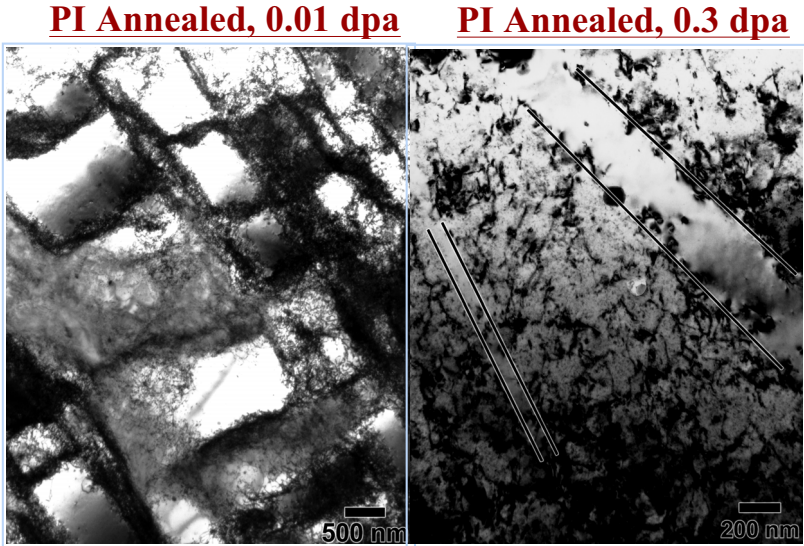
**Nature, August 24, 2000**

# Deformation Behavior in As-Irradiated and Post-Irradiation Annealed Pure Copper (PNNL & Risø National Laboratory)



- Post-Irradiation Annealed Condition**
- Dislocation cell structure: material deforms homogeneously at 0.01 dpa
  - Mixture of channeling and homogeneous deformation at 0.3 dpa

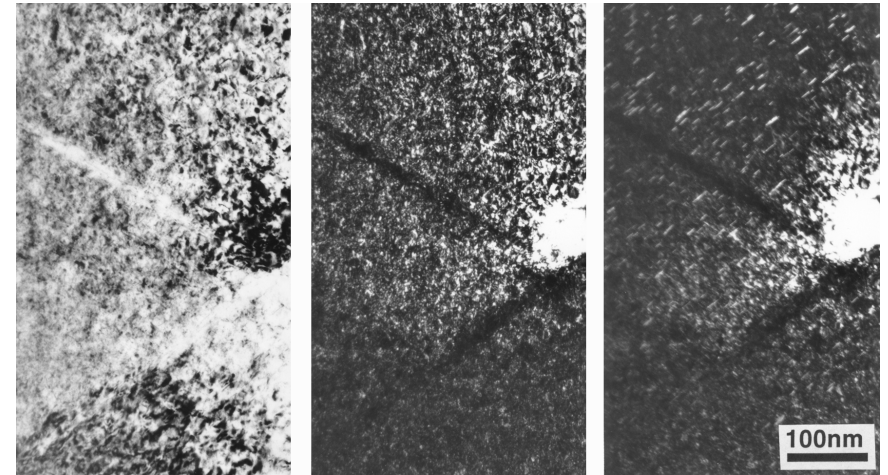
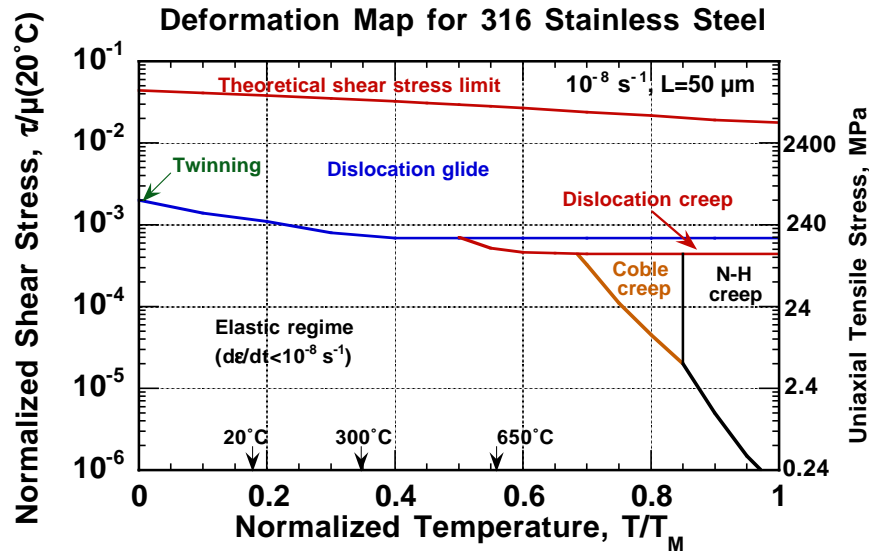
- As-Irradiated, 0.3 dpa**
- Cleared channels with little to no dislocation movement between the channels; localized deformation
  - Large increases in strength (6 to 8x)
  - Loss of uniform elongation and work hardening capacity
  - Formation of a clearly defined yield point



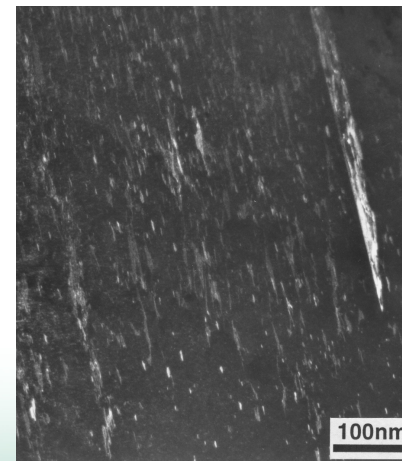
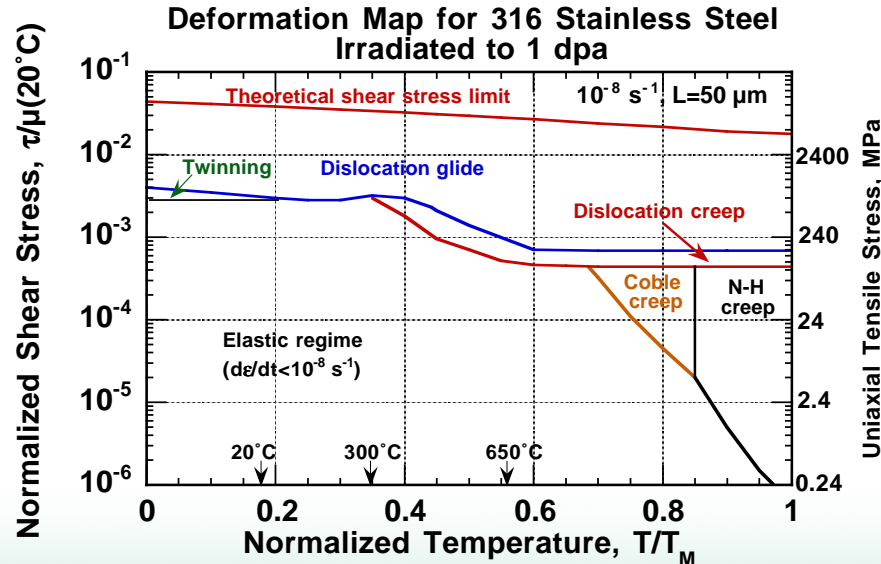


# Deformation mechanisms in FCC metals

Irradiation is a useful tool to produce controlled microstructures for deformation mechanics studies

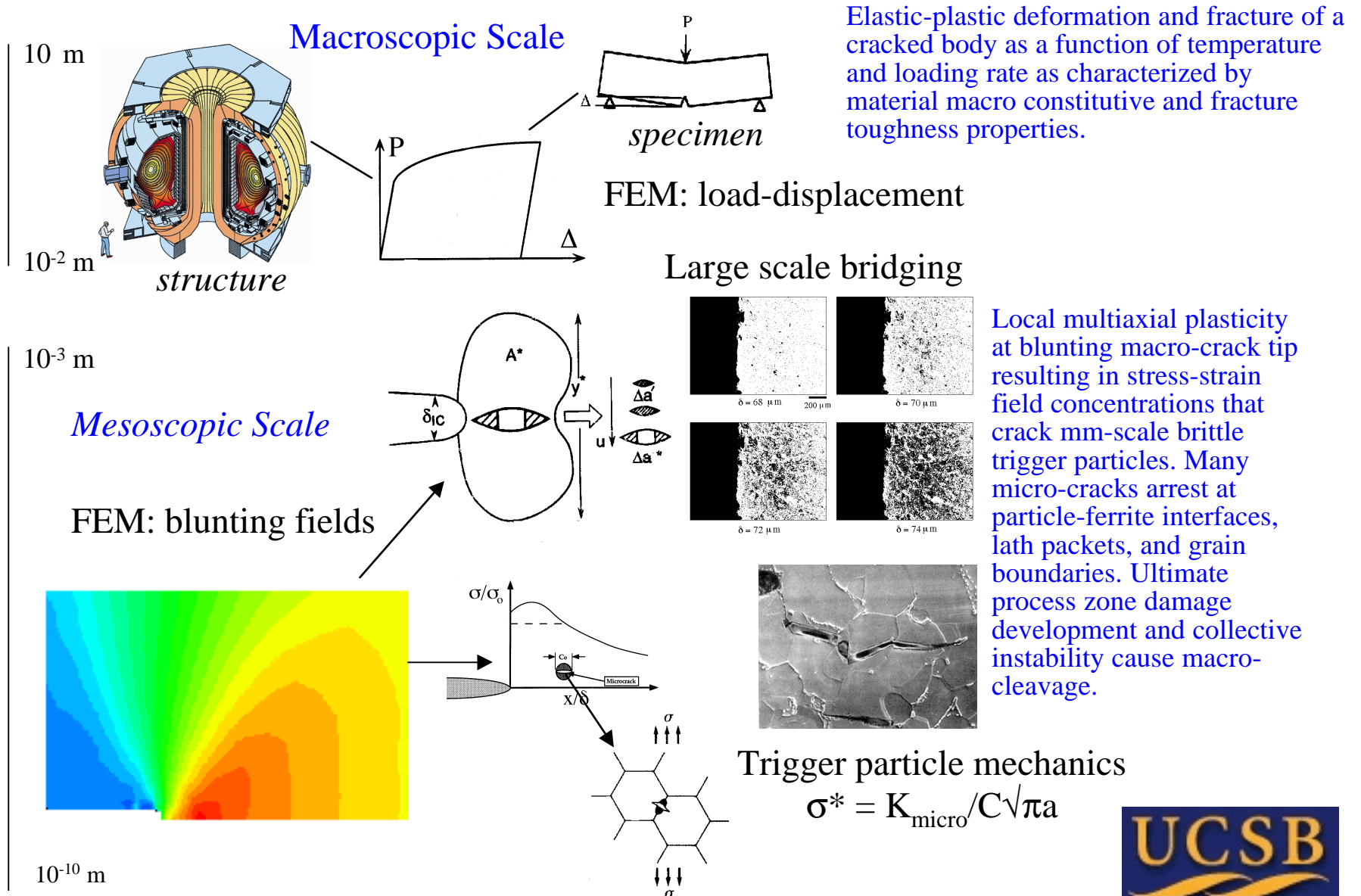


Channeling (Disl glide) occurs at higher temperatures ( $\sim 300^\circ\text{C}$ )



Twinning occurs at lower temperatures ( $< 200^\circ\text{C}$ ) and high strain rates

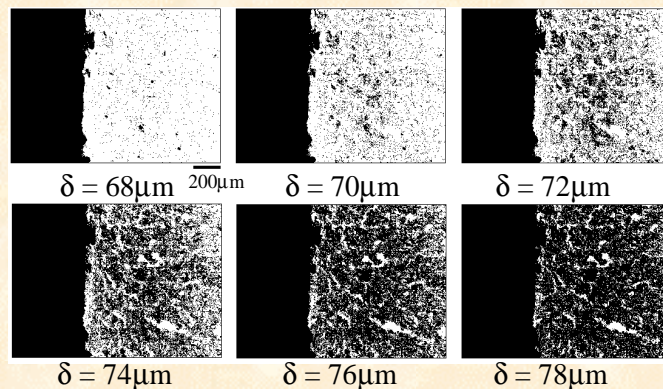
# Multiphysics - Multiscale Fracture Modeling - I



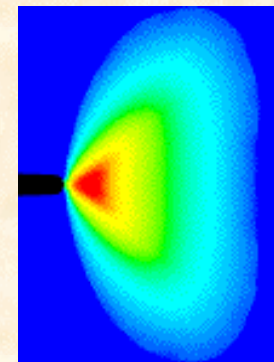
# Multiscale Research on Fracture Mechanisms, Mechanics, Models and Structural Integrity Assessment Methods

Fracture involves multiple processes interacting from atomic to structural scales. UCSB is developing multiscale physical fracture models and new engineering methods of fracture control using small-scale tests. Research combines theory, models, measurements and characterization of key processes at all pertinent length scales.

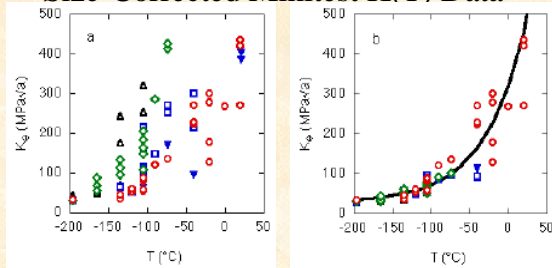
Tomographic Imaging of Cleavage



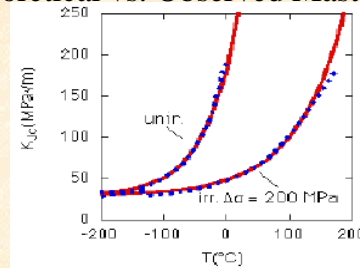
FEM Simulations of Crack Fields



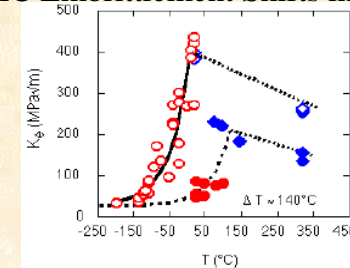
Size-Corrected Minitest K(T) Data



Theoretical vs. Observed Master Curve

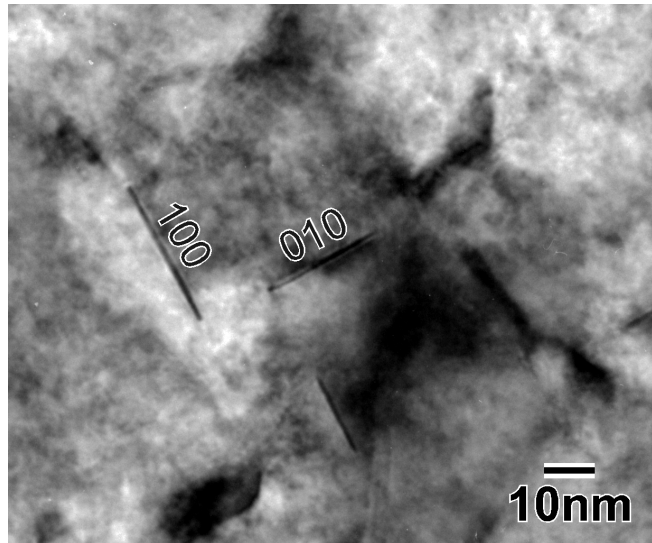


MC Embrittlement Shifts in F82H

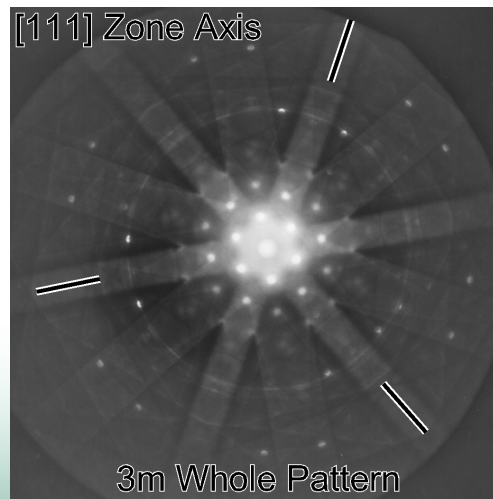
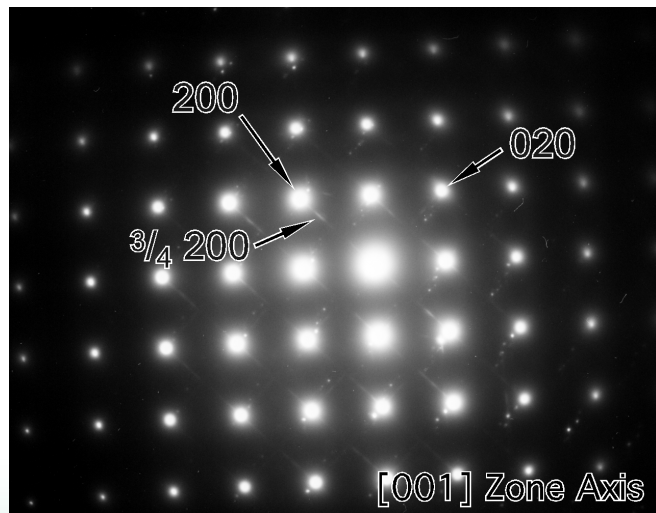
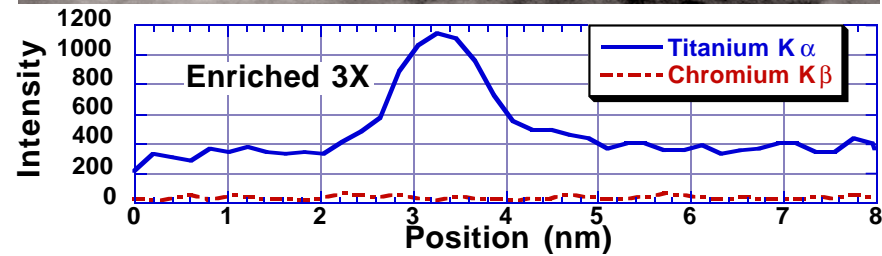
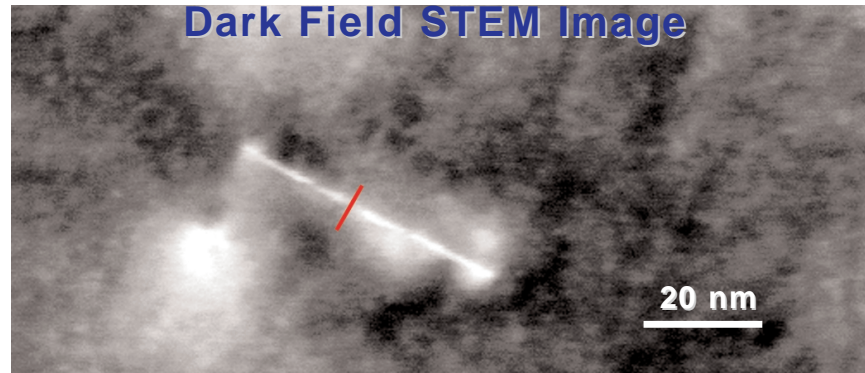




# Advanced Analytical Electron Microscopy Techniques are being used to Examine Precipitates in V alloys



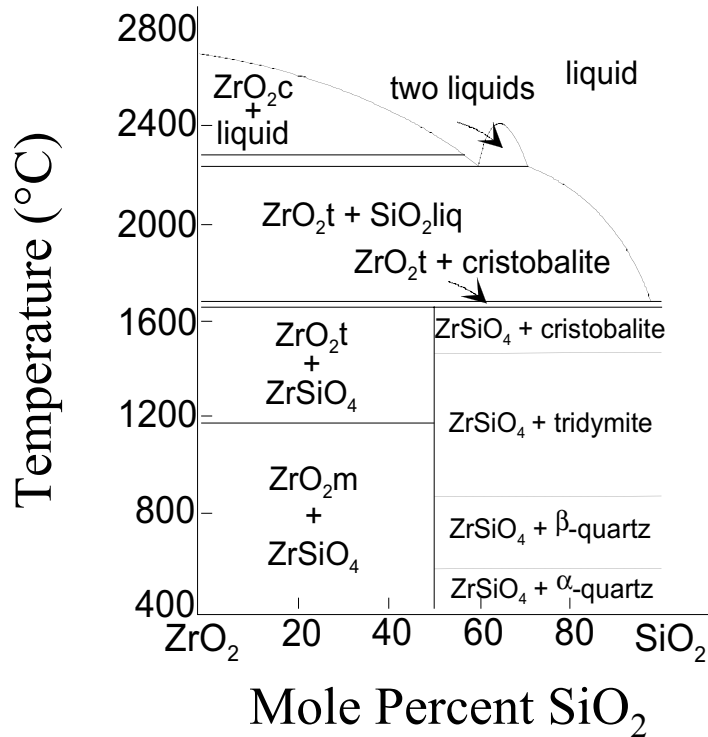
Solute Segregation Was Detected in V-4Cr-4Ti Following Neutron Irradiation to 0.5 dpa at Elevated Temperatures



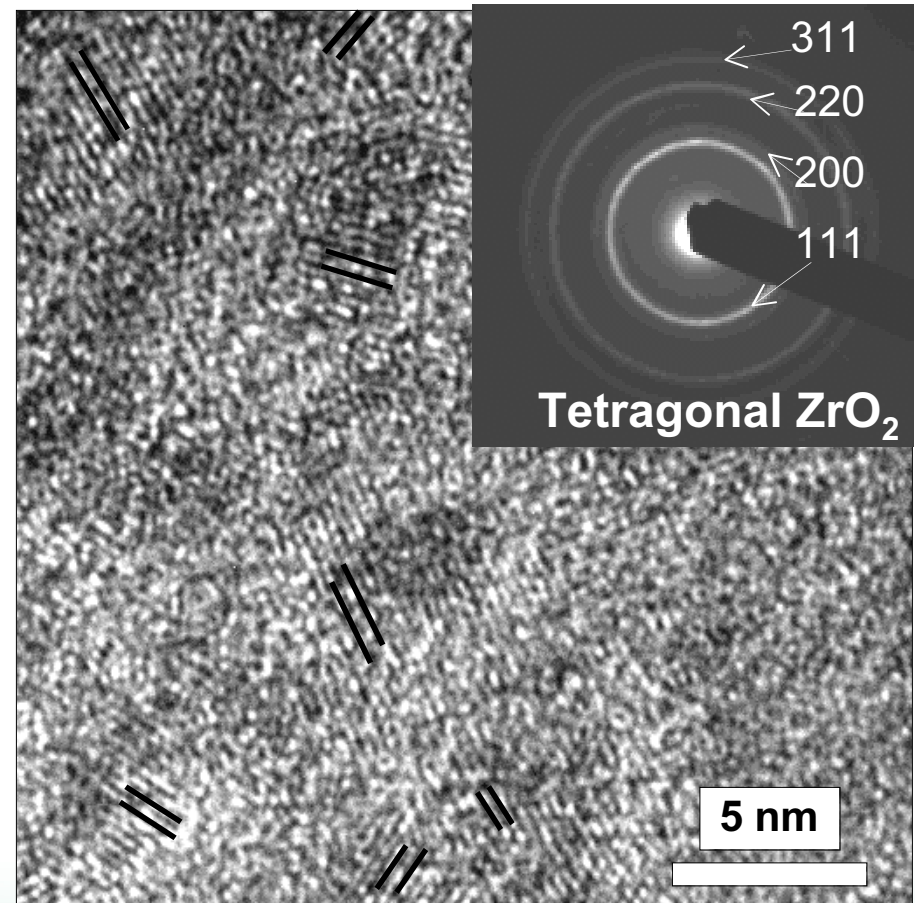
Analytical microscopy reveals Ti-rich precipitates with Fm3m space group

# Experimental evidence for nanoscale melting during atomic collisions has been obtained

ZrO<sub>2</sub>-SiO<sub>2</sub> Phase Diagram



Microstructure of Zircon Irradiated at 800 °C

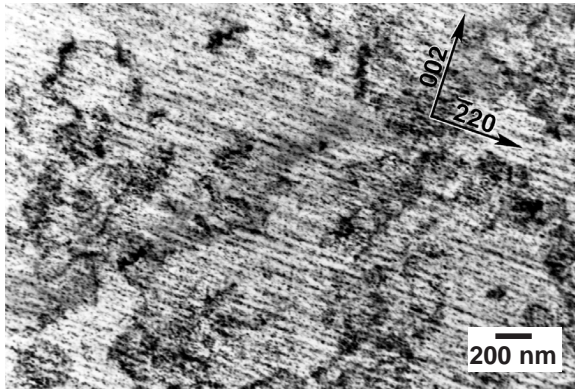


Nature, vol. 395, Sept 5. 1998, p. 56

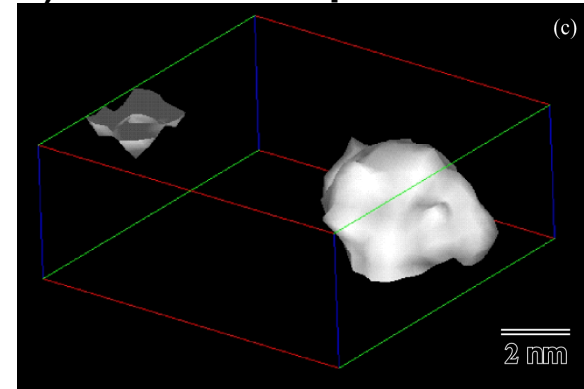


# Nanoscience appears in numerous places in the fusion materials science program

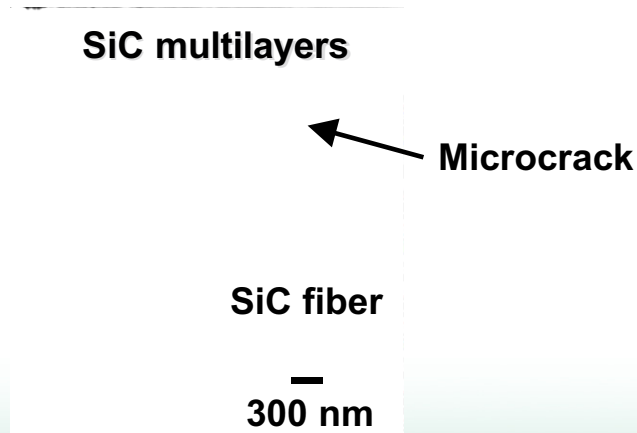
Nanoscale self-organization of defect clusters in neutron-irradiated Ni



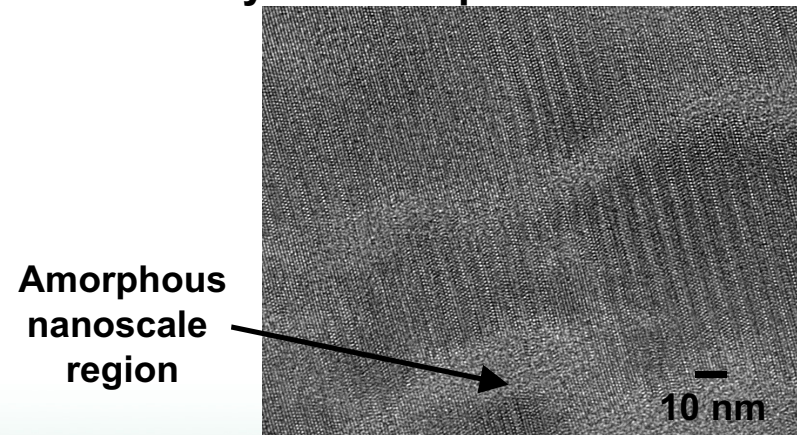
3-D atom probe iso-composition contour (Y, Ti, O) for nanocomposited ferritic steel



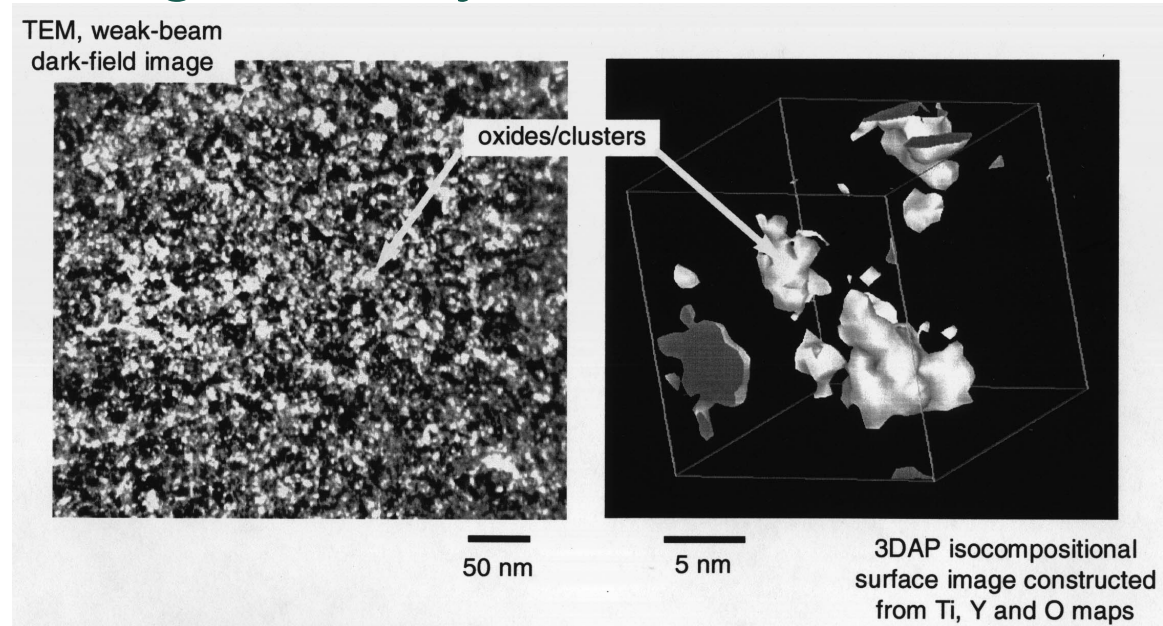
Crack-deflecting interfaces in ceramic composites give improved toughness



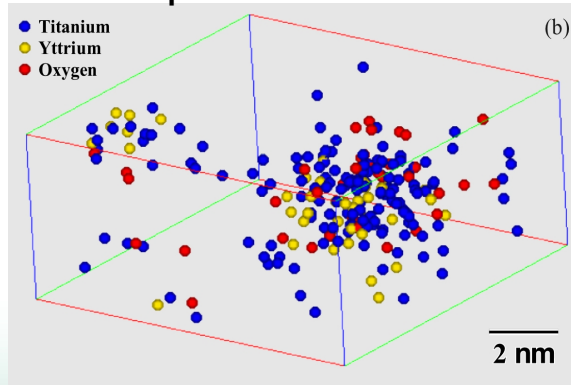
Atomic resolution analysis of crystal-amorphous transition in SiC



# Recent work at ORNL suggests that thermodynamics may be significantly altered at the nanoscale

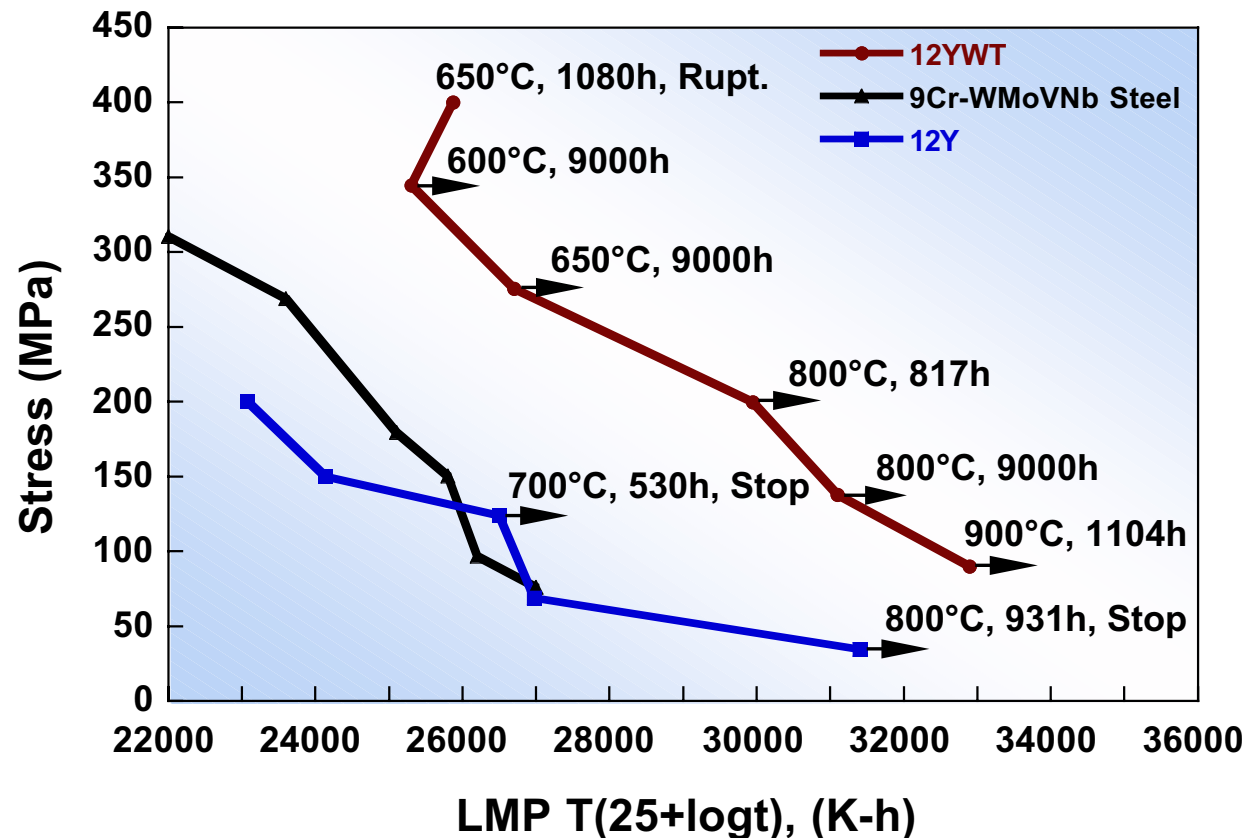


## Atomic composition of nanoclusters



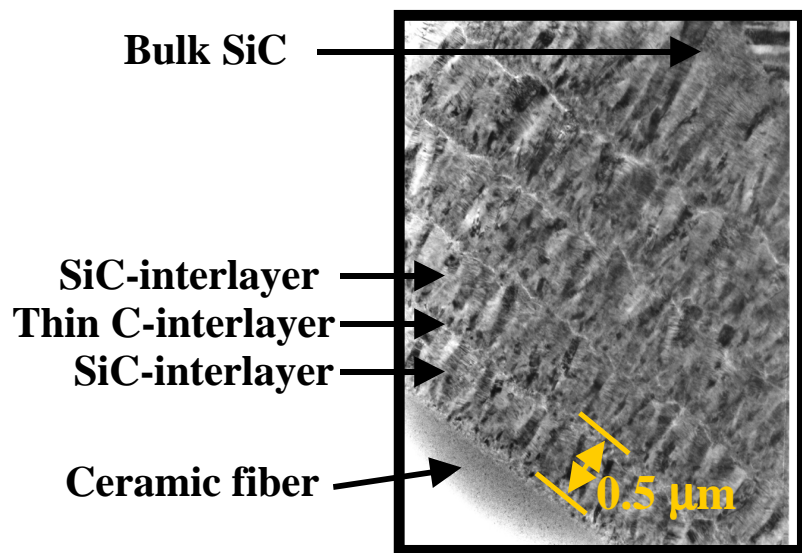
**Atomic analysis of new nanocomposited ferritic steel provides clues to its outstanding creep strength (6 orders of magnitude lower creep rate than conventional steels at 600-900 °C)**

# Discovery of Unprecedented Strength Properties in Iron Base Alloy

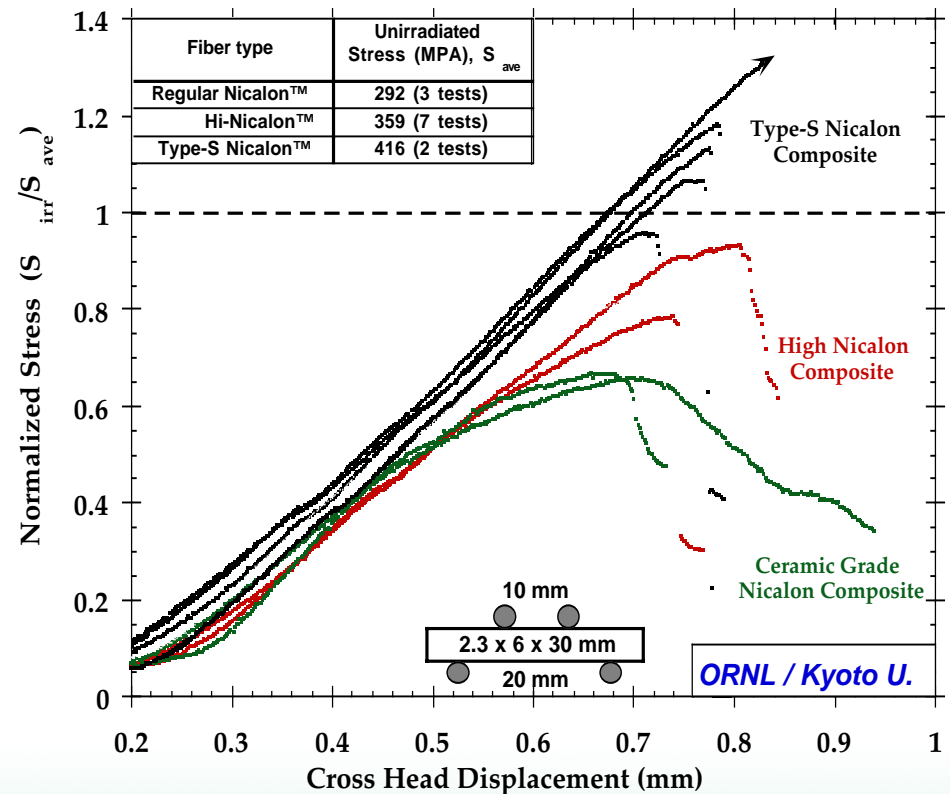


- Time to failure is increased by several orders of magnitude
- Potential for increasing the upper operating temperature of iron based alloys by ~200°C

# A science-based program involving tailored nanoscale microstructures is producing remarkable advances in radiation-stable ductile ceramic composites (SiC/SiC)



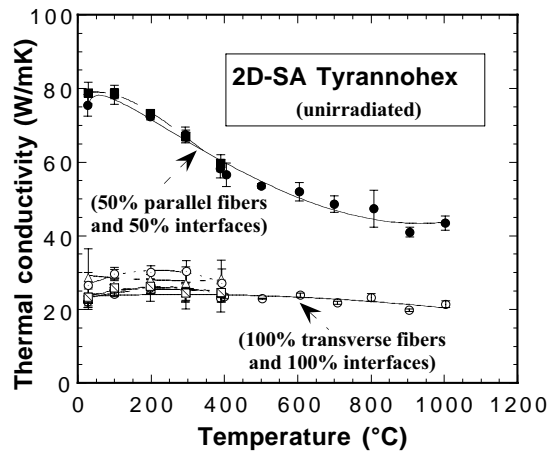
**FCVI SiC Matrix, C-interphase, Plain Weave Composite**  
 ~ 1 dpa, HFIR irradiation





# Thermal Conductivity of 2D SiC/SiC Composites

## Fusion Materials Program



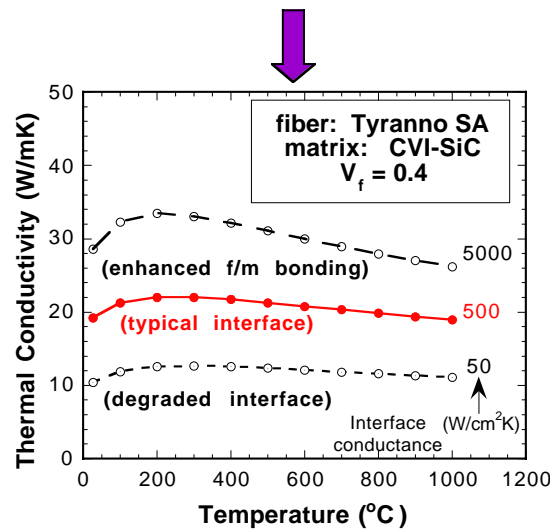
### Experimental:

- Number and quality of interfaces important
- Fibers parallel to conduction path useful (3D architecture)
- Samples currently being irradiated

## NERI Program

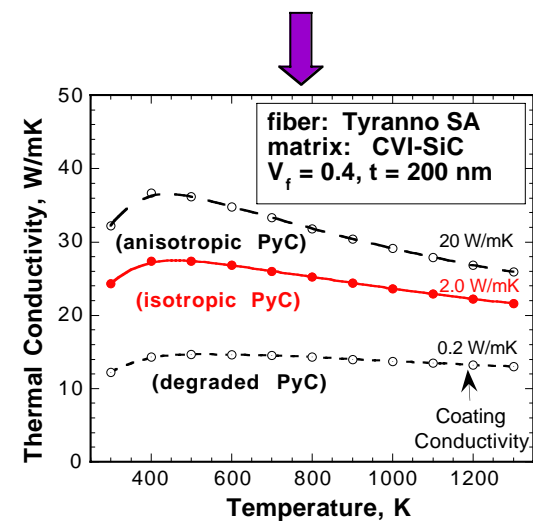
### Model 1: Thin Interface Conductance

- Strong bonding due to fiber surface treatment useful
- Degraded interface due to irradiation or fiber/matrix mismatch



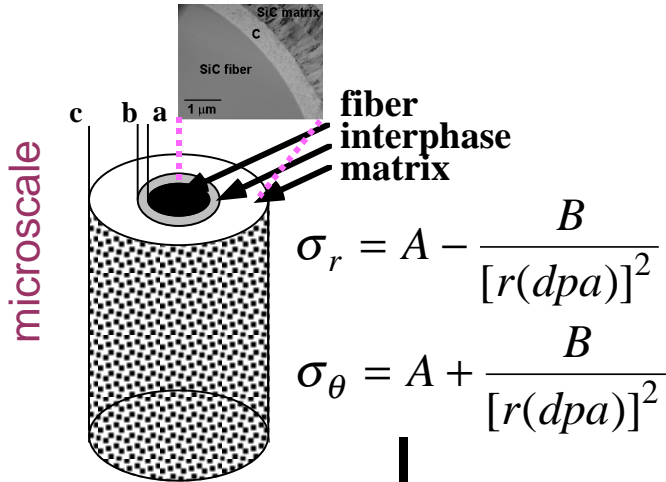
### Model 2: Interphase Conductivity

- Preferred orientation of graphitic crystallites
- Strong interface cohesion
- Degraded interphase due to irradiation or oxidation

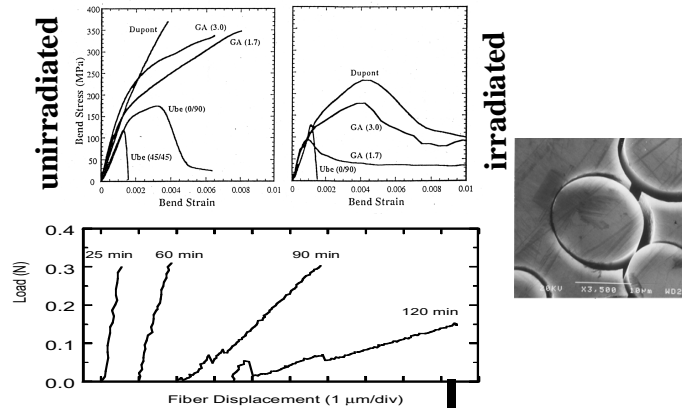


# Crack Growth in Ceramic Composites is a Potential Lifetime-Limiting Mechanism Controlled by Microscale Phenomena

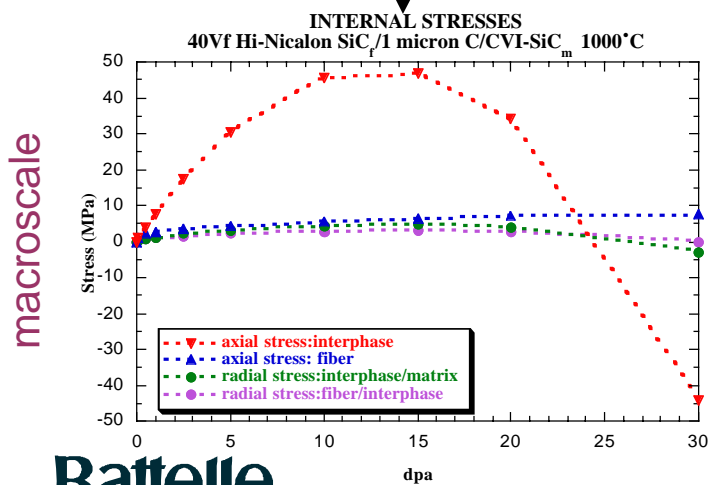
## Analytical modeling of internal stresses



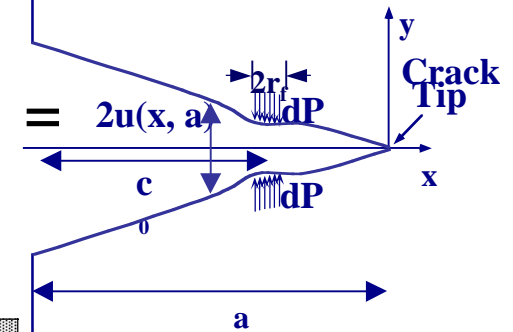
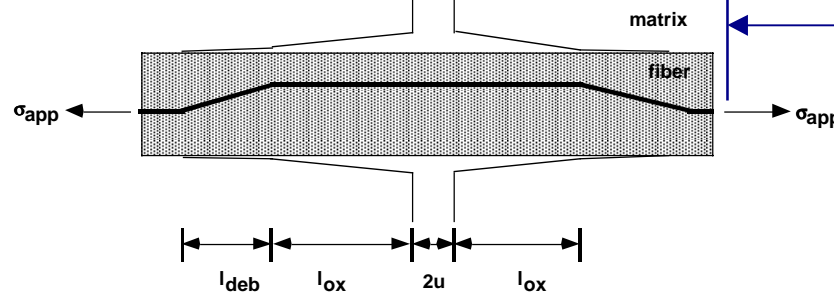
## Experimentally determined, semi-empirical, bridging-compliance relations



Micromechanical model for predicting subcritical crack growth due to microscale mechanisms.



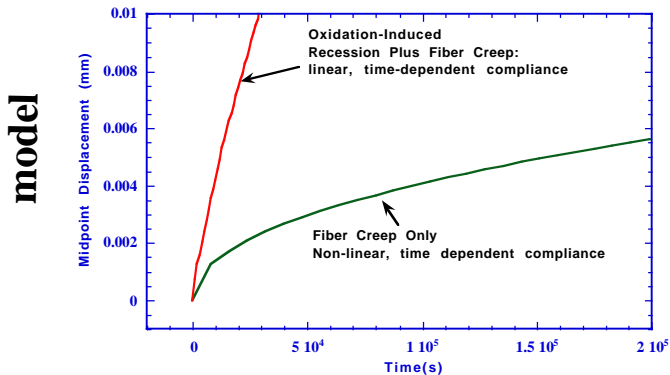
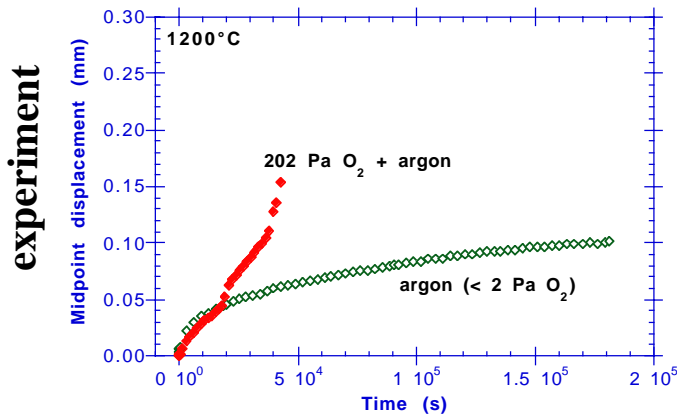
$$u_f = (\Phi_f^l + P_f \Phi_f^n) P_f$$





# Micromechanical Modeling Allows Prediction of Component Lifetime of Ceramic Composites

## Model verification



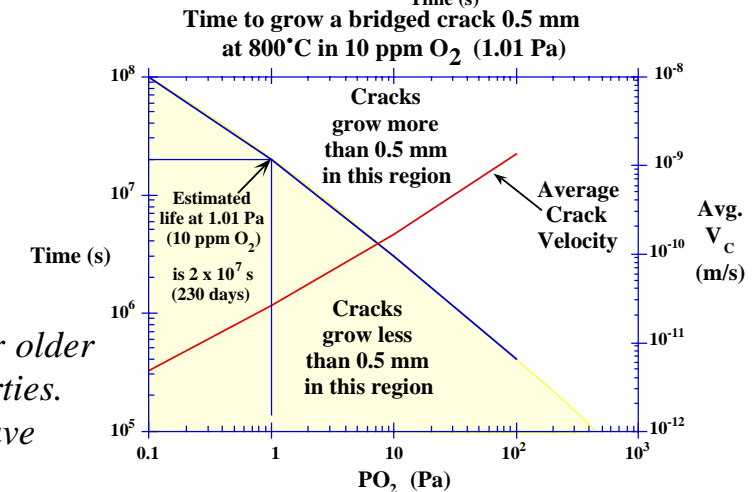
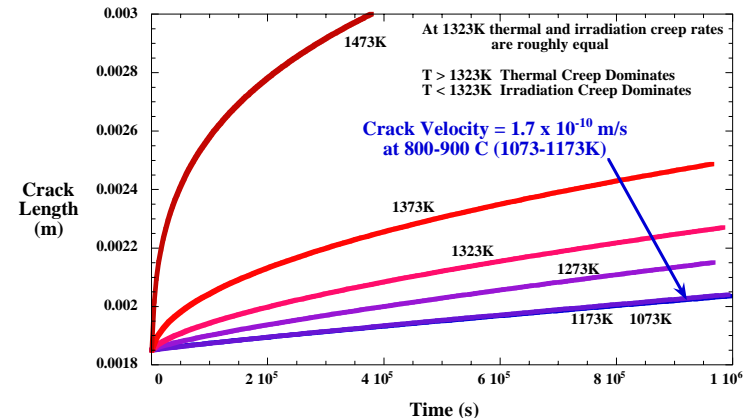
Oxygen atmosphere investigated in conjunction with DOE office of Basic Energy Science Program

## Predictive capabilities

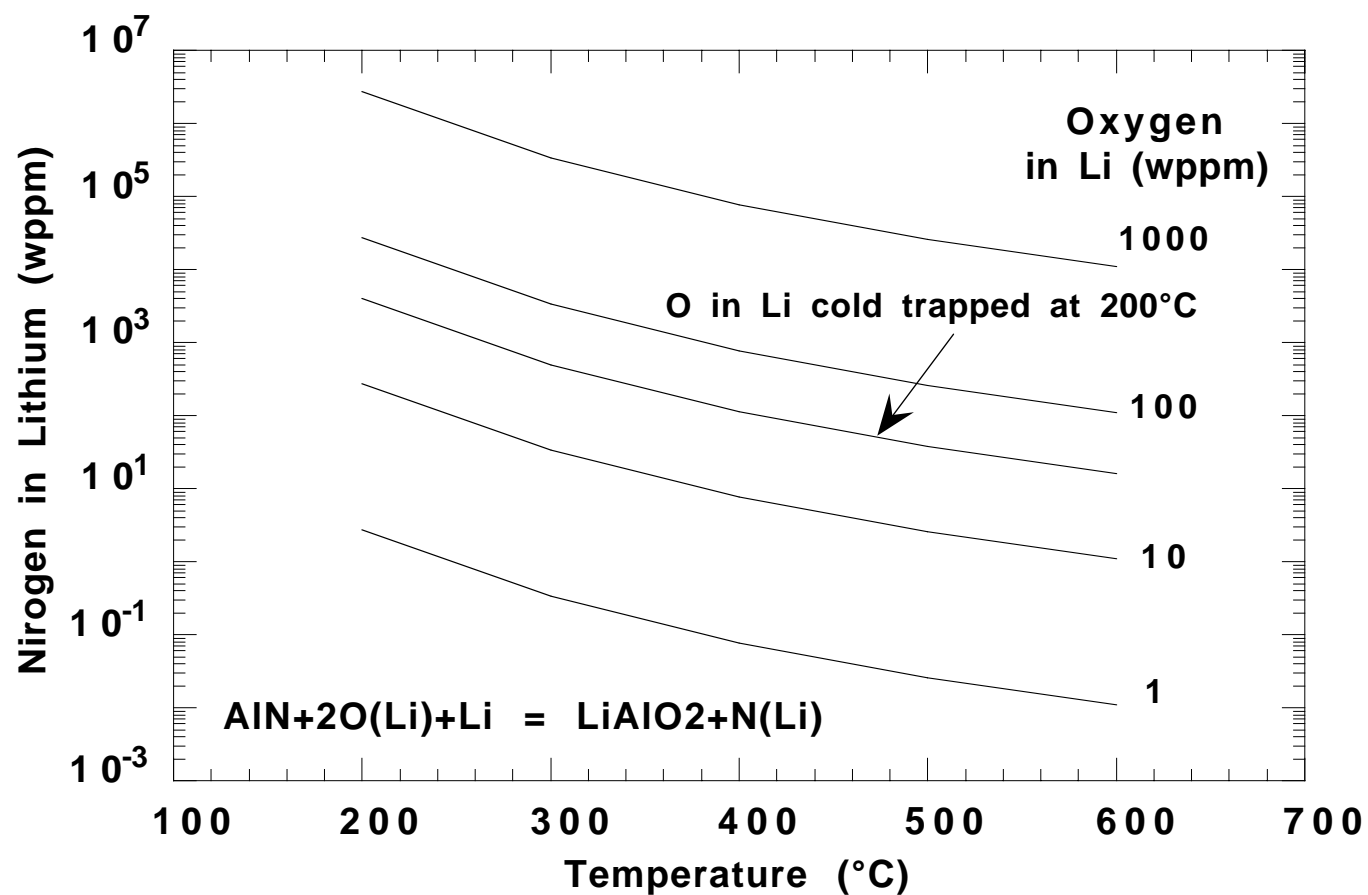
Irradiation-enhanced creep of fibers controls crack growth below  $\approx 1073$  K

Model predicts crack velocity and crack length

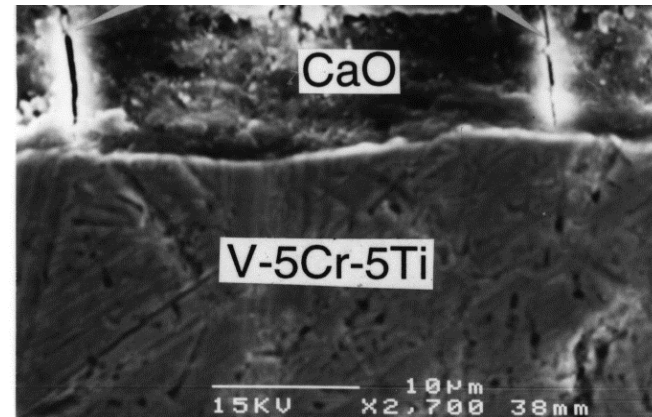
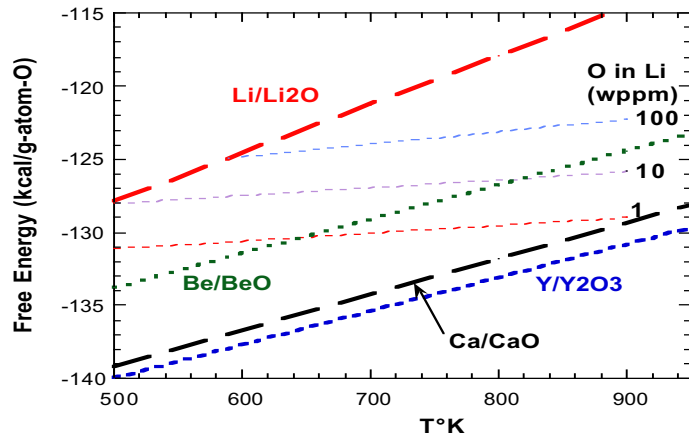
*NOTE: Lifetime predicted for older generation material properties. More recent materials have enhanced lifetimes.*



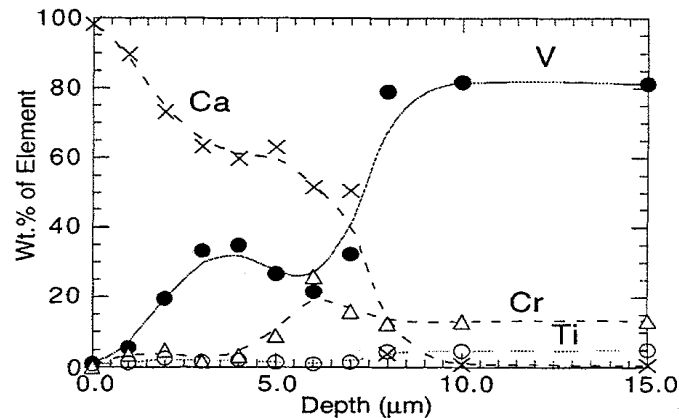
# Calculated Regions of Thermodynamic Stability for AlN in oxygen-enriched Li



# Thermodynamic Stability, Microstructure Characterization, and Property Evaluation of In-situ Formed "CaO" Insulating Coating on Vanadium Alloys

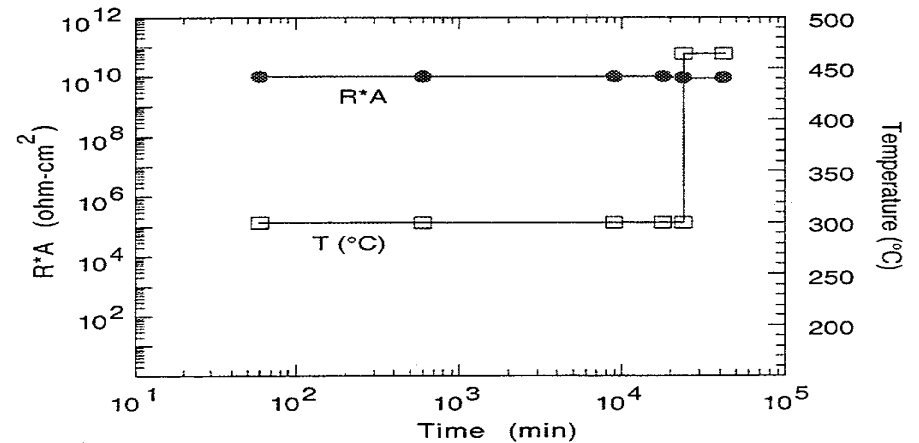


- Calculated thermodynamic stability of candidate oxides in lithium as function of oxygen content



- **Composition from EDS analysis vs depth for in-situ formed "CaO" coating on V-alloy**

- Microstructure of "CaO" coating on V-alloy

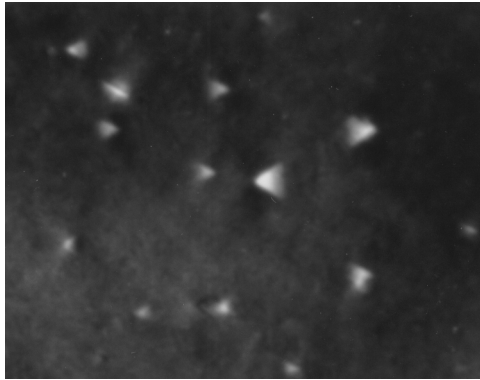


- In-situ resistance of "CaO" coating in lithium

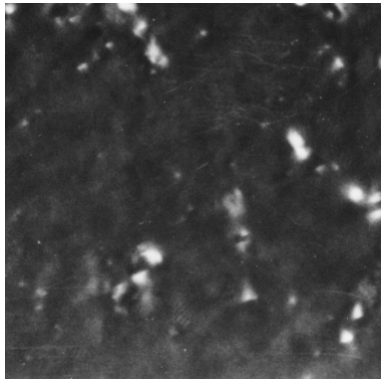
# One of the Most Important Scientific Results From the US/Japan Collaborations on Fusion Materials has been the Demonstration of Equivalency of Displacement Damage Produced by Fission and Fusion Neutrons

Similar defect clusters produced by fission and fusion neutrons as observed by TEM

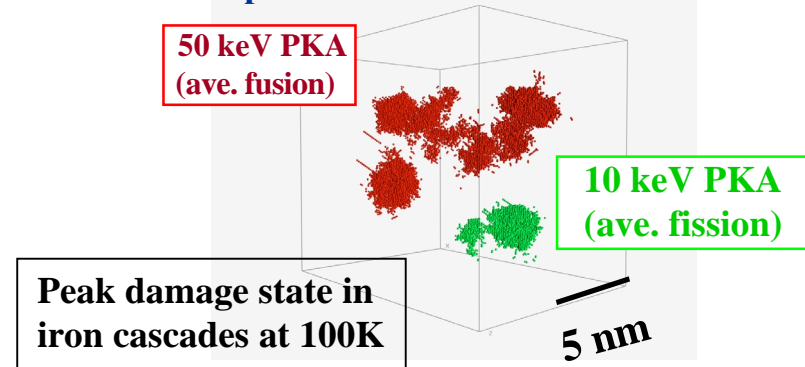
Fission  
(0.1 - 3 MeV)



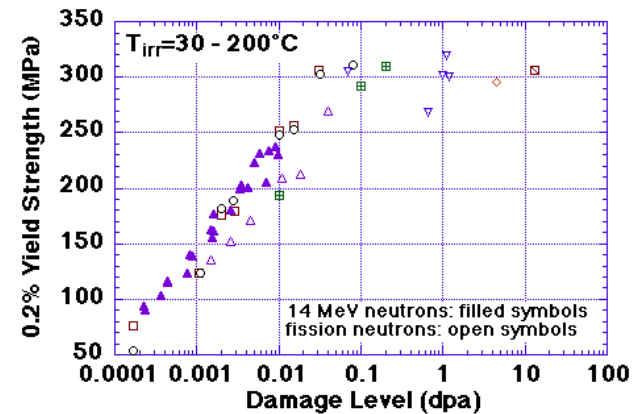
Fusion  
(14 MeV)



MD computer simulations of the displacement events show that subcascades and defect production are comparable for fission and fusion



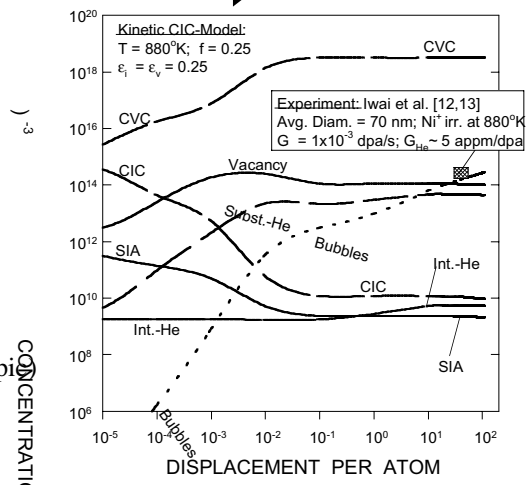
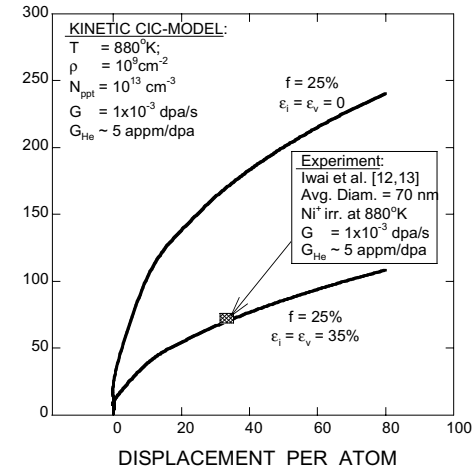
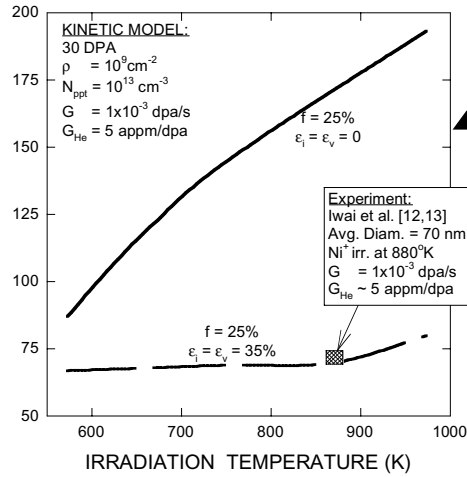
Similar hardening behavior confirms the equivalency



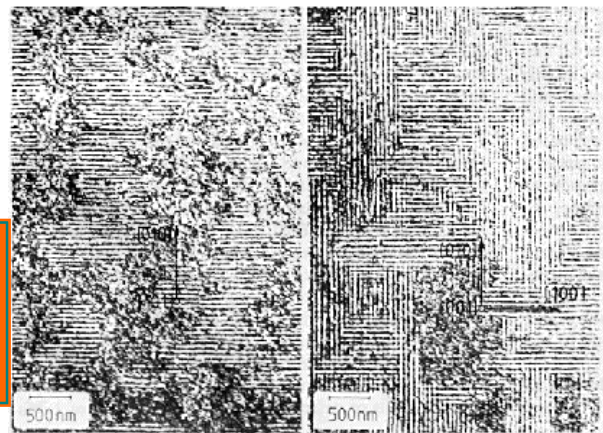
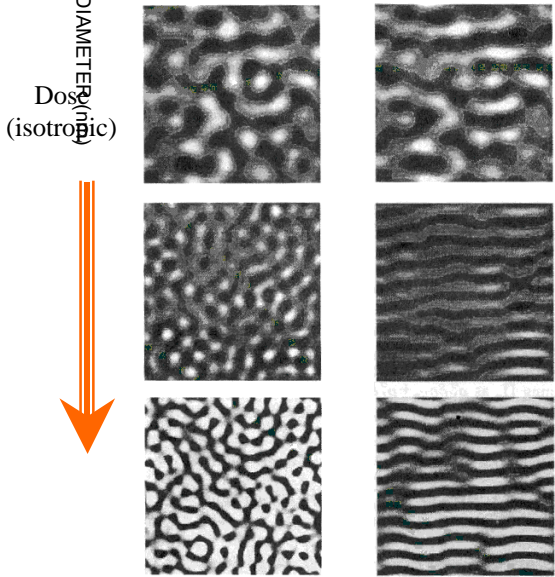
# UCLA Advanced Rate Theory Modeling of Microstructure Evolution: Main features

(1) Mobile cascade-induced clusters (CIC); (2) Continuous helium generation; (3) Coupled Nucleation & Growth; (4) Spatial self-organization.

Simulations & experiments for microstructure evolution in vanadium with helium effects



Simulations & experiments on self-organization of irradiated Cu microstructure.

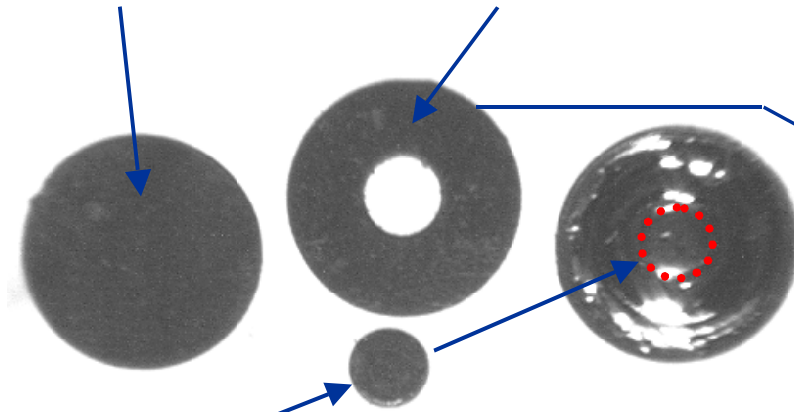




# Newly Developed Techniques Allow Greater Materials Science Output From Smaller Irradiation Volumes

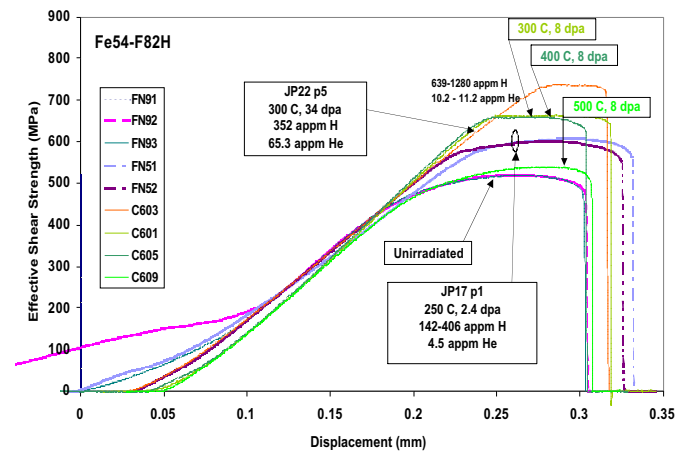
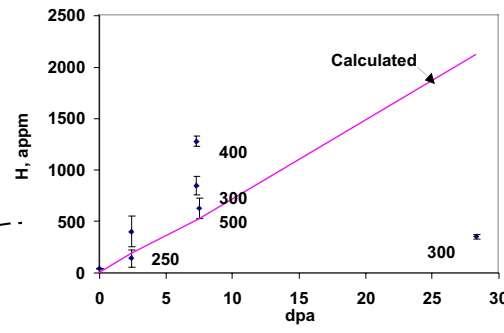
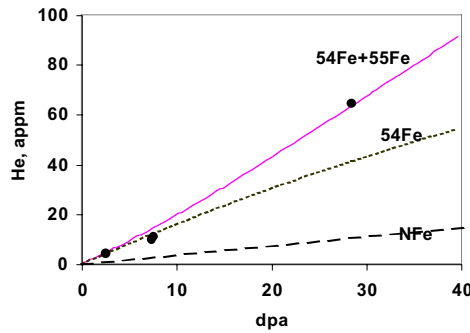
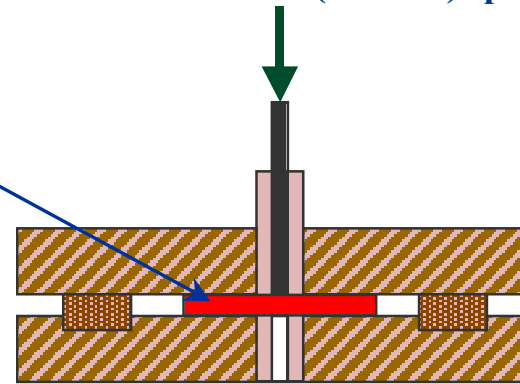
3 mm TEM disk is irradiated in fission reactor

He and H analyses on outer rim



Bonded into unirradiated disk to reduce radioactivity levels and waste generation in evaluation of microchemistry and microstructures

Shear punch test yields mechanical properties data that correlate with tensile data and can be correlated with data on conventional (full size) specimens

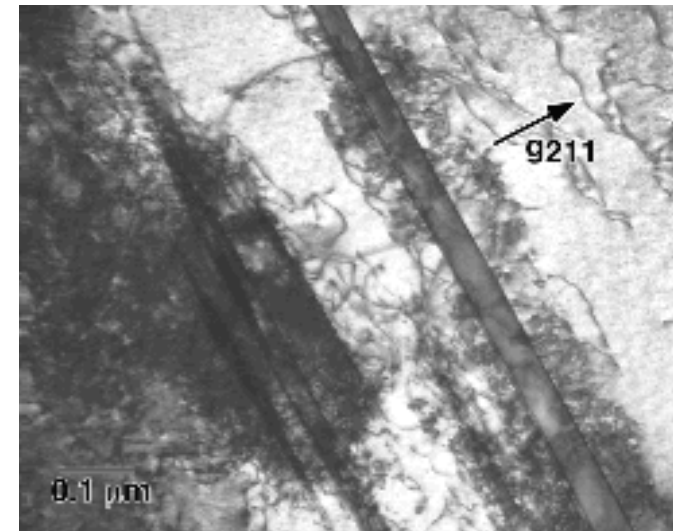
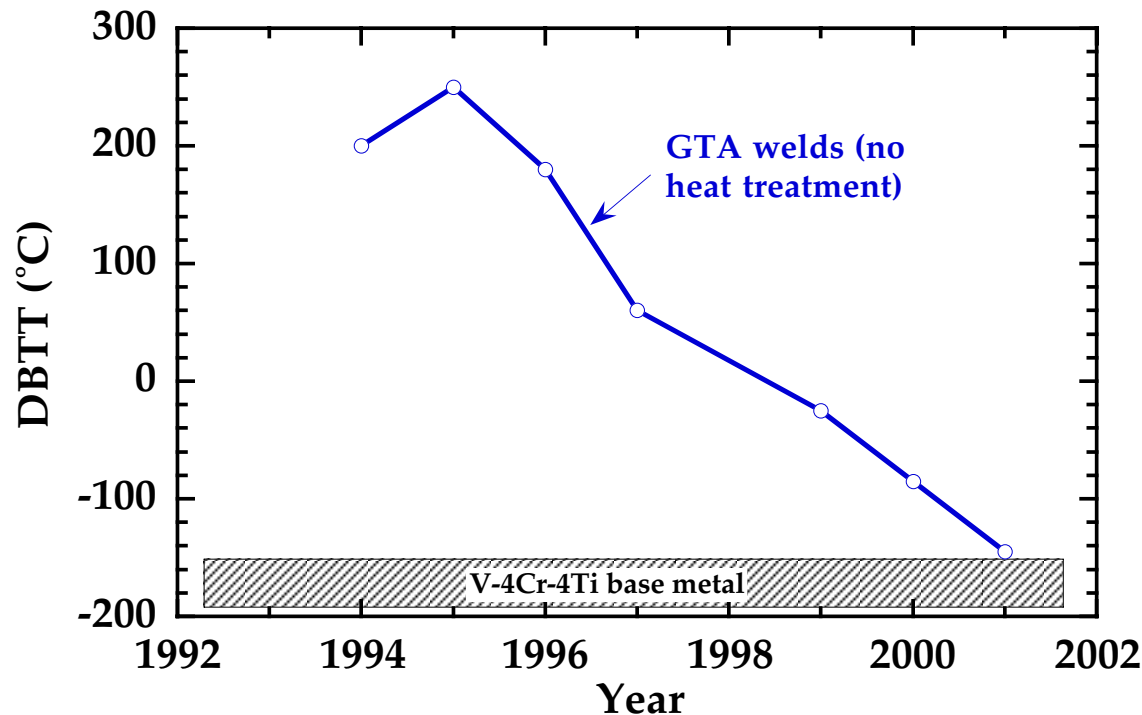


**Battelle**

Hydrogen and Helium analysis results

U.S. Department of Energy  
Pacific Northwest National Laboratory

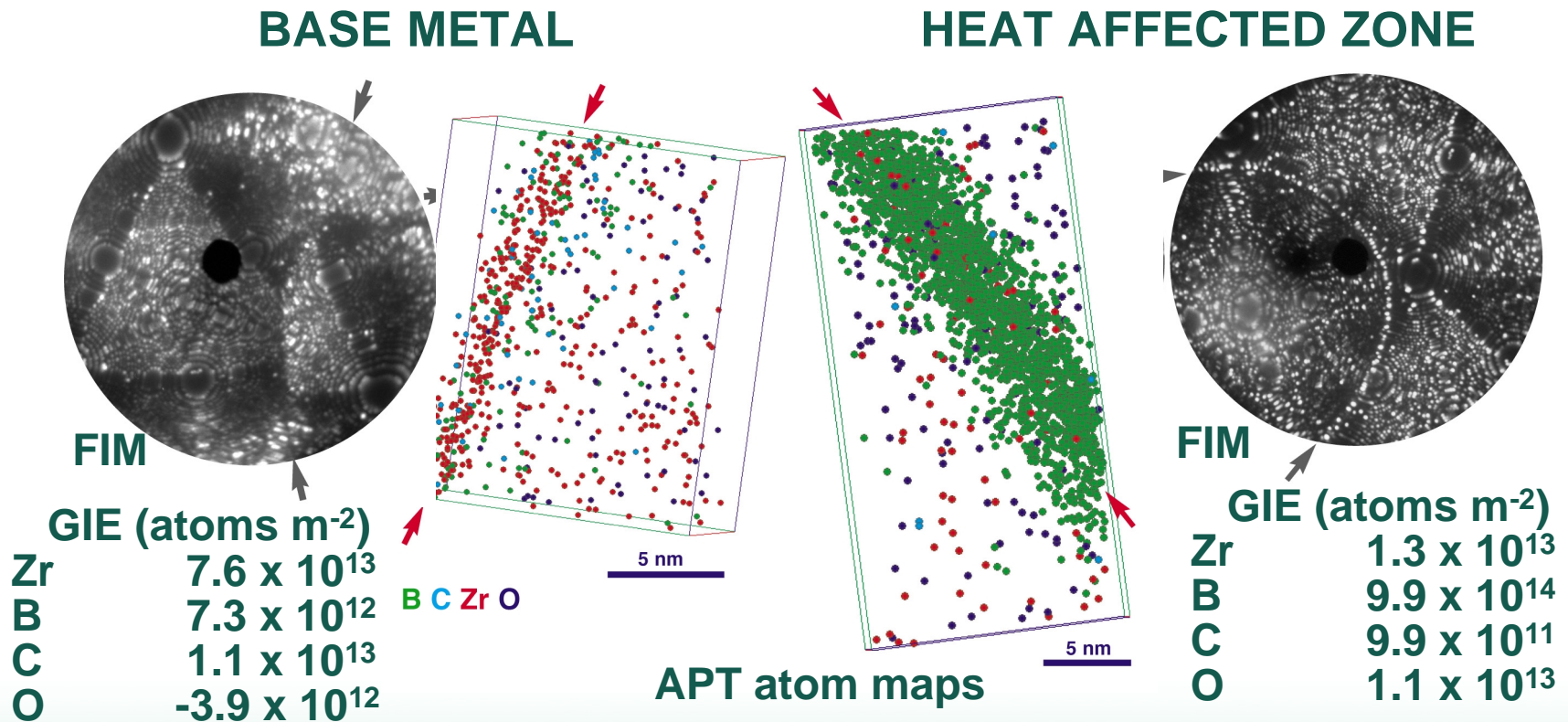
# A focussed, science-based welding program has successfully resolved one of the key feasibility issues for V alloys



– Results are applicable to other Group V refractory alloys (Nb, Ta)

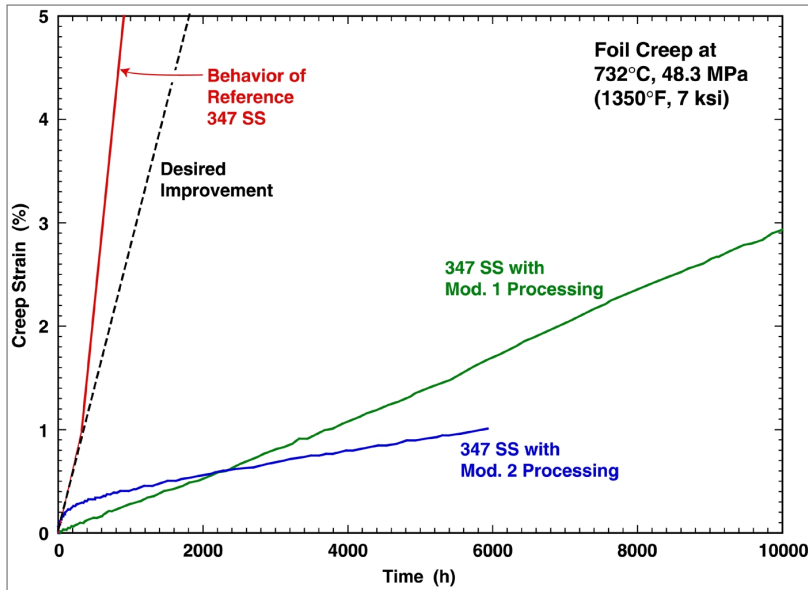
# Atom Probe Tomography Reveals Zr, B and C Segregation to Grain Boundaries Produces Improved Mo Weldments

- B, Zr (and C) segregation inhibits O embrittlement of grain boundaries
  - $E_{\text{tot}} \sim 20\%$ , transgranular fracture mode instead of typical  $e_{\text{tot}} \sim 3\%$ , intergranular fracture for Mo welds
- Bulk alloy composition: 1600 appm Zr, 96 appm C, 53 appm B, 250 appm O

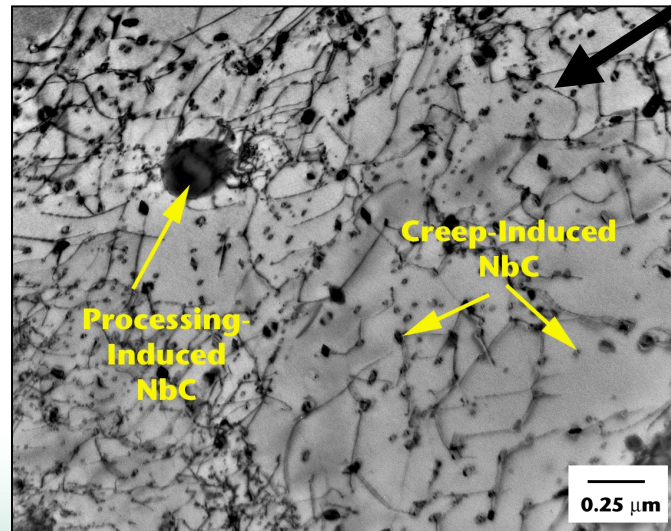
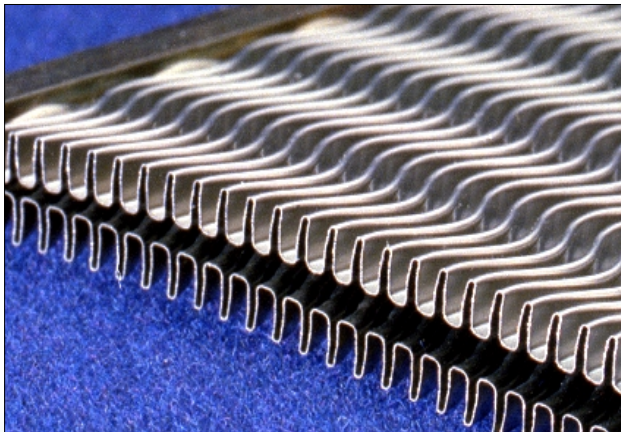
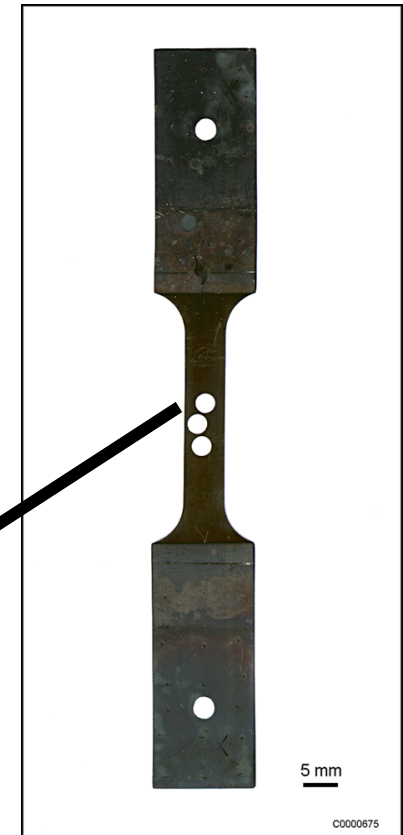




# Microstructure-Mechanical property knowledge derived from Fusion Materials Science investigations is being transferred to US Industry



Precipitate stability knowledge derived from radiation effects studies can be used to develop highly creep resistant alloys (microturbine recuperator)



OAK RIDGE NATIONAL LABORATORY  
U. S. DEPARTMENT OF ENERGY

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## The Materials Science Program Provides the Underlying Materials Science Knowledge Base within the VLT

Technology Program Element	Types of Materials Addressed	Key Materials Issues
<ul style="list-style-type: none"> <li>• <b>Materials Science</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>Structures</b></li> <li>• <b>Coatings</b></li> <li>• <b>Insulating ceramics</b></li> <li>• <b>Optical materials</b></li> </ul>	<ul style="list-style-type: none"> <li>• <b>deformation, fracture mechanisms</b></li> <li>• <b>thermodynamic, kinetic stability</b></li> <li>• <b>electric, dielectric degradation</b></li> <li>• <b>F center formation, stability</b></li> </ul>
<ul style="list-style-type: none"> <li>• Plasma Technology</li> </ul>	<ul style="list-style-type: none"> <li>• Plasma facing/high heat flux components</li> <li>• Magnet components</li> <li>• ICH/ECH launcher/antennas</li> </ul>	<ul style="list-style-type: none"> <li>• plasma interactions, heat transport</li> <li>• critical current, insulator perform.</li> <li>• low-loss coatings and feedthroughs</li> </ul>
<ul style="list-style-type: none"> <li>• Fusion Technology</li> </ul>	<ul style="list-style-type: none"> <li>• Fuels (tritium)</li> <li>• Breeder systems</li> </ul>	<ul style="list-style-type: none"> <li>• tritium permeation</li> <li>• thermal, neutronics, hydrodynamics</li> </ul>
<ul style="list-style-type: none"> <li>• IFE</li> </ul>	<ul style="list-style-type: none"> <li>• Chamber wall</li> <li>• Final optics</li> </ul>	<ul style="list-style-type: none"> <li>• durability, tritium retention</li> <li>• surface crazing, bulk defects</li> </ul>
<ul style="list-style-type: none"> <li>• Safety</li> </ul>	<ul style="list-style-type: none"> <li>• Structure, coolant, breeder</li> </ul>	<ul style="list-style-type: none"> <li>• volatilization, decay heat</li> </ul>
<ul style="list-style-type: none"> <li>• Advanced Design</li> </ul>	<ul style="list-style-type: none"> <li>• Overall integration</li> </ul>	<ul style="list-style-type: none"> <li>• compatibility, performance limits</li> </ul>

## Interactions with International Fusion Materials Community

<b>Science issue</b>	<b>Activity</b>	<b>US</b>	<b>Japan</b>	<b>EU</b>	<b>Russia</b>	<b>China</b>	
Deformation & fracture	V alloys	IEA working gp.			IEA working gp.		
		DOE/Monbusho					
Deformation & fracture, Nanoscience (ODS)	Ferritic steel	IEA working group					
Deformation mechanisms, enhanced thermal cond.	SiC/SiC	DOE/JAERI					
		IEA working group					
		DOE/Monbusho					
Cross-cutting theory & modeling phenomena	Theory & modeling	DOE/JAERI					
		IEA working group					
Electric, dielectric props.	Ceramic insulators	IEA working group					
		DOE/Monbusho					
Accelerator physics, liquid jet thermohydraulics, He gas cooling technology	Neutron source (IFMIF)	IEA working group					

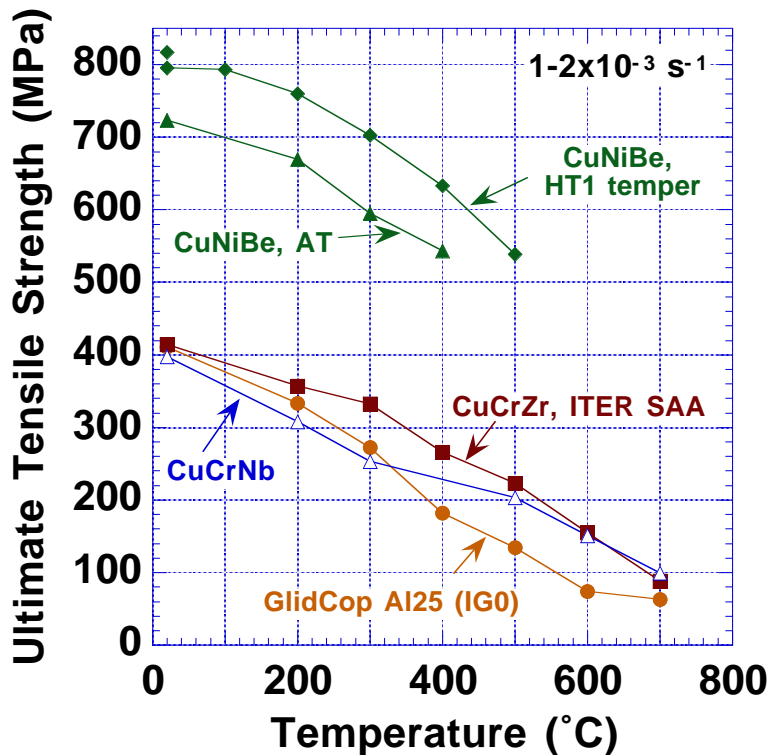
## The Fusion Materials Science Program will use its expertise to help address materials issues of plasma and IFE studies

- Early 2001: send out requests for expressions of interest in using expertise of materials program
- Mid-2001: review EOI's and prioritize
- Fall 2001: initiate work on highest priority tasks

# Conclusions

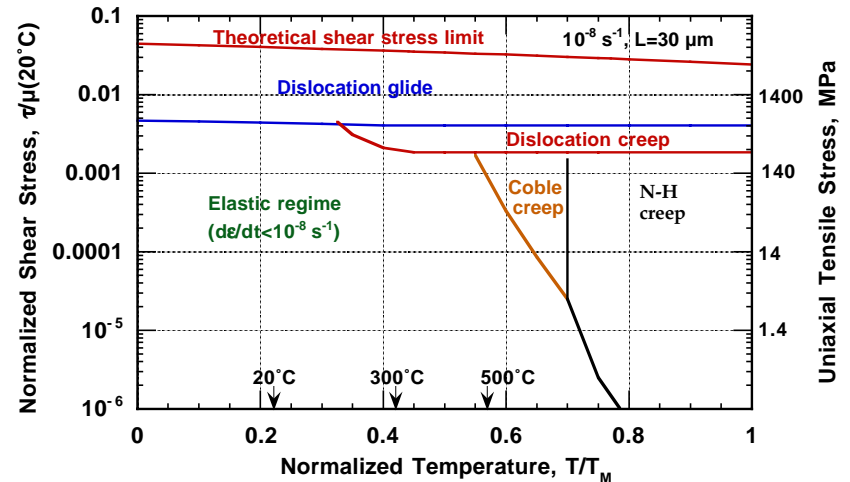
- **The program has been responsive to the 1998 FESAC panel recommendations**
  - **Enhanced theory & modeling effort is underway**
  - **FY02 strawman budget will not allow both international commitments and theory & modeling to be maintained at current levels**
- **The Fusion Materials Sciences program is pursuing simultaneous scientific excellence (fusion energy and materials science)**
- **Very strong ties have been established with the broader materials science community**
- **Fusion materials science research will serve as an increasingly valuable Enabling Technologies complement to the plasma science research program**

# Mechanical behavior of copper alloys can be understood on the basis of current materials science models of deformation



Applications to US industry (e.g., USCAR) as well as fusion energy sciences program

Deformation Map for CuNiBe (Brush-Wellman Hycon 3HP)



Deformation Map for Oxide Dispersion-strengthened Copper (GlidCop Al25)

