# Plans and Activities of
# MIT Center of Advanced Nuclear Energy Systems

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# CANES Development and Resources

Established in 2000 within Department of Nuclear Science and Engineering and the Energy Laboratory at MIT to offer options for improved nuclear energy technology and policy.

Home base for 15 full time faculty and research staff (10 NSE faculty members, 2 active retired faculty, and 3 research scientists). 10 other faculty and staff participate part time but have their main work at other units, particularly the reactor laboratory.

43 affiliated graduate students, of whom typically 70% are supported by research

20 affiliated undergraduate students, as UROP and thesis students.

*Funding level of about $5 M/yr in the last 3 years:*

*40% DOE (including its laboratories),*
*10% Other government (NRC, KAPL),*
*25% Industry and Private (currently AREVA, EPRI, Shaw Group), and*
*25 % International sources (TEPCO, Toshiba, Alfaisal University,MIST)*

Since 2000, CANES issued, some 150 reports resulting from research, all are listed on web page: http://mit.edu/canes/

# Center For Advanced Nuclear Energy Systems

| Research Programs | | | |
|---|---|---|---|
| Advanced Power Reactors | Nuclear Fuel Cycle Economics and Policy | Nuclear Systems Performance Management | Nuclear Energy and Sustainability |

| Education Programs | | National & International Collaborations |
|---|---|---|
| Professional Courses<br>- Nuclear Plant Safety<br>- Reactor Technology for Power Plant Executives – with INPO<br>- Risk-Informed Operational Decision Making<br>- Materials Degradation Management – now EPRI | Symposium Series<br>- High Burnup LWR Fuel<br>- Nuclear Energy and the Hydrogen Economy<br>- Simulation of Fuel Cycle<br>- Next Generation Reactor<br>- Innovative Nuclear Systems<br>- Rethinking the Fuel Cycle<br>- Supercrit. CO2 Power Cycle<br>- Directions for Breakthrough Research | * Battelle Energy Alliance for INL management<br>* Nuclear Regulatory Commission for Adv. React.<br>• EPRI/ENI Waste Manage.<br>* TEPCO on BWR advanced technology<br>* CEA on fuel cycle issues<br>* INET-Tsinghua Univ. on gas reactors |

# A new phase of The INL- MIT Collaboration

- In February 2005, BEA became the managing coalition of INL, and with it MIT enhanced its collaboration with INL as a member of the INL-NUC.
- BEA - NUC agreement stipulates INL support for Academic Centers of Excellences, which are emerging at a time to strengthen university-lab relations for nuclear energy science and technology development
- MIT's ACE effort will focus on improving the efficiency and reliability of the designs of advanced systems with emphasis on issues of fuels and materials performance
- MIT ACE aims at integration of science based simulation with engineering, and the integration of scientific outlooks and industrial constraints that can produce reliable future designs

# The ACE Focus & Activities

- The integration of science and engineering to establish innovative designs and improved methodologies
  - Improved performance of LWRs
  - Options for advanced reactor fuels and materials.
  - Integration of PRA in design
- The integration of multiphysics modeling in addressing materials
  - Electrochemistry of electrolyzer cells
  - Crack initiation and growth
- Strong collaborations across universities, labs and industry
  - NERI on fast reactor design (MIT, Ohio State, Idaho State, GE)
  - INL-Univ. Consortium for high temp. materials

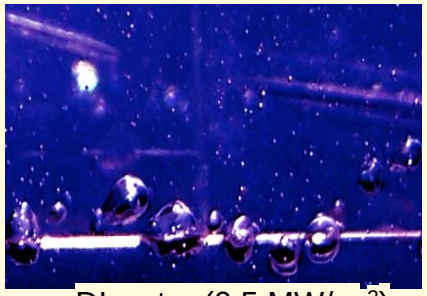
# Examples of CANES Innovations

- High power density PWRs and BWRs
  - Advanced fuel designs that maintain or enhance safety
  - Use of nanofluids to increase heat removal or thermal margin*
  - Ceramic cladding materials for high temperature water reactors
- Enhanced Performance of Advanced Reactors
  - Integration of probabilistic risk assessment in design
  - A truly modular design of advanced reactors
  - High efficiency $CO_2$ Brayton Power Cycle
  - A new model for transition heat transfer in gases*
- Nuclear Applications in transportation systems
  - The design of a hydrogen production system using a medium temperature reactor*
  - Materials for catalytic heat exchanger for HTR-hydrogen plant coupling*
- Innovation in Fuel Cycles
  - A PWR fuel assembly that produces zero net transuranics
  - A fast reactor plant to allow flexible conversion ratio*
  - A system model for the nuclear fuel cycle*

* Innovation that benefited from INL support

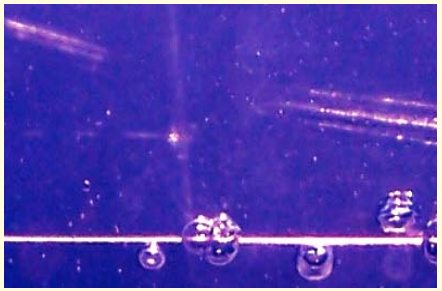
# Nanofluids for Nuclear Applications

The CHF enhancement appears to correlate with the presence of a layer of nanoparticles that builds up on the heated surface during nucleate boiling

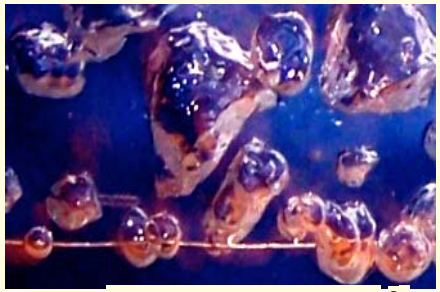


DI water (0.5 MW/m $^2$)

DI water (1 MW/m$^2$)

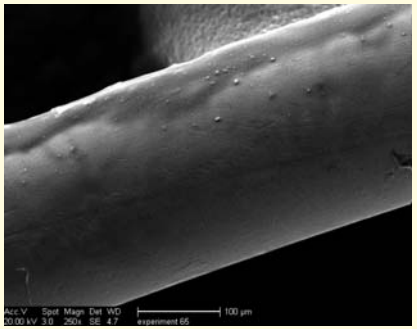


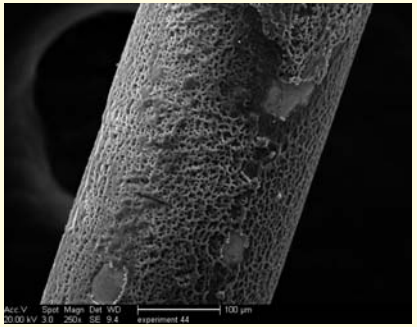
Nanofluid (0.5 MW/m$^2$)



Nanofluid (1 MW/m $^2$)

Pool boiling of DI water and 0.01%v Alumina nanofluid at the same heat flux on stainless steel wire.





SEM images of steel wires taken after boiling DI water (TOP) and 0.01%v alumina nanofluid (BOTTOM).

Measurements of nanofluid CHF in a forced convection loop are also underway at MIT. Such measurements are the first attempt to assess the effect of nanofluids on flow boiling CHF, which is the situation of interest for most nuclear applications.

# Ceramic SiC as a Clad for LWR Fuel

**A project involving MIT, Westinghouse, Gamma Engineering, and ORNL**

Objective is to enable high power density, higher burnup, and higher water exit temperatures a means to improve future LWR economics

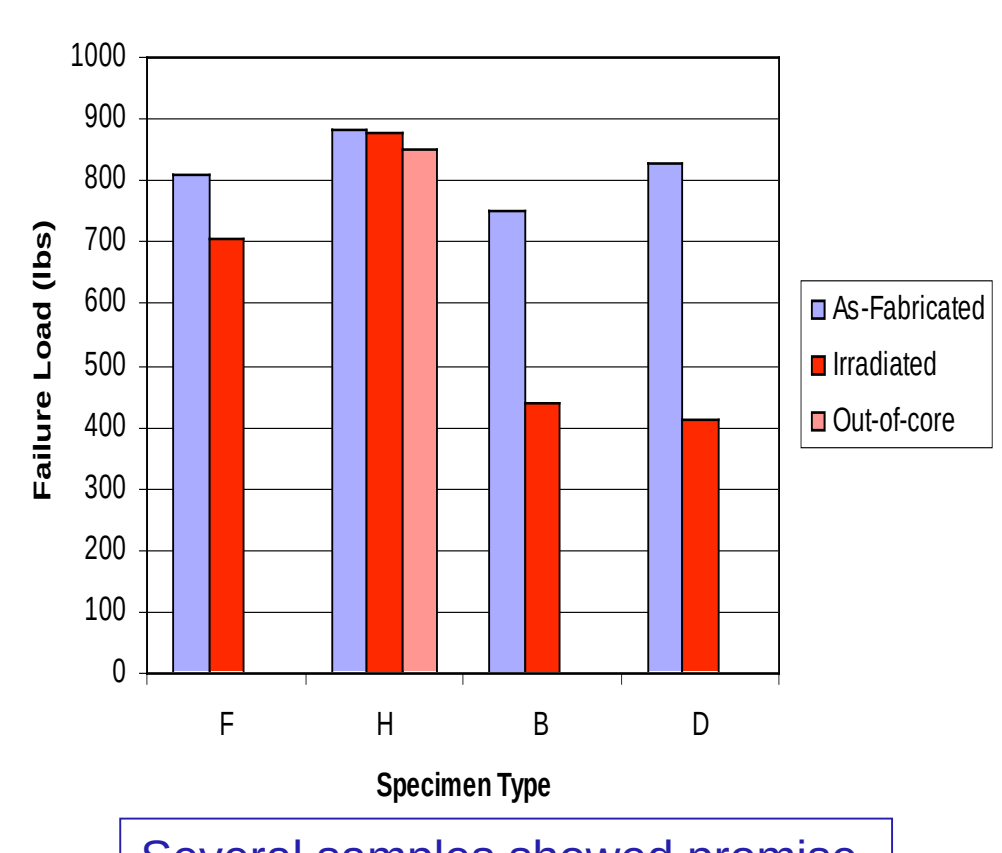
| | Zr | SiC |
|---|---|---|
| Long-term Service Temperature | ~750ºC | -1700ºC |
| Cross-Section | ~193 mb | ~148 mb |
| Thermal Conductivity | 33 watt/m/ºK | 5 watt/m/ºK |
| 17% Steam Corrosion in 400 sec | <12OOºC | -19OOºC |
| BWR water corrosion @360ºC@ 32 days (recision rate) | 1 micron | <0.1 micron |

1. Good performance during irradiation
   - Gap changes slowly with time, even during a transient due to low creep below 1000 ºC. Large margin to dissociation at 2000 ºC
   - Relevant clad properties do not degrade with time, temperature, or radiation (after initial conductivity reduction)
2. Very low operating and accident corrosion rates
   - Estimated <10% Zr corrosion rate in BWR conditions
   - $UO_2$/SiC interaction not an issue
   - SiC/steam/air corrosion rates $10^{-6}$ to $10^{-7}$ of Zr corrosion rates
   - Reduced hydrogen production during severe accidents
3. Potential for allowing high clad temperature during transients, thus eliminating Critical Heat Flux issues
4. Reduced cladding neutron absorption cross sections

# Summary of MITR Irradiation Testing

- Specimens under PWR coolant conditions

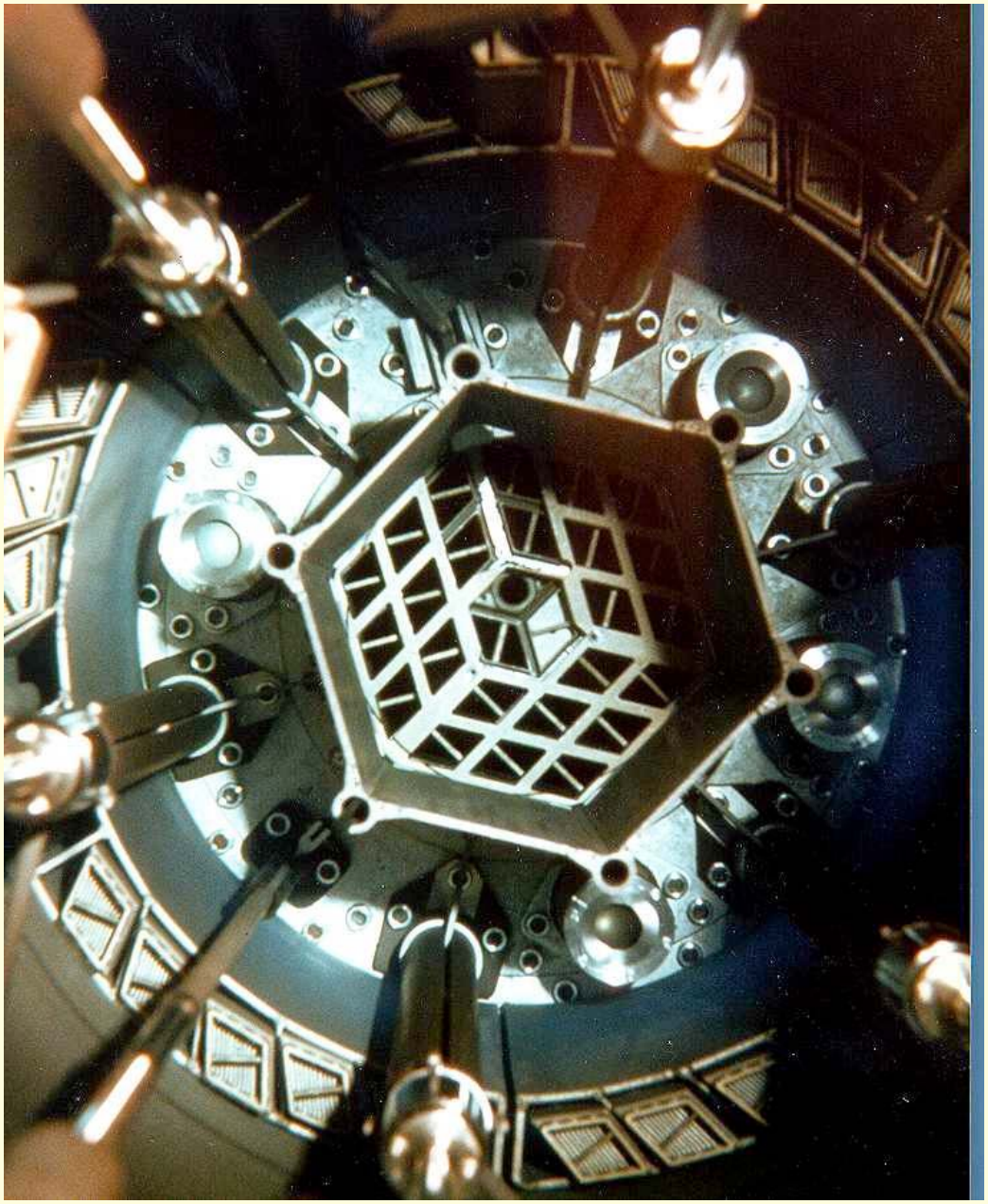
  (300 C, 10 MPa, 20 cc/kg $H_2$, 800 ppm B, 2.2 ppm Li)
- Initial exposure of 24 in-core samples and 15 above-core samples for 68 EFP Days, 4 months elapsed time, with interim examination of sample subset (see figure)
- Weighing and visual inspection at MIT, mechanical property testing at ORNL
- Second exposure of 12 new and 12 continued samples for 156 EFP Days ended October 9. Examination is now beginning.




Several samples showed promise, But not all

# The MIT Research Reactor

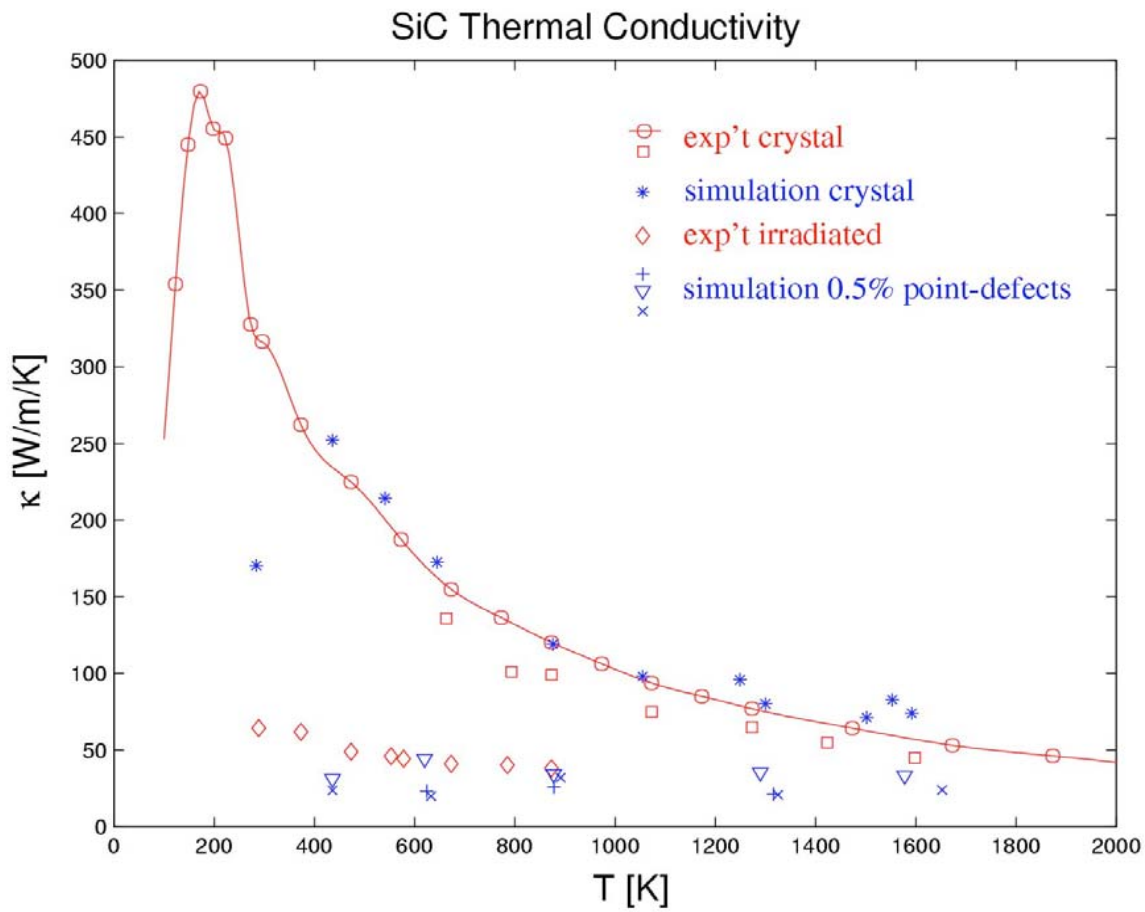
**MITR-II Top View Looking Down at Core**



- 5MWth
- Water cooled,
- Heavy water reflected
- Several beam ports
- 3 central test locations

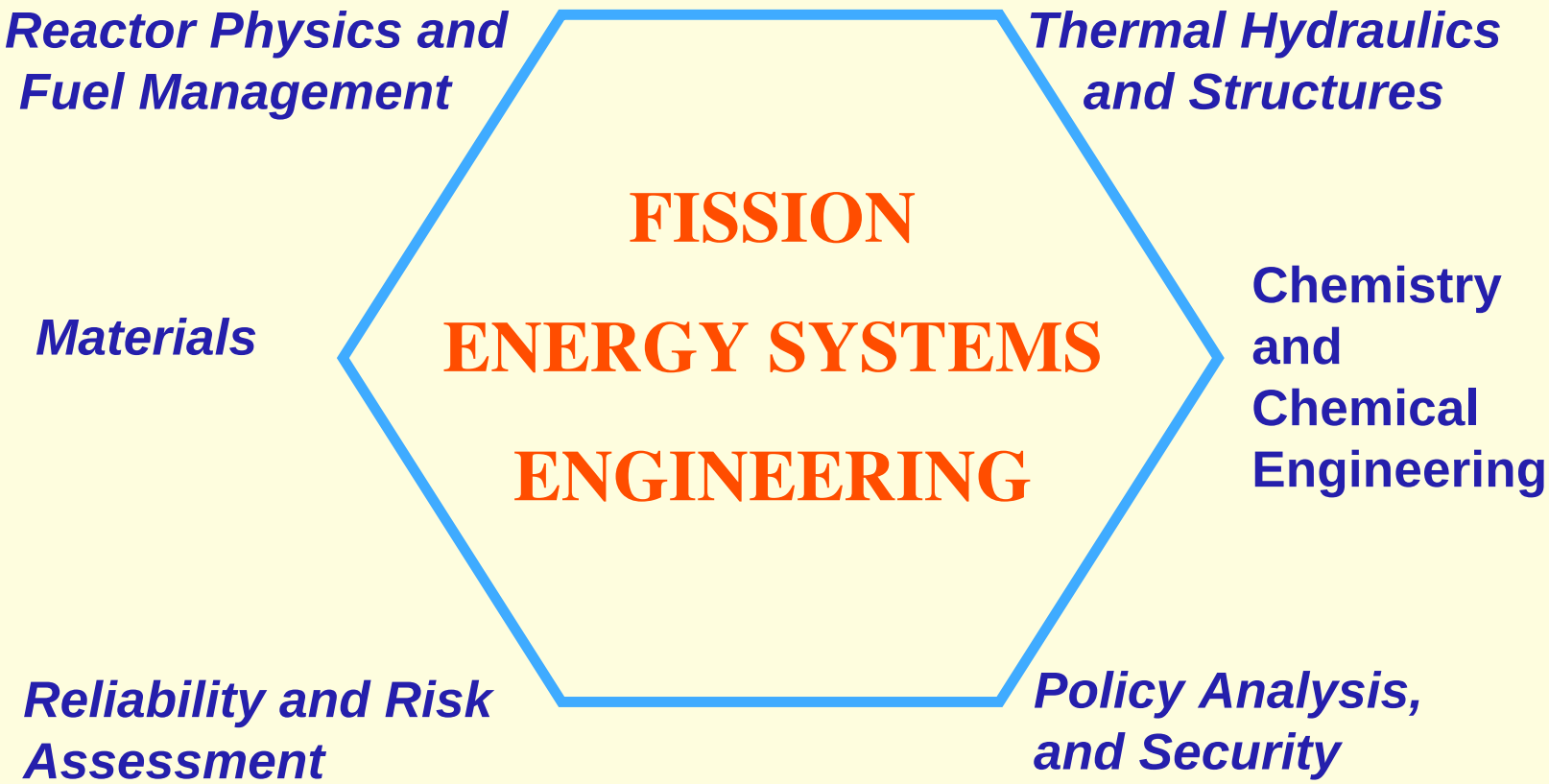
# Simulation is for many materials a reliable predictor

Understanding the mechanical and thermal behavior of irradiated SiC is a nuclear materials issue for fission and fusion technologies, well beyond the HTR needs.




J. Li, L.J. Porter, S. Yip, J. Nuclear Materials 255, 139 (1998).
L.J. Porter, J. Li, S. Yip, J. Nuclear Materials 246, 53 (1997).

# Disciplines of Fission Energy Engineering



# Faculty and Staff in Fission

***Forget*, Driscoll, Bernard, Hejzlar, Pilat, Shatilla**

***Buongiorno, Kazimi, Todreas, Hu***

**FISSION ENERGY**

**SYSTEMS**

**ENGINEERING**

***Ballinger*, Hobbs, Yildiz, Yip, McKrell**

***Barton, Tester, Forsberg Kohse***

***Apostolakis, Golay***

***Kadak, Lester***

** Faculty * Non-NSE Faculty * Emeritus Professor * Research Scientist*

*•Underlined names are on collaborative appointments with INL*