



Nuclear Science User Facilities Sensors and Sensor Materials

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Changing the World's Energy Future

Brenden J Heidrich



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Nuclear Science User Facilities Sensors and Sensor Materials

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In-Pile Instrumentation Development Program
Idaho National Laboratory

Nuclear Science User Facilities (NSUF) General

- **Established in 2007 as DOE Office of Nuclear Energy's first and only user facility**
 - Link intellectual capital with nuclear research infrastructure to fulfill mission of DOE Office of Nuclear Energy
 - Focus: Irradiation effects in nuclear fuels and materials
 - Provide access to capabilities and expertise at no cost to the user
 - Support experiment design, fabrication, transport, irradiation, PIE, disposition
- **Projects are selected through open, competitive proposal processes**
 - Consolidated Innovative Nuclear Research FOA (1 call/year)
 - Irradiation and Post Irradiation Examination (PIE) (\$500K - \$4.0M, up to 7 years)
 - Beamline or PIE only (\$50K to \$750K, up to 3 years)
 - Irradiation only (\$500K - \$1.5M, up to 3 years)
 - Rapid Turnaround Experiments (3 calls/year)
 - Not part of the CINR FOA
 - Proposals welcome from university, national laboratory, and industry applicants



A Consortium Offering Research Opportunities

Neutron
Irradiations

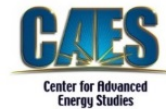
Ion Irradiations

Gamma
Irradiations

Post Irradiation
Examination

Characterization
Beamlines

High
Performance
Computing



Nuclear Fuels and Materials Library (NFML)

- The library includes over 6000 specimens from NSUF projects, legacy research projects, commercial reactors, and research reactors
- Most specimens are neutron irradiated with small number of ion irradiated materials
- Web-based searchable database through nsuf.inl.gov
 - Material or fuel composition
 - Specimen configuration
 - Irradiation conditions
 - Publications
- Specimens Include:
 - Steels – Conventional and Advanced
 - Nickel and Uranium Alloys
 - Ceramics
 - High purity elemental materials
 - Actinides
 - Various fuel forms and constituents (Please contact NSUF)





NSUF Workscopes

University, National Laboratory, or Industry Applicants

**NSUF 1.1: TESTING OF ADVANCED MATERIALS OR ADVANCED SENSORS
FOR NUCLEAR APPLICATIONS**

NSUF-2.3: ADVANCED IN-REACTOR INSTRUMENTATION

- NSUF 1.2: IRRADIATION TESTING OF MATERIALS PRODUCED BY INNOVATIVE MANUFACTURING TECHNIQUES
- NSUF 1.3: NUCLEAR MATERIALS DISCOVERY AND QUALIFICATION INITIATIVE
- NSUF-2.1: CORE AND STRUCTURAL MATERIALS
- NSUF-2.2: NUCLEAR FUEL BEHAVIOR AND ADVANCED NUCLEAR FUEL DEVELOPMENT
- NSUF-2.4: HIGH PERFORMANCE COMPUTING AT IDAHO NATIONAL LABORATORY

University Applicants

- FC-2.5: SEPARATE EFFECTS TESTING IN TREAT USING STANDARD TEST CAPSULES



NSUF 1.1 TOPIC: Testing of Advanced Materials for Sensors or Advanced Sensors for Nuclear Applications

Challenge: Conduct irradiation testing and post-irradiation examinations

1. Advanced materials for sensors, or
2. Advanced sensors for nuclear applications

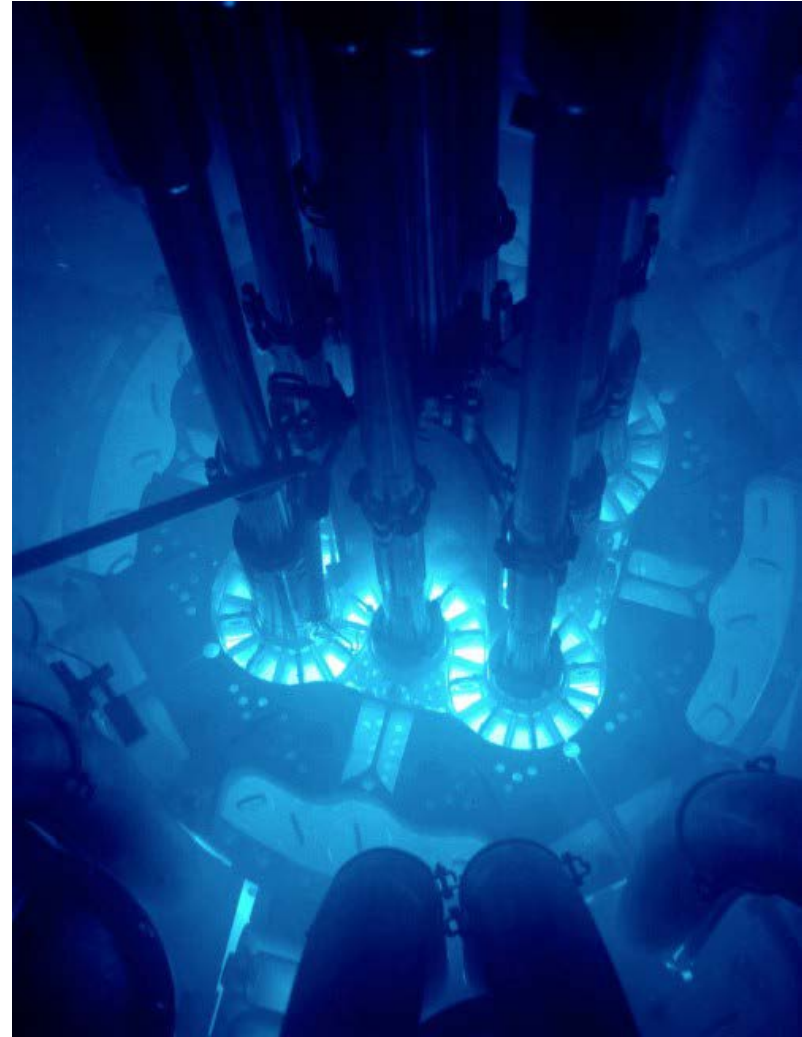
Successful Applications will include:

- A description of the materials/sensors
- Irradiation and post irradiation examination needs
- The role of the materials in new sensors, controls, communications or associated applications
- The purpose and application of the developed sensor in nuclear energy systems

Note: This funding does not support research and development activities to develop materials or sensors, but rather the cost associated with the irradiation of sensors and materials

NSUF-2.3: ADVANCED IN-REACTOR INSTRUMENTATION

- Support qualification of advanced in-reactor instrumentation
 - For characterization of materials under irradiation in test reactors
 - For on-line condition monitoring of power reactors
- Advanced instrumentation, sensors, and measurement techniques for use in advanced reactors is encouraged



NSUF-2: NSUF Access Only Workscopes

- **Objective**

- Provide access to the capabilities of the NSUF for research projects supporting the DOE Office of Nuclear Energy mission

- **Types of Projects**

- Irradiation only (Typically sensors)
- Irradiation and PIE
- PIE only
- Beamline (Ion or Characterization)

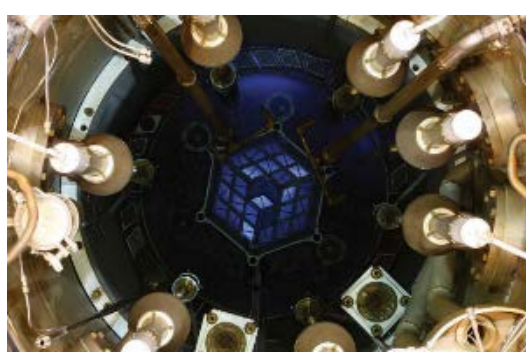
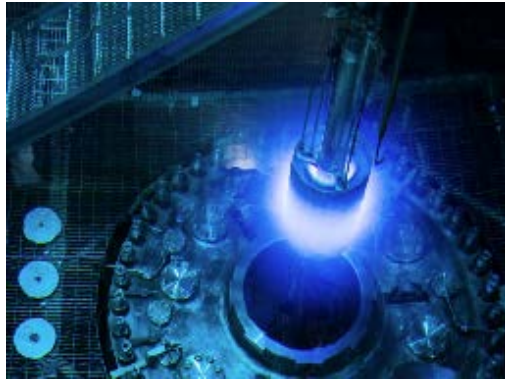
- **Restrictions**

- Open to university, national laboratory and industry applicants
- R&D support funding for applicant not provided
- Source, scope and duration of R&D funding must be identified
- NSUF does not fund travel, salaries, or other user costs

NSUF Changes and Reminders

- NSUF-2 workscopes are open to university, national laboratory and industry applicants (**Change from FY 2019 FOA**)
- NSUF process described in Appendix D
- Non negotiable User Agreement in Appendix E
- LOI, Pre-Applications, Preliminary SOW, Final SOW, Full Applications submitted by Lead Applicant
- Cost Estimates (for NSUF Access) prepared and submitted by NSUF Technical Leads
- Preliminary development effort must be complete and applicant ready for NSUF
 - Applicant must demonstrate readiness in Pre-Application and Full Application
 - NSUF Readiness Criteria described in FOA Part I B.2.2

NSUF Neutron Irradiation Capabilities



Testing Strategy for Novel Materials

Irradiation Testing Hierarchy

1. Ion Beam Irradiation Facilities

- Proof-of-Concept
- Allow immediate feedback of performance
- Ease of instrumentation
- Ease of environmental tuning

2. University Research Reactors

- Proof-of-Principle (First 1% and 10% testing)
- Instrumentation development (pulsing for TREAT)
- Neutron radiography
- Experiment modeling & validation efforts

3. High-Performance Test Reactors

- Proof-of-Performance
- Prototypical environment (licensing)



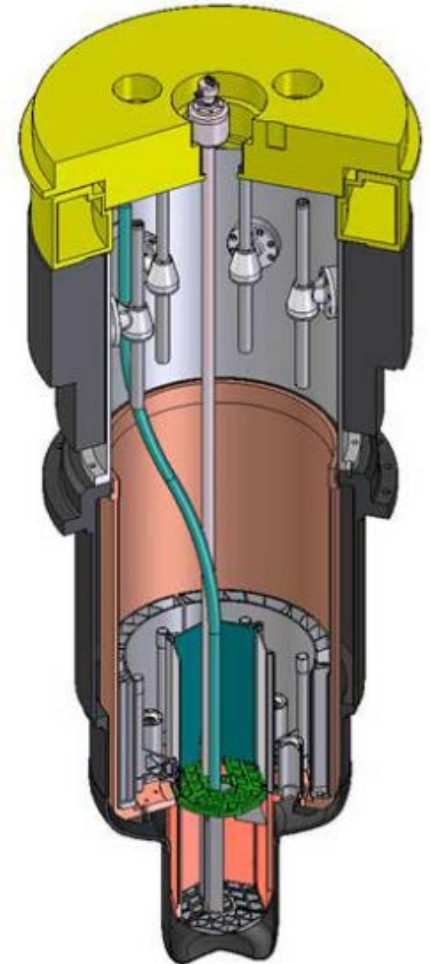
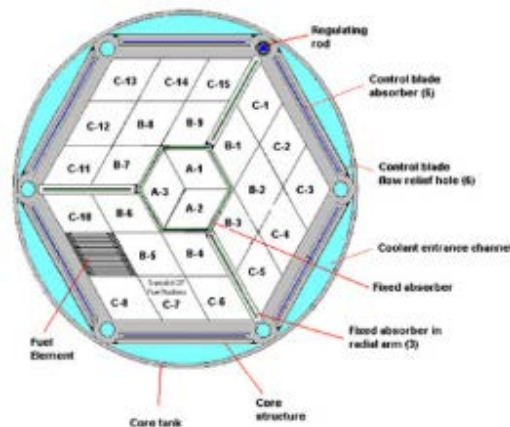
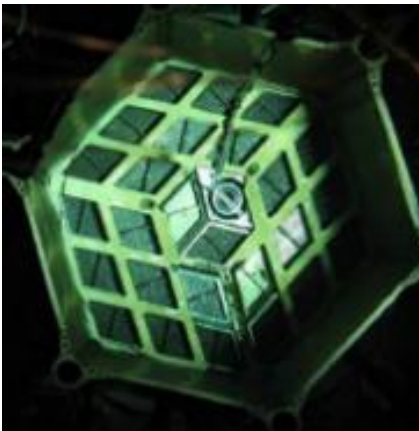
Massachusetts
Institute of
Technology



MIT Nuclear Reactor Laboratory

The MITR has the capability to perform a wide range of experiments in the reactor's core.

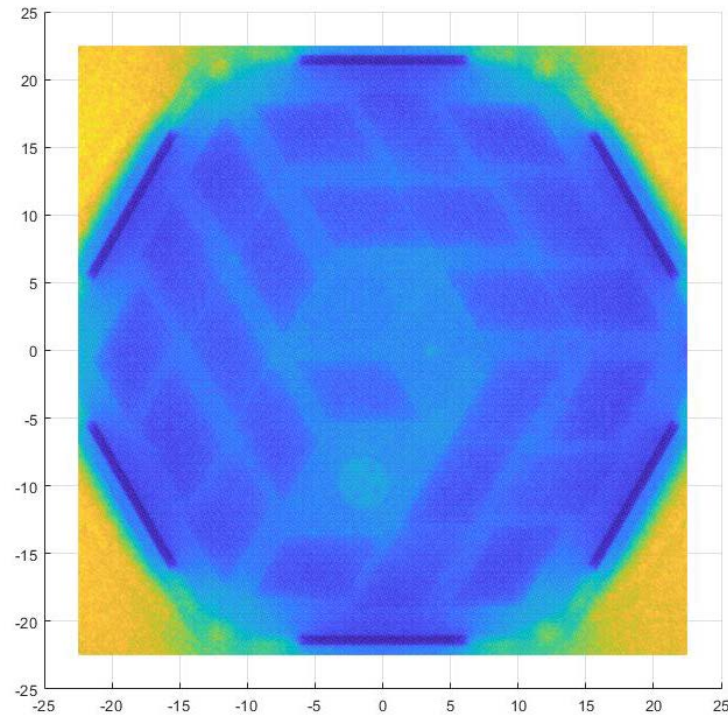
- An inert gas-filled irradiation tube (**ICSA**) for sample capsule irradiation at $<900^{\circ}\text{C}$
- Forced-circulation coolant loops that replicate conditions in both PWR & BWR,
- High temperature ($>900^{\circ}\text{C}$) irradiation facility for materials irradiations in inert gas (He/Ne),
- Custom, dedicated facilities for irradiations in unique conditions (e.g., molten fluoride salts).
- Fast flux $1.2 \times 10^{14} \text{ n/cm}^2\text{-s.}$
- Thermal flux $0.4 \times 10^{14} \text{ n/cm}^2\text{-s}$



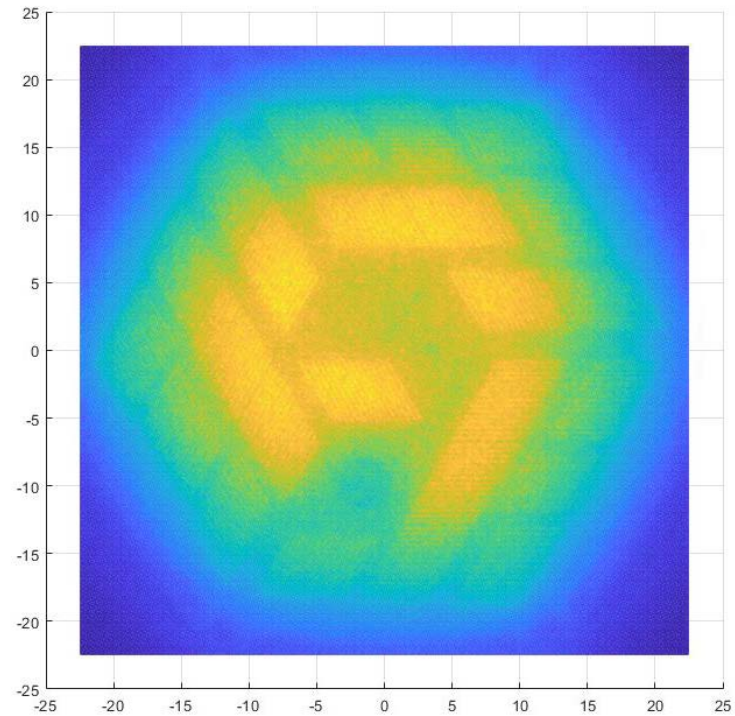


MITR Neutron Energy Spectrum

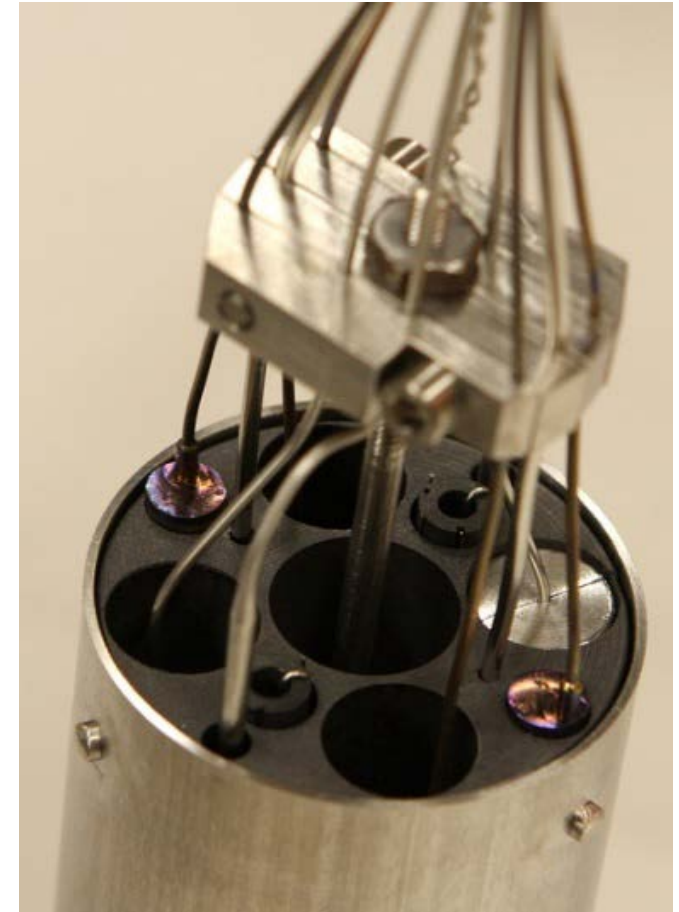
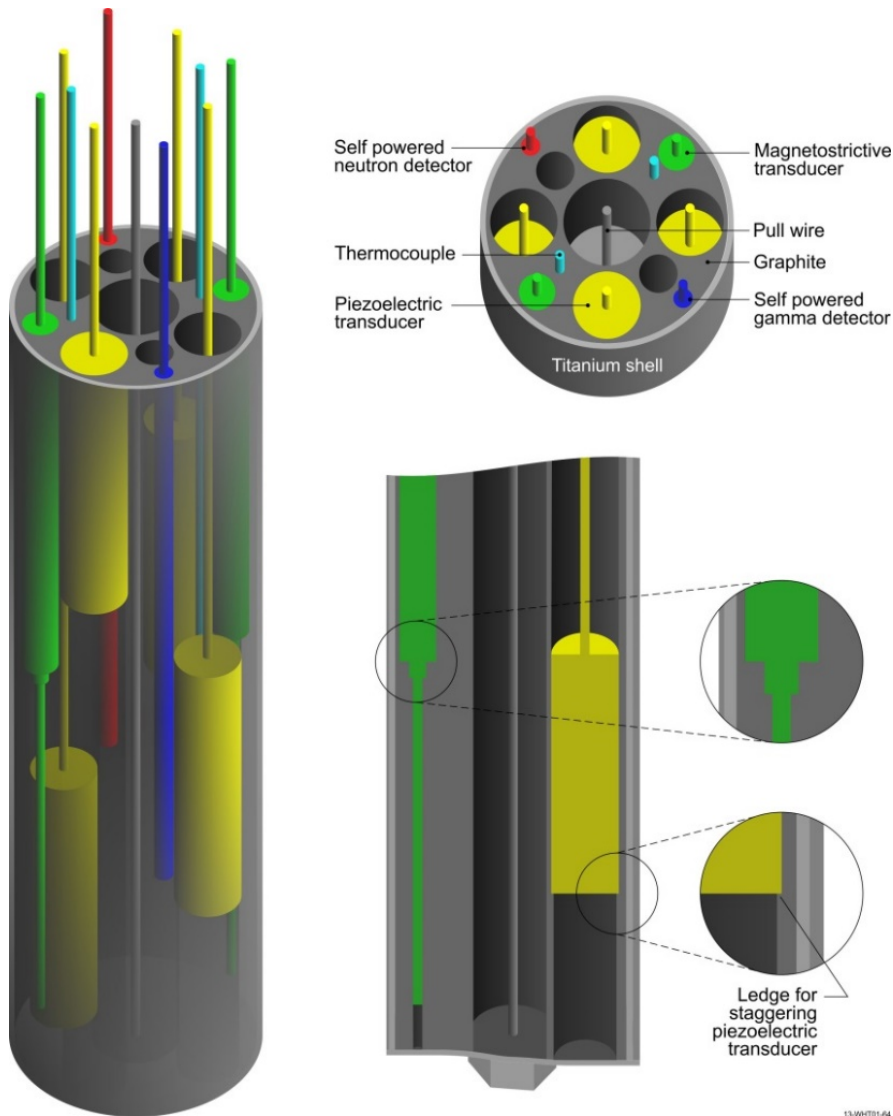
Thermal Neutron Intensity



Fast Neutron Intensity



ULtrasonic TRAnsducer (ULTRA 1& 2)



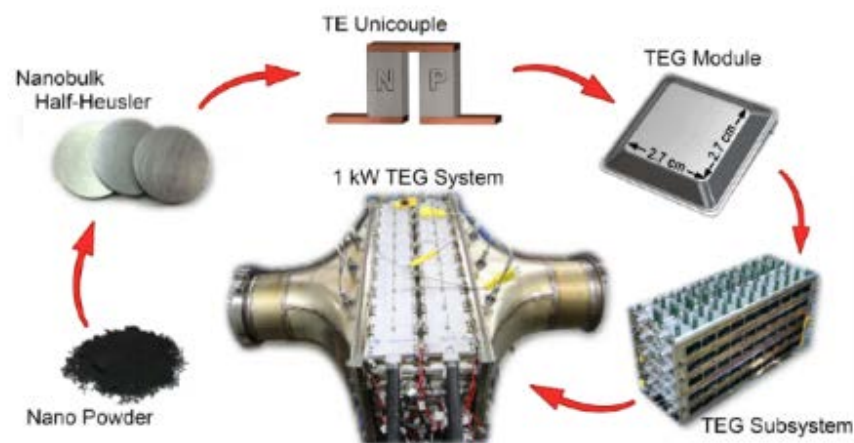
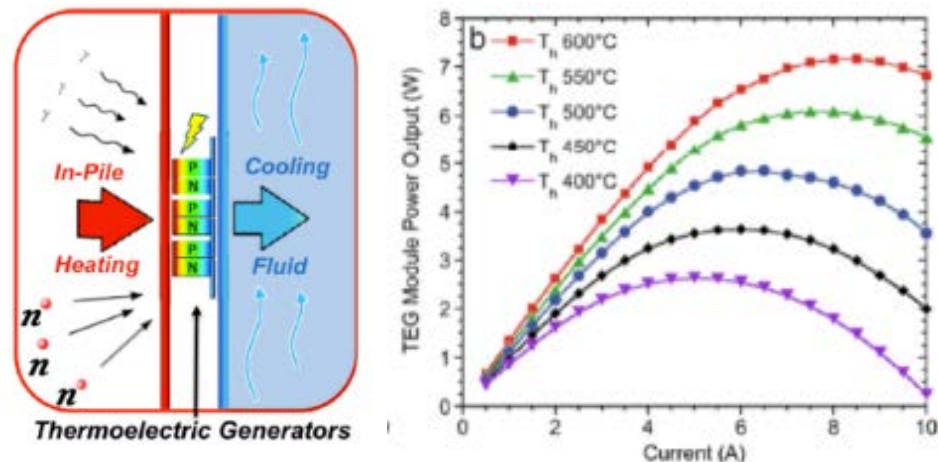
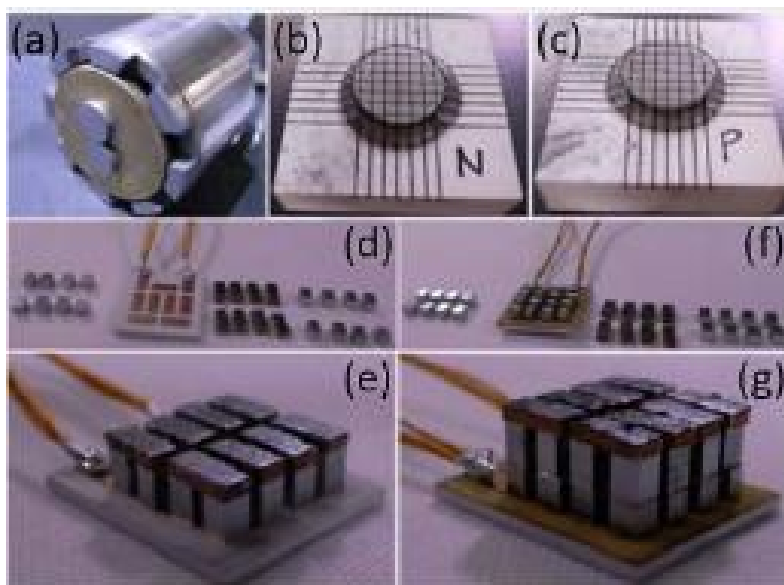
Credit: Josh Daw (INL)

Nanostructured thermoelectric materials and generators for in-pile power harvesting

Michigan Ion Beam Laboratory MIT Reactor

In-Core Sample Assembly (ICSA)

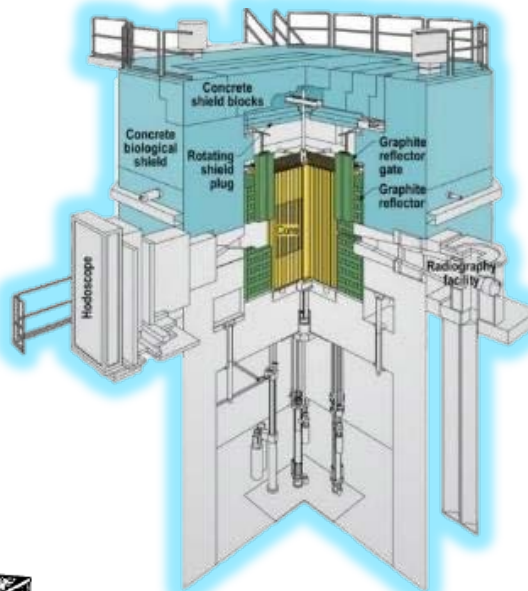
- 2 cycles (~6 months in reactor)
- $0.3\text{-}0.5 \times 10^{21} \text{ n/cm}^2$, $E > 1.0 \text{ MeV}$



Credit: Yanliang Zhang (Notre Dame)

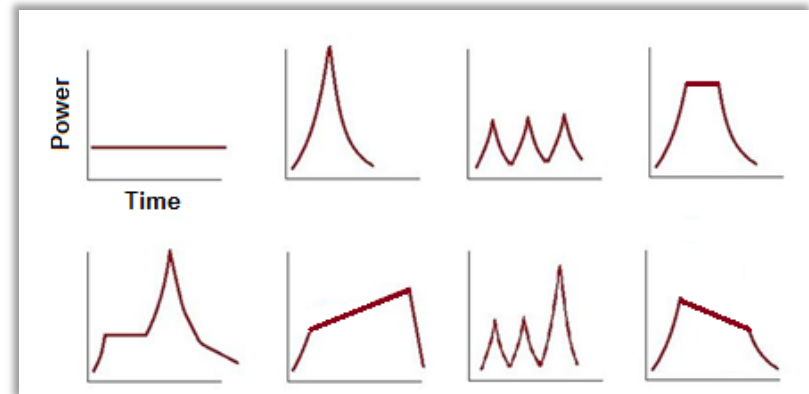
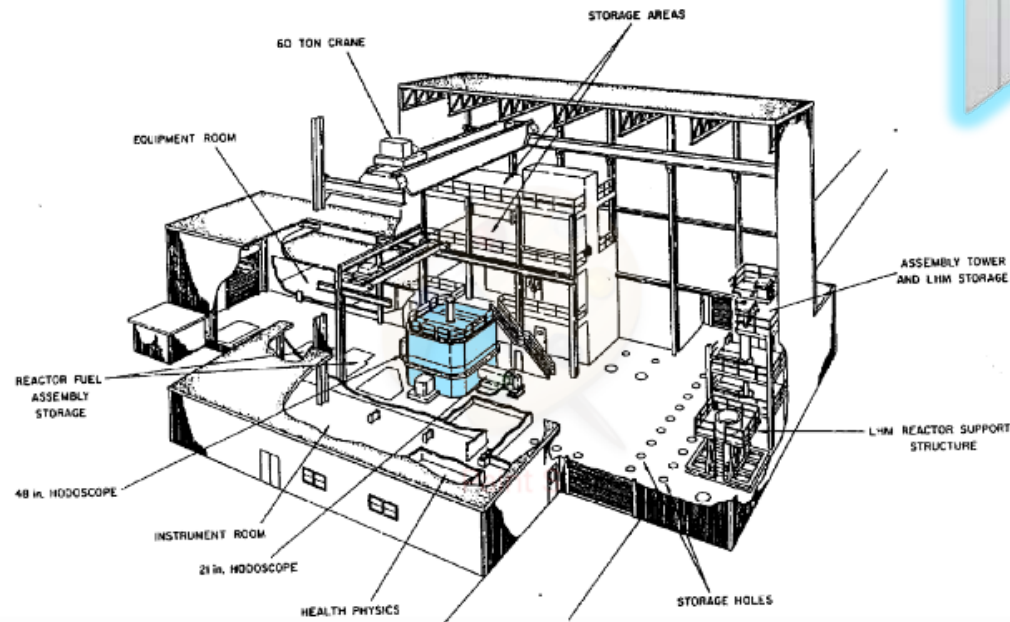
Transient Reactor Test (TREAT) Facility

- Operational in 1959.
- Upgrades in 1962, 1972, 1982, 1988 – most recent provided significant upgrades to instrumentation and control systems
- Restarted Nov. 2017
- First fuel experiments Sept. 2018



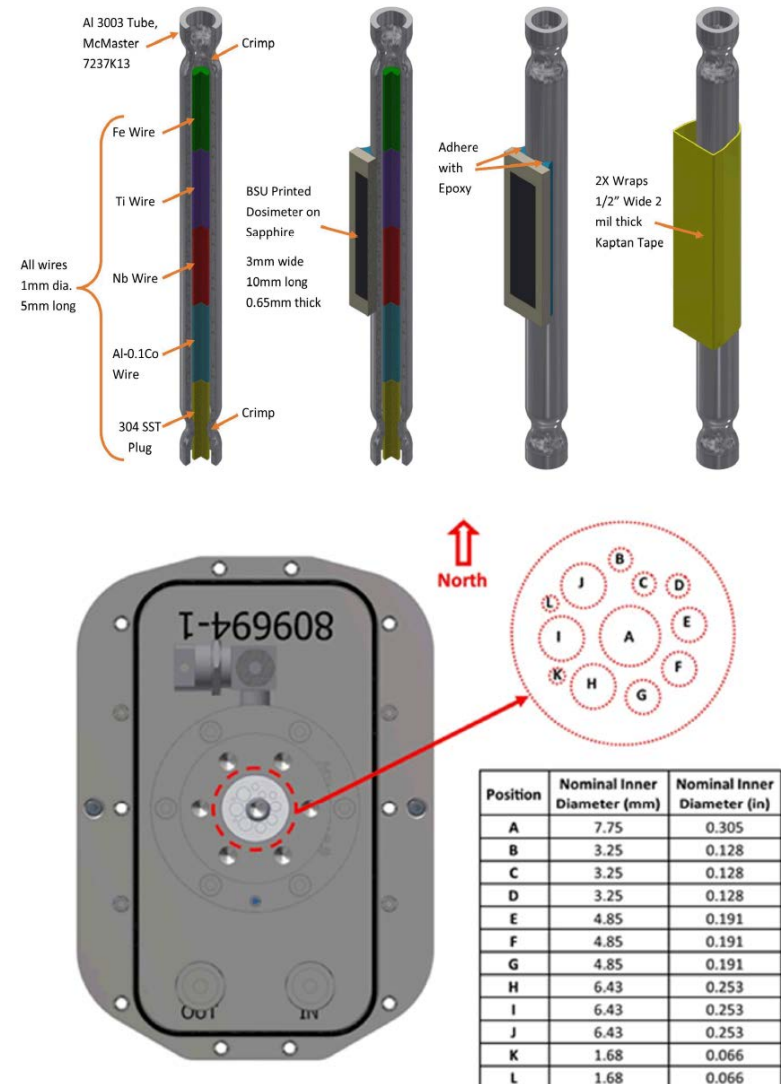
TREAT's brilliant design provides flexibility to support a variety of testing missions

- 19 GW Peak Transient Power (~2500 MJ energy limit)
- Core: ~1.2 m high, 19 x 19 array of 10 x 10-cm. fuel assemblies
- Instantaneous, large negative temperature coefficient (self protecting driver core)



Neutron Sensor and Instrumentation Test

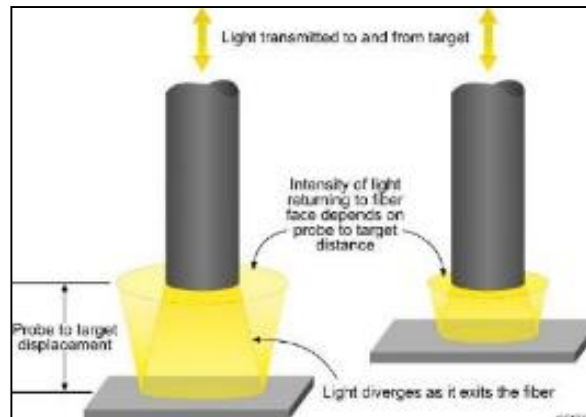
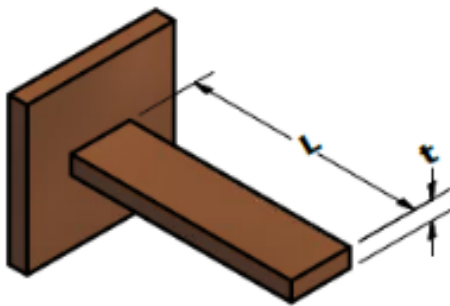
- Modular Instrumentation and Materials Irradiation Capability (MIMIC) test hardware
- SPND, FC, TC, flux wires
- Evaluate neutron sensor performance under a variety of transient irradiations in TREAT focusing on each sensor's **neutron sensitivity, signal linearity, and overall degradation**.
- Repeated linear ramp, stepwise insertion, and temperature limited pulse transients in TREAT will enable MIMIC-N to demonstrate each sensor's performance.



Indirect Measurement of Microstructure using Resonant Ultrasound Spectroscopy

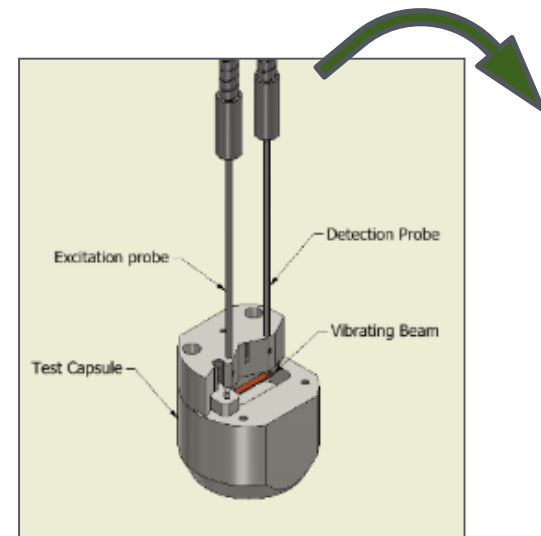
- Microstructure plays an influential role in the mechanical properties of materials.
- Materials subjected to irradiation and high temperatures can undergo significant microstructure evolution.
- By monitoring the mechanical properties, we can deduce changes in the microstructure.

Cantilever Beam Basis for an In-pile sensor



Simple Optical Fiber based method for measuring displacement

Test capsule will be integrated with the BUSTER module for radiation testing in the TREAT reactor.



Contact Information

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- In-Pile Instrumentation Development Program Lead: **Patrick Calderoni**
Patrick.Calderoni@inl.gov
- NSUF Website
nsuf.inl.gov



NSUF-2 Focus Areas

- **NSUF-2.1: CORE AND STRUCTURAL MATERIALS**

- Understanding irradiation effects such as aging and material degradation (e.g. fatigue, embrittlement, void swelling)
- Development of radiation resistant materials for current and future reactor applications

- **NSUF-2.2: NUCLEAR FUEL BEHAVIOR AND ADVANCED NUCLEAR FUEL DEVELOPMENT**

- Increase fundamental understanding of the behavior of nuclear fuel
- Improve performance of current fuels or develop advanced fuels
- Irradiation and thermal effects on microstructure, thermophysical and thermomechanical properties, and chemical interactions
- Projects should aim at proposing simple irradiation experiments with post irradiation examination investigation of fundamental fuel performance aspects such as radiation damage, species diffusion or fission products
- Coupling of experimental methods with modeling and simulation is encouraged

NSUF-2 Focus Areas

- **NSUF-2.3: ADVANCED IN-REACTOR INSTRUMENTATION**
 - Support qualification of advanced in-reactor instrumentation
 - For characterization of materials under irradiation in test reactors
 - For on-line condition monitoring of power reactors
 - Advanced instrumentation, sensors, and measurement techniques for use in advanced reactors is encouraged
- **NSUF-2.4: HIGH PERFORMANCE COMPUTING AT IDAHO NATIONAL LABORATORY**
 - Provide scientific computing capabilities to support efforts in advanced modeling and simulation (Falcon and Lemhi)
 - Proposals in this area may address a wide range of research activities
 - Performance of materials in harsh environments (including the effects of irradiation and high temperatures),
 - Performance of existing light water and advanced nuclear reactors
 - Multiscale, multiphysics analysis of nuclear fuel performance