NRIC National Reactor Innovation Center

Experimental Infrastructure Overview

2025 NRIC Developer Workshop

Sanjay Mukhi

06/23/2025

MIS-25-85694

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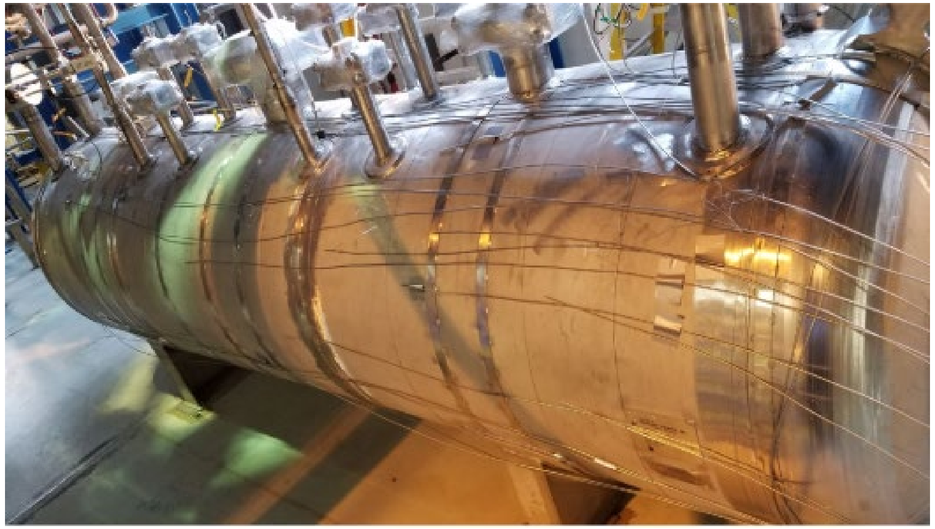
Mechanisms Engineering Test Loop

2025 Status

Derek Kultgen, Ph.D., P.E., PMP

Overview



- 5 Test Vessels and 2 Operational Tanks to Host Experiments
- 750 Gallons of Reactor Grade Sodium
- Maximum Operating Temperature 1000°F Flowing or 1200°F Static (28” Vessels)
- 3 Electromagnetic Pumps and Flow Meters
- Na_2O Sodium Oxide Measuring and Removal
- ASME Code Stamped

Experiments

<u>Learn by Doing</u>

- Gear Test Assembly
- Gripper Test Assembly
- Thermal Hydraulic Experimental Test Article
- Sample Basket
- Bearing Test Article
- Flow Test Article

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National Reactor Innovation Center Developers Workshop

MAGNET / He-CTF

T.J. Morton

MIS-24-78309

MAGNET / He-CTF

Non-Nuclear Component and System Testing

MAGNET / He-CTF

Microreactor **AG**ile **N**on-nuclear **E**xperimental **T**est bed / **He**lium **C**omponent **T**est **F**acility

- Examine thermal-hydraulic performance in a configurable environment
- Verify models with experimental data
- Test in a non-nuclear environment for post-testing examinations without activation/contamination concerns

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Features

Closed Loop Gas Cooling

- Reciprocating compressor
- Thermal mass flow meter (gas specific)
- Process heater for inlet temperature control
- Recuperator
- Chilled water cooler
- Integrated system operation options (e.g., Brayton-cycle power conversion, thermal storage, collocated microgrid)

Open Loop Air Cooling

- Variable speed screw compressor
- Venturi flow meter
- Flow and pressure control
- Process heater for inlet temperature control

Operating Envelope

Closed Loop Gas Cooling

- Nitrogen or Helium
- ≤ 650°C Test Article Tout
- ≤ 650°C Test Article Tin
- ≤ 20 bar(g)
- 1.86×10^{-2} m^3/s at 20 bar(g)
- 80 kW process gas heating
- 250 kW electric resistance heat

Open Loop Air Cooling

- 8.61×10^{-2} m^3/s at 1 bar(g)
- ≤ 650°C Texhaust
- 350°C Test Article Tin
- ≤ 10 bar(g)
- 80 kW process gas heating

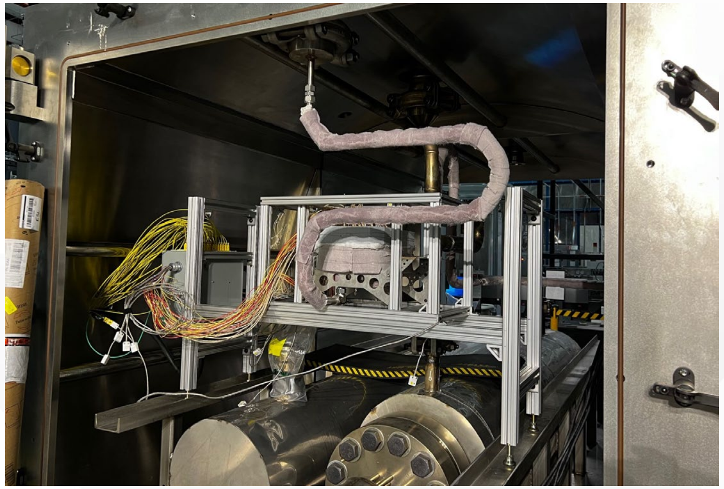
Testing

Heat Exchangers:

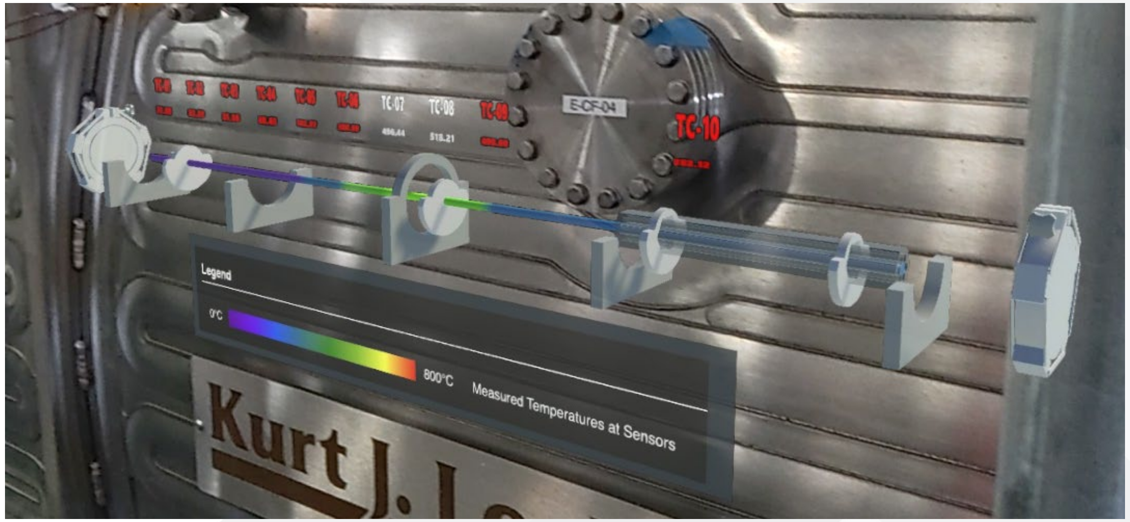
- Helium or Nitrogen to low-pressure air
- Flexible configuration
- 80 kW process heat for pre-heating both streams to prototypic conditions
- HX Testing Run to Date
  - Proprietary, commercial, shell-and-tube HX
  - High performance, prototype CPHX (U-Wisconsin)

Core Segments:

- Cartridge heaters (208V/1Ø, 240V/3Ø, 480V/3Ø)
- Configurable, expandable data acquisition
- Demonstrated test capability with single heat pipe test with digital twin integration



HPIHX



Digital Twin Visualization of Single Heat Pipe Test

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INL/EXP-xx-xx

Advanced Test Reactor (ATR)

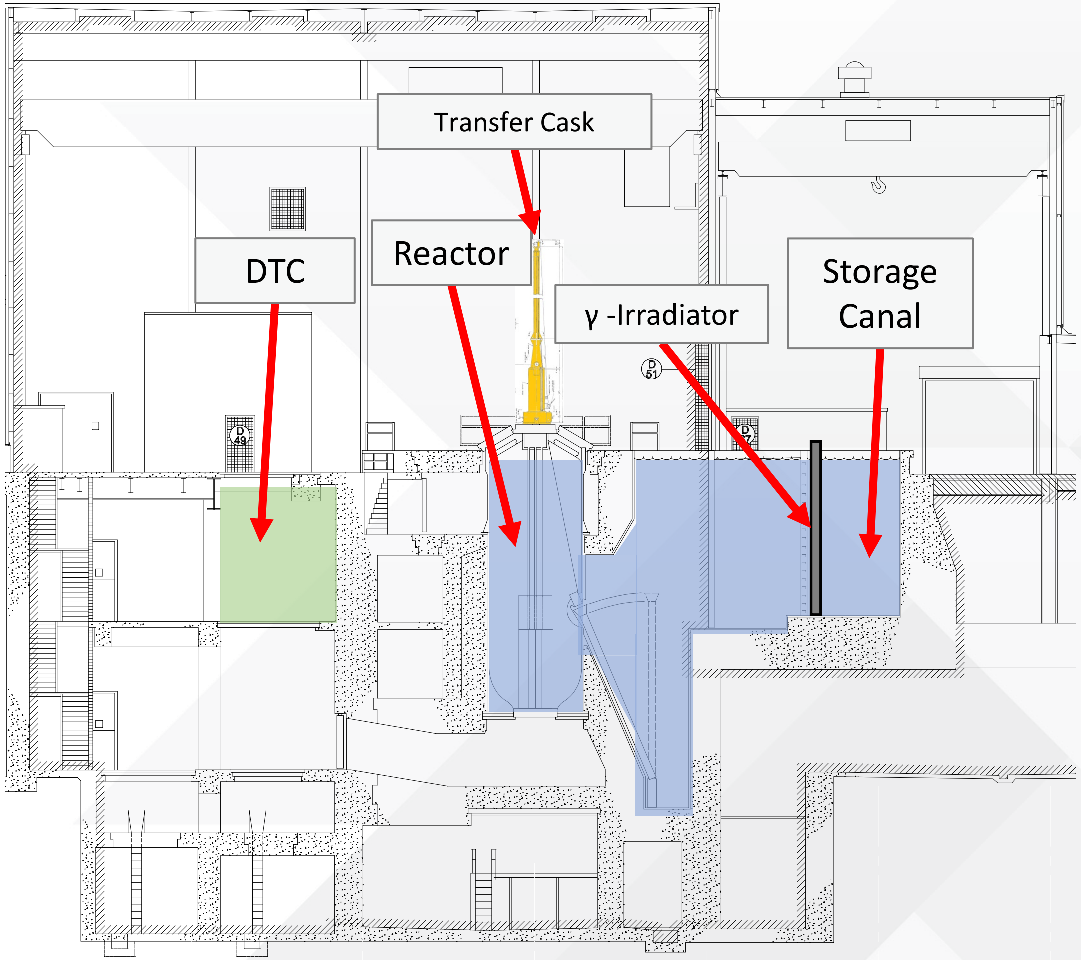
An Overview of Capabilities

Daniel K. Sluder, PE

ATR Experiment Engineer
Nuclear Safety Analyst

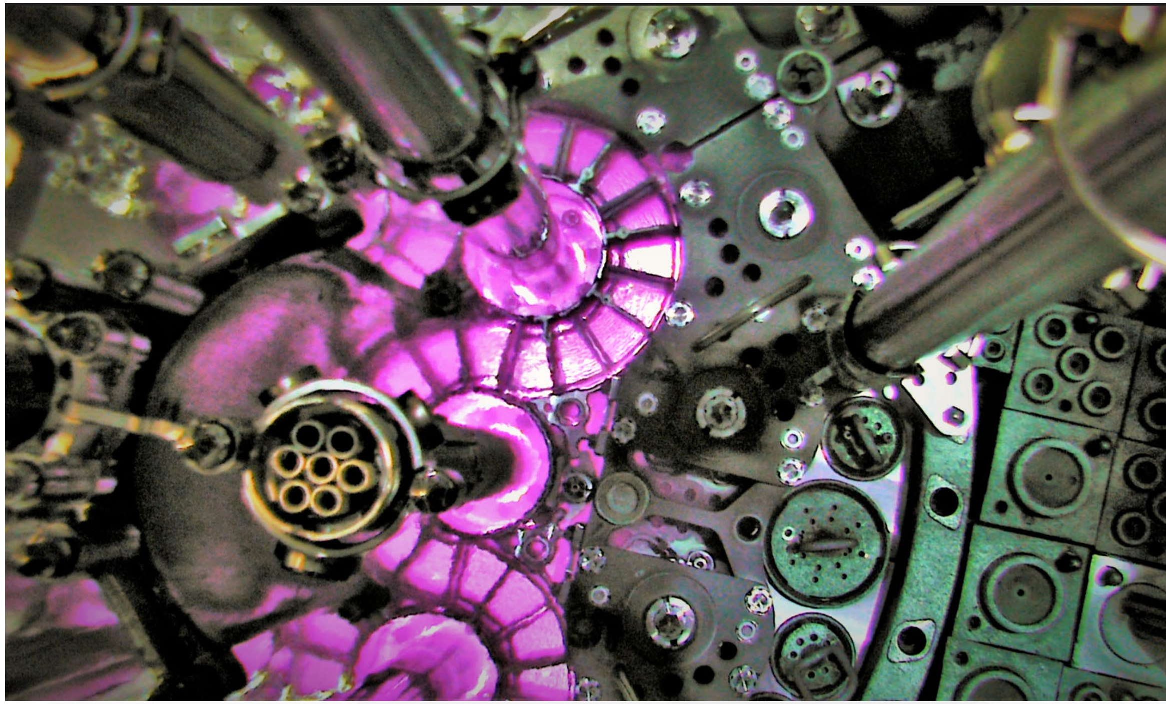
ATR Description (Facility)

- Reactor
  - $250MW_t$
  - Light Water
- Storage Canal
  - Storage
  - Wet sizing
- Gamma Irradiator
  - Driver Fuel Source
  - $\leq 5 \times 10^6 R/hr$ exposure
- Dry Transfer Cubicle (DTC)
  - Sizing facility
  - Air atmosphere



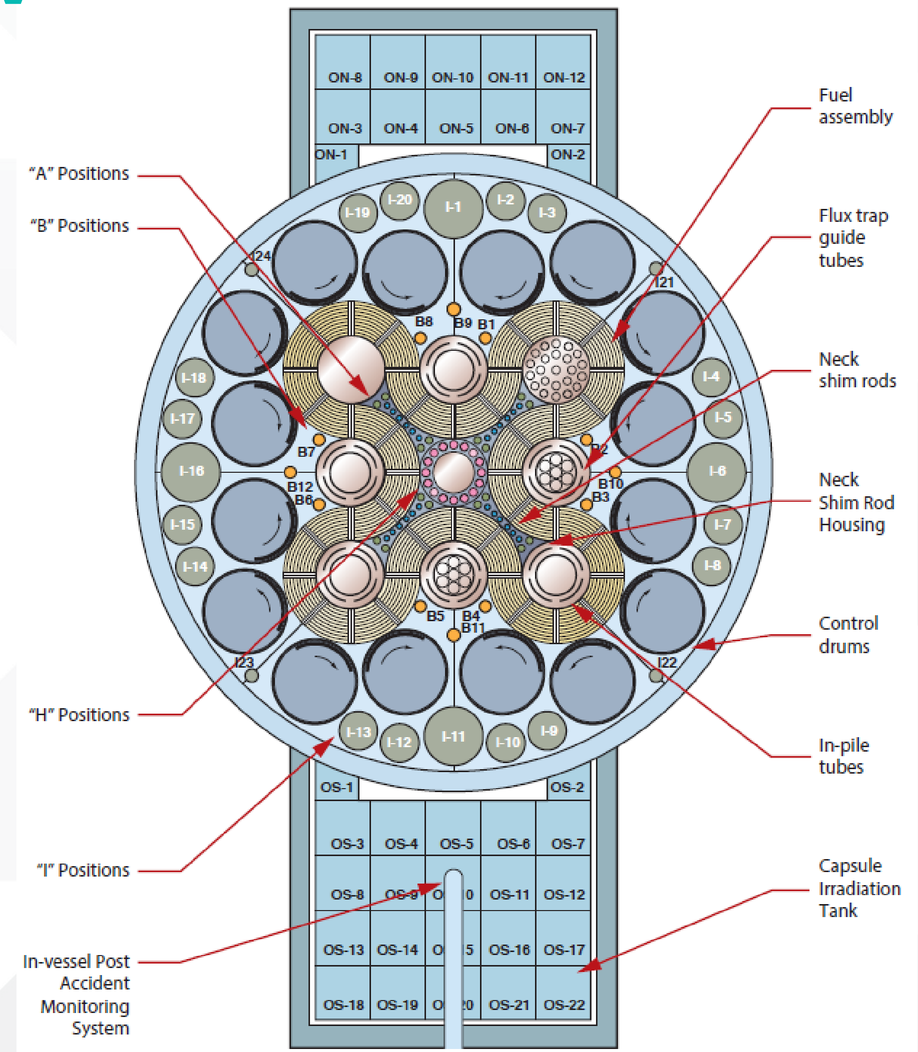
ATR Description (Reactor)

- General Parameters
  - Low Temperature and Pressure
  - Light Water
  - Aluminum Clad Driver Fuel
- Clover Shape Design
  - Reactor "Tilt" Capability
  - Nine Flux Traps
- Two types of operational cycles
  - Standard (~110 MW, 60 day)
  - PALM (~170 MW, ~7 day)



Experiment Overview

- Variety of Experiment Positions
  - Flux Traps
  - Inboard Positions
  - Outboard Positions
- Variety of Experiment Types
  - γ-Irradiation
  - Simple Capsule
  - Instrumented Capsule
  - Gas Loop
  - Pressurized Water Loop (PWL)



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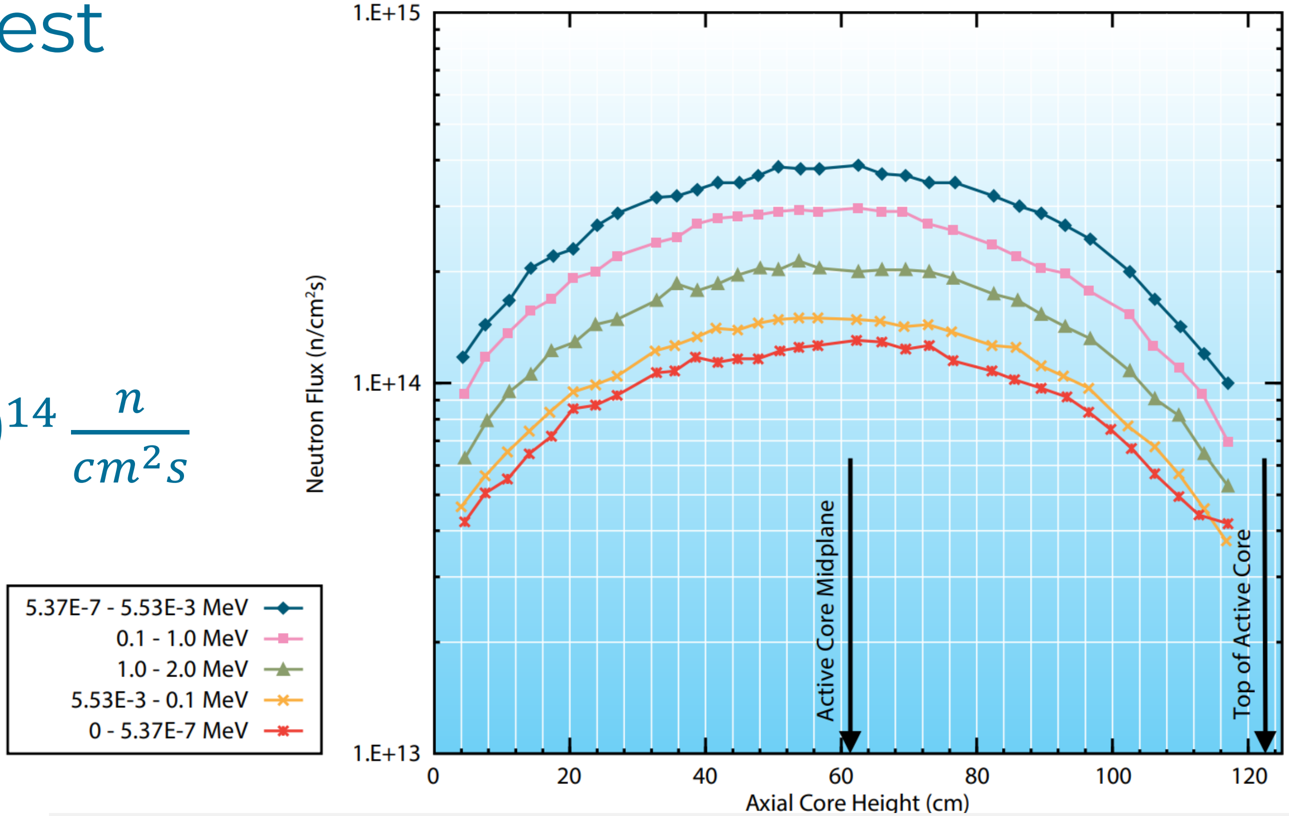
Thermal and Fast Spectrum Testing

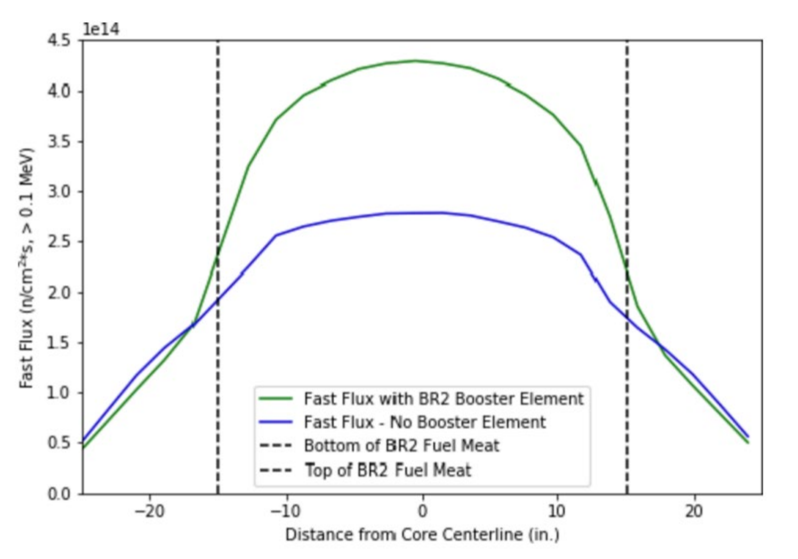
- ATR is primarily a thermal test reactor
- Thermal flux range
  - Position dependent
  - Between 1×10^{13} and $4.4 \times 10^{14}\ \frac{n}{cm^2 s}$

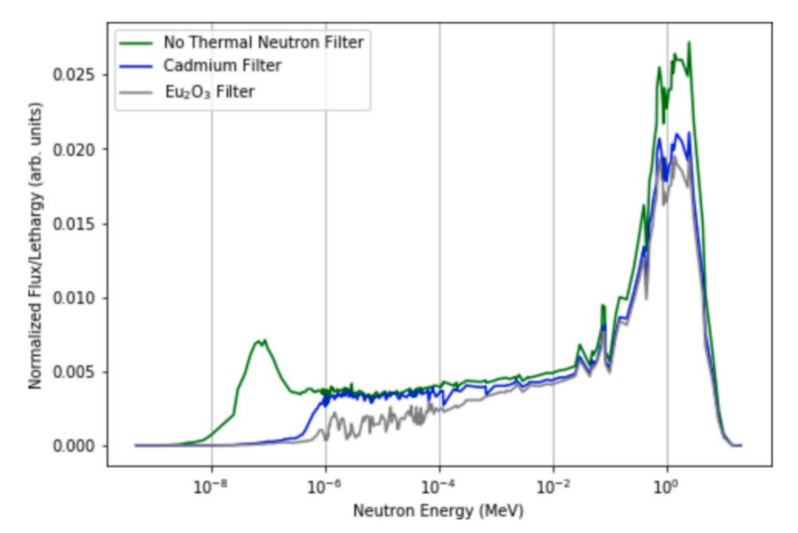


Unperturbed five-energy group neutron flux intensity profiles over the active core length of the ATR center flux trap for total reactor power of 125 MW.

Thermal and Fast Spectrum Testing

- Fast Reactor Environments may be simulated
- Cadmium neutron filters are used to reduce thermal flux
- Booster fuel elements have also been proposed to increase fast flux ([Curnutt 2022](#))

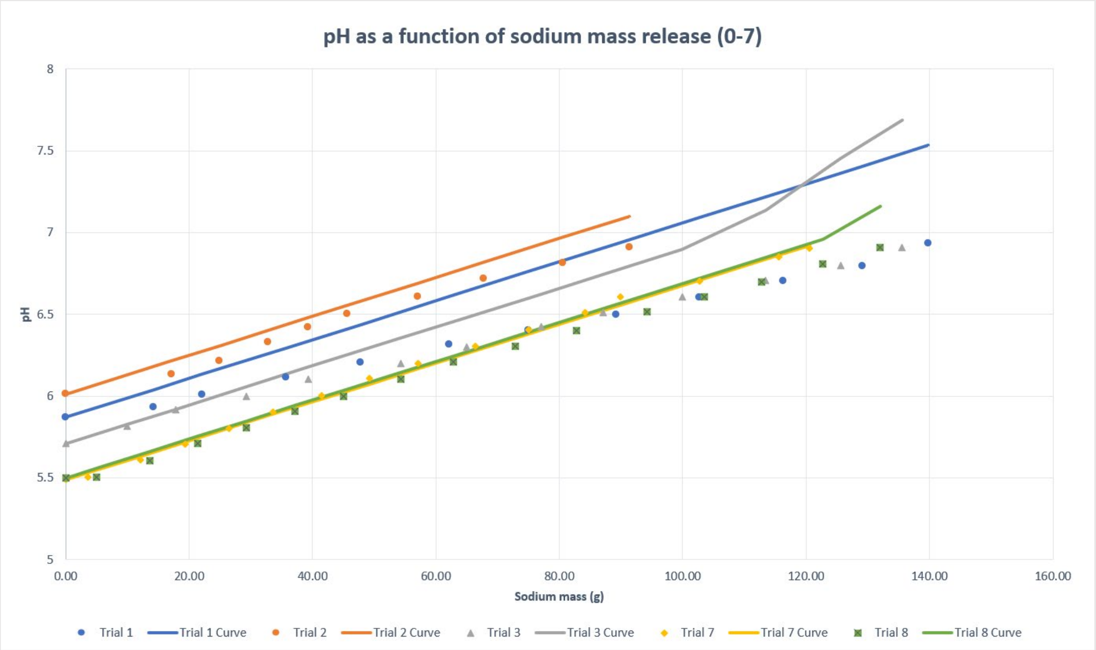




Innovation Center

Advanced Material Testing

- Standard fuel and materials testing
- Advanced fuel and materials testing capability
  - Sodium bonded fuels
  - Molten salt fuel ($NaCL-UCl_3$ and $UF_4-NaF-KF$)
  - Metallic eutectic mixtures



Data from an experiment safety evaluation for sodium bonded experiments.

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Sample Preparation Laboratory (SPL) Overview-June 2025

B. D. Miller, E. Flynn, J. Trent, S. Moore, C. Judge

What is SPL and Why is it Needed?

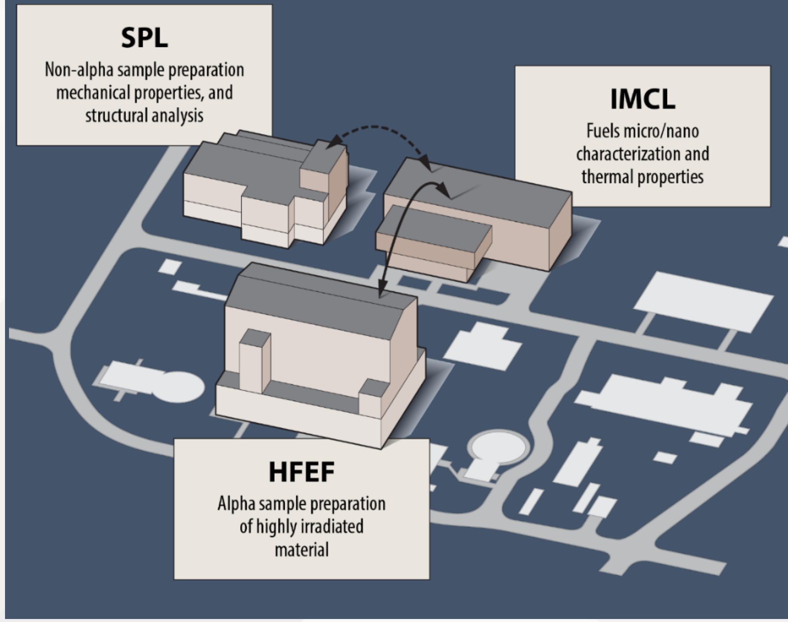
- SPL's mission will be ***to support characterization of engineering and microstructural scale reactor structural materials***
- Post-irradiation examination
- ***Hazcat 3 facility***
- ***Sample preparation***
- ***Mechanical properties testing***
- ***Microstructural analysis***
- ***No loose alpha bearing materials***
- Office space
- Machine shop (Future)

SPL

SPL Location and other Primary PIE Capabilities at MFC

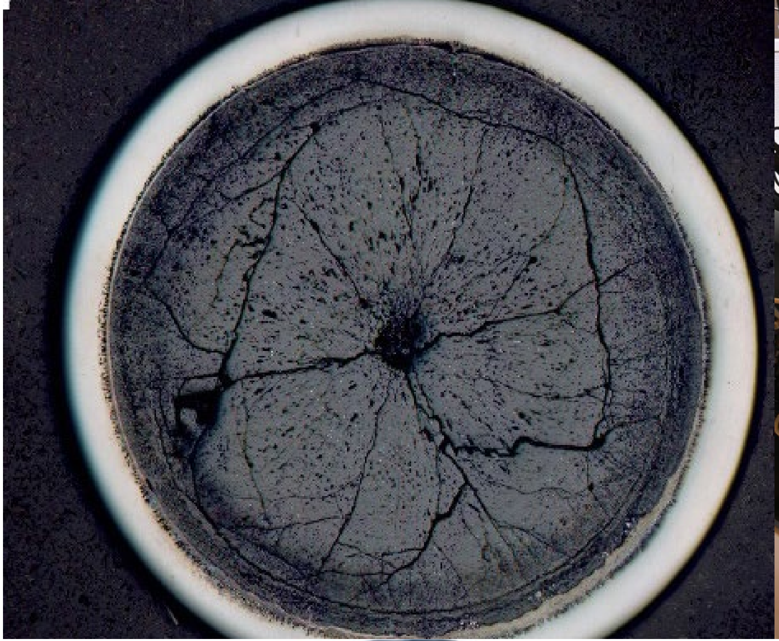
- HFEF handles full sized fueled experiments (Engineering Scale)
- IMCL provides high end microscopy, thermal testing, and small-scale mechanical testing of irradiated materials including sample preparation of commercial fuel pellet sized experiments
  - Micro to atomic scale
- **SPL handles alpha clean structural experiments for microstructural characterization**
  - **Engineering through sub-micron level**
- HFEF, IMCL, and SPL are broadly available to the nuclear research community through the Nuclear Science User Facilities, University partnerships, DOE programs, and Strategic Partnership programs

MFC



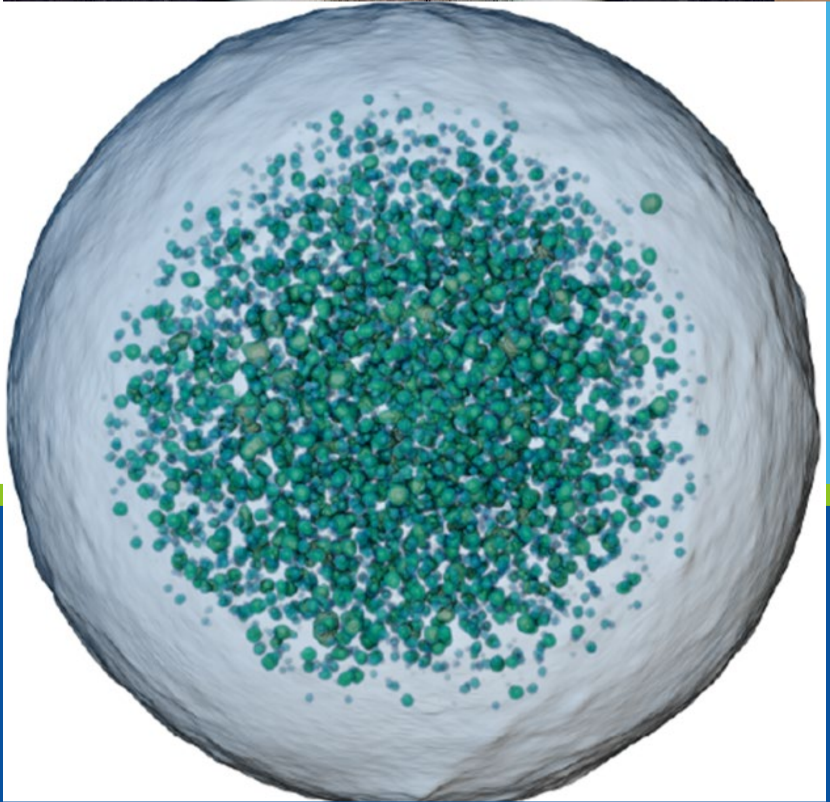
SPL Design Parameters

- Approx. 4088 m^2/44,000 ft^2. (3 stories)
  - Braced frame structural steel with 0.3m/1ft. solid, grouted, reinforced concrete masonry unit (CMU) exterior walls
  - Seismic Design Category 2, Limit State B
- Divided into office space and laboratory space
  - User facility building designed for easy access by visiting researchers
  - 762m^2/8,200 ft^2 office space, 3100m^2/33,000 ft^2 laboratory space
  - Office space provided on all three floors
- 1st floor: Shielded sample preparation line and instrument enclosures
- 2nd floor: Hoods, gloveboxes, transfer cell of the shielded sample preparation line
- 3rd floor: Manipulator repair area, personnel decontamination room, and ventilation



Daniel Murray

Characterization Department Manager



The Irradiated Materials Characterization Lab

MIS-25-85276

Battelle Energy Alliance manages INL for the
U.S. Department of Energy's Office of Nuclear Energy

Idaho National Laboratory

INL multiscale approach PIE to support US NE mission

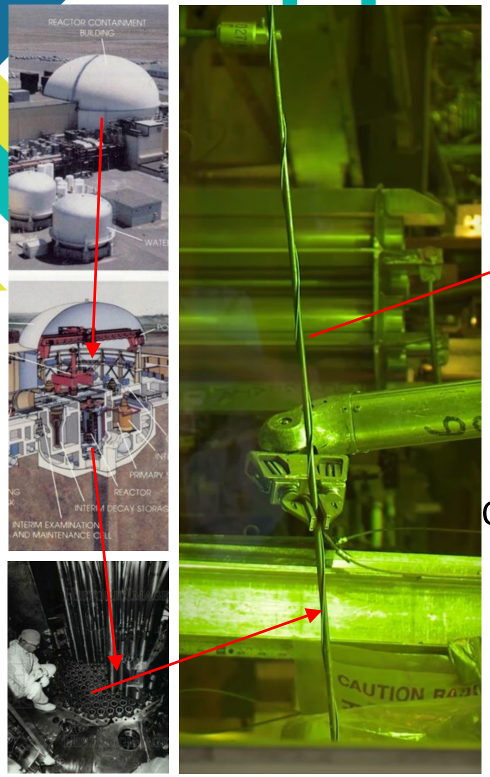
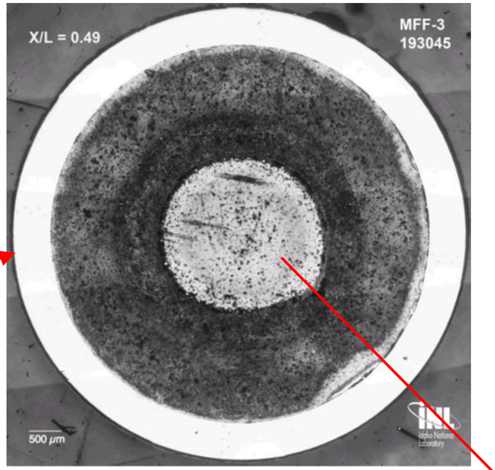
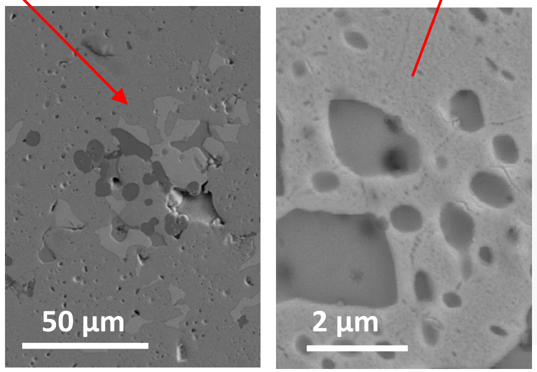


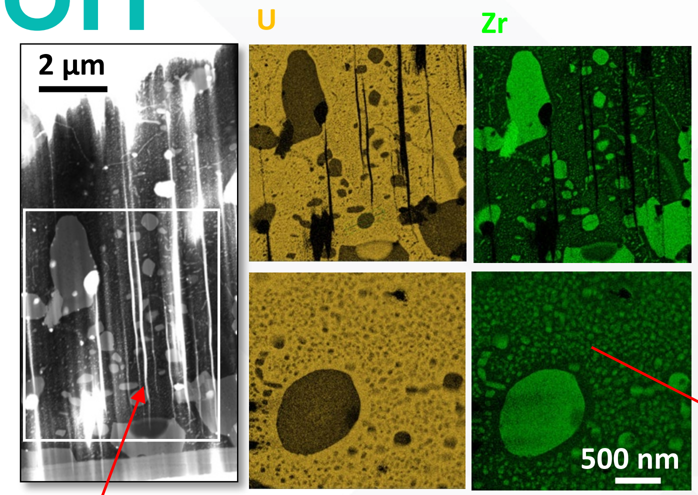
Photo observation of U-10Zr fuel pins irradiated in Fast Flux Test Facility (~1 m)



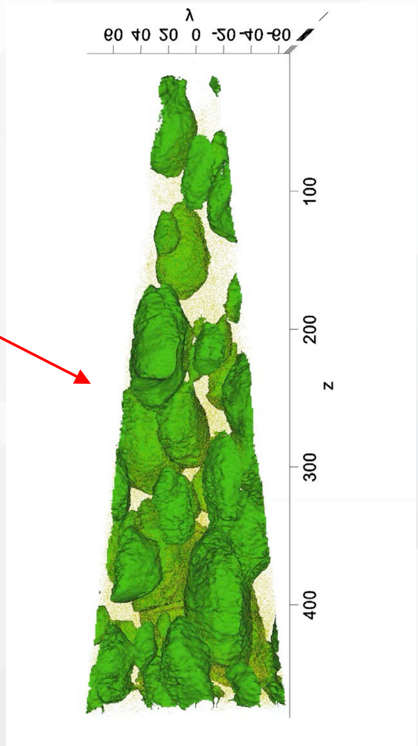
Optical microscopic examination (U-10Zr fuel) (1mm, 10^{-3} m)



Scanning electron microscopy characterization of U-10Zr grain and precipitate (1 μm, 10^{-6} m)



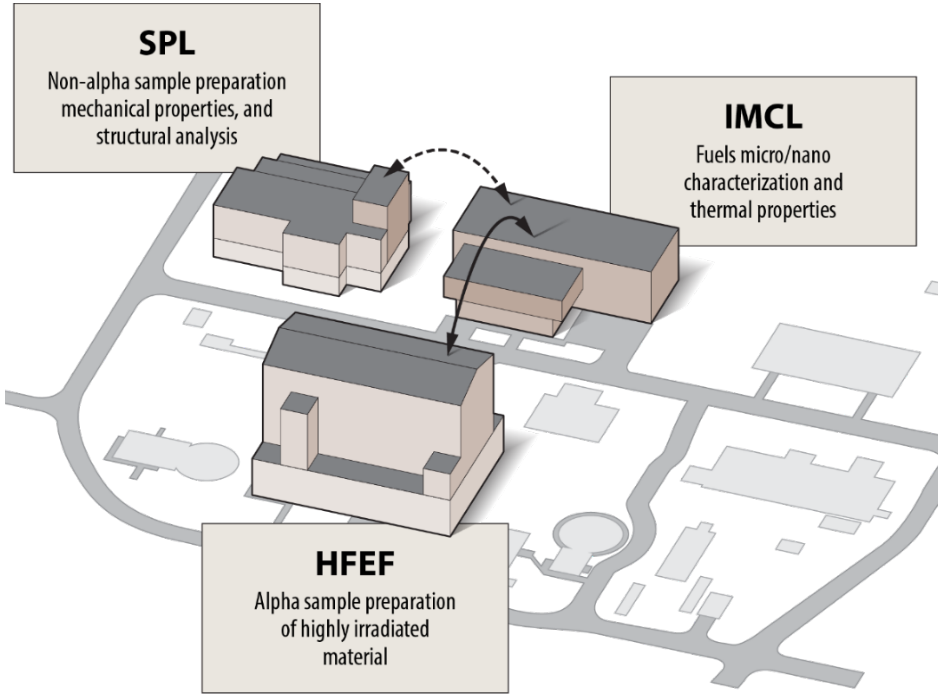
Transmission electron microscopy identification of Zr nano precipitate (2-5 nm, 10^{-9} m)



Atom probe tomography study of Zr atom distribution in 3D (3 Å, 10^{-10} m)

PIE capabilities span 10 orders of magnitude

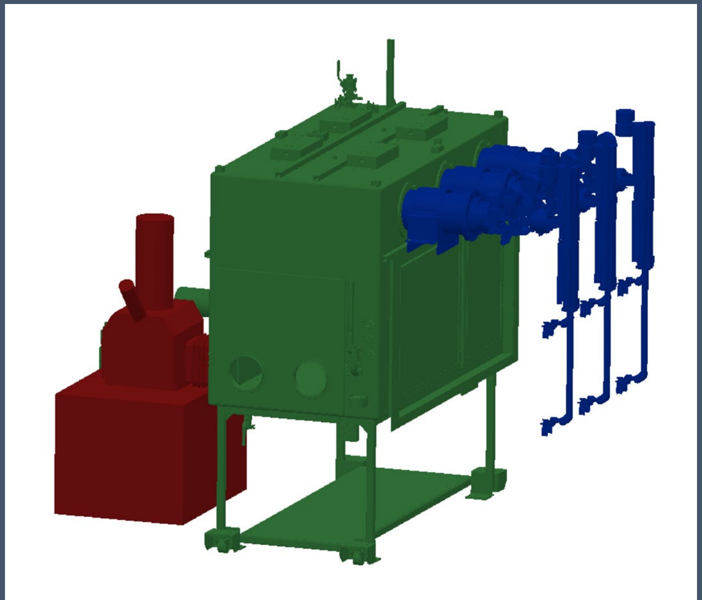
Current PIE capability at INL

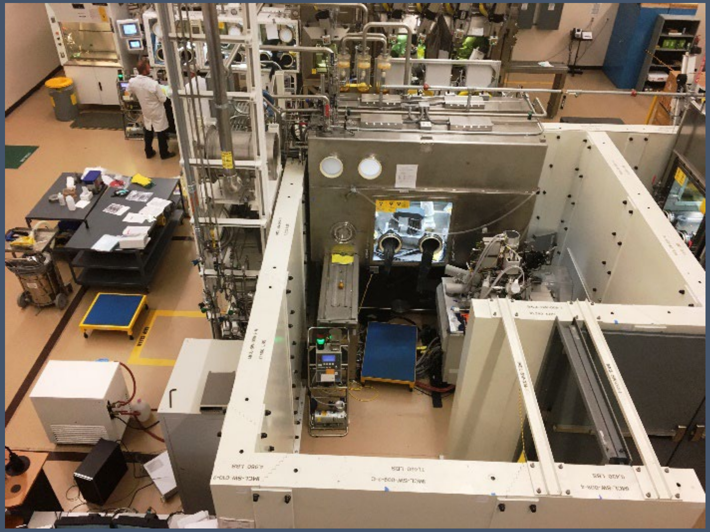


- IMCL provides high end microscopy, thermal testing, and small-scale mechanical testing of irradiated materials including sample preparation of commercial fuel pellet sized experiments
- IMCL, SPL, and HFEF are broadly available to the nuclear research community through the Nuclear Science User Facilities, University partnerships, DOE programs, and Strategic Partnership programs

Design Features of IMCL

- Haz Cat 2 Nuclear facility
- "Accessible" Shielded instrumentation
  - Steel walls provide the shielding
  - Glove box controls contamination
  - Inert atmosphere in glovebox prevents sample oxidation
- Remote or contact equipment loading/unloading and operation





Current IMCL Instrumentation

- Shielded FEI Quanta dual-beam focused ion beam (**FIB***)
- Shielded FEI Helios dual beam Xe plasma FIB (**P-FIB***)
- Shielded CAMECA SX-100R electron probe microanalyzer (**EPMA**)
- FEI Titan Themis 200 **TEM** with probe corrector and **EELS**
- Shielded Sample Preparation Area (**SSPA**)
- Shielded Thermal Property cell
  - **LFA**
  - **TGA**
  - **TCM**

- Unshielded JEOL 7600 **FEG-SEM**
- PANalytical XRD and Bruker **micro-XRD**
- Unshielded Zeiss Versa 520 **x-ray microscope**
- Quantum Design Physical Property Measurement System
- CAMECA LEAP 5000 **Atom Probe**
- Unshielded FEI Helios Hydra dual beam plasma **FIB/SIMS**
- Alemnis and PI-88 is-situ **nanoindenters**

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The Hot Fuel Examination Facility (HFEF)

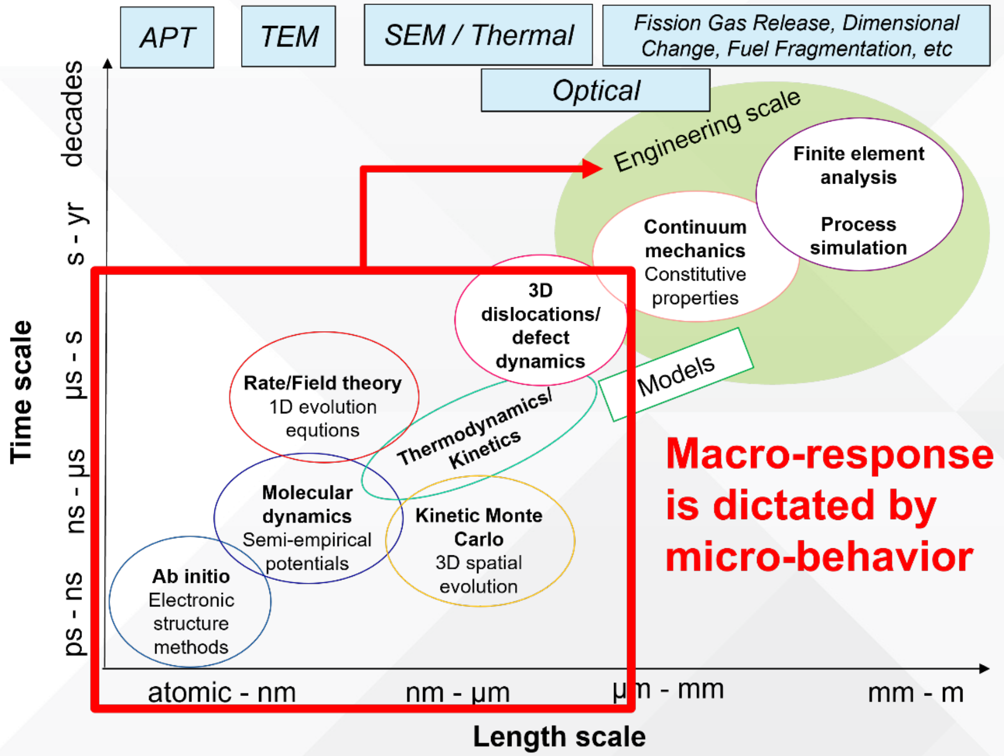
Engineering-scale fuels Post-Irradiation Examinations (PIE)

Fabiola Cappia, Ph.D.

Characterization and Advanced PIE Division

Technological innovation: focus on materials performance

- We need to re-think about science being not only phenomenological investigation
- An opportunity to pursue innovation that enables
  - Increase cost-effectiveness of materials
  - Streamline the use of multiple, correlative investigations to maximize throughput
- Shift into entrepreneurial mindset
  - De-risk new material technologies to anticipate the needs of future deployment areas



Materials science remains your building block

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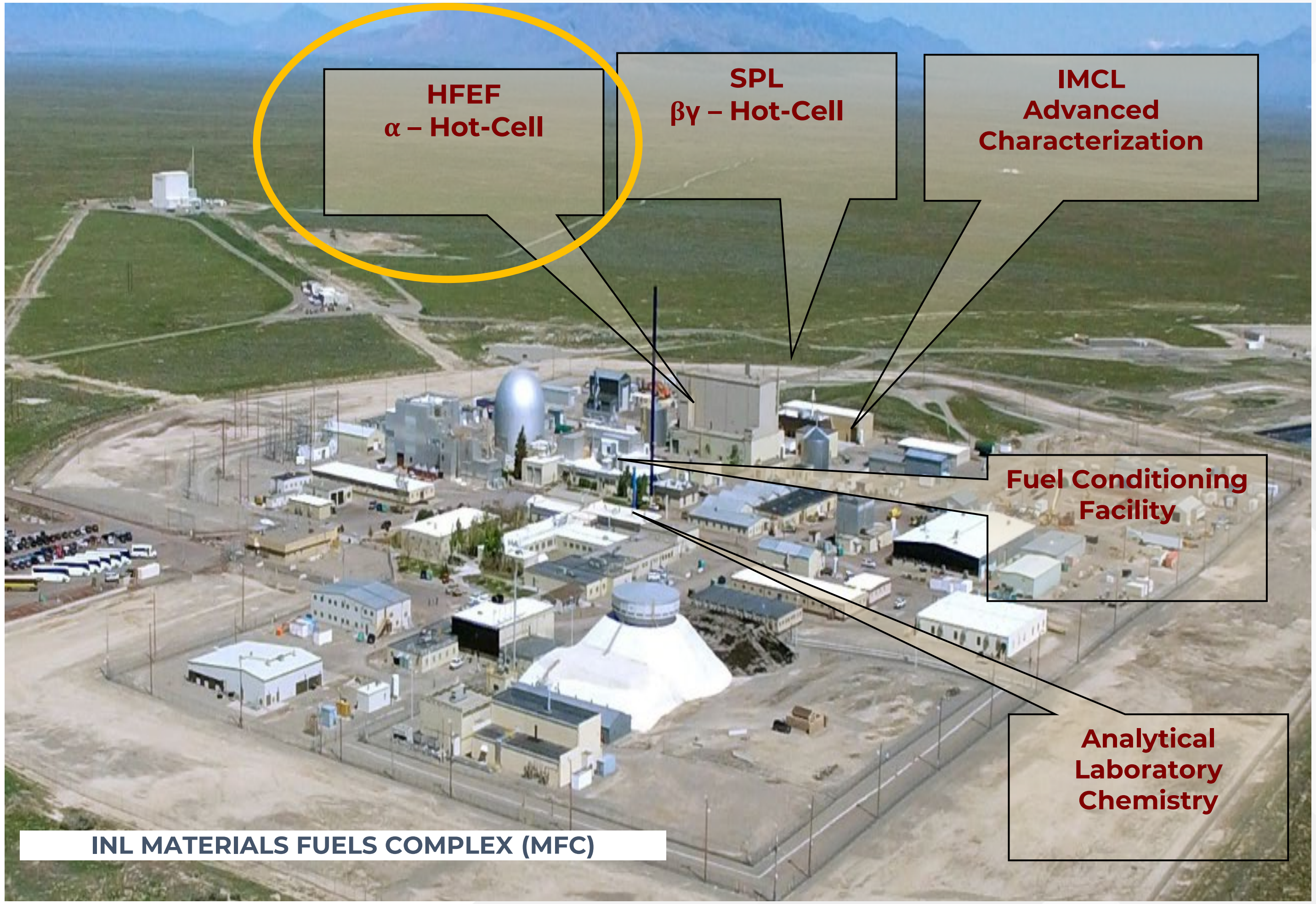
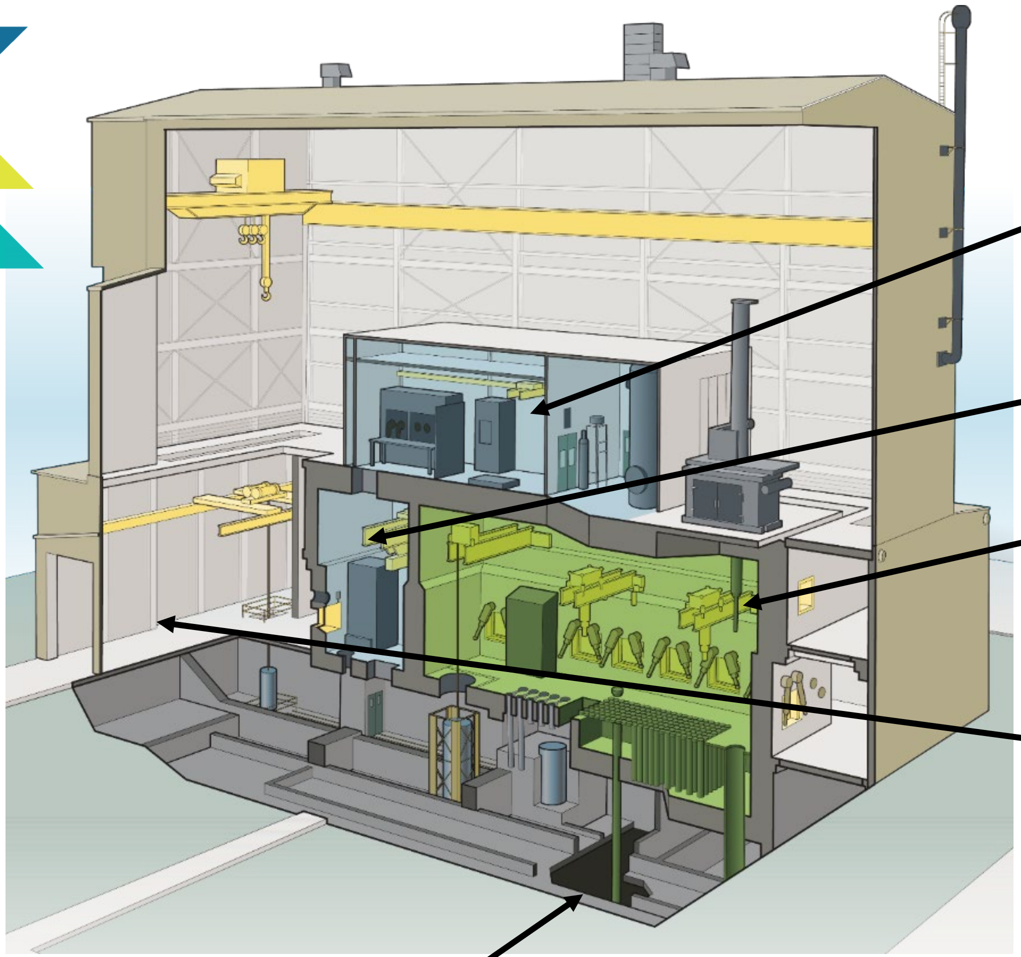
The hotcell system at MFC

- Access to the **integrated irradiation and PIE facilities and capabilities.**
- Expertise across multiple focused area
- Facility Capabilities
  - Engineering Scale Characterization PIE
  - Mechanical Testing PIE
  - Microstructural Phenomenological PIE



HFEF: engineering scale PIE



HRA (experiment receipt, transfer to IMCL/EML, maintenance activities)

Decon cell (air cell)

Main Argon cell

Truck lock area

NRAD reactor (neutron imaging, neutron tomography, irradiation capabilities)

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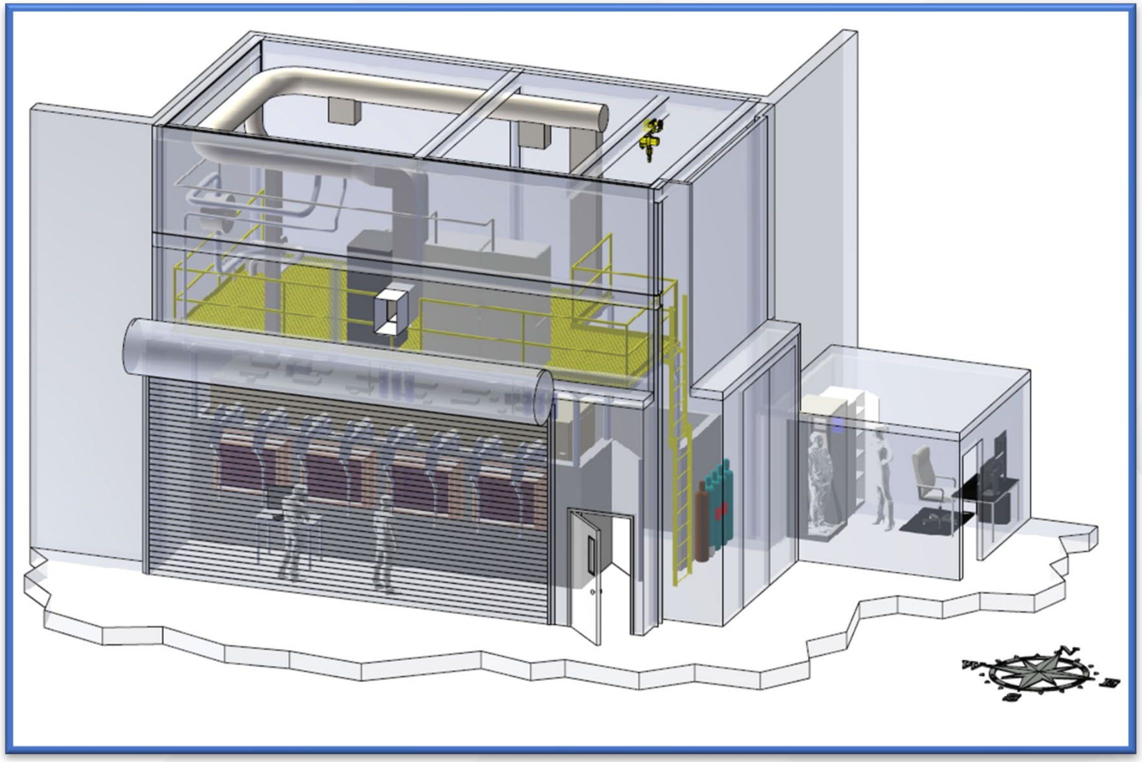
MSTEC

Molten Salt Thermophysical Examination Capability

Toni Karlsson (PI/TPOC) and Carson Stronks (PM)

Overview

- Location
  - MFC, FCF, rm 35
  - Analytical Lab, hot cells, and irradiation facility on same campus
- Compatible Materials
  - Chloride, fluoride salts
  - Fresh fuel salts and irradiated fuel salts
  - Pyrophoric material - U, Pu metal
  - Gases – H_2, HCl, Cl_2, HF, F_2, NF_3
  - Beryllium containing salts
  - Many others
- State-of-the-art, versatile workspace



shielded modular hot cell with an inert argon atmosphere, housing characterization equipment for synthesis and determining thermal/chemical properties of high temperature liquids focusing on but not limited to actinide and irradiated fuel salts

MFC = Materials and Fuels Complex
FCF = Fuels Conditioning Facility

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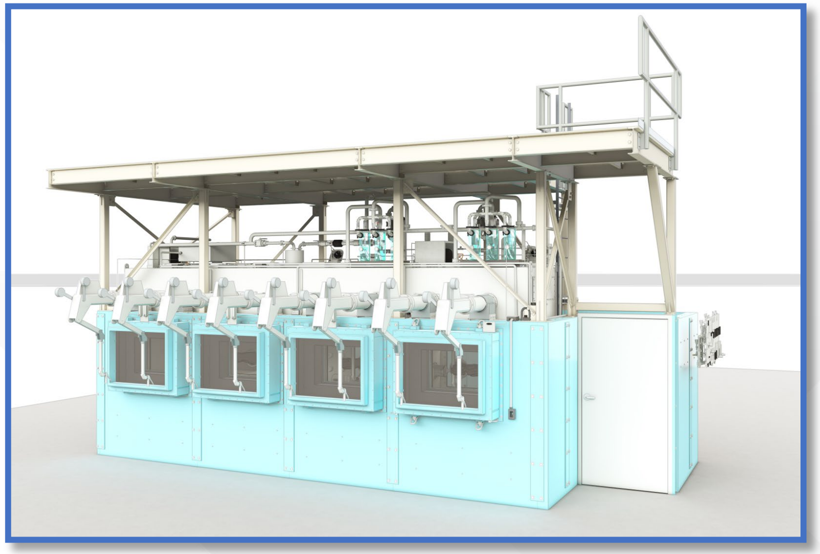
Overview

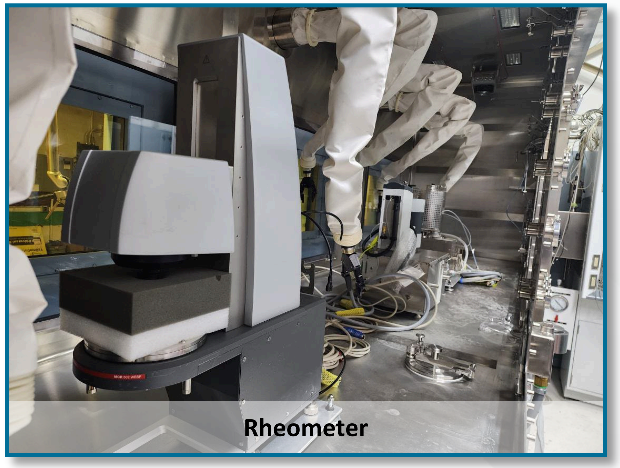
- Experimental examination facility focused on high temperature chemistry
  - 6.5m (length), 1.2m (width), 1.8m (height)
  - Part glovebox, part hot cell
  - Partition wall to separate “clean” from “dirty” side
- Non-Irradiated Salts
  - TRU glove box with 8” glove ports.
  - Connected to a fume hood with small and large transfer chamber
- Irradiated Salts
  - Steel shielding with remote manipulators and leaded glass.
  - Working with irradiated or higher dose materials
  - Cask and French Can connection for transferring irradiated samples
  - Shieled storage compartments

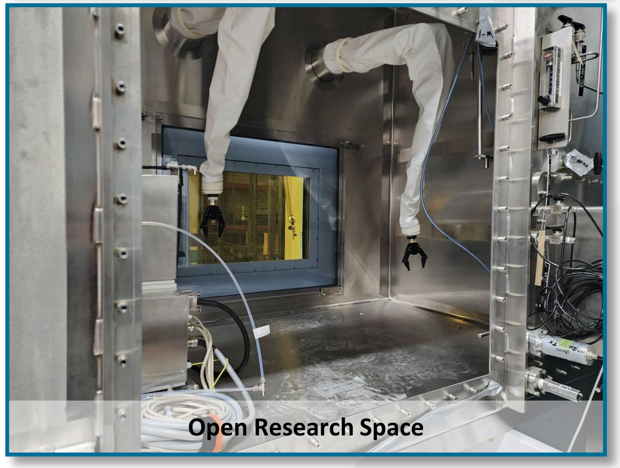


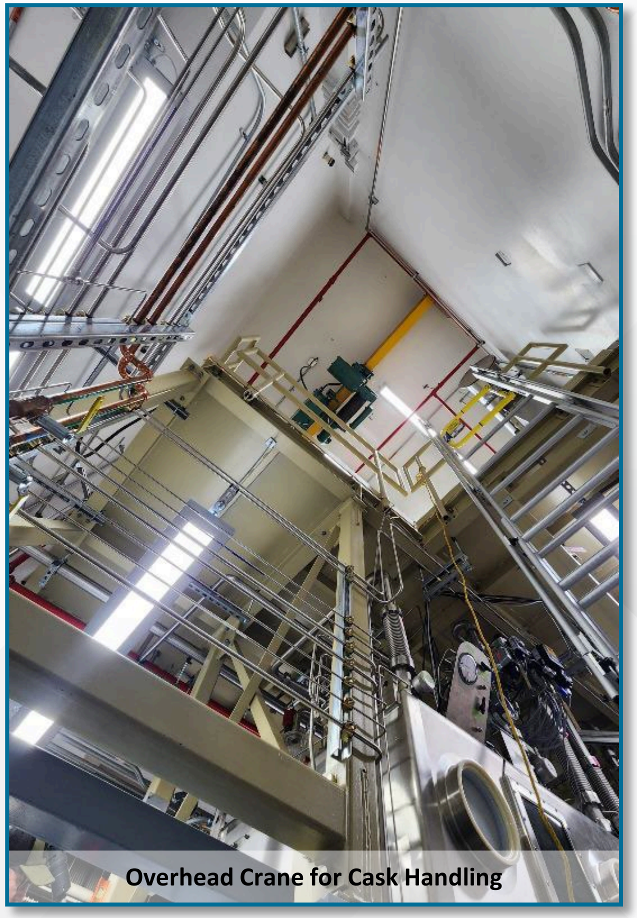
TRU = Transuranic

Overview

- Instrumentation (≥ 1000°C)
  - Rheometer
  - Densitometer/pycnometer
  - Simultaneous Thermal Analyzer (STA)
  - Differential Scanning Calorimeter (DSC)
  - Electrochemistry/Separations
  - Versatile experimental space
  - Synthesis
  - Sample prep equipment
- Not only for MSR related research: fuel cycle, batteries, space fuels, liquid metals fuels/wall material, etc.


Rheometer


Open Research Space


Overhead Crane for Cask Handling

STA = Simultaneous Thermal Analyzer
DSC = Differential Scanning Calorimeter
MSR = Molten Salt Reactor

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INL Creep Testing Capabilities

Boopathy Kombaiah, Materials Scientist, BEA/INL
Ryan Bouffioux, Engineer, BEA/INL

INL Creep Testing Capabilities

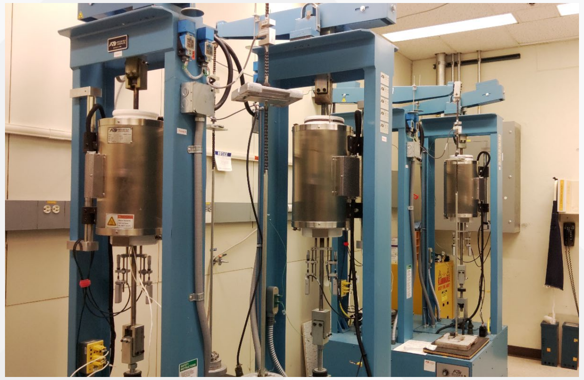
Motivation – Advanced Reactors

- Developing, emerging, and nascent advanced reactor technologies involve new materials, manufacturing methods
- Extreme operating conditions
- In some cases, material service life needs to be defined or reassessed

INL Creep Testing Capabilities

Facilities – INL Research Center (REC-603)

- 20x creep frames studying general creep behavior, notch strengthening
    - Some vintage systems no longer economical to support or upgrade, being evaluated for disposition
    - Multiple obsolete frames already removed to accommodate installation of 4x modern frames
- 2x creep frames equipped for stress relaxation measurements, 1200°C capable
- Creep rupture frames



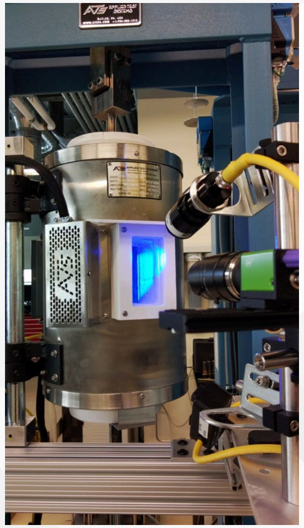
- Research focus: AMMT/ART (gas-cooled reactors, fast reactors, microreactors), concentrated solar, fossil energy

AMMT: Advanced Materials and Manufacturing Technologies
ART: Advanced Reactor Technology

INL Creep Testing Capabilities

Facilities – Energy Innovation Lab

- 8x full-size thermal creep frames
  - Parallel loading capability; digital imaging correlation (DIC) analysis
- 4x additional frames relocated from across INL, in process of installation and commissioning
- 3x subsize creep frames
  - Minimal footprint, easily relocated, rapid setup
- Research focus: AMMT/ART (gas-cooled reactors, fast reactors, microreactors), concentrated solar, fossil energy

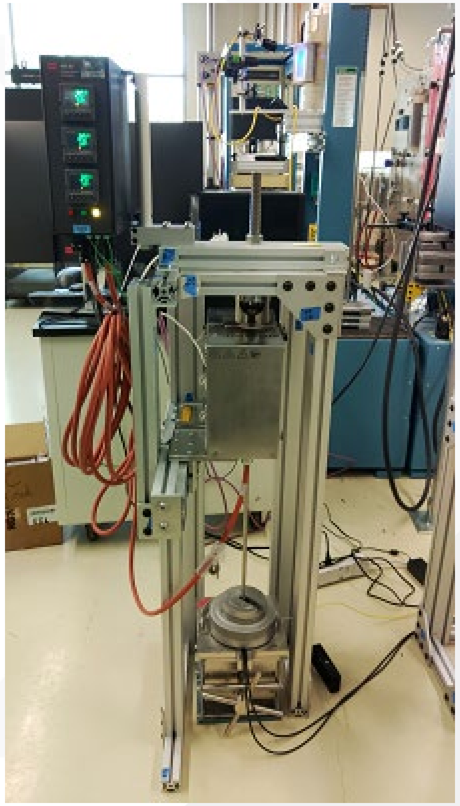


AMMT: Advanced Materials and Manufacturing Technologies
ART: Advanced Reactor Technology

INL Creep Testing Capabilities

Subsize Creep Frames (cont.)

- NRIC-directed work scope
- Developed, built, validated FY20-22
- Currently supporting non-rad testing for AMMT/ART, thousands of hours of accumulated runtime
- Being evaluated for deployment to INL Sample Prep Lab (SPL) Experimental Test Bed (ETB)
  - ETB has lower radiological threshold than typical hot cell: rapid setup, flexible arrangement, easier release/removal



AMMT: Advanced Materials and Manufacturing Technologies
ART: Advanced Reactor Technology

INL Creep Testing Capabilities

Facilities – Materials and Fuels Complex

- 3x full-size thermal creep frames
  - Non-radiological (currently)
  - Air testing to 1000°C
  - 20:1 lever ratio producing up to 10000 lbf load
  - Direct load and automated hot step load capable

- Research focus: DOE Office of Science basic science study of creep behavior in 304L, Ni-base high entropy alloys, and Ni-Re alloys

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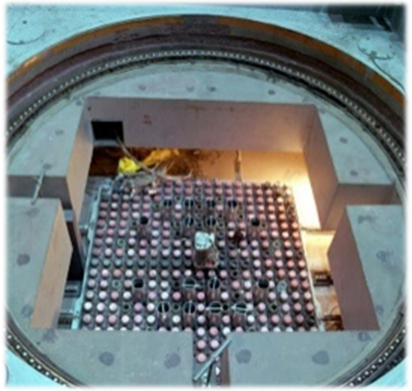
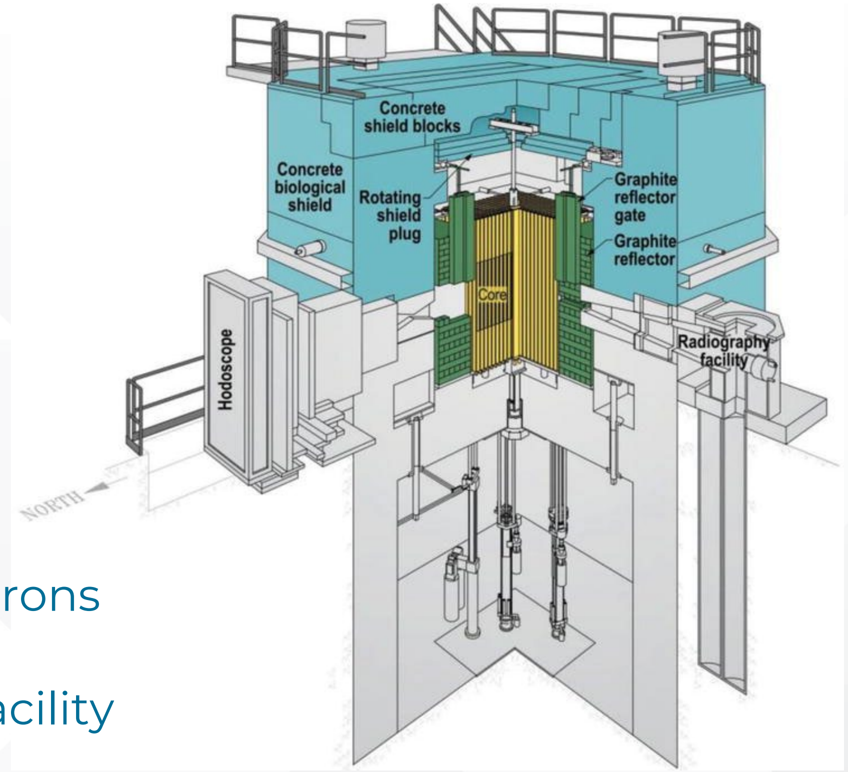
The Transient Reactor Test Facility (TREAT)

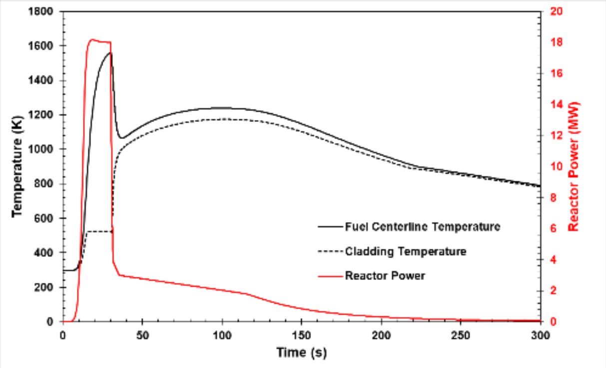
D. Crawford, N. Woolstenhulme



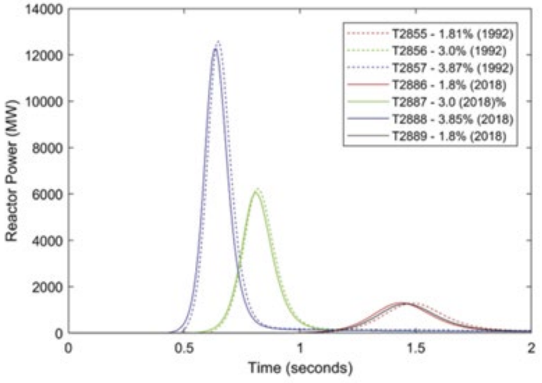
Background on TREAT

- TREAT operated from 1959-1994, later refurbished & resumed operation in 2017 to support fuel safety testing
- Zircaloy-clad graphite/fuel blocks comprise core
  - Virtually any power history possible within ~2000 MJ core transient energy capacity
  - From milliseconds to minutes: Pulses, Ramps, LOCA
- Fuel motion monitoring system “hodoscope” observes fast neutrons emitted from specimens to track fuel relocation in real time
- Reactor also can be a neutron source to adjacent radiography facility
- Experiment vehicle does everything else
  - Safety containment, specimen environment, and instrumentation

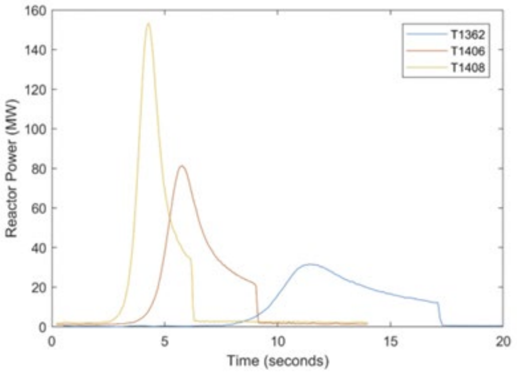




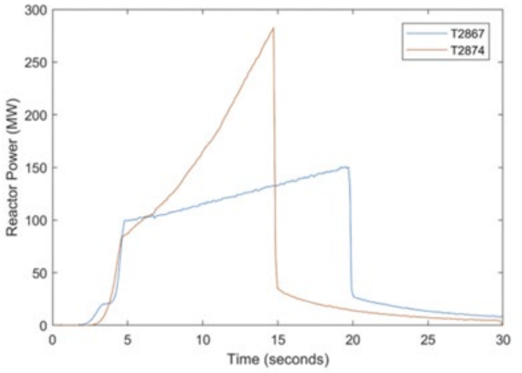
LOCA Shaped Transient



GW-Class Fast Pulses



MW-Class “Slow” Pulses



Overpower Ramps

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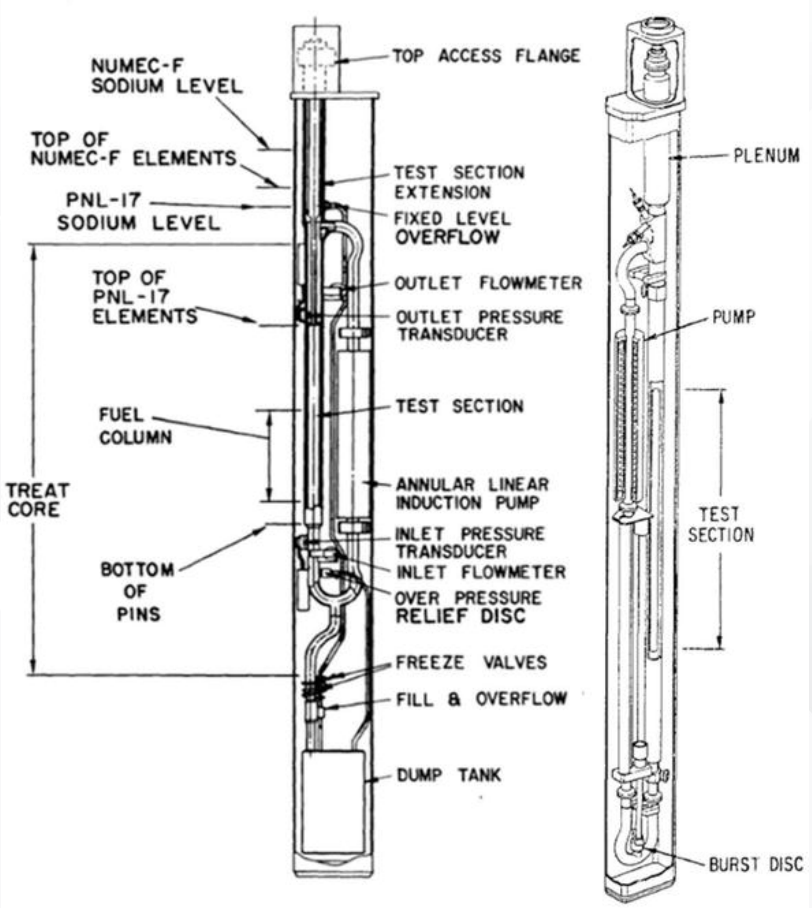
Experiment Design

- TREAT: A concrete-shielded block of graphite with a uranium “impurity”
  - No shielded cubicles or reactor pressure vessel
  - Cooled by air blowers during 80 kW steady state runs, and to cool core down after transients
- Supports one primary experiment at a time, and pivots between missions frequently
  - LWR tests one week, SFR tests the next
- Double-contained package type experiments most successful layout
  - Pre-irradiated specimens assembled into casks at HFEF, transported in casks
  - Electrical service and instrumentation leads connections on top of experiment rig
  - Fresh fuel experiments can be usually be irradiated and examined without using hot cells



TREAT’s Historic “Loop in a box” workhorse sodium loop, the inspiration for most modern TREAT tests

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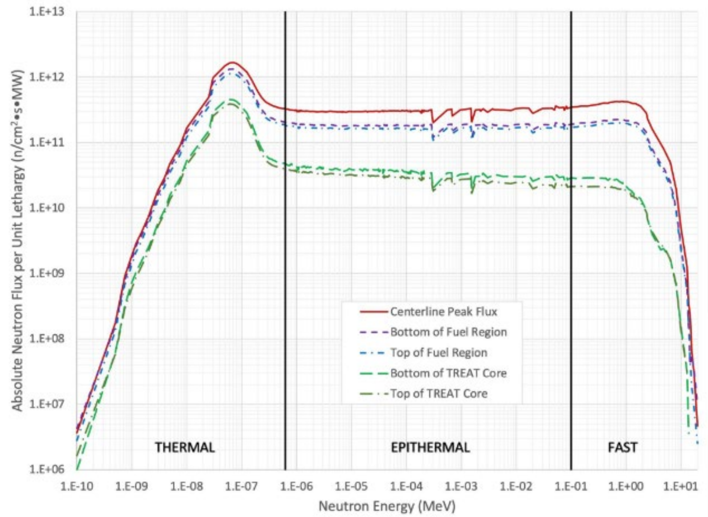
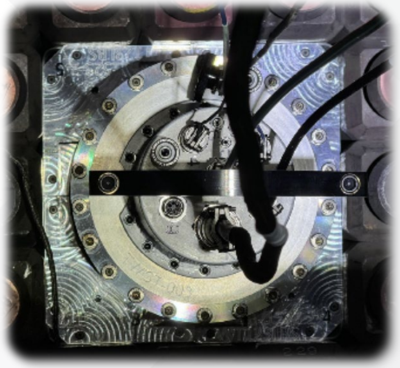
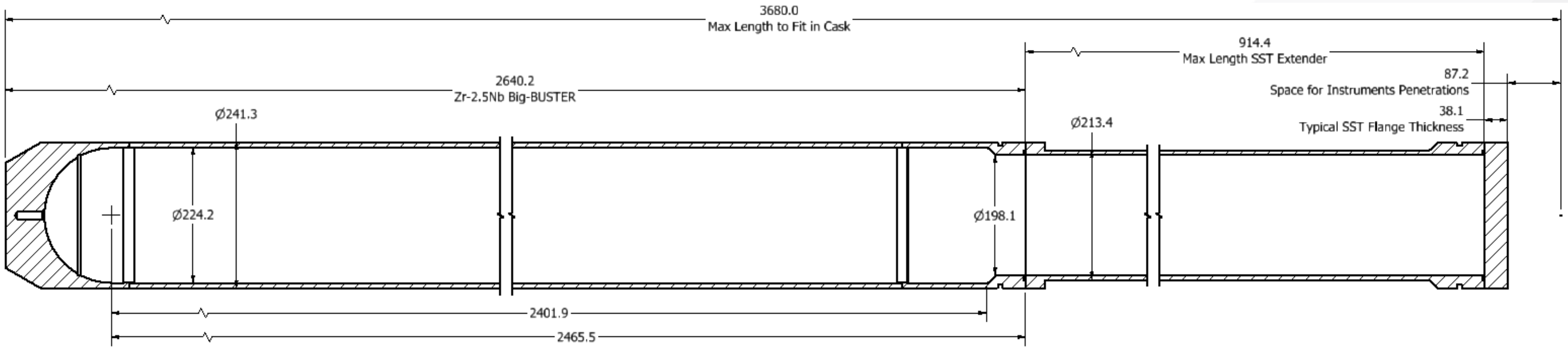
Big-BUSTER

- Enlarged version of the Broad Use Specimen Transient Experiment Rig (Big-BUSTER) developed for modern experiments
  - Reusable nuclear grade outer safety containment, commercial grade inner capsules/loops
  - Large as possible within existing transport casks (shipment between TREAT & HFEF)
  - Graphite moderators and all Zry hardware delivers more, better-thermalized flux to test
    - Max transient fluence ~2.2E16 n/cm^2 (pulse)
  - Maximizes nuclear heating capability in specimens



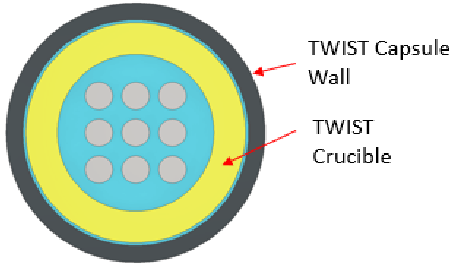


Big-BUSTER in TREAT core

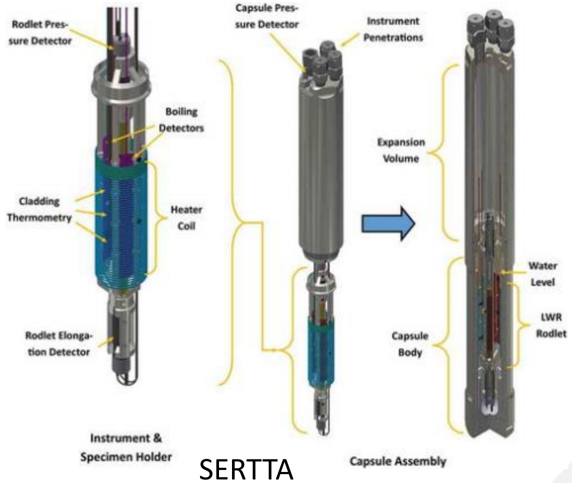


LWR Test Capabilities

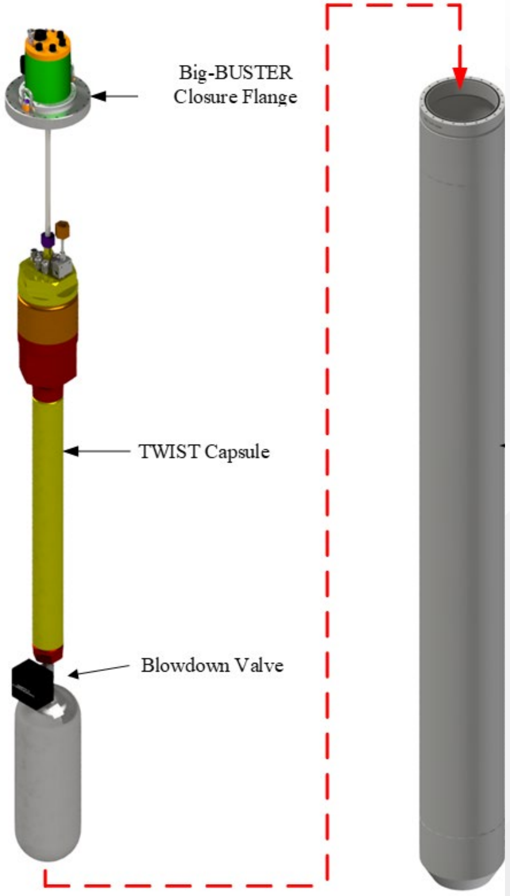
- Existing SERTTA capsule available now for low-cost irradiations
  - Capable of RIA pulses on 10 cm specimens
- Larger TWIST capsule currently undergoing in-reactor commissioning tests
  - Capable of RIA & LOCA , up to 60 cm rods or small bundles
- TWERL water loop (Development underway)
  - Full forced convection for multi-specimen assemblies
- Sensors available to measure temperature, pressure, boiling fraction, & acoustic emission



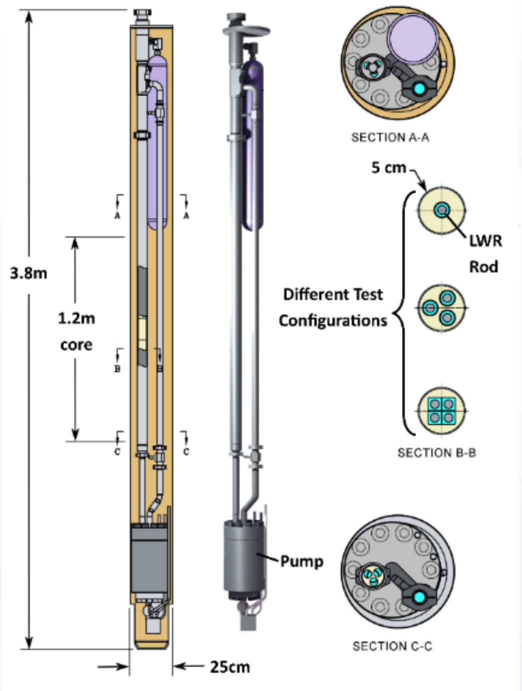
Sketch illustrating 9-rods in TWIST



SERTTA



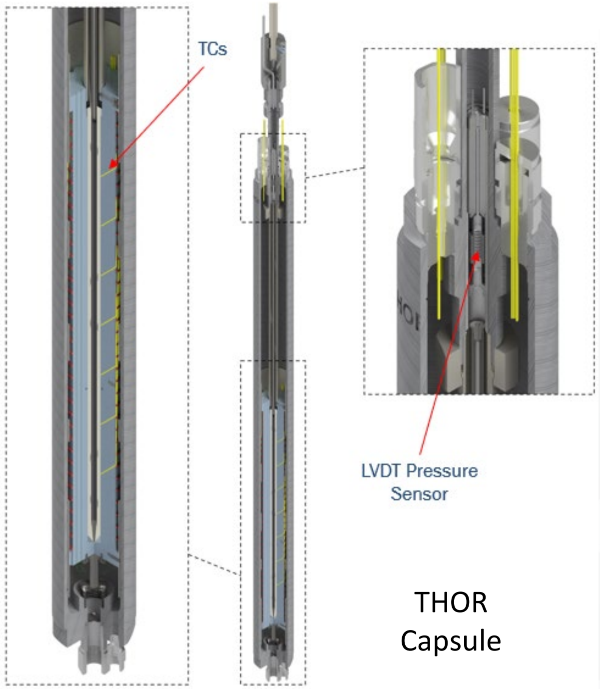
TWIST (LOCA Config)



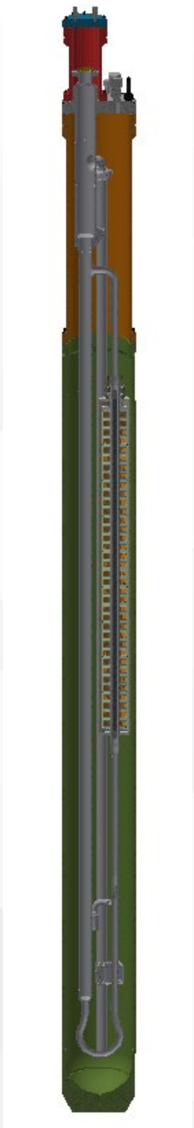
TWERL

SFR Test Capabilities

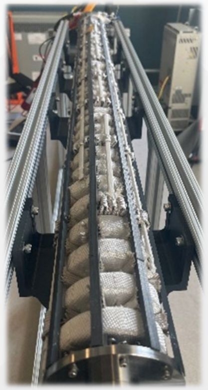
- THOR heat sink sodium capsule
  - Capsule sensors: TC's, LVDT for pressure/elongation, acoustic emission sensor for cladding rupture detection
  - THOR tests have been through a few HFEF-TREAT campaigns, glitches have been worked out, a workhouse capsule for testing single-pin, EBR-II length specimens
- Sodium loop (Mk-IIIR, first deployment late 2025)
  - Forced convection loop provides prototypic thermal hydraulic conditions
  - Loop equipped with coolant temperature, pressure, and flowrate instrumentation
  - Options for 2 or 3 pins in individual flow tubes, or single 7-pin mini-bundle, length capacity for FFTF length pins



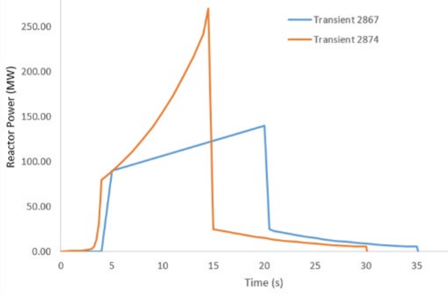
THOR Capsule



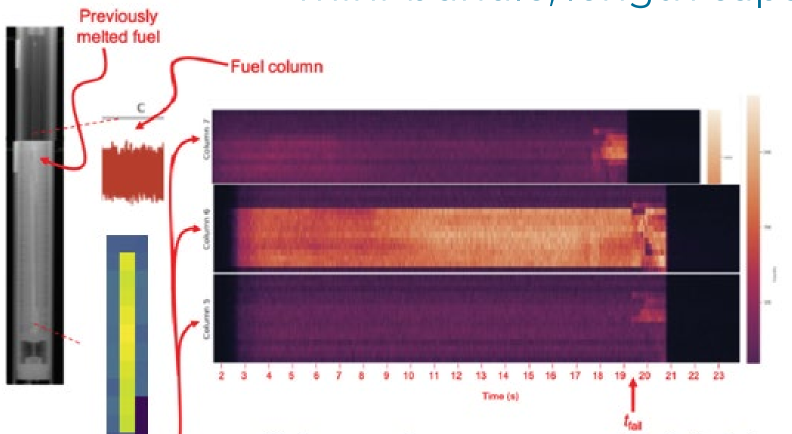
Sodium Loop



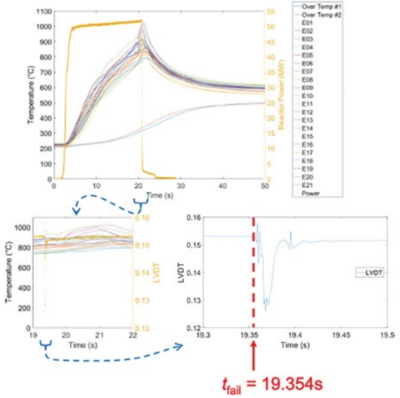
Modernized Induction Pump



Overpower Ramp Transients

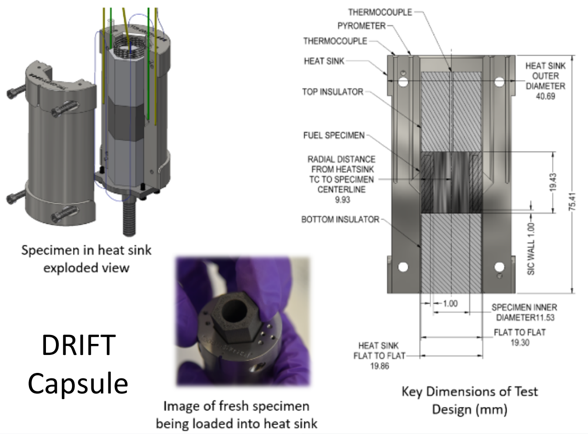


Hodoscope and pressure sensor corroborate fuel pin burst timing just after 19 sec



HTGR and Other Capabilities

- Existing DRIFT Capsule
  - Used for AM SiC TRISO testing under TCR program
- GHOST Capsule (first test early 2025)
  - Helium environment, graphite heat sink, designed for testing TRISO compacts
  - High temperature pre-transient electrical heater
- Existing SIRIUS capsule
  - High temperature capsule with corresponding instrumentation
  - Used for space nuclear propulsion fuels testing to simulate engine startup ramp to power
  - Flowing hydrogen loop to be installed in future
- Molten salt (as coolant or fuel)
  - Loop concepts have been brainstormed, seems feasible
- Other ideas or needs
  - Let us know, there's probably a way to make it work in TREAT

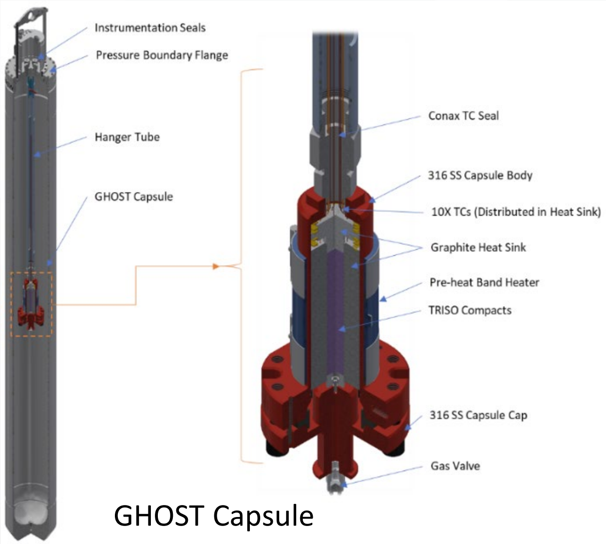


Specimen in heat sink exploded view

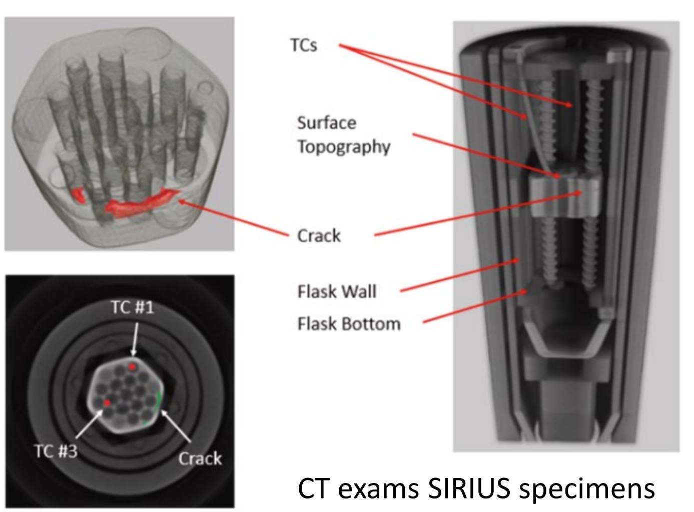
DRIFT Capsule

Image of fresh specimen being loaded into heat sink

Key Dimensions of Test Design (mm)



GHOST Capsule



CT exams SIRIUS specimens

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