INL/MIS-23-75627-Revision-0

Inauguration of the LOCA Blowdown Capsule for TREAT and Updates on Rodlet Re-Instrumentation

December 2023

Klint Stephens Anderson

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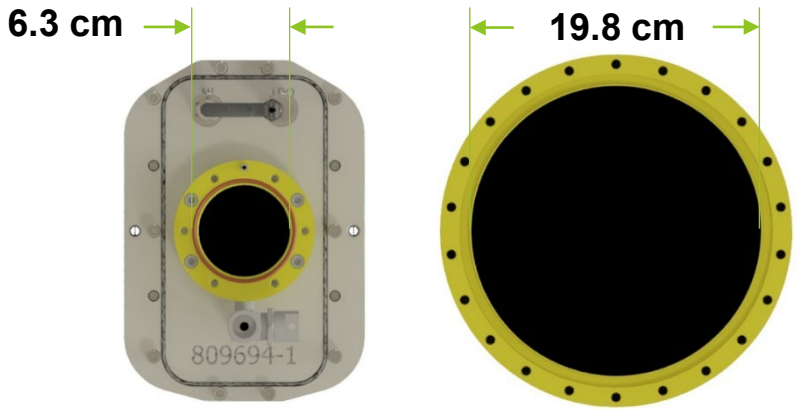
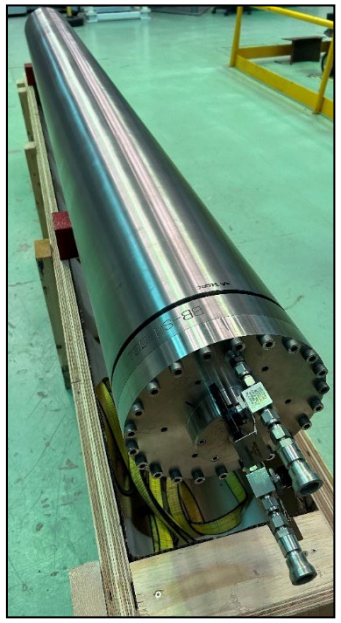
INL Idaho National Laboratory

Transient Reactor Test Facility (TREAT) Large Experiment Capability Upgrade

- Since restart in 2017 – TREAT experiments have utilized a safety containment device called Broad Use Specimen Transient Experiment Rig (BUSTER)
- Long known testing needs would outgrow BUSTER
- Big-BUSTER was conceived ~ 3 years ago
- September 2023: Big-BUSTER is deployed in TREAT to support several current needs
- First deployment for first TWIST experiment



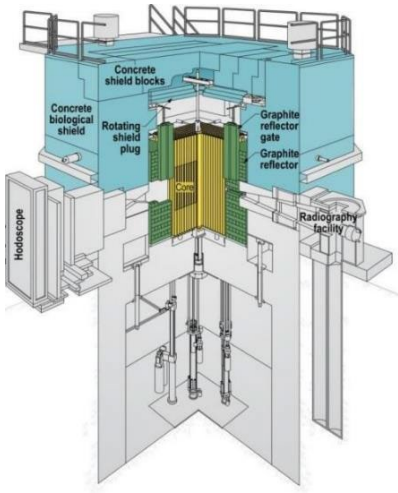
Comparison of Small-BUSTER and Big-BUSTER

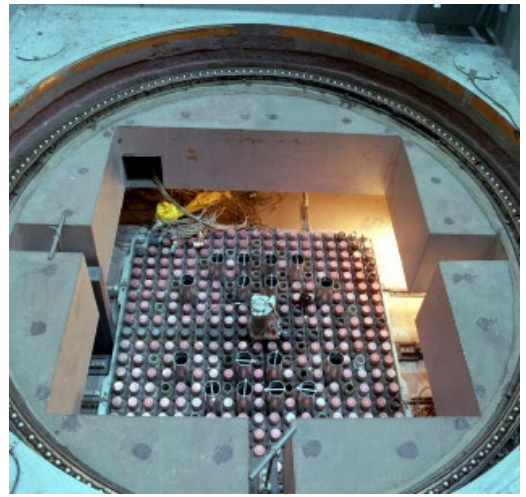


LWR Experiments in Big-BUSTER

SERTTA water capsule

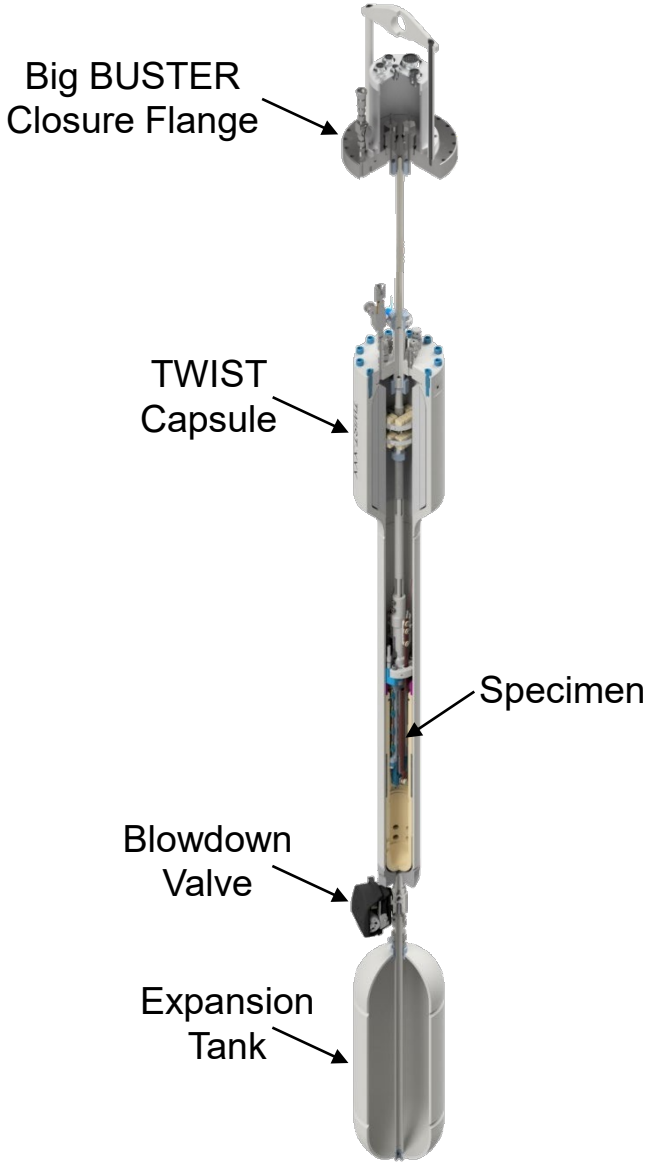
TWIST water blowdown capsule

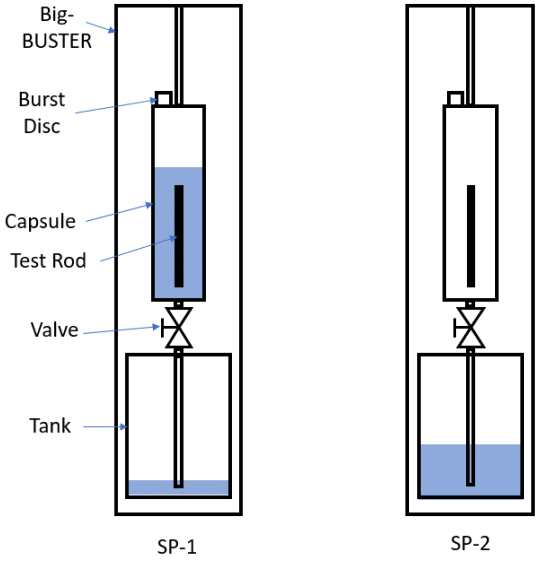


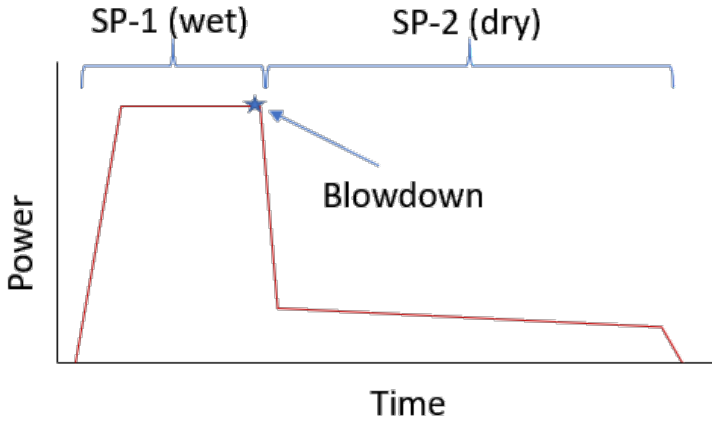


Transient Water Irradiation System for TREAT (TWIST)

- Simulates LWR Loss of Coolant Accidents (LOCA)
- State Point 1 (SP-1)
  - Water in capsule at 20° C and ~ 500 psi (3.4 MPa)
  - ~30 second transient segment ~40MW reactor power
  - Nucleate boiling to achieve LWR fuel temperature state
- State Point 2 (SP-2)
  - Valve opens, water drains in ~2-3 seconds
  - ~100 second transient segment ~5 MW reactor power
  - LOCA “prototypic” specimen temperature rise

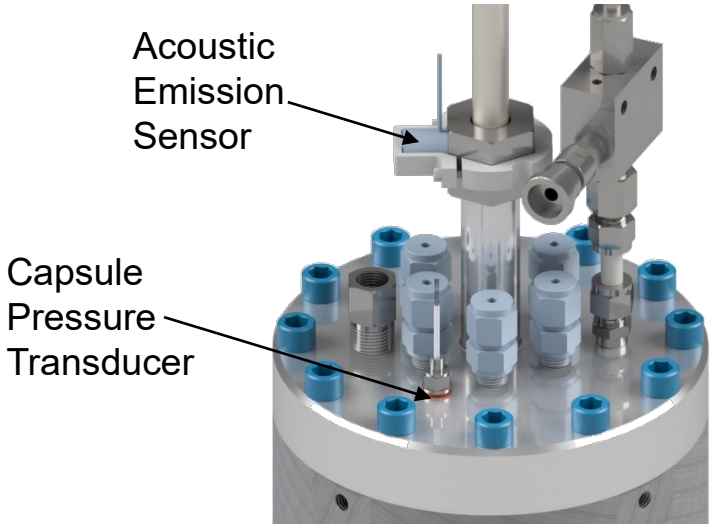


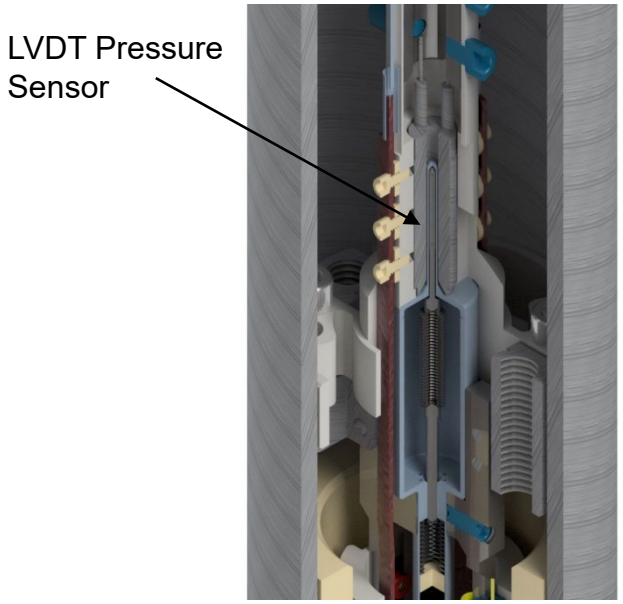


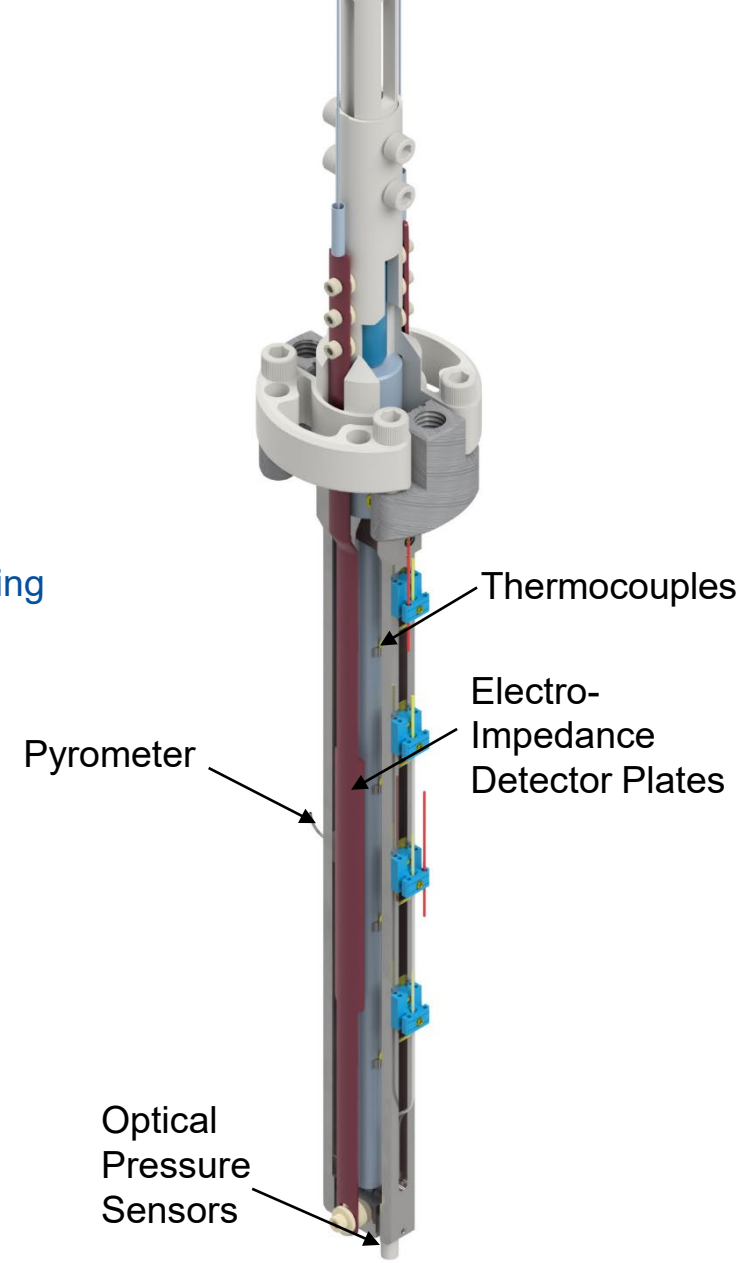


Instrumentation

- Instrumentation Package Includes
  - 6-10 thermocouples measure cladding and water temperature at various axial elevations
  - Thermocouple for centerline fuel temperature or LVDT for rodlet pressure measurements
  - Pressure Transducer for capsule pressure
  - Optical Pyrometer for cladding temperature
  - Fiber Optic Pressure Sensors located inside the capsule
  - Electro-Impedance Detector Plates measure phase change events, water level, and cladding deformation
  - Acoustic Emission Sensor for cladding rupture detection
  - Fuel Motion Monitoring System will observe fuel relocation during the experiment
  - Post Irradiation Radiography will be performed with little movement of the device



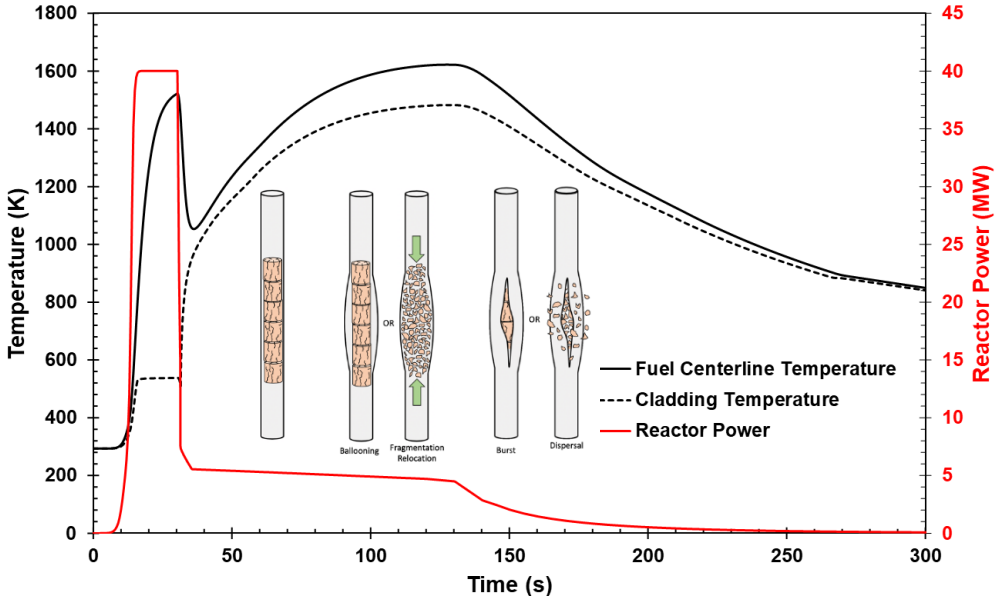




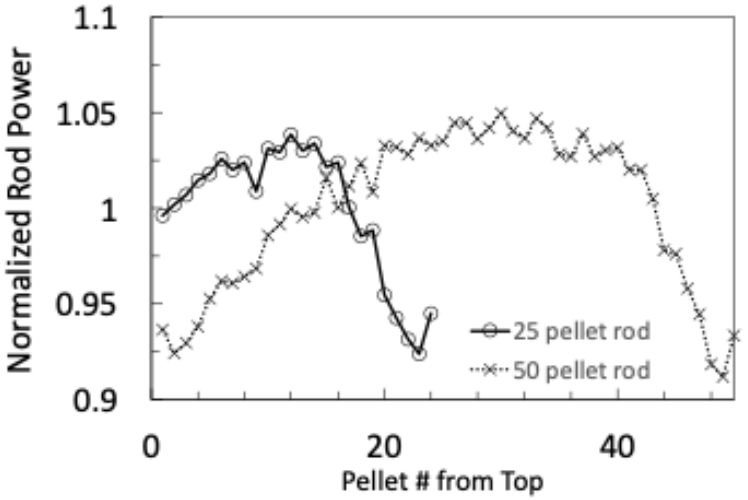
Experiment Performance

- Designed to incorporate rodlets with up to 50 cm fueled lengths
  - Two rodlet lengths will be tested
- The design was optimized to be prototypic of PWR LOCA conditions

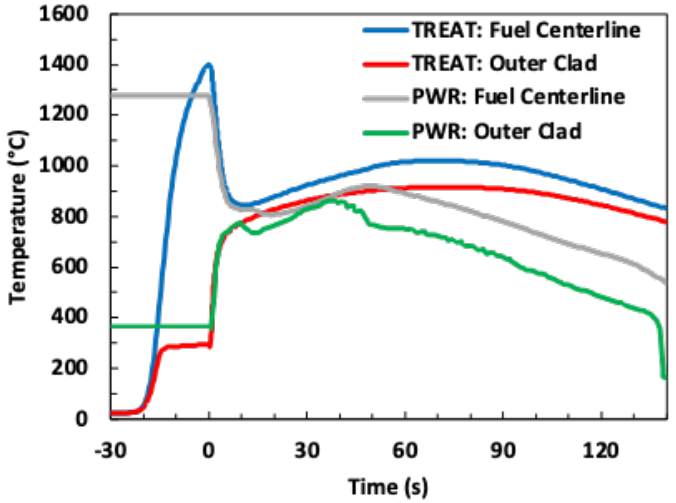
Example Transient Design



Axial Power Distribution



Temperature Comparison of TWIST and PWR LOCA



Long Rodlet Configuration

Extreme case calculated (RELAP) for HBU fuel to determine TREAT capability, lower power/temperature transients to be used for typical UO_2-Zry fuel rod testing

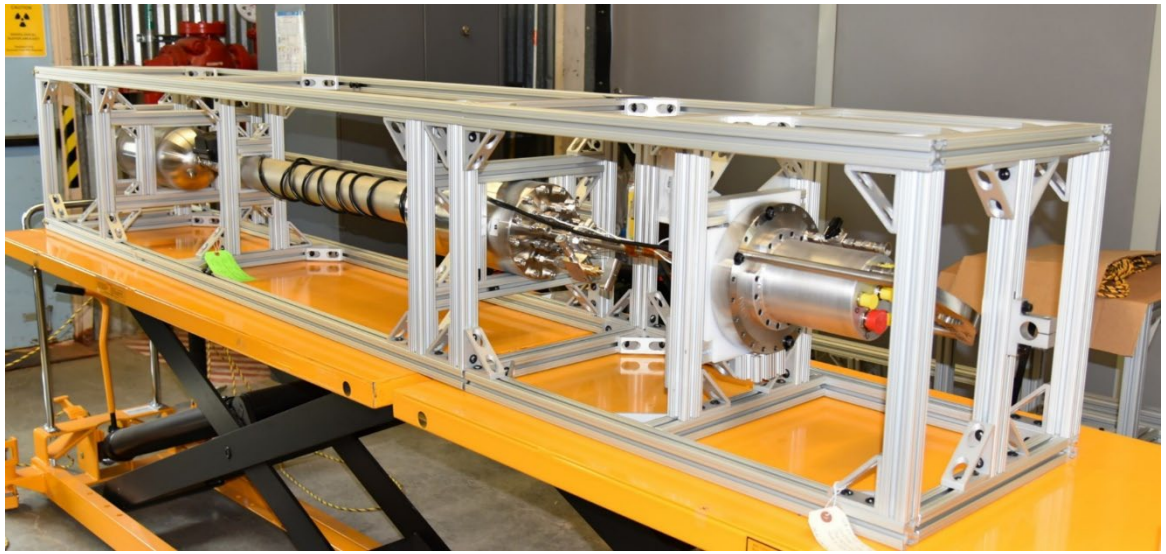
TREAT LOC-Commissioning (LOC-C) Test Matrix

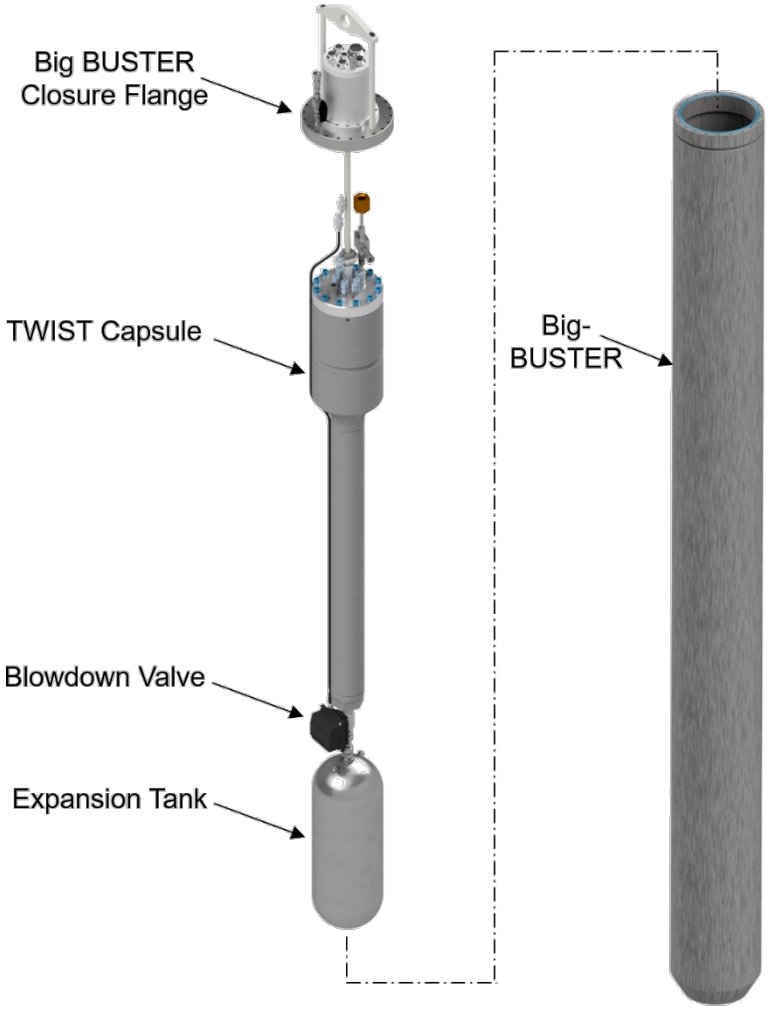
- Fresh fuel tests to establish/demonstrate/qualify complete experimental system for LOCA testing in TREAT
- Characterize fuel power, thermal-hydraulic conditions, and instrumentation performance
- Useful for initial modeling "benchmarks”

Test ID	Fuel Length (cm)	Rod Free Volume (cc)	Rod Internal Pressure (MPa)	Peak Cladding Temperature (K)	Purpose
LOC-C-1A & B	25	15	0.1	520	Fuel power validation – core configuration 1, instrumentation qualification
LOC-C-2	25	15	0.1	1173	Fuel power validation – core configuration 2, instrumentation qualification
LOC-C-3-A thru E	25	15	0.1	520-1373	Thermal hydraulic validation, instrumentation qualification
LOC-C-4	25	15	~12	1173	Full LOCA simulation with pressurized rod, instrumentation qualification
LOC-C-5	50	15	~12	1273	Long rod, full LOCA simulation with pressurized rod, instrumentation qualification

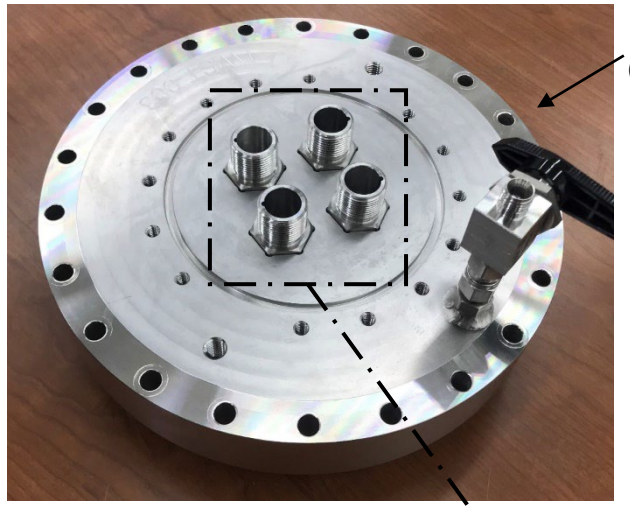
Completed Work

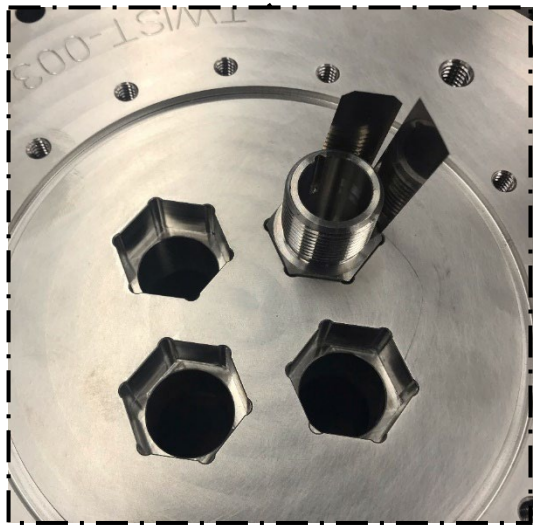
- Inauguration of the LOCA blowdown capsule for TREAT
  - Completed fabrication, assembly, and irradiation of the first experiment utilizing the TWIST capsule (LOC-C-1), requiring the deployment of the Big-BUSTER test device in TREAT
  - Completed the assembly of the LOC-C-2 experiment
  - The size of the TWIST capsule required coordination between multiple INL facilities all working in parallel
  - The inauguration of the TWIST capsule restores LOCA safety testing capability to the United States





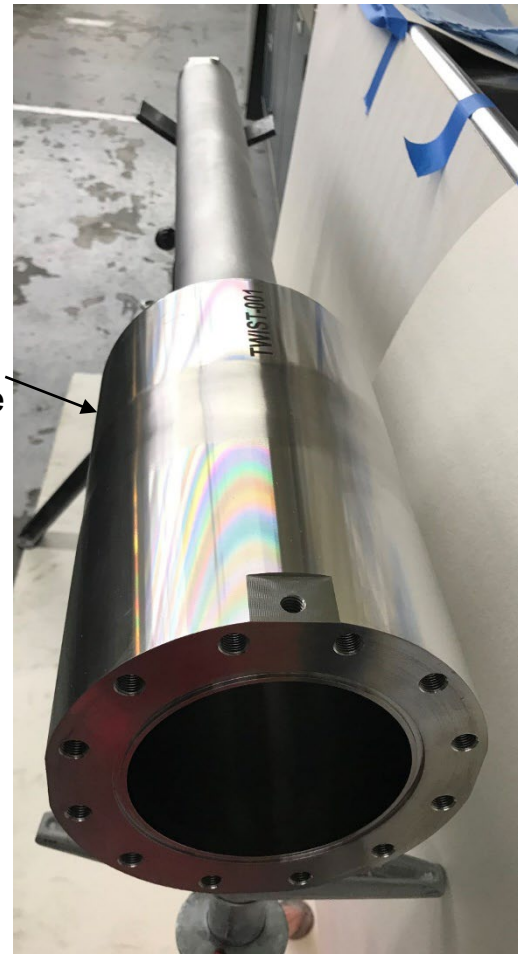
Component Fabrication





Big BUSTER
Closure Flange

TWIST
Capsule

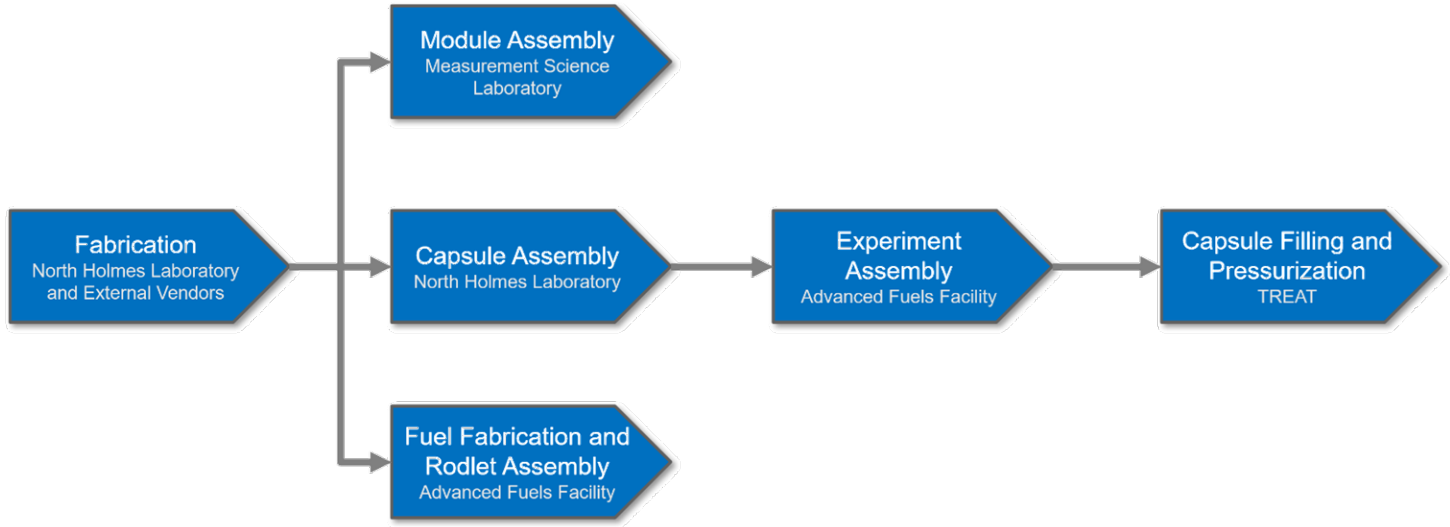


Capsule Filler Pieces

Specimen Holder Support

Examination and Testing

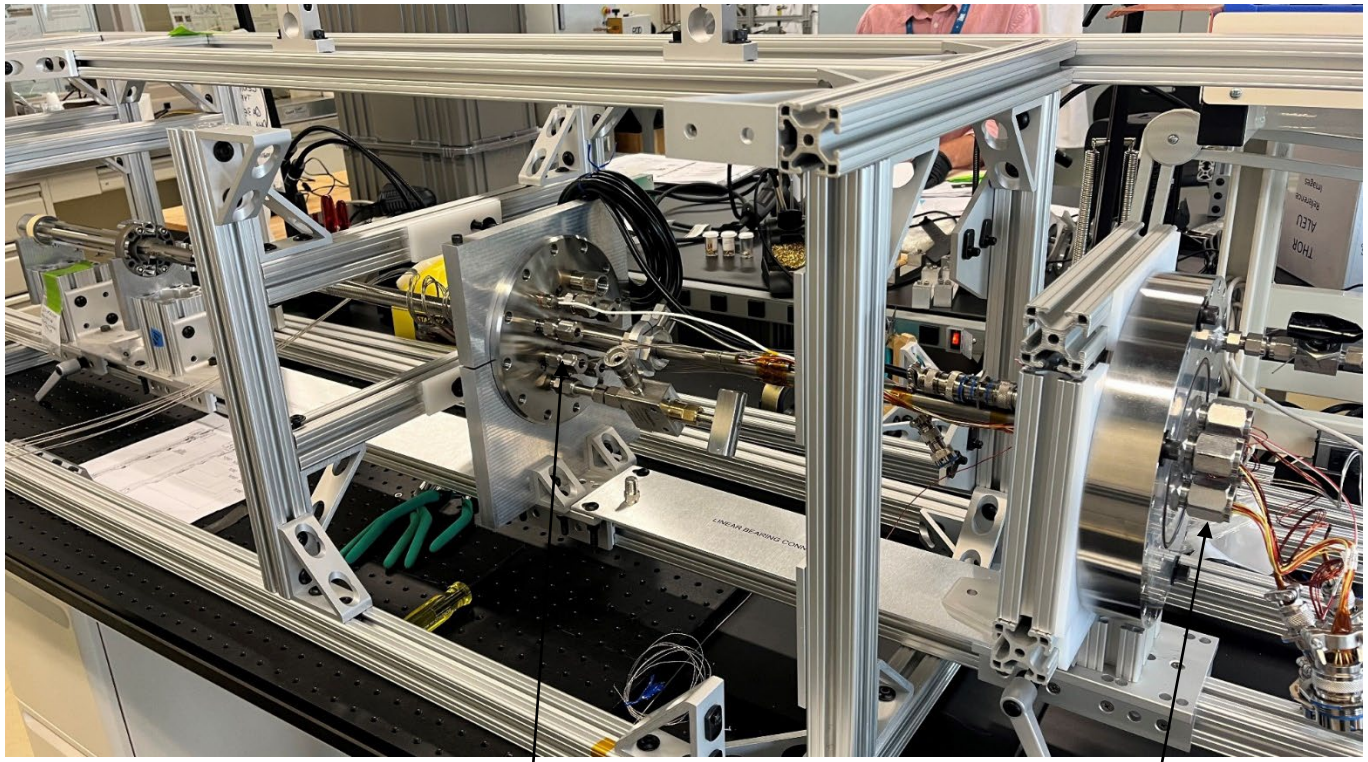
- Components were fabricated at internal INL machine shops and by external vendors
- Following fabrication, components were inspected, examined, and pressure tested at INL North Holmes Lab (NHL) prior to assembly



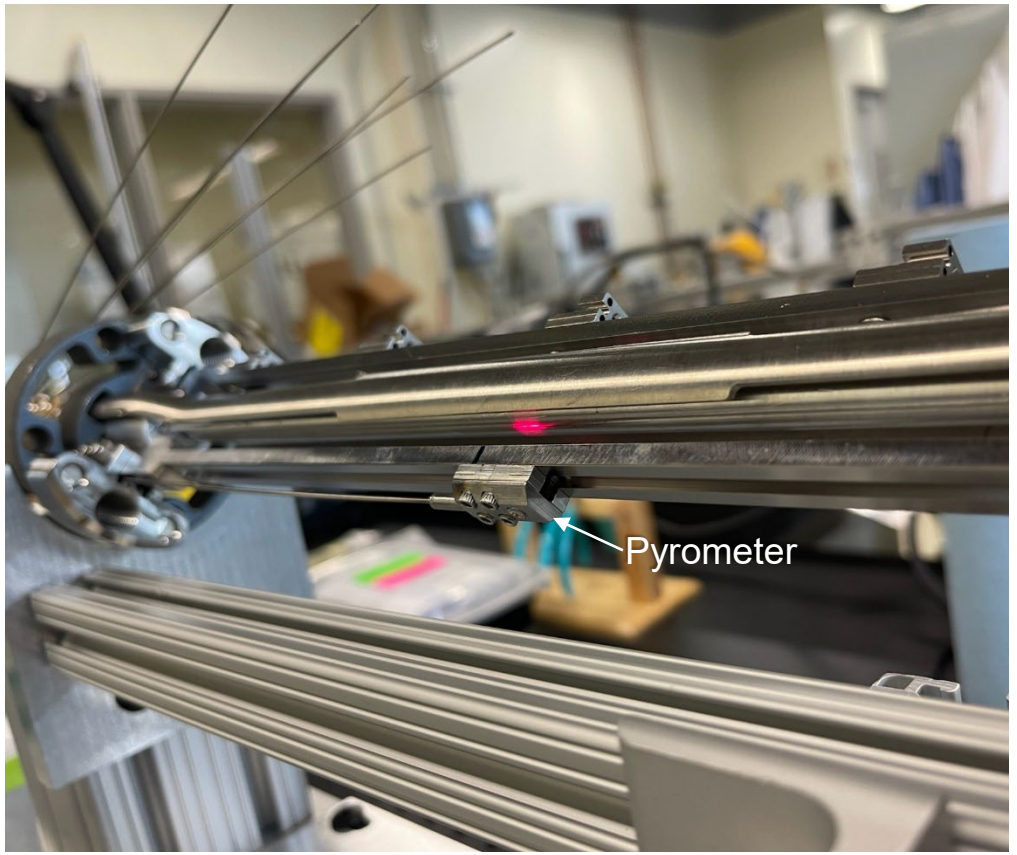
Capsule and expansion tank assembly

Module Assembly

- Specimen holder module and instrumentation assembled, tested, and calibrated at the INL Measurement Science Laboratory (MSL)



Compression Seal Fittings on the Capsule and Big-BUSTER Flange

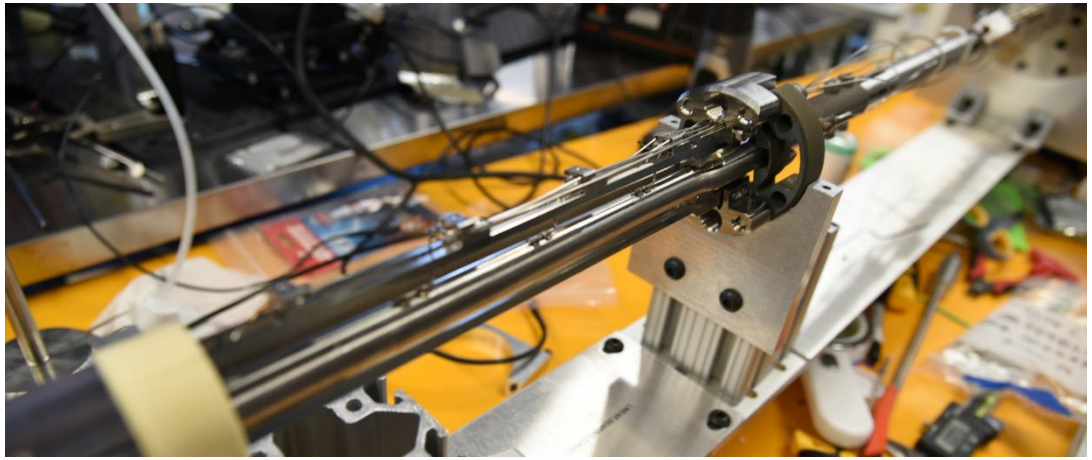


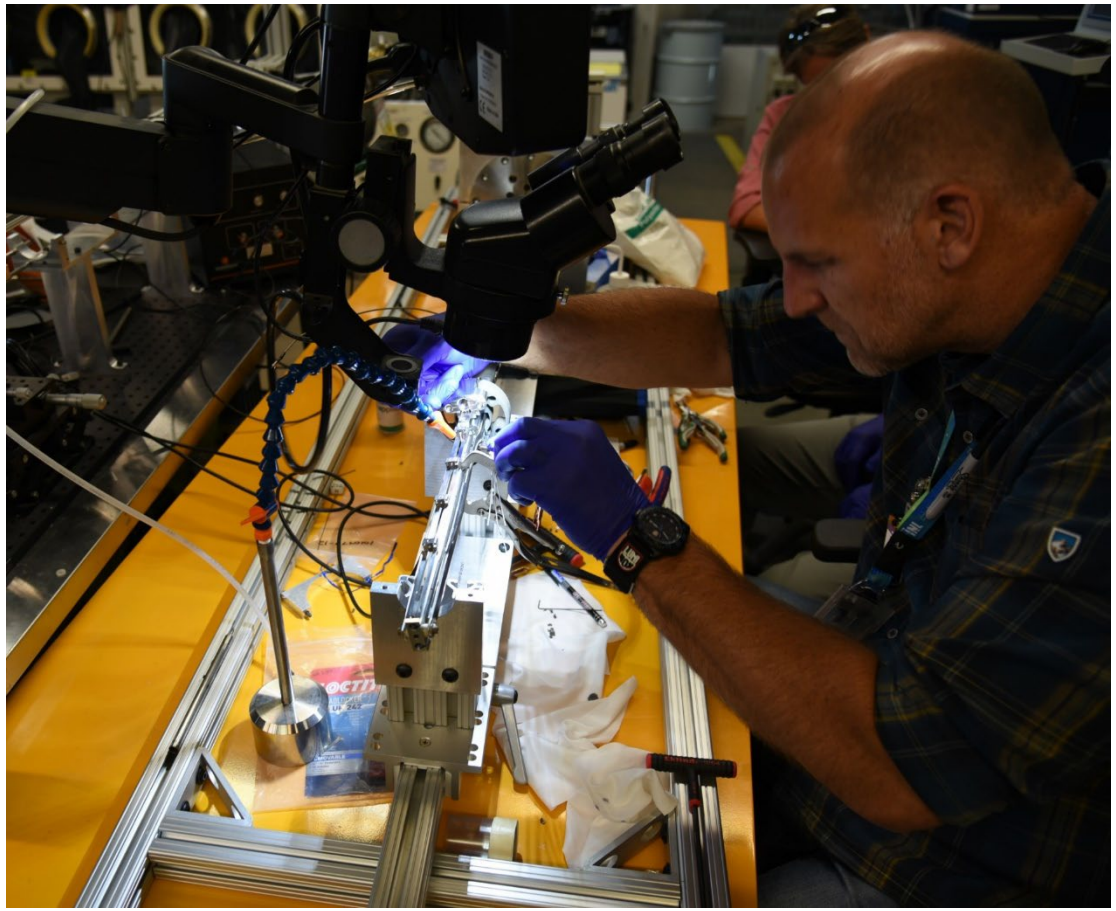
Final Assembly

- The module and capsule assembly were delivered to the INL Advanced Fuels Facility (AFF) for final assembly
- Aluminum frame served as an assembly fixture, shipping crate, and upending stand

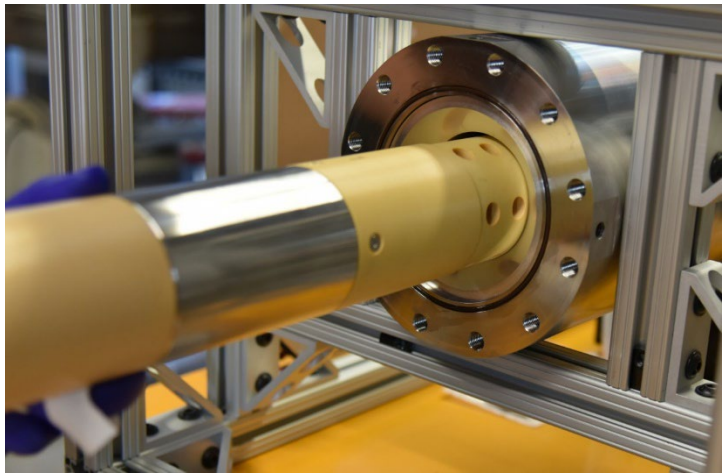
Fuel Rodlet Assembly

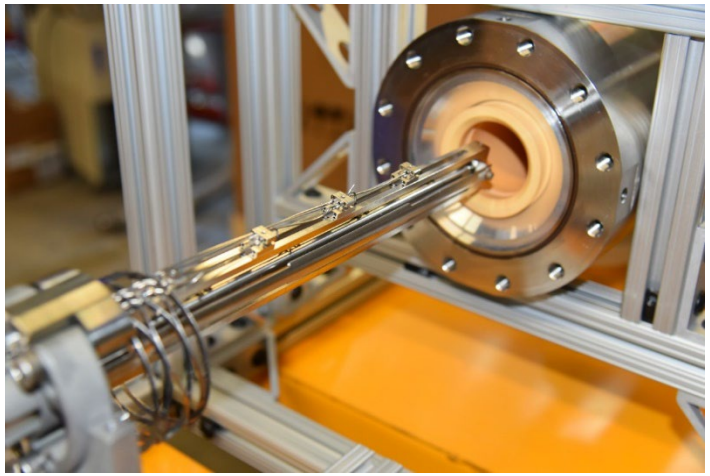
- At AFF the rodlet was assembled, loaded into the module, and thermocouples were secured to the cladding using zircaloy weld clips

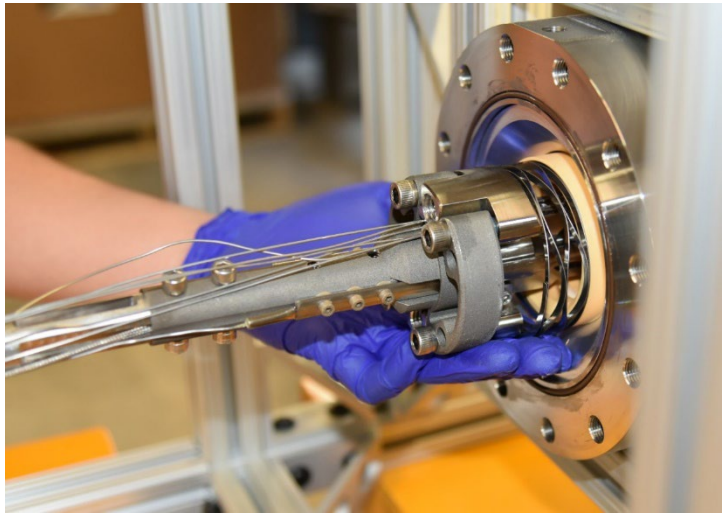


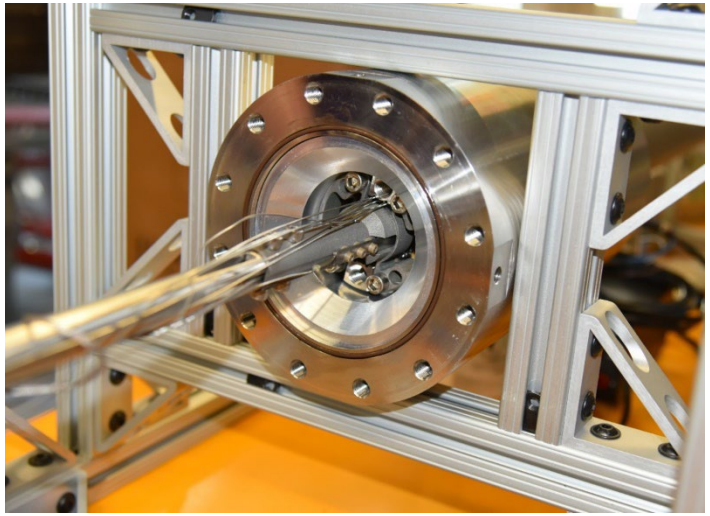


Experiment Assembly



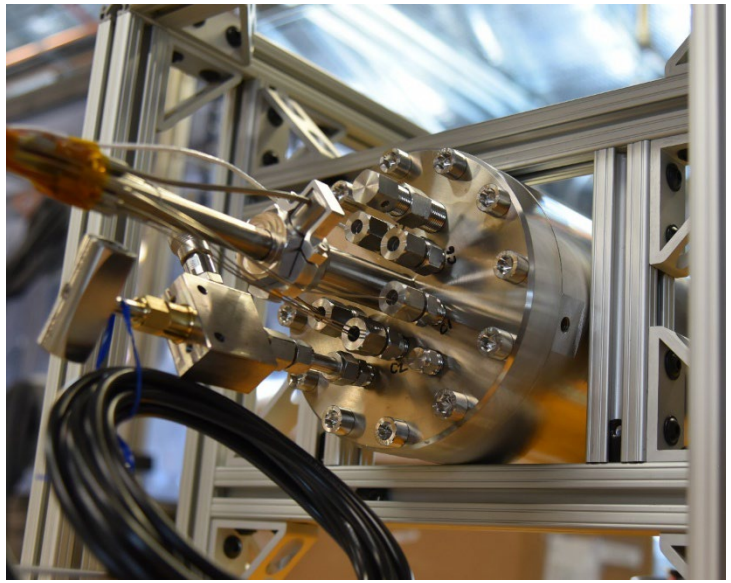






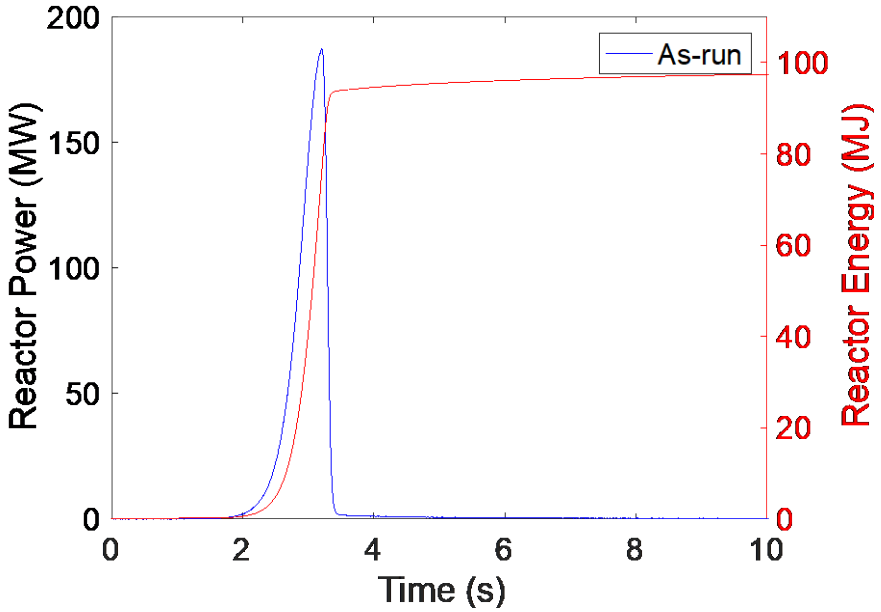
Final Assembly and TREAT

- The TWIST experiment assembly was completed at TREAT
  - The capsule was filled with water and pressurized to 500 psi (3.4 MPa)
  - after an argon purge
  - Capsule leak check and installation in Big-BUSTER
  - Big-BUSTER leak check passed with Viton sealants

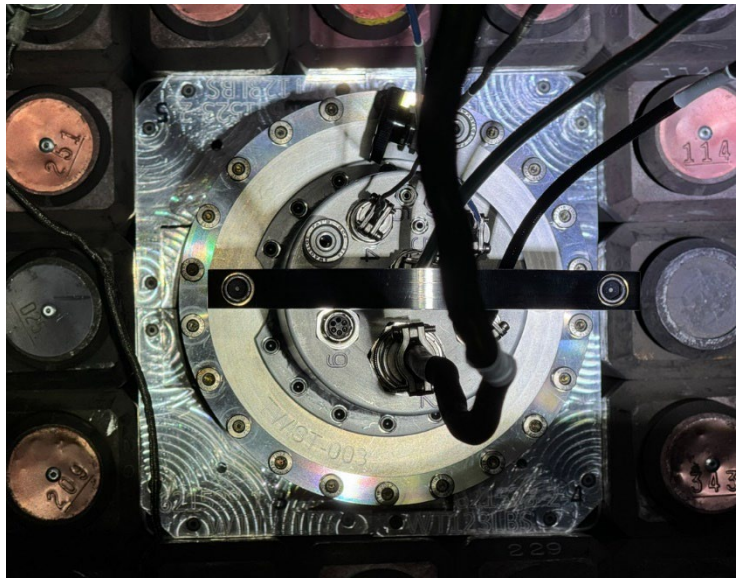


LOC-C-1A Transient

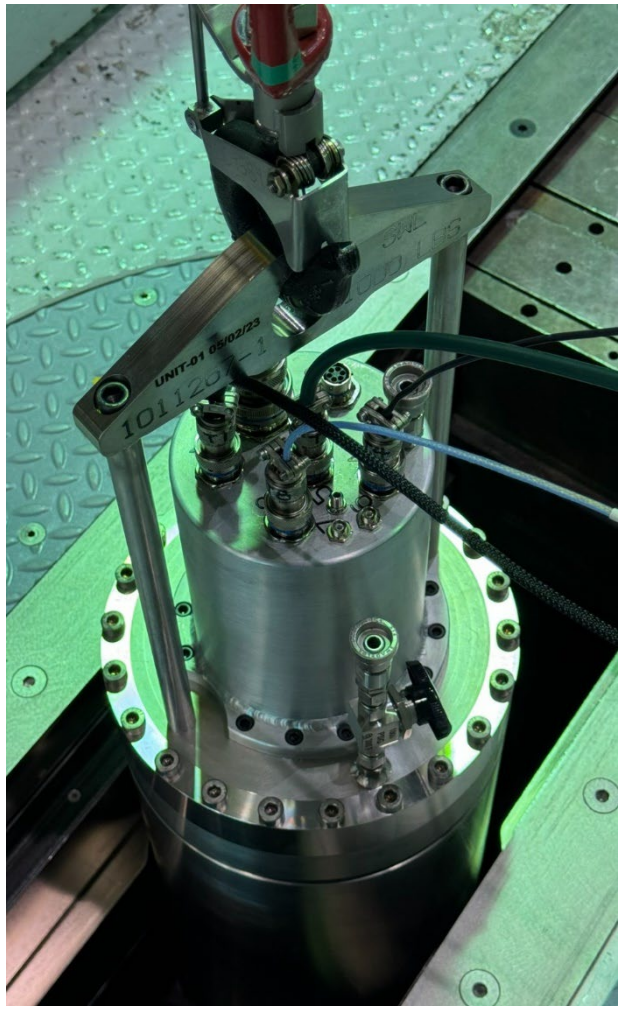
- Completed the fabrication, assembly, and first commissioning test of the TWIST device
- LOC-C-1A Transient
  - Total Energy: 100 MJ
  - Peak Power: 189 MW



LOC-C-1A Reactor Power History



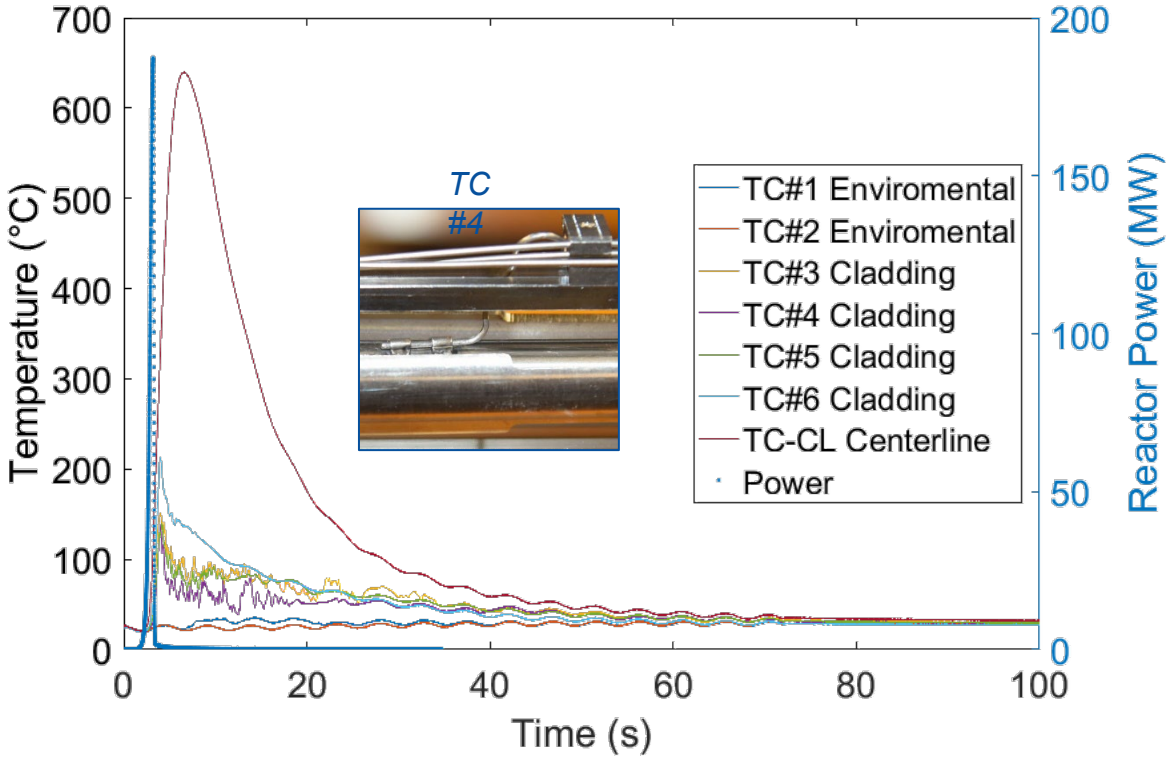
TWIST in TREAT Core Reconfigured for Big-BUSTER

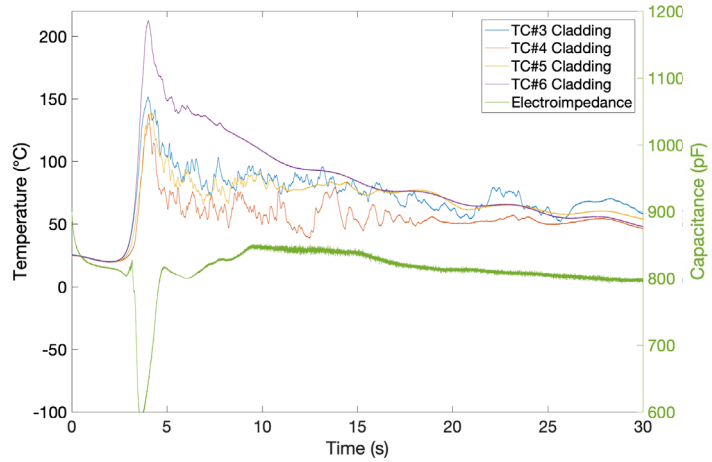


TWIST Installation into TREAT Core

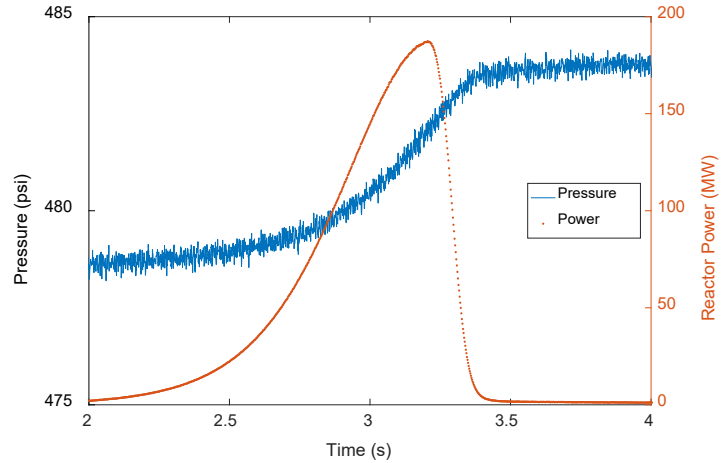
LOC-C-1A Results

- Peak measured centerline T: 640ºC
- Cladding surface T: 213ºC





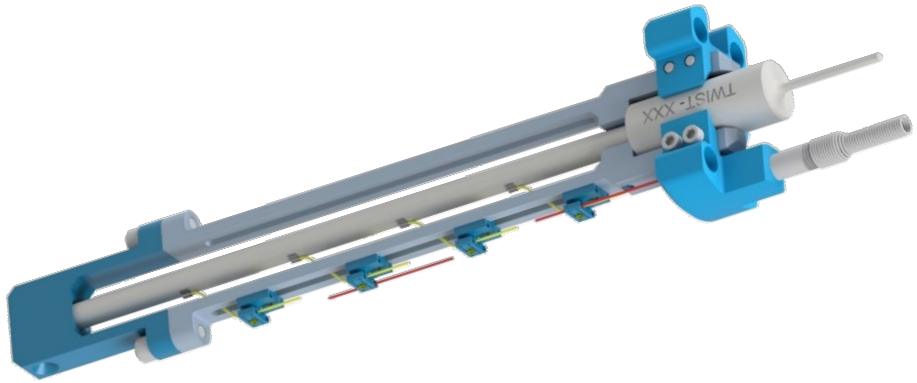
- Electroimpedence Sensor to be used for water phase change, level detection and cladding deformation sensing
  - C-1A only produced coolant phase change, signal corresponds well with cladding TC data

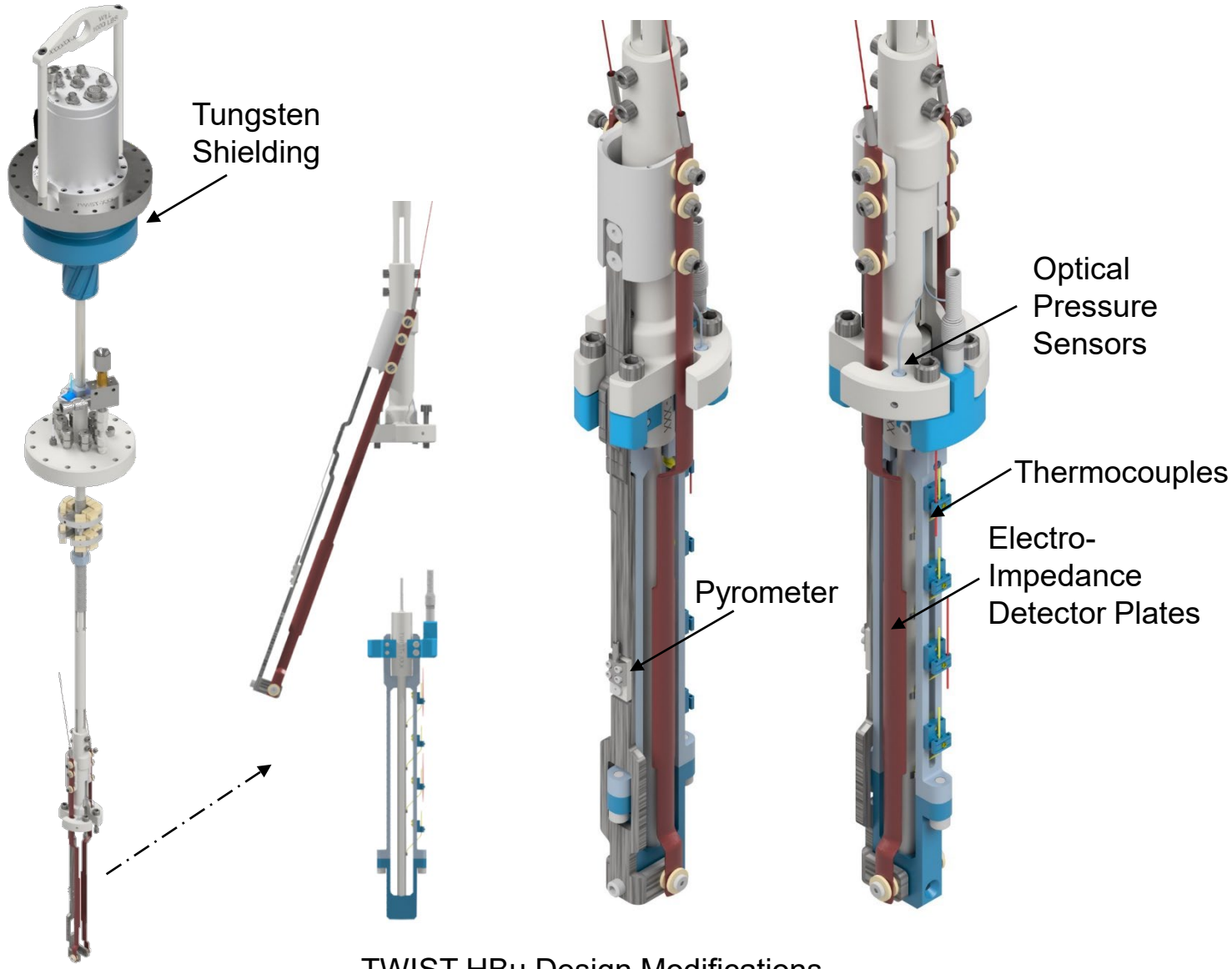


- Off-the-shelf capsule pressure sensor shows promising irradiation resistance
  - Likely some minimal thermal effect

Next steps

- Additional tests making up the TWIST commissioning series will be completed this fiscal year
- Design modifications of internal components for assembly in HFEF with High-Burnup (HBu) fuel is currently being finalized

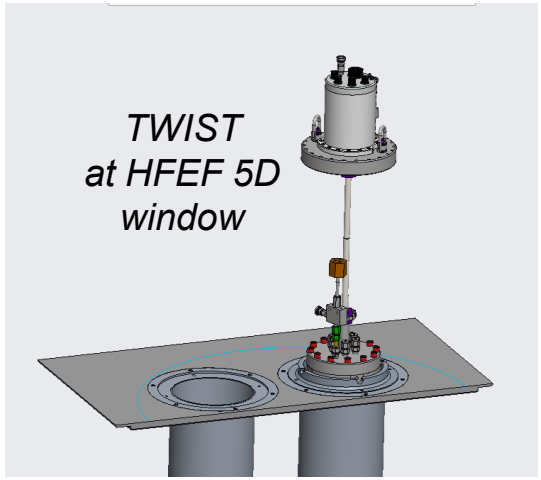




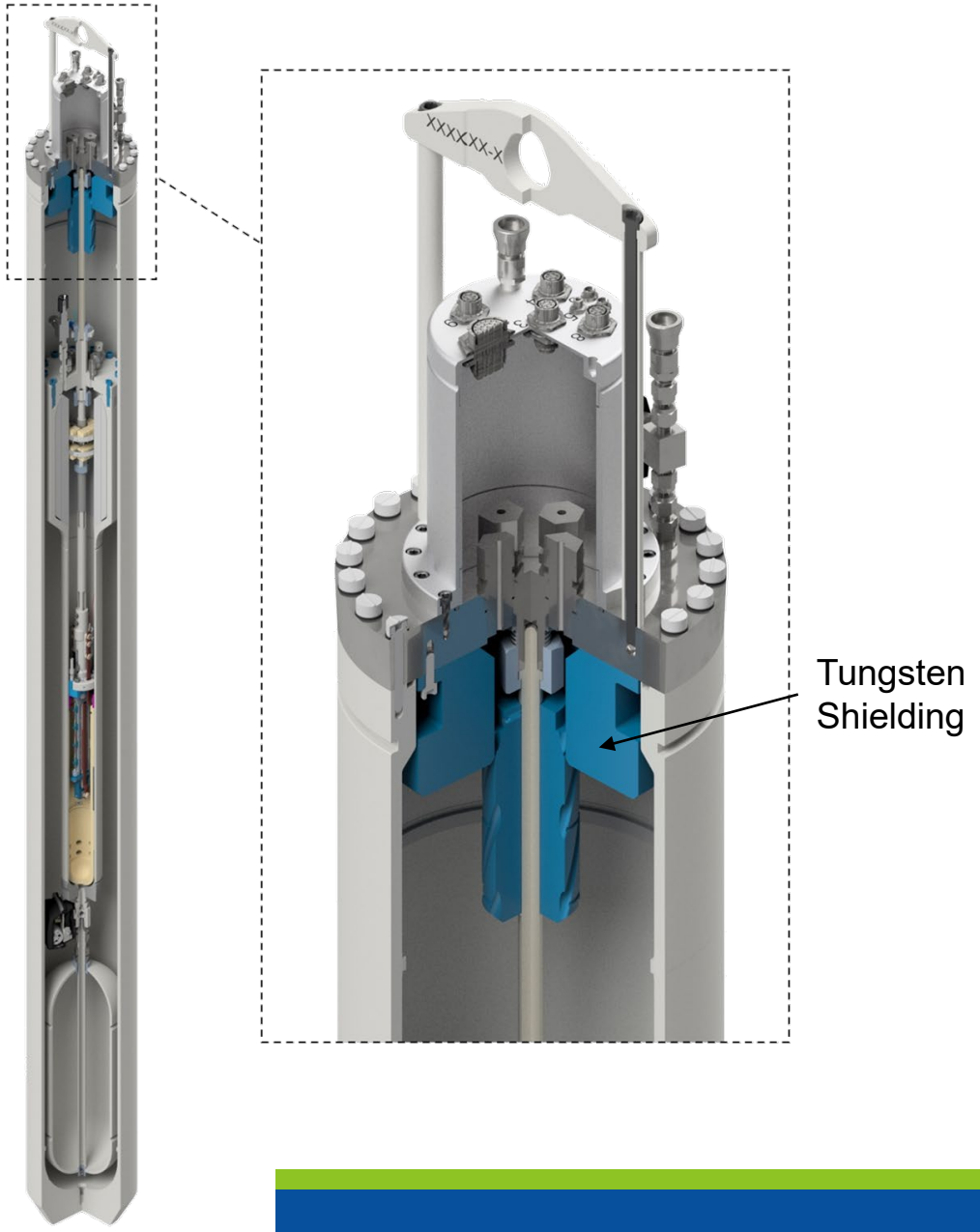
TWIST HBu Design Modifications

TWIST HBu

- TWIST will serve as the LWR testbed for TREAT experiments with pre-irradiated fuel and is planned to be used for both LOCA and reactivity-initiated accident (RIA) experiments starting in late calendar year 2024
- Hot cell assembly engineering currently underway
  - Considerations for shielding and contamination control

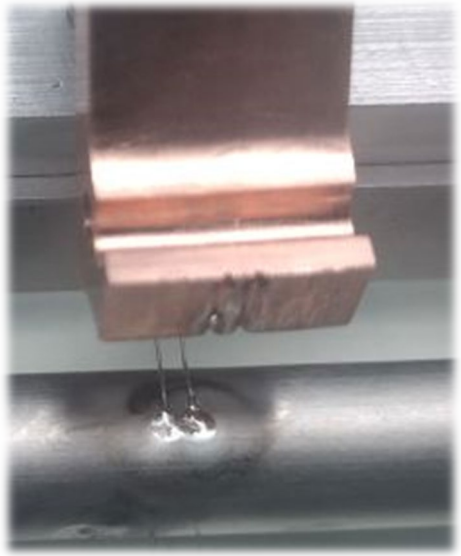


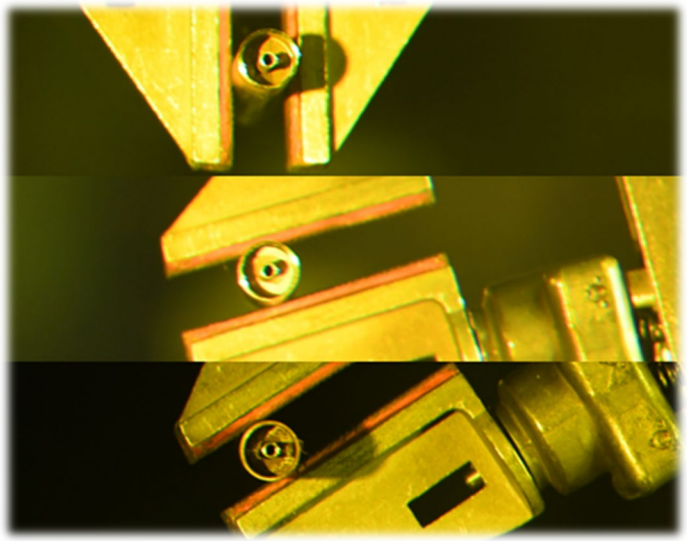
RIA
Configuration

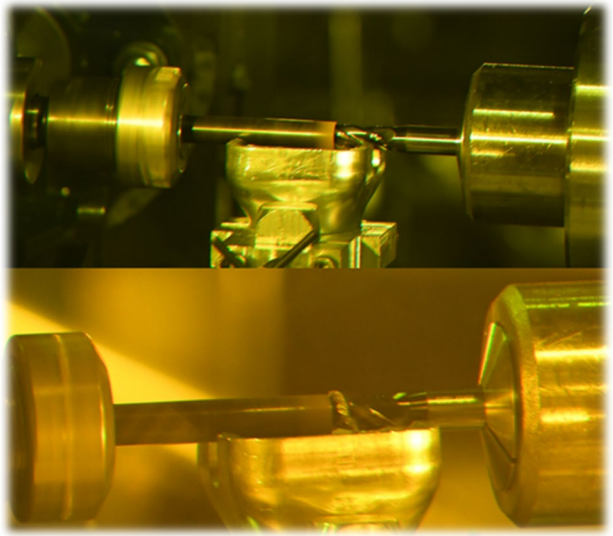


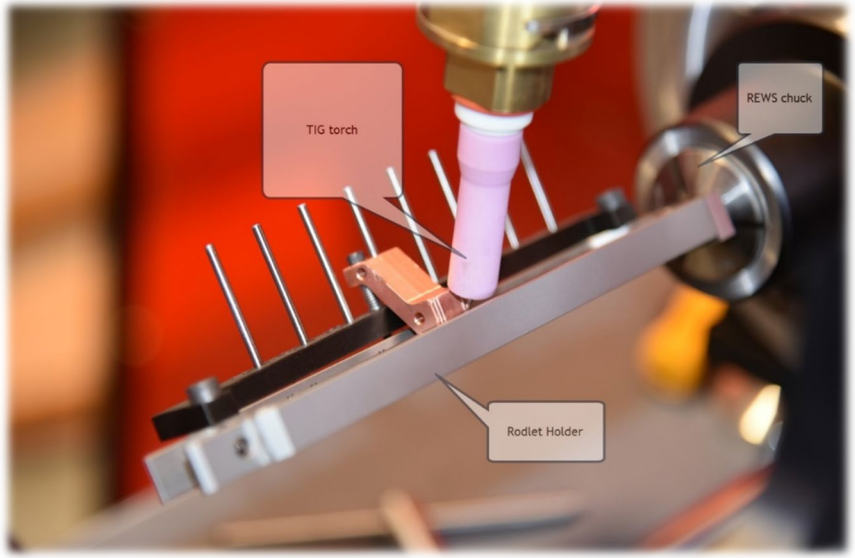
HFEF: Integrating TCs into Irradiated Rods for Continued Irradiation

- Design work, prototyping, and in-cell trials for:
  - Rod segmenting and end-defueling
  - Cladding surface TC welding for TREAT RIA tests
  - Pellet centerline drilling and TC-sleeve insertion





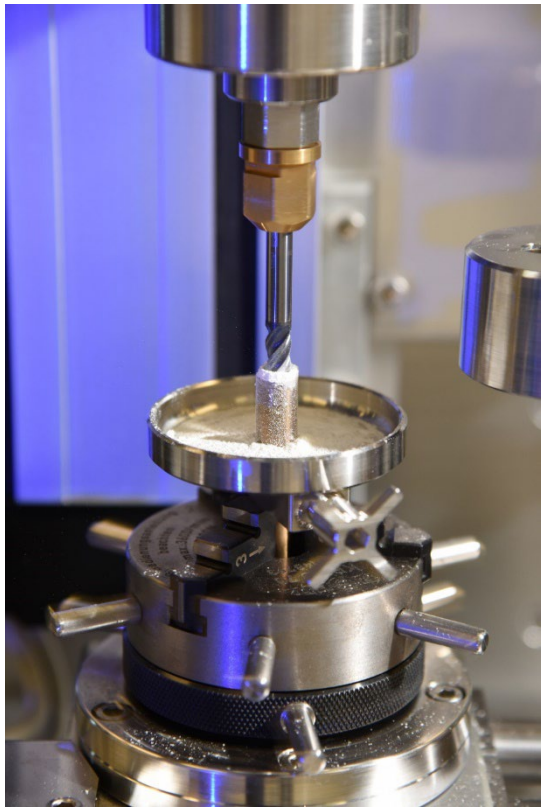




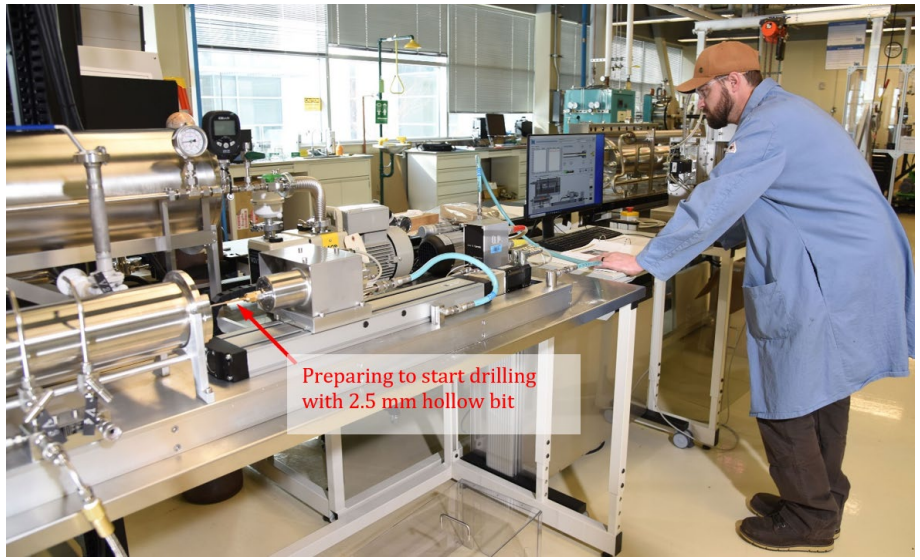
For more on HFEF evolutions contact Jason Schulthess

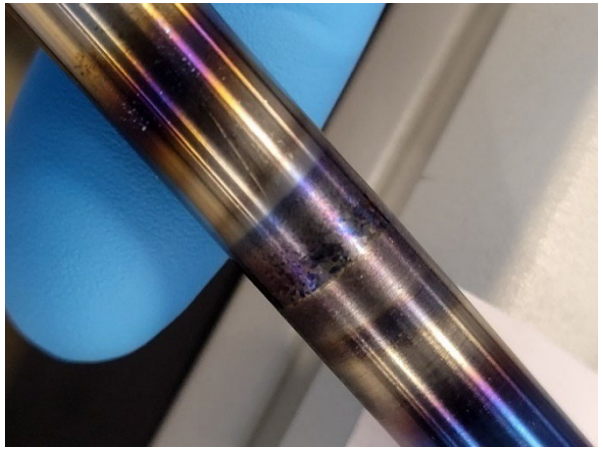
Halden Welding Modules

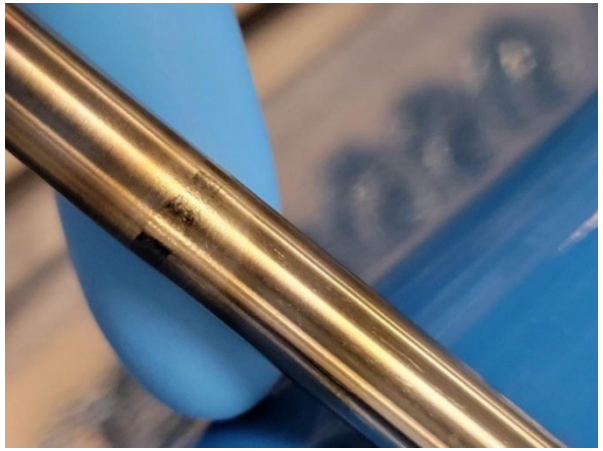
- Set of defueling, drilling, and welding Modules from Halden are providing opportunity to transfer knowledge and compare to INL developed systems



Defueling module removing surrogate pellet material from rodlet mockup







Welds made in the welding chamber. Top poor atmosphere control, bottom with good atmosphere control.

Idaho National Laboratory

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