NRIC National Reactor Innovation Center

The Hot Fuel Examination Facility (HFEF)

Engineering-scale fuels Post-Irradiation Examinations (PIE)

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Why PIEs matter

- **Regardless of the type of reactor**, the harsh environment for component service poses **materials challenges** that need to be understood and controlled for sustainable deployment.
- **Materials degradation is extremely complex** due to the interwoven effect of various environmental conditions, stress states and source of damage.
- **The ultimate goal of Post-Irradiation Examinations (PIE) is the determination of the degradation phenomena**

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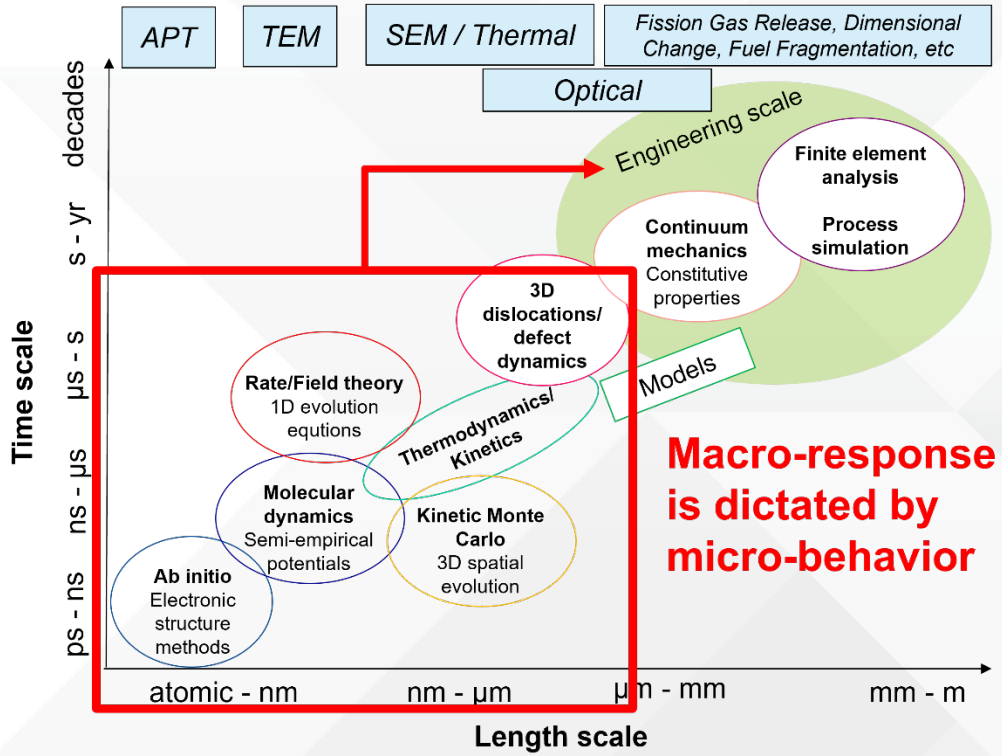
Technological innovation: focus on materials performance

- 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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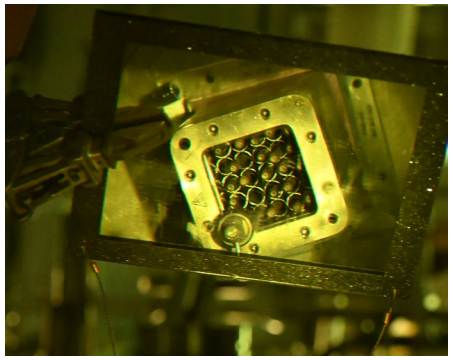
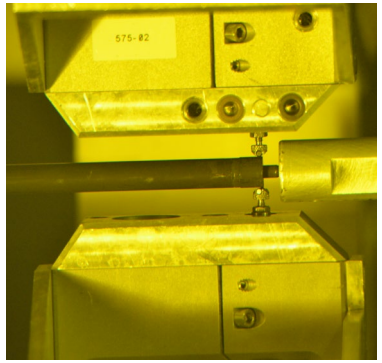
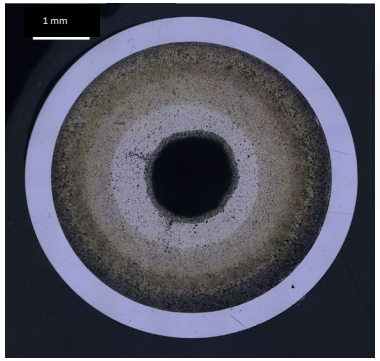
PIE strategy

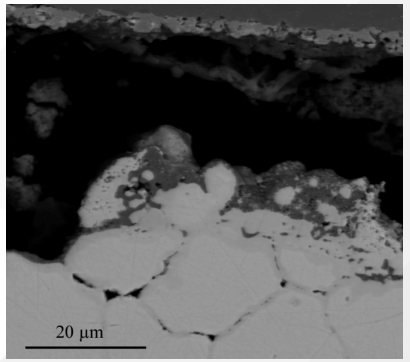
Scale of Examination	Macro	Micro	Sub-micro
	Engineering Scale Characterization		Advanced Characterization

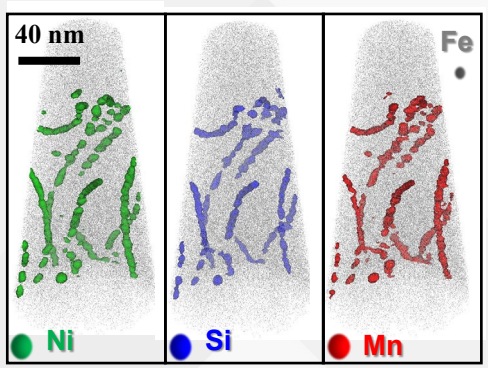
	Non-destructive examinations			Destructive examinations							
Techniques	Visual examination Gamma scanning	Neutron radiography Dimensional analysis	Element puncturing	Metallography Chemical analyses Mechanical testing	SEM EPMA XRD	Thermophysical property measurements (LFA, TCM, DSC)	In-situ micro-mechanical testing FIB-based 3D reconstruction	TEM APT			
Examples of evaluated performance	Surface defects Fission product distribution	Dimensional changes	Internal pressure	Isotopic concentration Burnup Embrittlement	Fuel-cladding chemical interaction	Thermal conductivity degradation	3D component distribution and segregation Defect population				







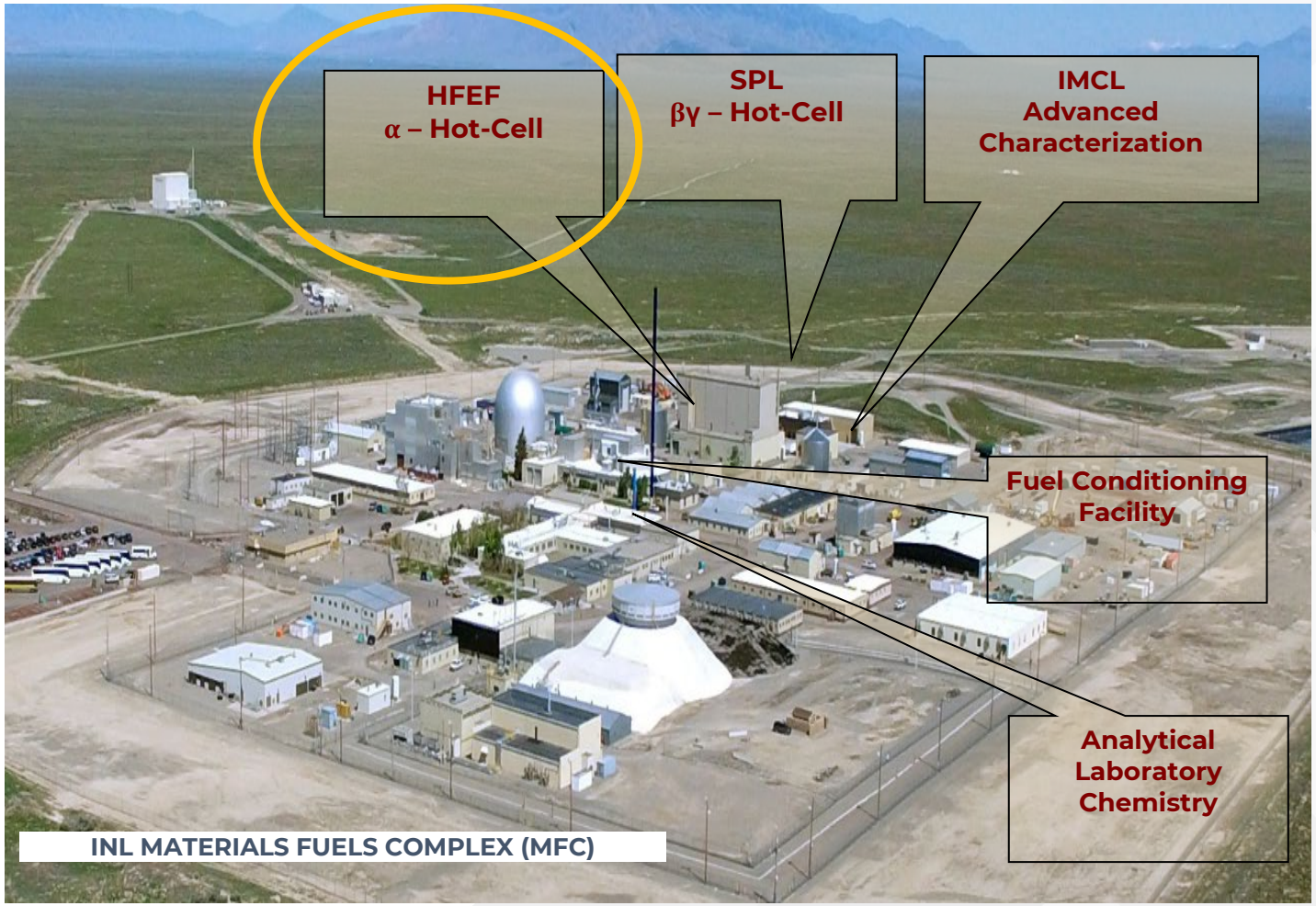




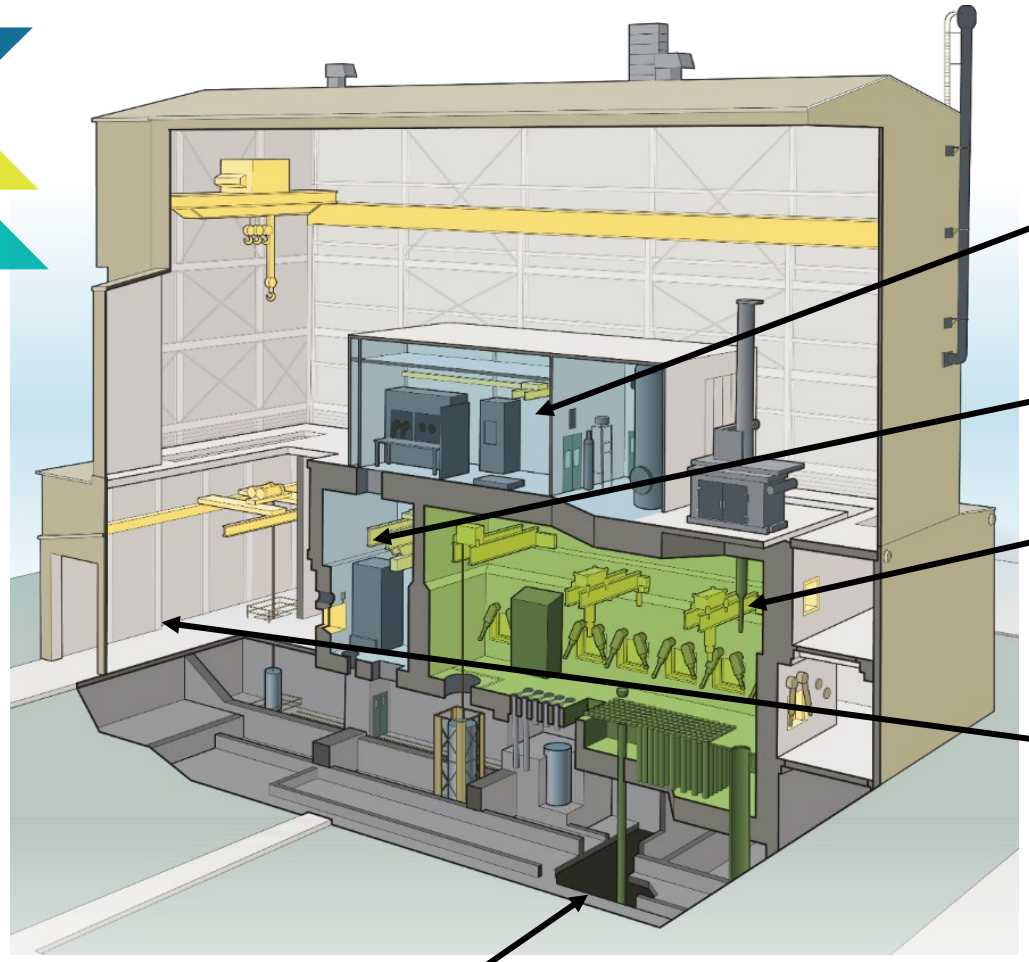
Protocols and techniques are adapted to the goal of the specific study/project

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

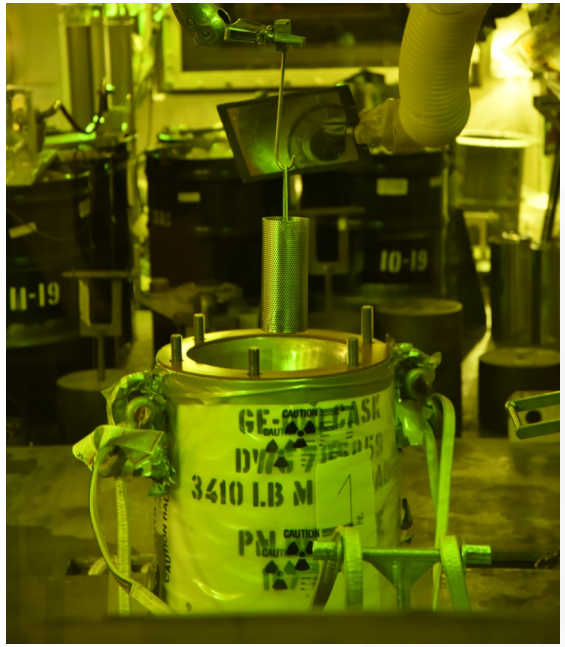
Truck lock area

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

HFEF: Cask Receipt

- Supports a variety of casks
  - NAC-LWT
  - GE-100
  - BRR
  - HFEF-15 Cask (TREAT)

Cask operations to prepare for unload

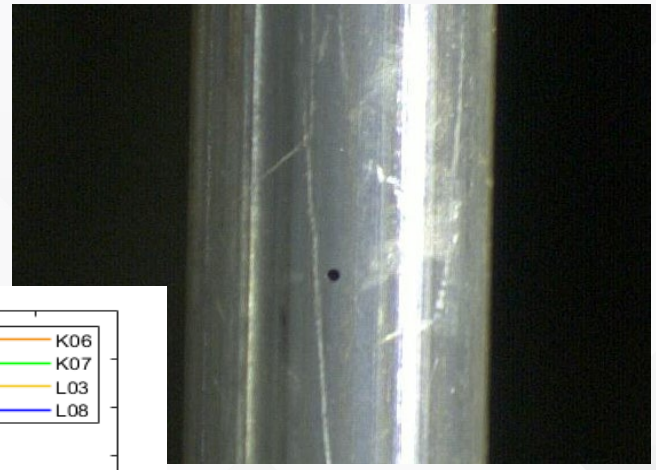


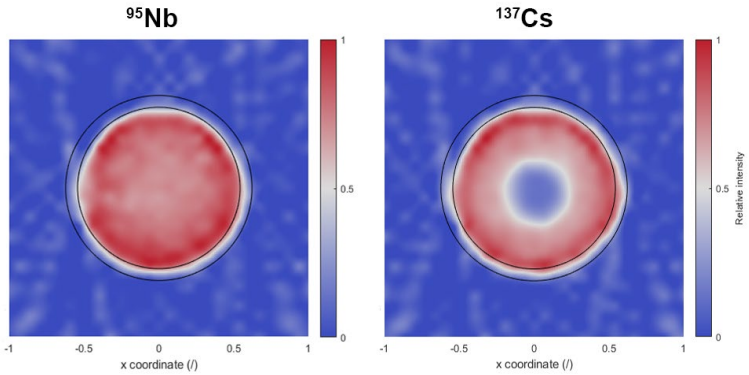
GE-100 unloaded in the main cell

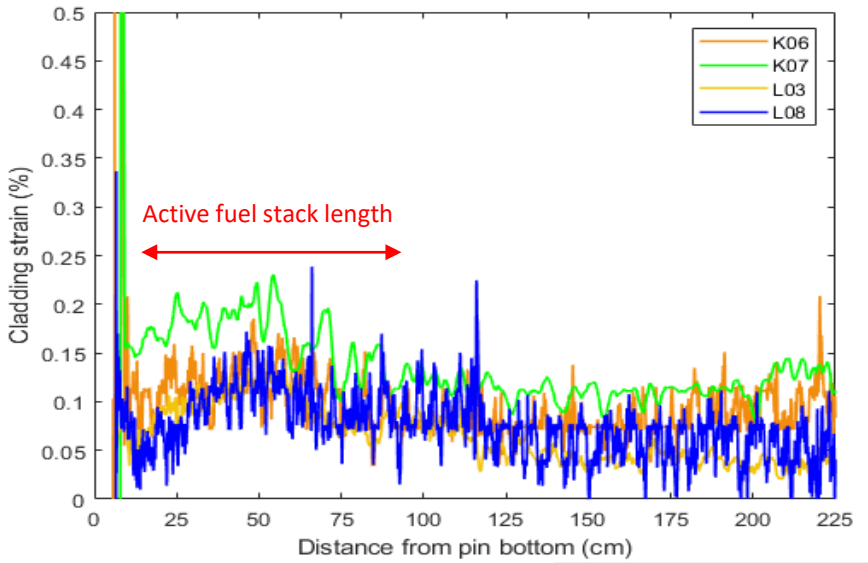
NAC-LWT on the high bay crane

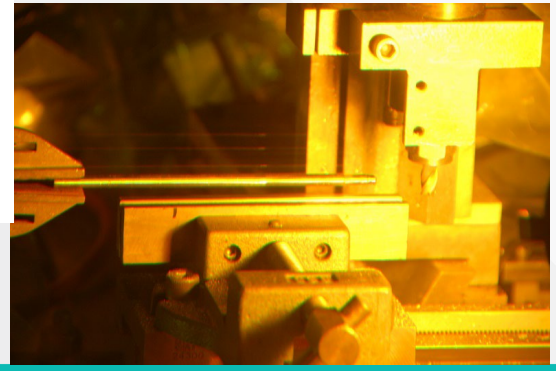
HFEF: NDE and Disassembly

- Main NDE capabilities:
  - Visual examinations
  - Neutron radiography (thermal, epi-thermal)
  - Gamma scan (axial, radial isotopic data) and Eddy current
  - Metrology (dimensional change)







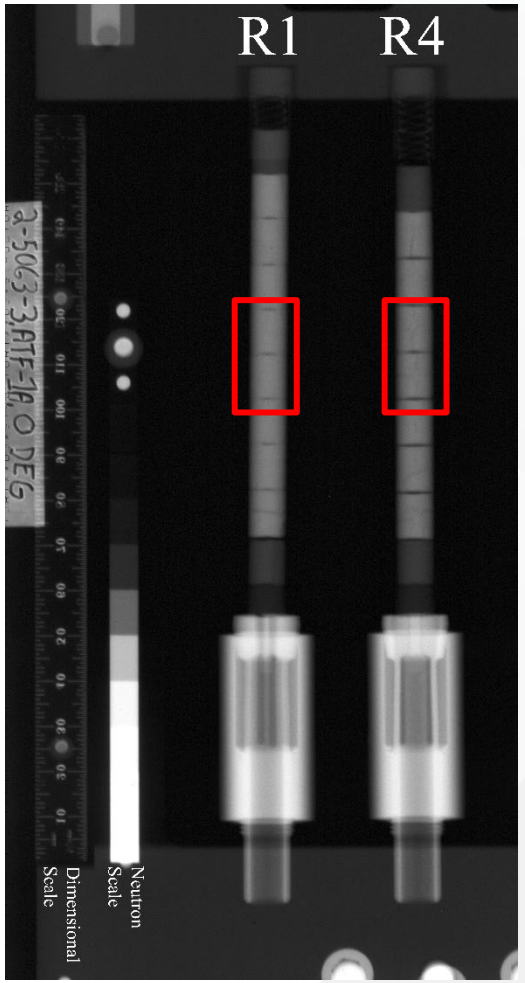


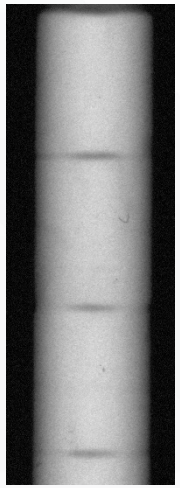
- Equipment available for precision disassembly of irradiation vehicles and preparation for further examination

Neutron Radiography

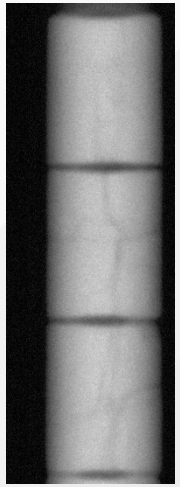
Provides comprehensive information about the internal condition of irradiated nuclear fuel. Examples of data:

- Fuel stack cracking
- Fuel stack elongation
- Pellet-pellet or active stack/blanket interface integrity





ATF-1A R1 – UO_2



ATF-1A R4 – UO_2 + SiC fibers

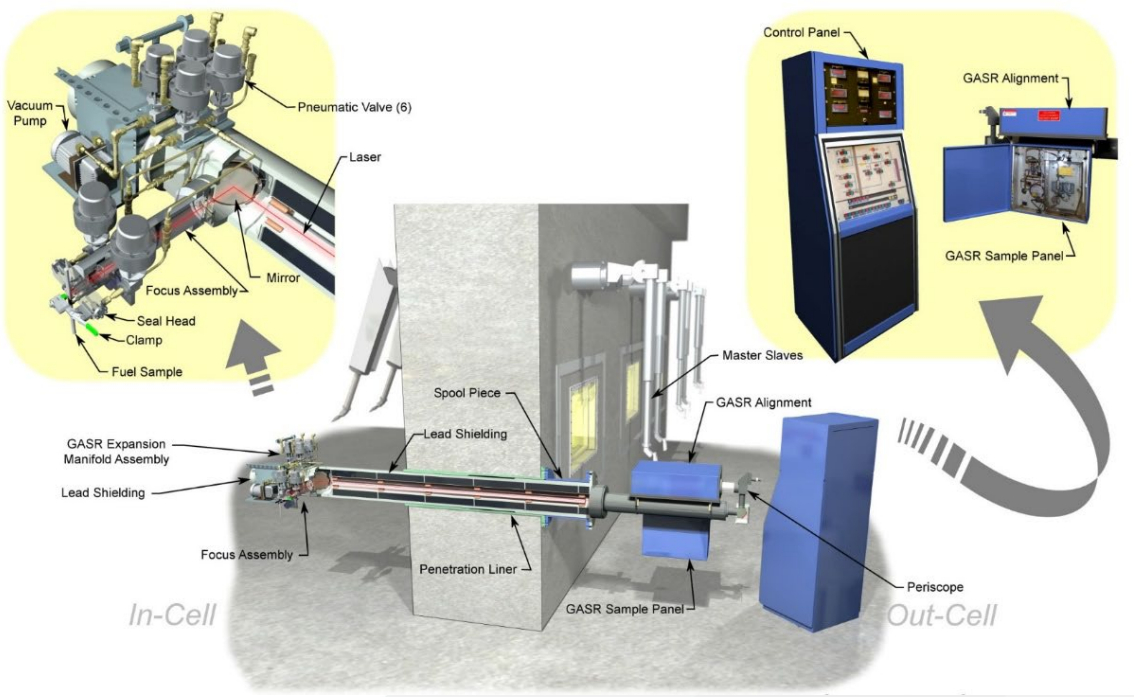
DE and Additional Capabilities

- Main DE capabilities in HFEF:
  - Fission Gas Release
  - Sample preparation
  - Pycnometry
  - Microscopy
  - Microhardness testing
  - Mechanical testing

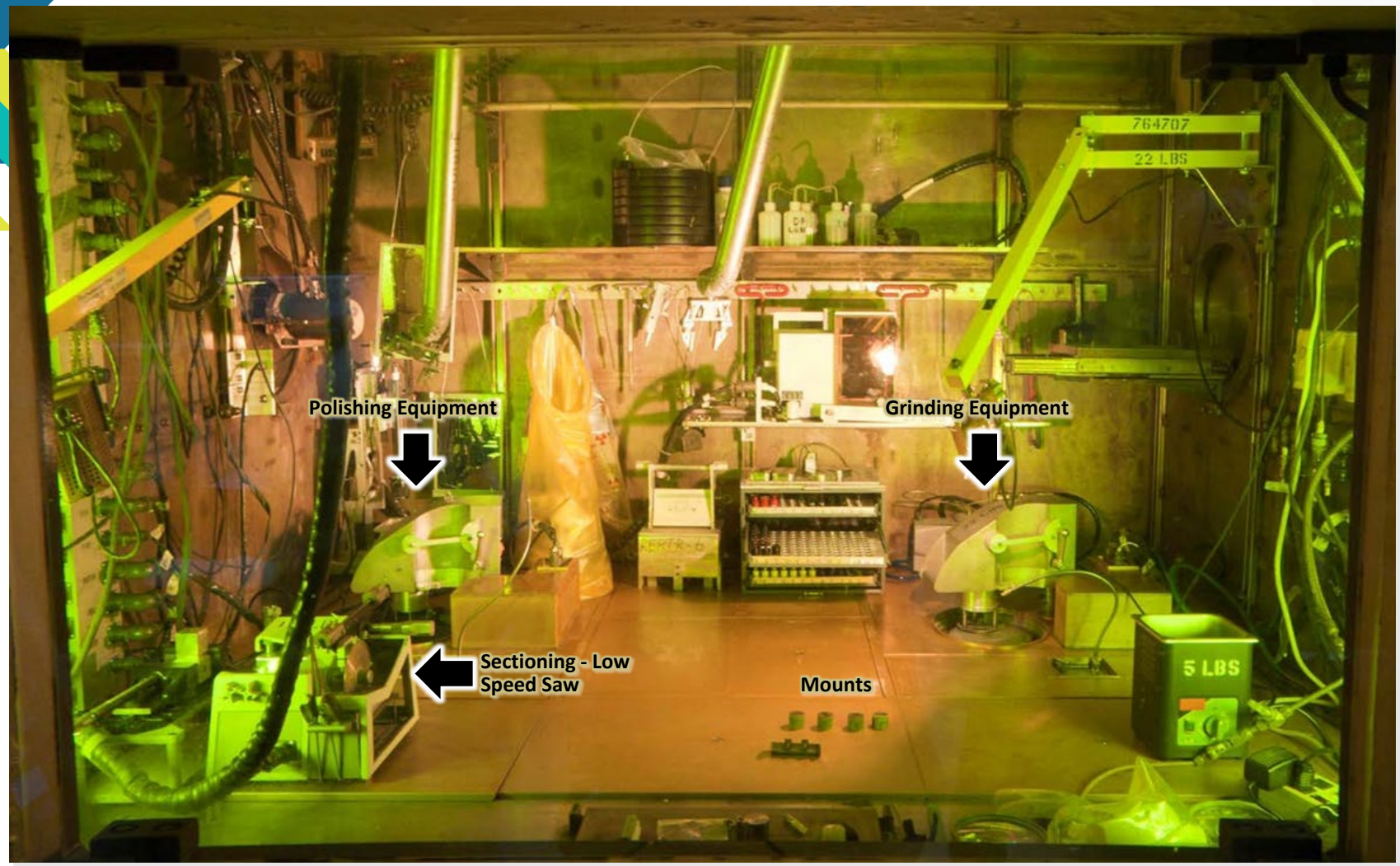
- HFEF additional capabilities:
  - Rod refabrication
  - FACS furnace (TRISO)
  - Oxide-reduction and electro-refining furnaces
  - Casting furnace

Fission Gas Release Measurement

- GASR system refurbished in 2021
- Diameter range: 0.174-0.032 in
- Length range: 1 to 152 in
- Cladding thickness: 0.01-0.125 in
- Observed accuracy ± 5% for pressure and volume (varies with experiment)
- Gas samples are collected outside cell and sent for isotopic composition determination using mass spectrometry
- Operational envelope extended to very small specimens (1/2 size of SFR pin) in 2023 – measures volumes smaller than 1cc (but accuracy decreases)

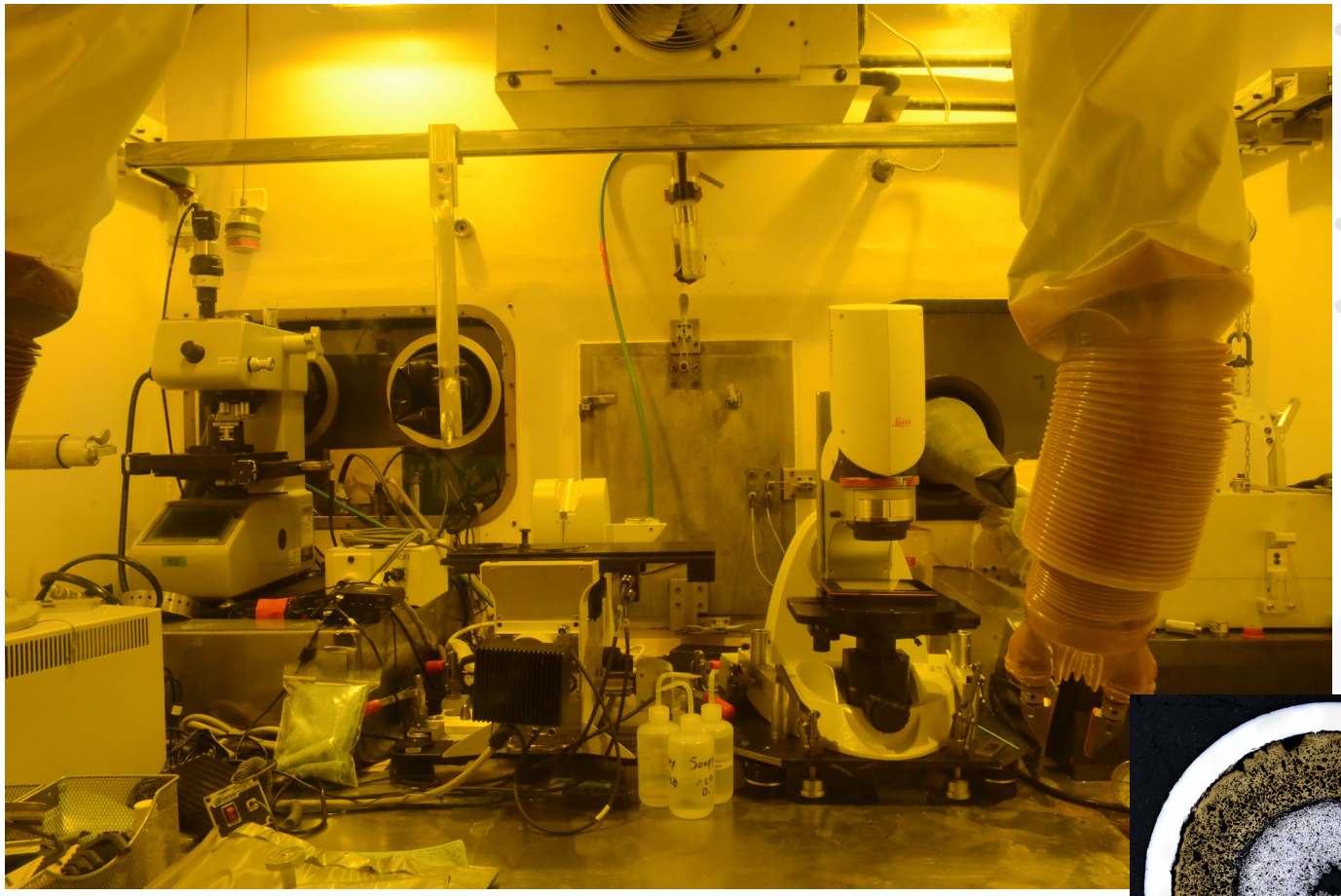


Sample Preparation – Containment Box



- Dedicated window with specialized equipment
- Custom-built mounts and preparation techniques
- Chemical etching and dissolution processes possible

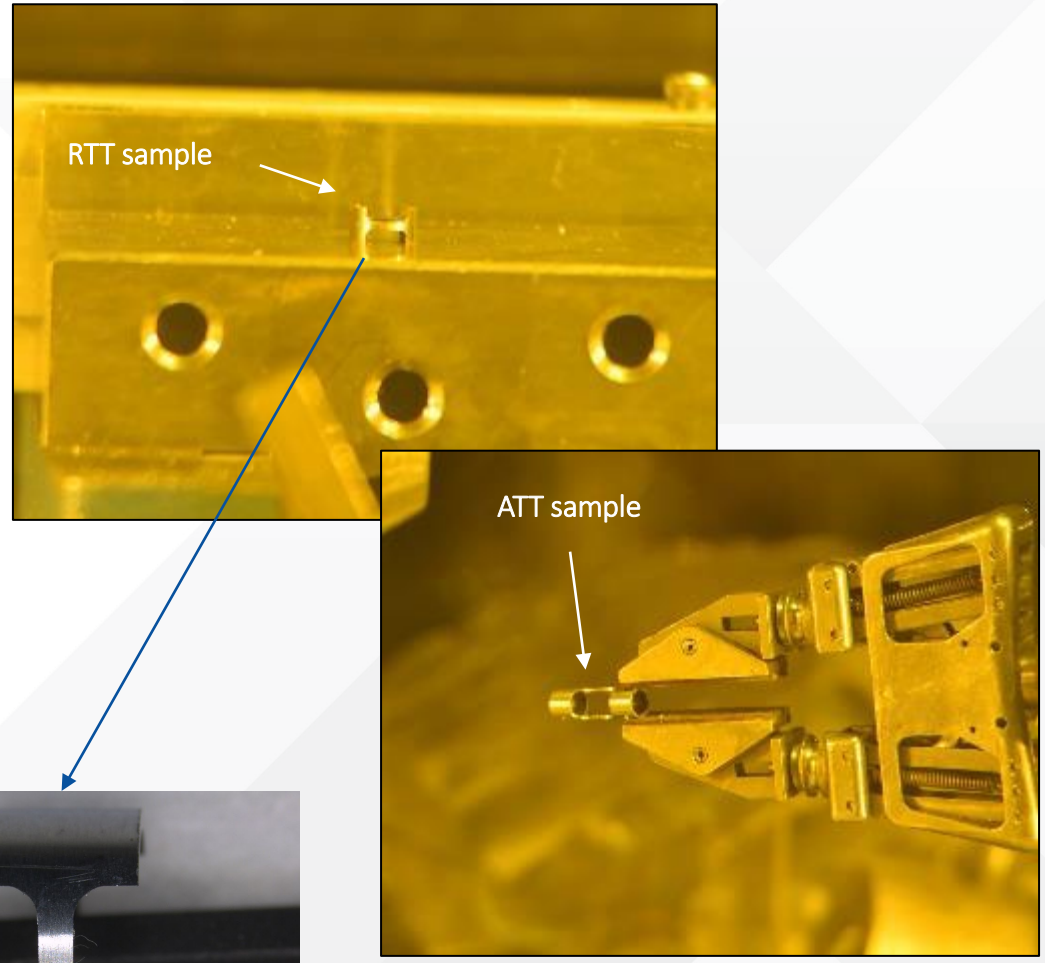
HFEF: Metallography and Microhardness

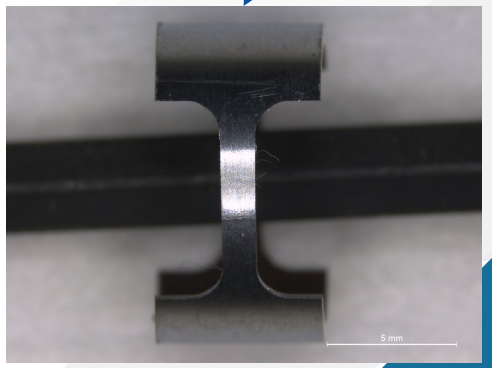


- LECO microhardness tester (25 gf to 1kg) both Vickers and Knopp testing
- Leica inverted microscope
- Leica stereomicroscope installed in 2021 to expand microscopy capabilities (used mainly for mechanical testing specimens, but multi-magnifications can be covered with 3 lenses

Mechanical testing (1/2) – Sample in-Cell Machining

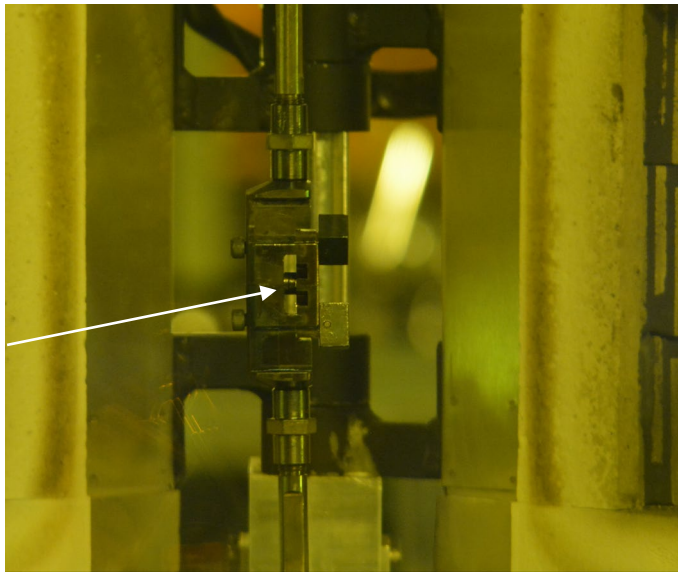
- Development of in-cell mechanical testing capabilities to support qualification of cladding includes ability to machine highly radioactive specimens in the hot cell environment
    - Completed in-cell machining for ring tensile test (RTT) and axial tube tensile (ATT) test specimens at HFEF
- CNC machine being installed FY25 to increase the throughput of sample machining and improve defueling for refabrication purposes





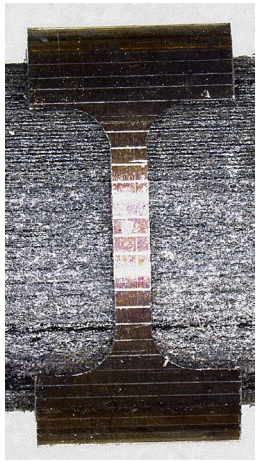
Cr-coated Zr-4 RTT sample machined in cell, gauge view

Mechanical Testing (2/2) – RHT and ATT

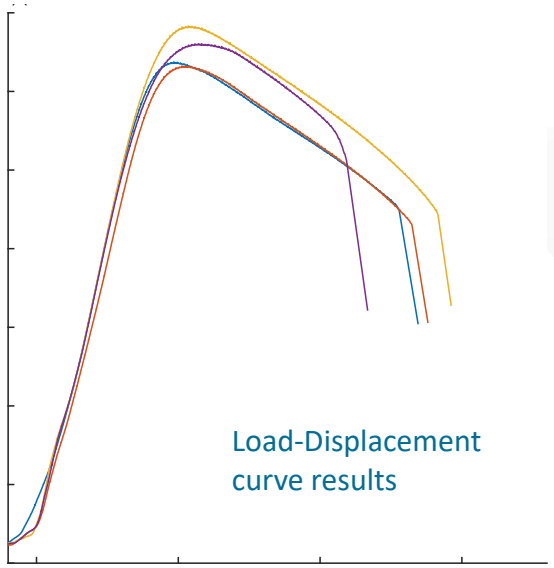


Cladding ring sample

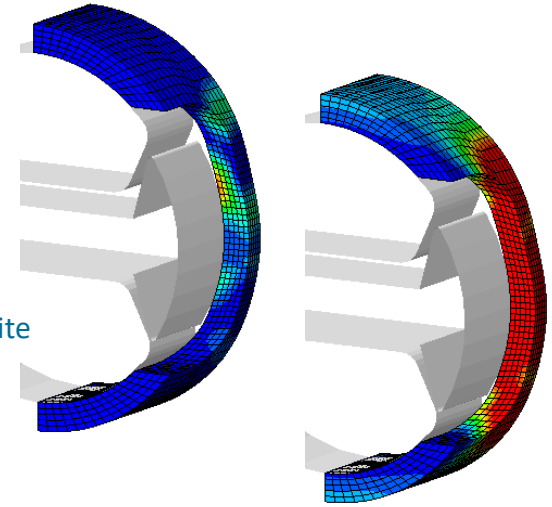
Test train in load frame at HFEF



Ring sample, machined in-cell



Load-Displacement curve results



Paired finite element analysis

- Instron Model 5869
- Various load cells can be installed (50kN, 5kN, 2kN, 500N)
- Heating up to 1200°C. Currently testing for RHT and ATT up to 400°C
- Max crosshead speed 500mm/min (dependent on test and load)
- RHT and ATT fully demonstrated in 2021
- In addition to RHT and ATT a variety of other tests can be executed (3- and 4-point bend test, RCT)

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HFEF In-Cell Furnaces

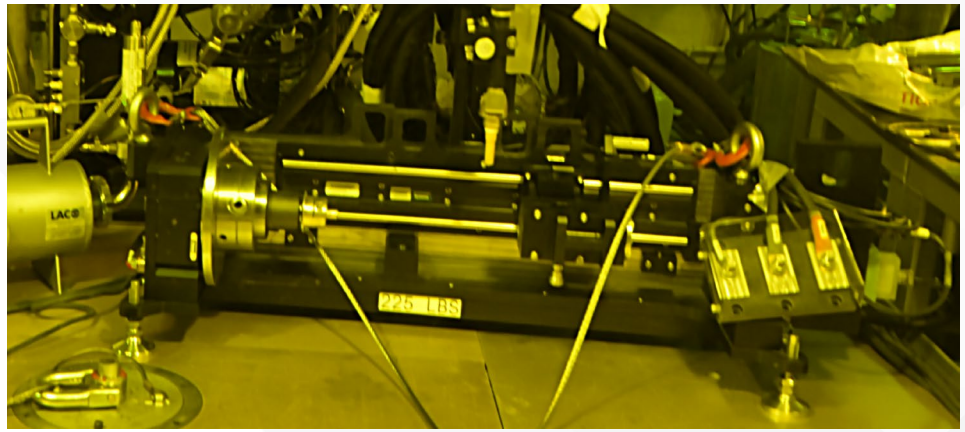
- **Blister anneal furnace**
- Large furnace which can accommodate
- Licensed to 600°C, could be extended to 1100°C
- Slow heating rate: 3°C/min
- Suitable for slow heating type of experiments

- **Bakeout furnace**
- Smaller furnace which can accommodate samples <7 in. I.D. × <12 in. long
- Licensed to 1200°C
- Can be connected to the on-line cold trap of the FACS furnace for released gas (Kr-85) measurements

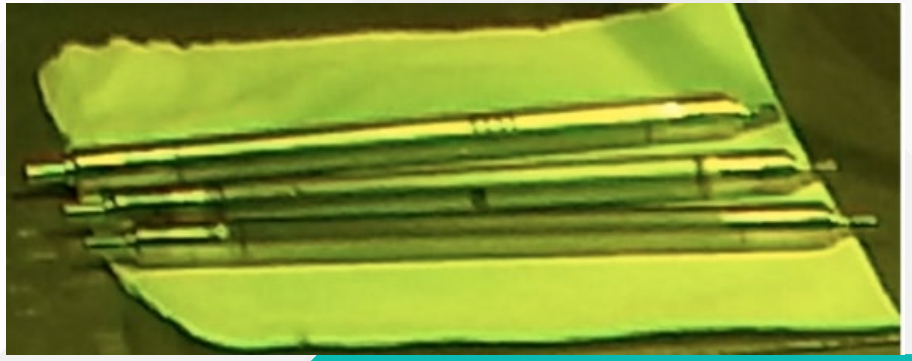
- **FACS furnace**
- Dedicated to TRISO safety testing
- Designed to fail TRISO particles >1600°C
- On-line detection of gamma emitters (Kr-85) and cold-plate for collection of released fission products

Rod Refabrication

- A new refabrication capability was established in HFEF to harvest material from previously irradiated fuel experiments.
- This includes harvesting the material from the parent, defueling the ends both mechanically and chemically, welding on new endcaps and finally seal welding the new rodlet.
- Installed in the decon cell in HFEF
- Supports safety testing in TREAT



Above: one of two new welding systems installed to perform fuel refabrication in HFEF.
Below: fuel rodlets refabricated as part of demonstration of new refabrication capability.



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