U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

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Instrumentation for Transient Testing Experiments (TREAT)

Advanced Sensors and Instrumentation Annual Webinar

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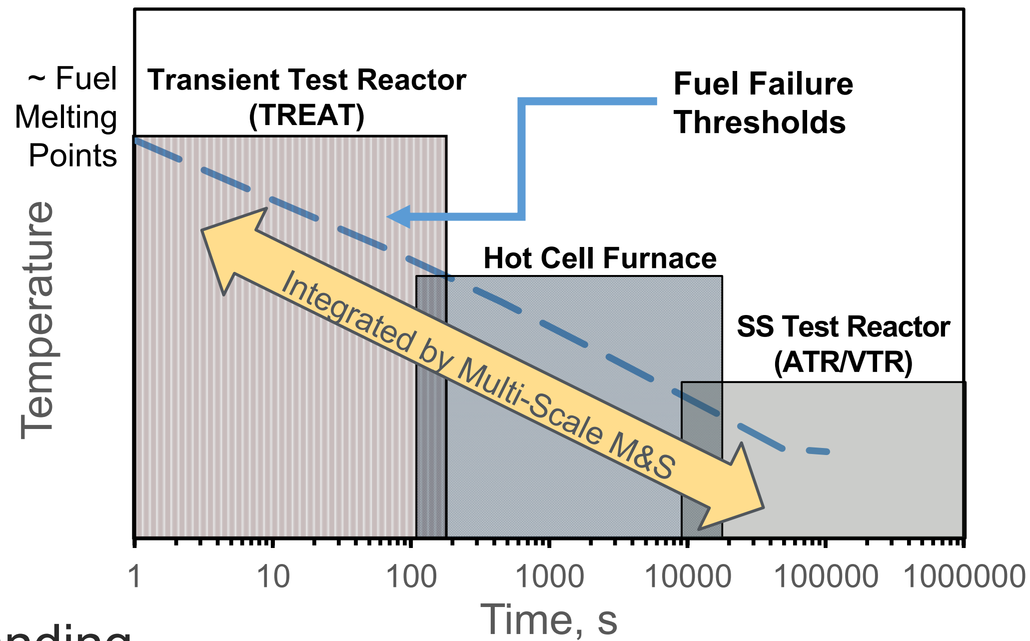
Idaho National Laboratory

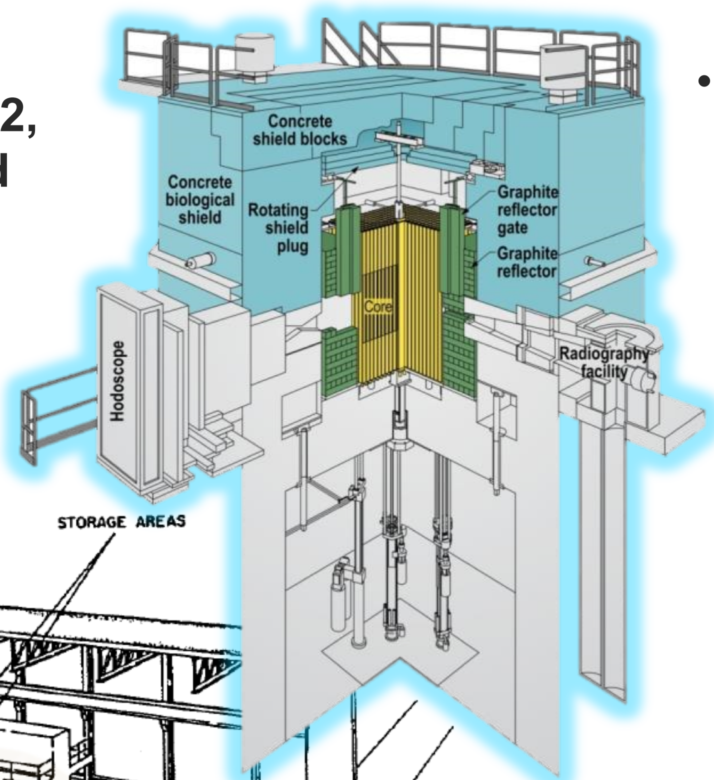
Transient Testing for Fuel Safety Research

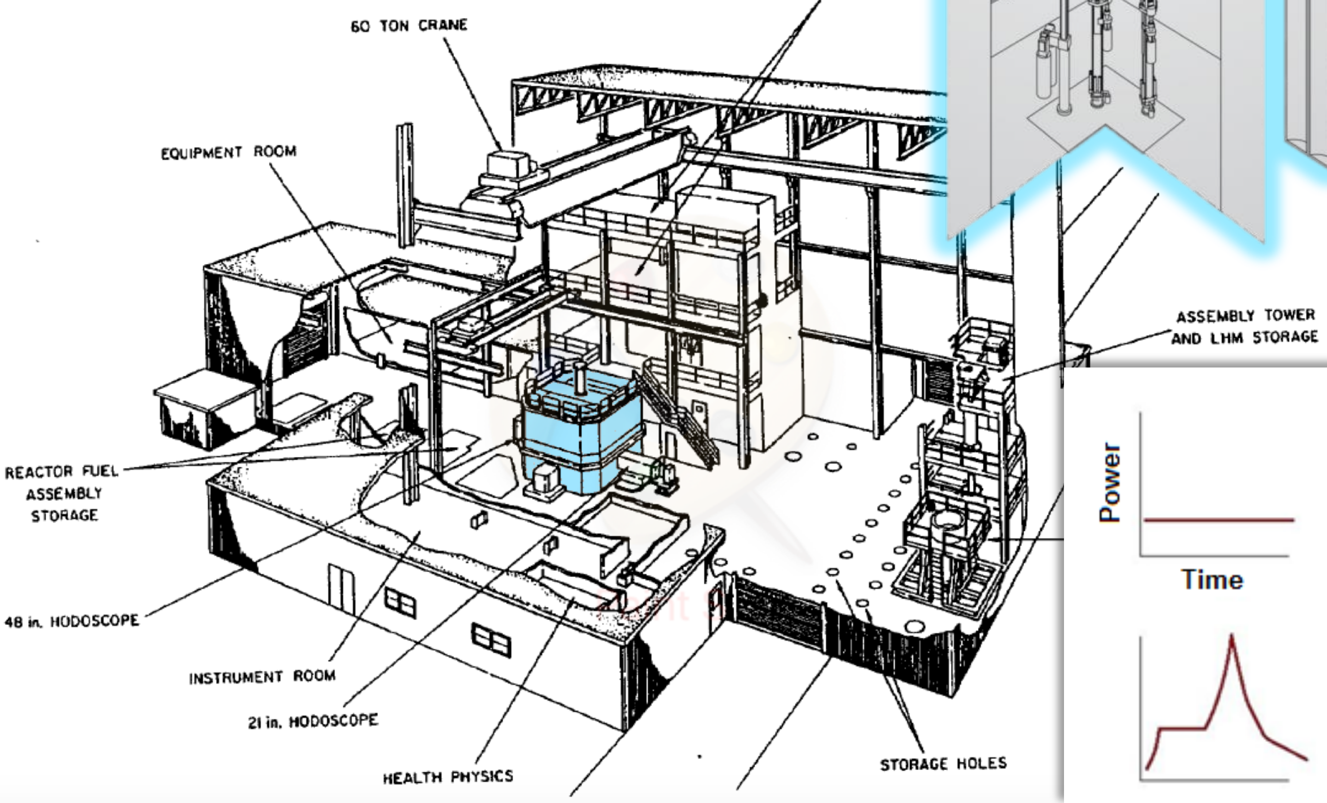
- **Transient testing is a key experimental approach for fuel safety research requiring a transient test reactor**
  - Optimization of LWR Fuel Technology
    - Improved fuel safety criteria
    - LWR fuel burnup extension
    - Accident tolerant fuels
  - Enabling Advanced Reactor Technology
    - Establish fuel safety criteria for new reactor types
  - Fuel Behavior Science
    - Separate effects tests to improve fundamental understanding of material behavior using short tem, dynamic irradiation



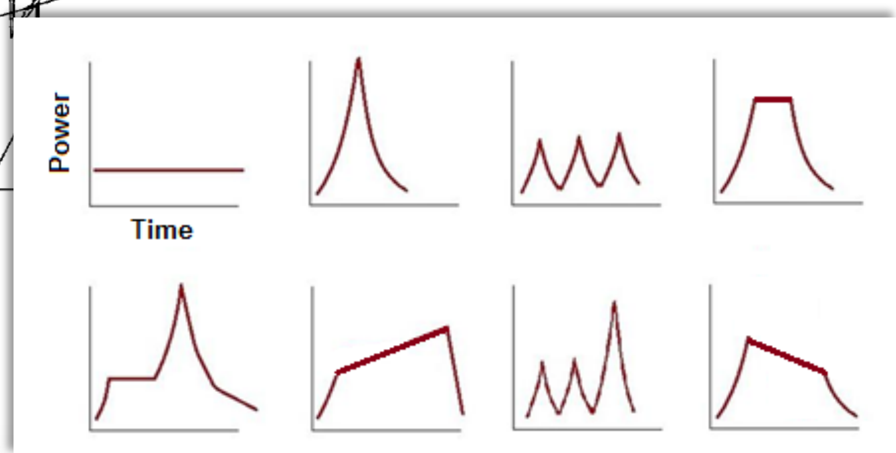
Transient Reactor Test (TREAT) Facility

- 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!



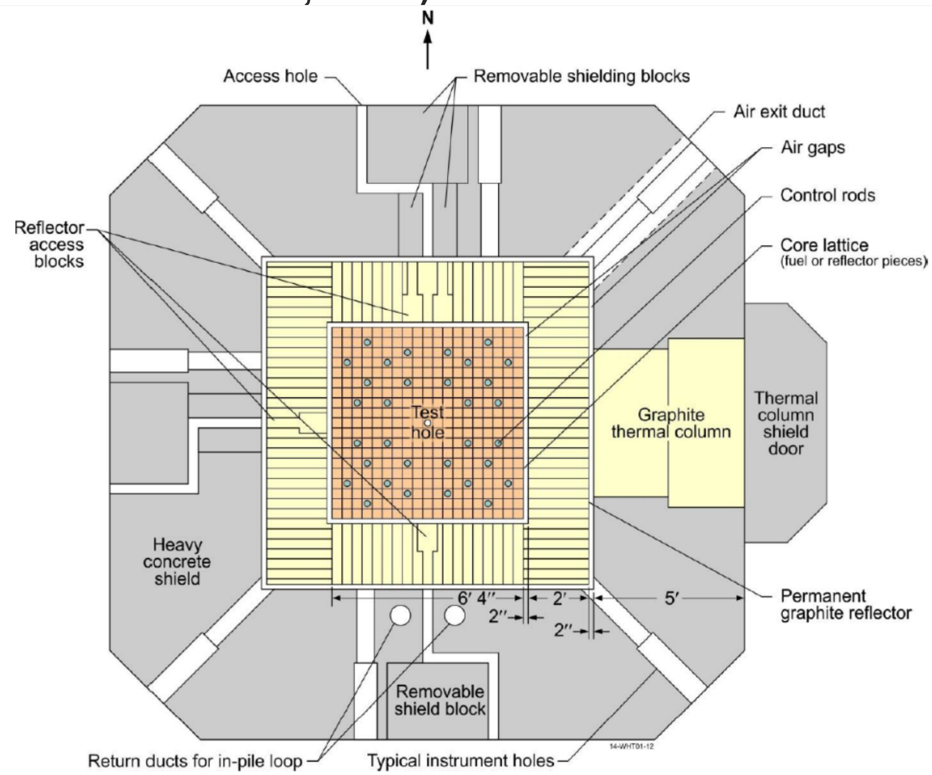


- TREAT's brilliant design provides flexibility to support a variety of testing missions
  - 19 GW Peak Transient Power (~2500 MJ energy limit)
  - Core: ~1.2 m high, 19 x 19 array of 10 x 10-cm. fuel assemblies
  - Instantaneous, large negative temperature coefficient (self protecting driver core)



Key Application Characteristics

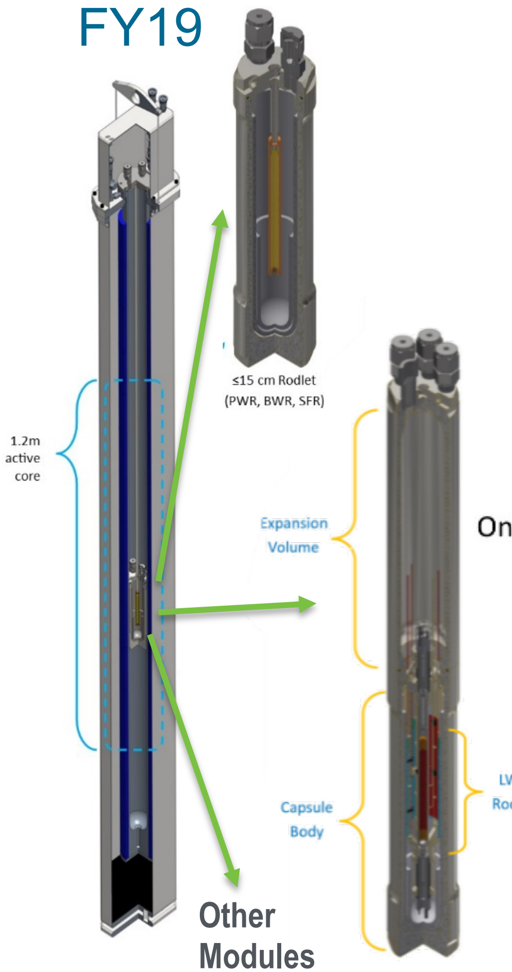
- Dry core (air) design provides variety of options for access with many ports around the core
- Experiment environments may be quite harsh (postulated reactor accident conditions) and varied (gas, liquid; H2O, Na, …)
- Experiments typically arrive in packaged-devices with instrumentation, inserted into center core location; integration of instrumentation into experiment devices is generally non-trivial (feedthroughs, size constraints, etc.)
- Peak neutron flux ~10^{17} n·cm^{-2}·s^{-1}
- Max neutron fluence ~10^{16} n·cm^{-2}
- Gamma heating may be very high (~150 ΔK for stainless steel)
- Response time and data acquisition rates are crucial for many experiment objectives
- Relatively short wire runs (~10-20 m)
- Design features provide flexible platform for in-pile instrumentation R&D.



Experimental Devices of a New Generation

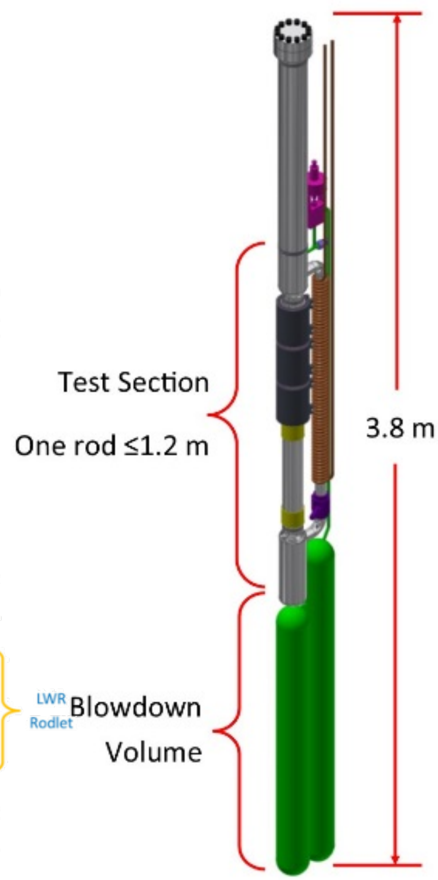
- **TREAT experiment devices** – gas, water, liquid metal environments

FY19



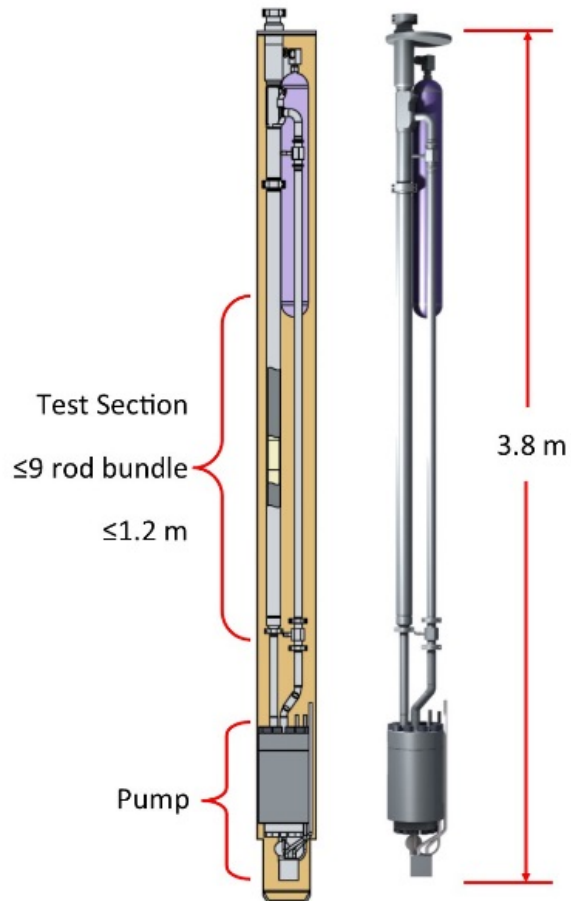
MARCH system - Modular device for efficient experiments in a variety of coolant environments

FY20



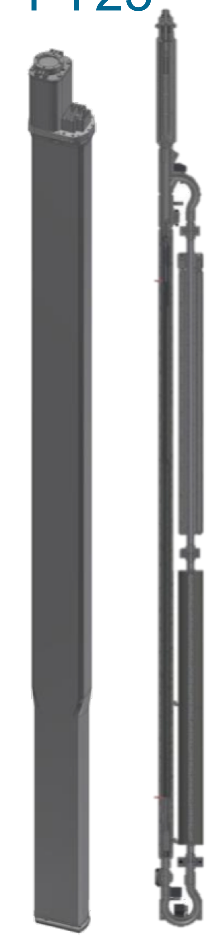
Large, single vessel capsule, RIA/LOCA, various coolants /thermal conditions possible

FY23



"TWERL"
PWR Flowing Water Loop

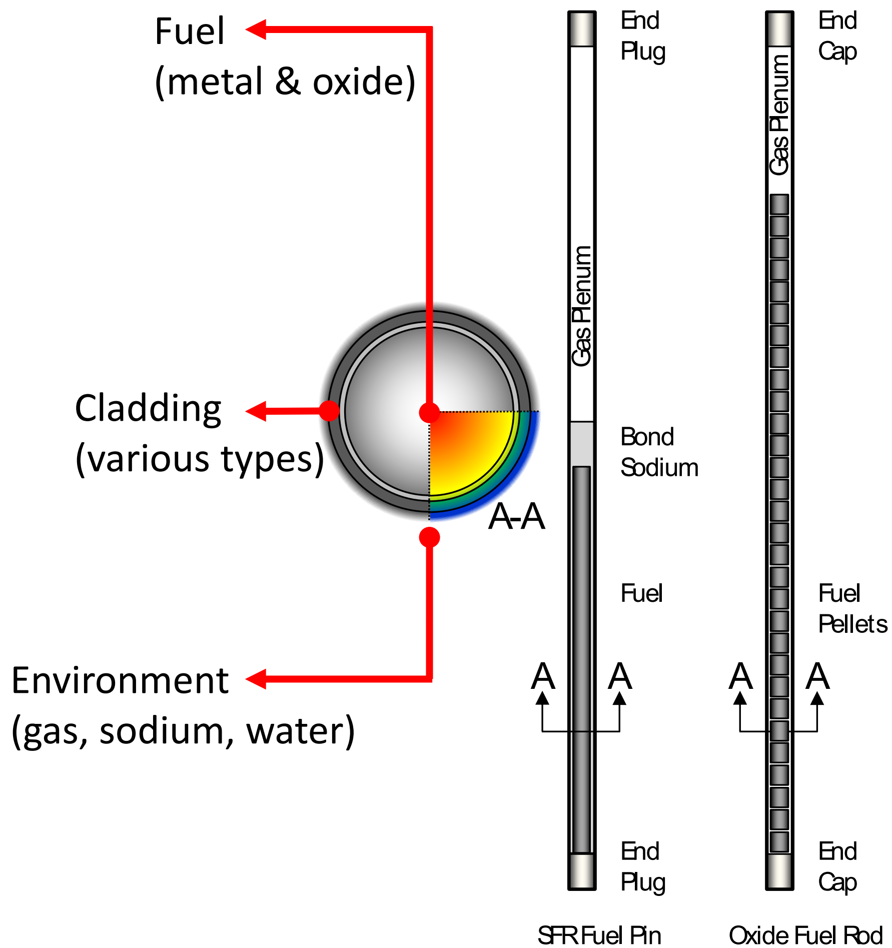
FY23



"Mark-IV"
Flowing Liquid Metal Loop (based on historic TREAT design)

Measurement Targets

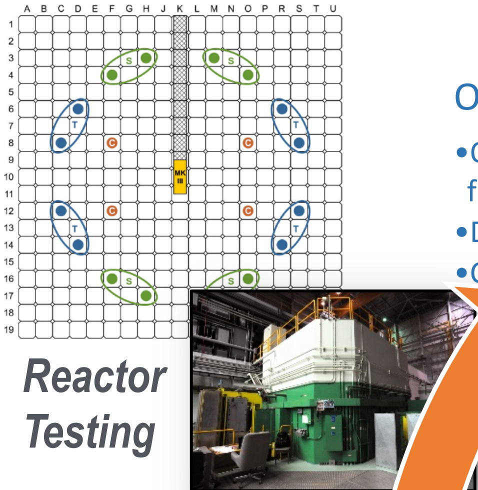
- Fuel, cladding and surrounding environment
  - Neutron Flux – spectral and dynamic behavior
  - Temperature – surface temperature, fuel temperature to melt, coolant temperature
  - Mechanical Behavior (Dimensional and Pressure) – fuel and rod elongation, fuel plenum pressure, radial deformation, coolant pressure and voiding
  - Fission product – composition, distribution, transport, release
  - Material Properties and chemistry
- Many instruments under development in these areas



Challenges and Opportunities

- **Environment resistance –** irradiation, temperature, pressure, material compatibility
- **Non-intrusiveness –** non-contact, non-destructive application
- **Miniaturization -** facilitates proximity to specimen and experiment integration
- **Remote application –** facilitate installation onto pre-irradiated specimens
- **In-core electronics** – wireless connectors, in-core options, signal conditioning, ADC, enable more signals to/from experiments
- **High resolution** in space **and** time
- **Reliable calibration** with **practical implementation**

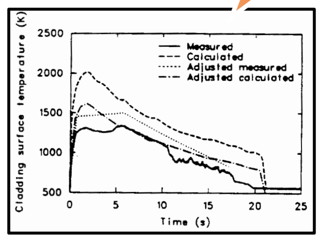
Development & Qualification



Reactor Testing

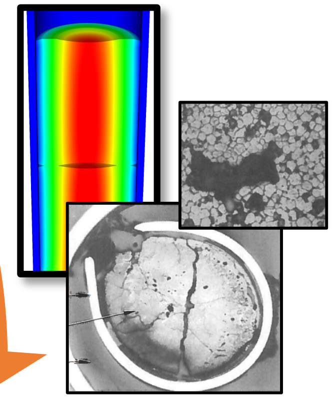
Operation

- Quantified uncertainty in final configuration
- Development closeout
- Continued support



R&D Input

- Fuels (other) programs
- Assessments & studies
- Review of alternatives



Conceptual Formulation

- Facility & experiment constraints
- Proof-of-concept testing

Instrumentation Development and Qualification Process (at TREAT)

Qualification/Acceptance

- Testing in TREAT
- Experiment integration
- Implementation Support

Design & Demonstration

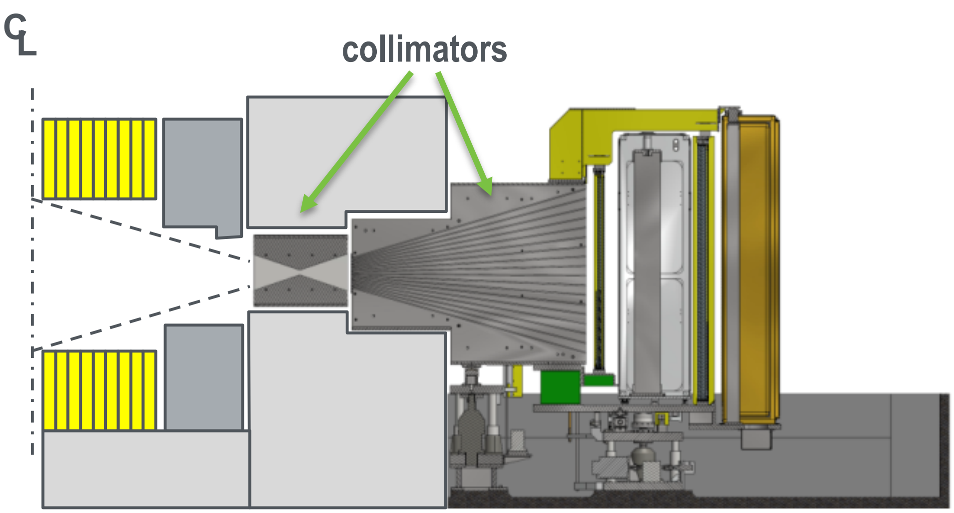
- Conceptual-to-final design
- Engineering development
  - Experiment integration
  - Refinement & optimization
  - Characterization & testing
  - Out-of-Pile
  - In-Pile
  - Uncertainty quantification

High Temperature Test Laboratory at INL

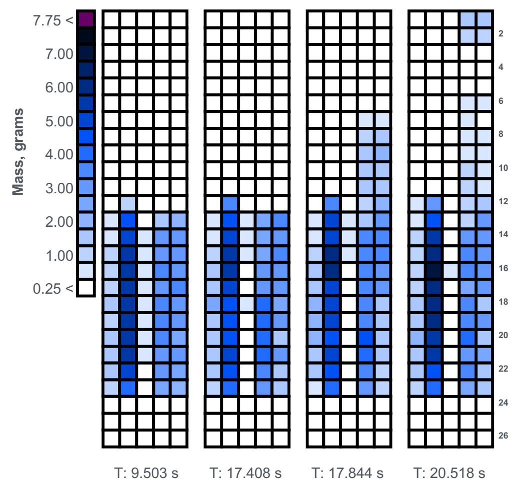
In-Situ Fuel Motion Monitoring System

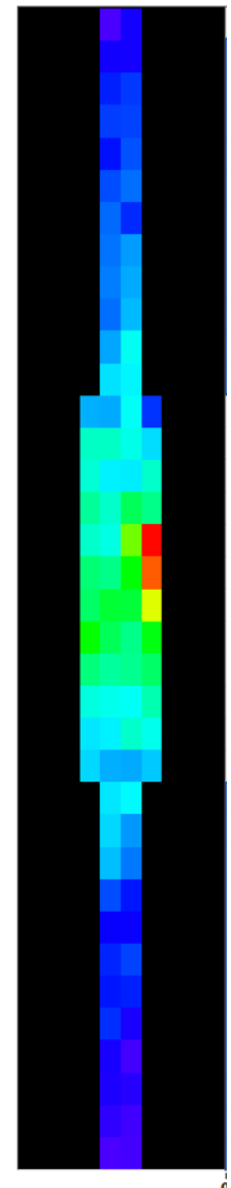
- **TREAT Fast Neutron Hodoscope**
  - Key capability for monitoring fuel motion during a transient
  - Fission-born fast neutrons emitted from the specimen travel through the experiment containment wall, through a collimator, and into a detector array
  - Provides pixelated view of fuel mass in each collimator slot
- **Refurbished and operational →**

TREAT Core



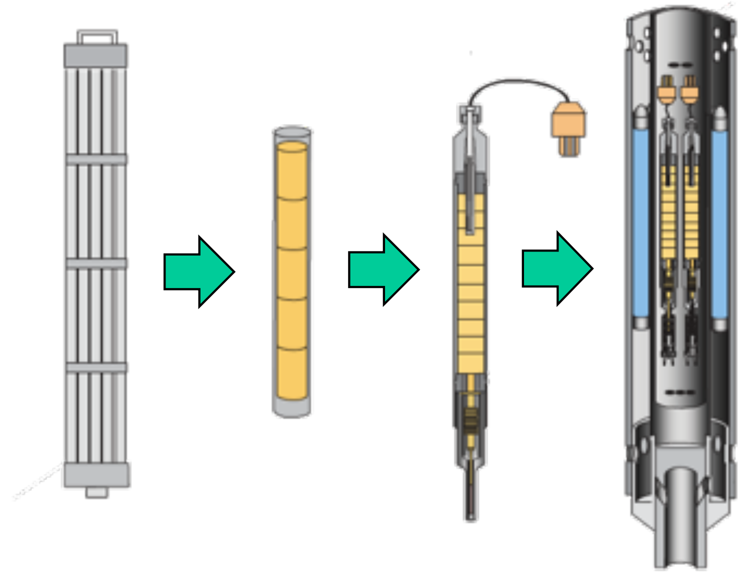
Examples of hodoscope data from TREAT

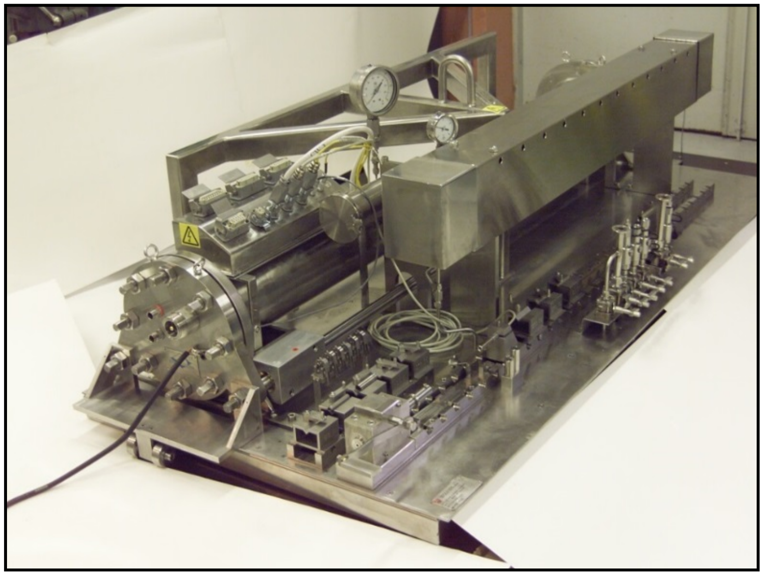




Fuel Rod Remanufacturing and Instrumenting

- Surviving irradiation lifetime is not prerequisite!
- Instrumenting rods
  - preirradiated (ATR/commercial/other) for TREAT (transient) testing
  - preirradiated (ATR/commercial/other) for ATR (SS) testing and measurement
- Working with IFE to establish comprehensive capabilities in hot cells at INL Materials & Fuels Complex by ~2022
- Becoming important piece of R&D and qualification process

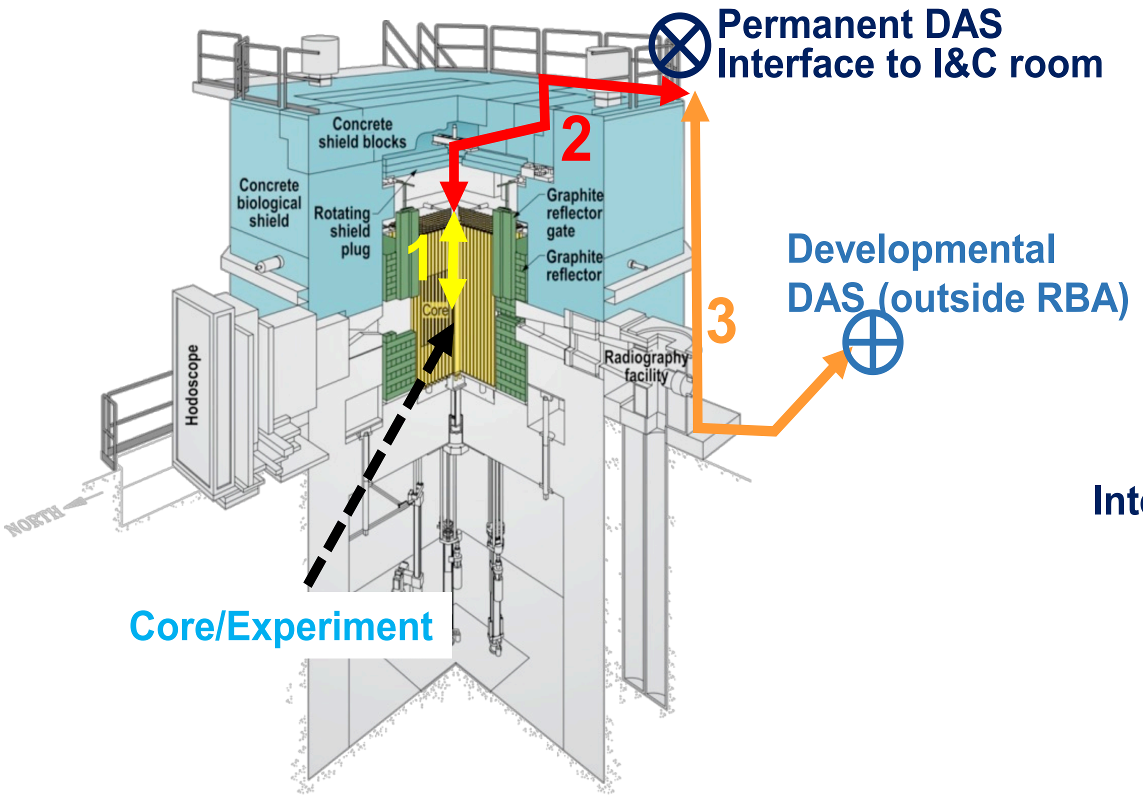




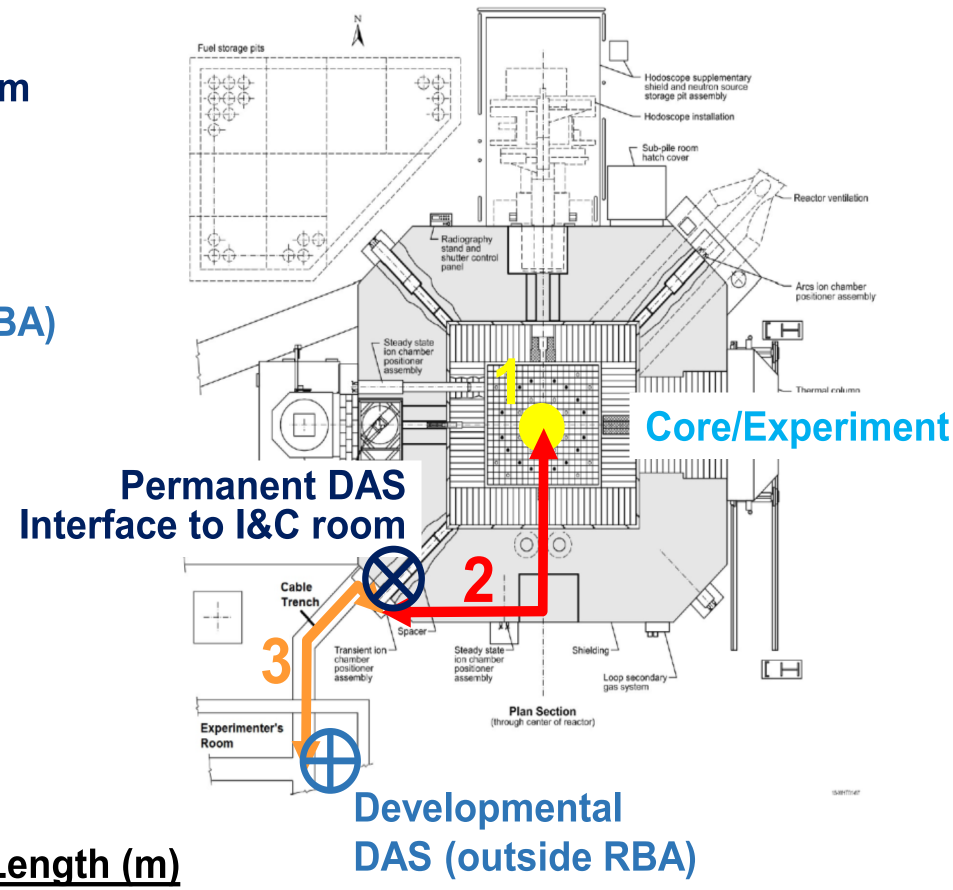
Core Access

- Remote access to DAS from control building during operations

TREAT Cutaway View



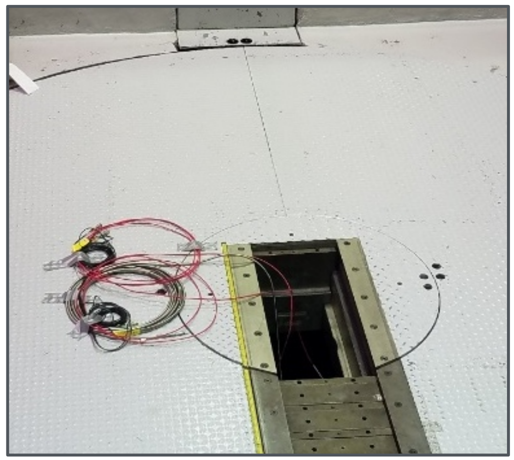
TREAT Plan View

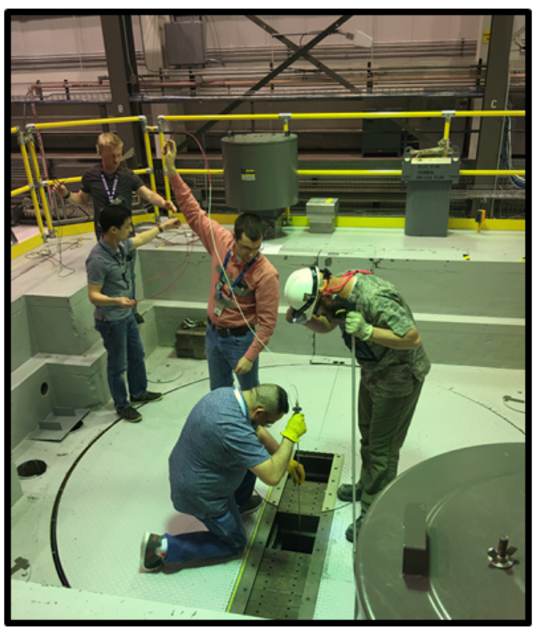


Number	Segment Length (m)
1	1.5
2	10
3	11

Recent In-Pile Insertions

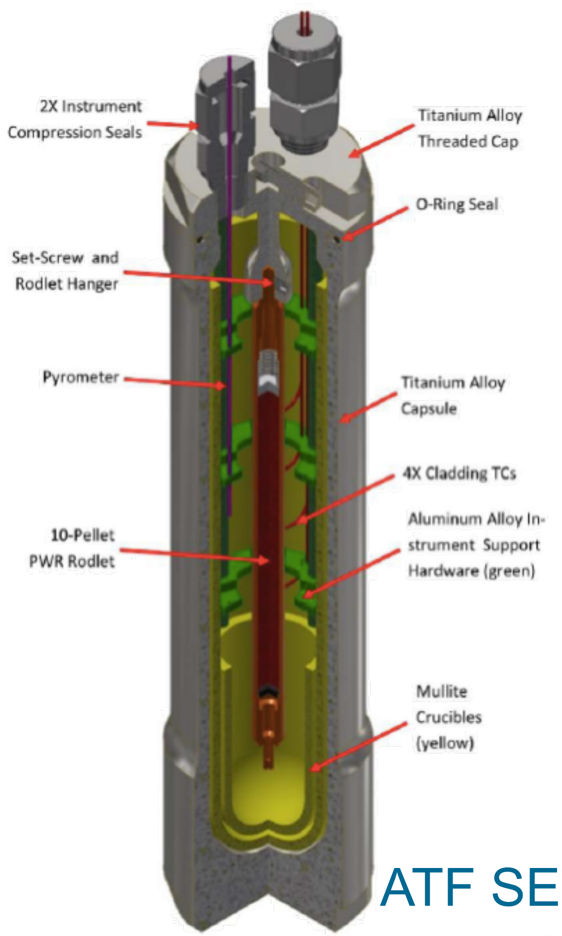
- Sensors in core since reactor became available in April
- Sensor insertion on the reactor top
  - Mineral-insulated Metal-sheathed cables: thermcouples, SPNDs, MPFD
  - Optical fiber

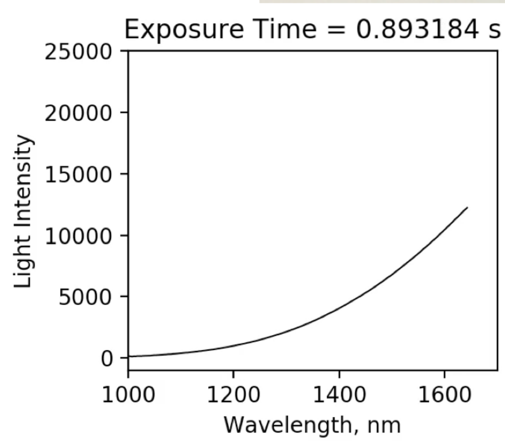




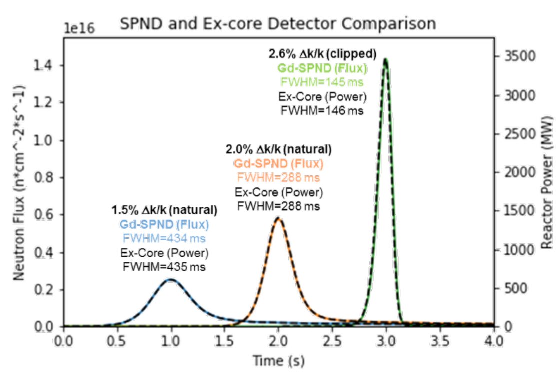
Recent Experiment Example

- In-pile performance evaluations since April 2018
- SETH for ATF program in September 2018
  - Thermocouples
  - Infrared pyrometer
  - Self-powered neutron detectors

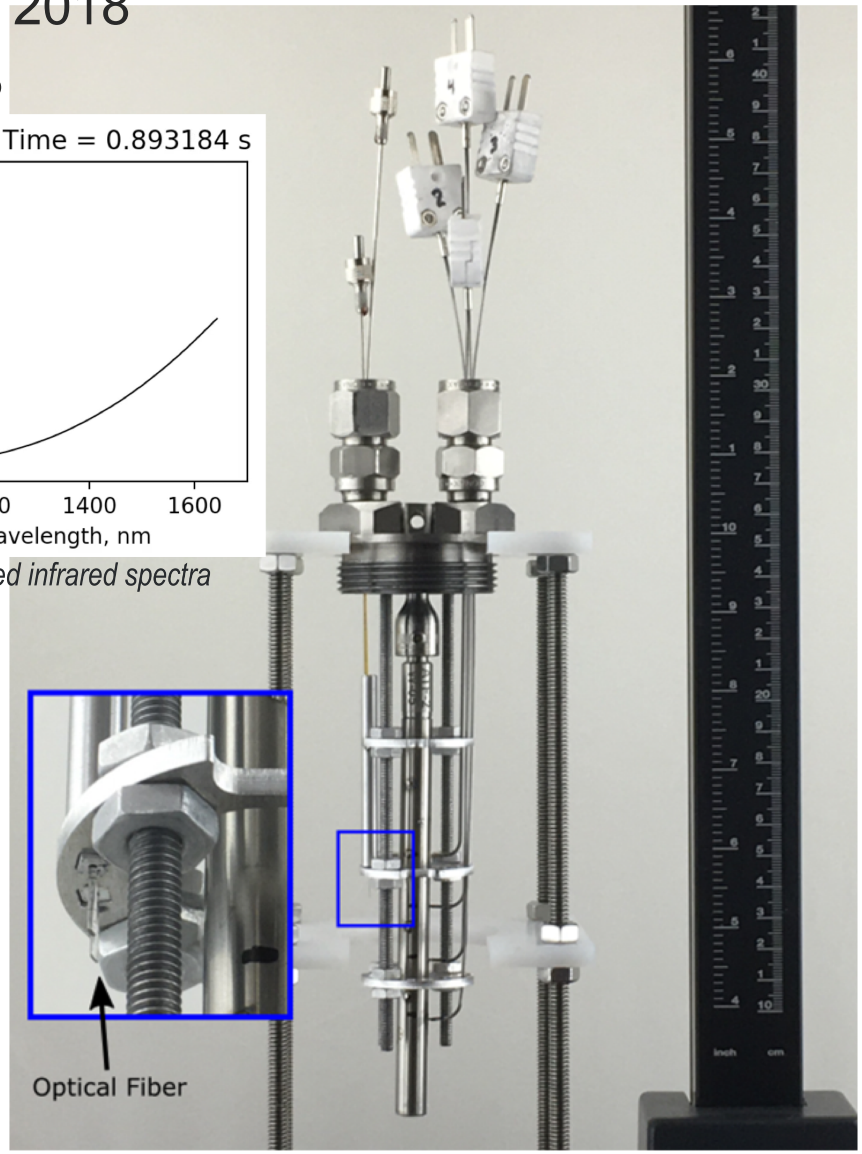




Example of measured infrared spectra during SETH



SPND data from summer 2018 transients



ATF SETH experiments: study specimen energy coupling with TREAT

Summary

- Instrumentation is a vital component of transient testing
  - Reactor access is superb!
  - In-pile testing of sensors ongoing since April 2018
  - TREAT will utilize significant quantities and varieties of instrumentation – focused in the near term on testing classical nuclear fuel forms (fuel in cladding)
- Wide range of environments under design for testing
  - Gas, Water, Sodium… molten salts?
- Device qualification requires thermal hydraulic and in-pile characterization and in-pile experiment hardware integration
  - Capabilities now exist to bridge proven technology into TREAT experiments – extending to pre-irradiated materials
  - Fuel rod refabrication and reinstrumentation is crucial tool for instrument strategy

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