INL/MIS-22-69612-Revision-0

TREAT Slide Decks for Alabama A&M

October 2022

Doug Crawford, Chad M Macready, Aaron E Craft

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Idaho Falls, Idaho 83415

http://www.inl.gov

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TREAT Overview

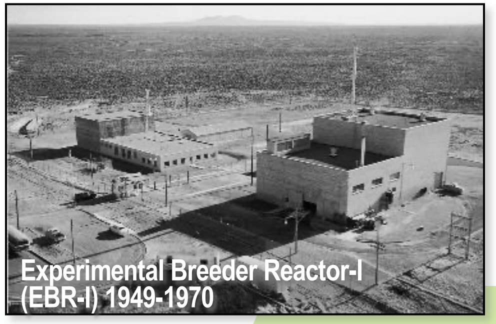
Presentation to Alabama A&M

Materials & Fuels Complex, Idaho Falls, ID

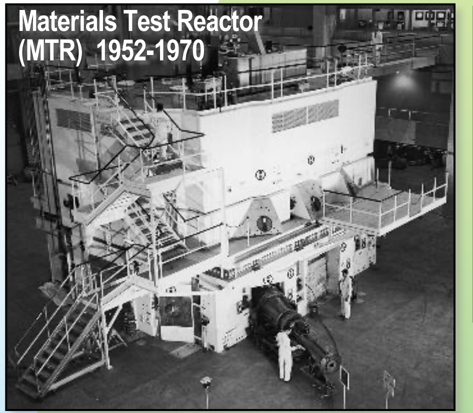
Idaho National Laboratory

INL’s beginning as National Reactor Testing Station

- Established in 1949 on 890 square miles of remote federal land
- Argonne’s EBR-I was the first reactor for the nation’s new test bed
- Materials Test Reactor followed soon after to provide irradiation testing of fuels and materials for other reactors in planning stages


Experimental Breeder Reactor-I (EBR-I) 1949-1970


S1W aka Submarine Thermal Reactor (STR)

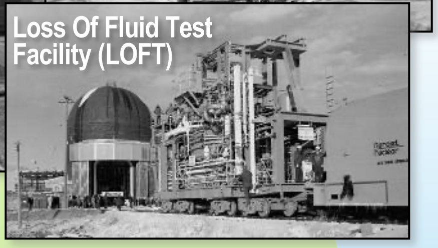

Materials Test Reactor (MTR) 1952-1970

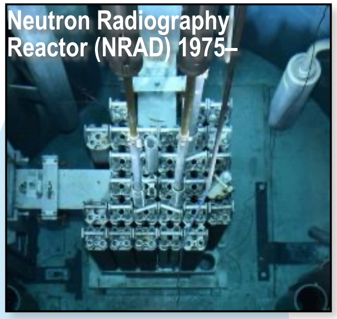

Special Power Excursion Reactor Tests I though IV (SPERT)

- Additional reactor concepts explored transient and other safety testing to help validate safety codes
- Thermal hydraulic systems testing

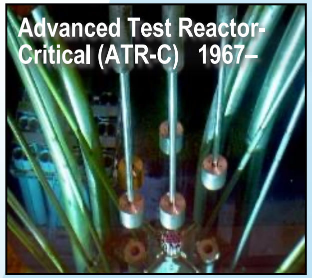

Experimental Breeder Reactor-II (EBR-II) 1964-1994


Power Burst Facility (PBF) 1972-1985


Loss Of Fluid Test Facility (LOFT)


Neutron Radiography Reactor (NRAD) 1975–


Transient Reactor Test Facility (TREAT) 1959-1994 2017--


Advanced Test Reactor-Critical (ATR-C) 1967–


Advanced Test Reactor (ATR) 1967–

1949 | 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s

World's Energy Future

INL Facilities

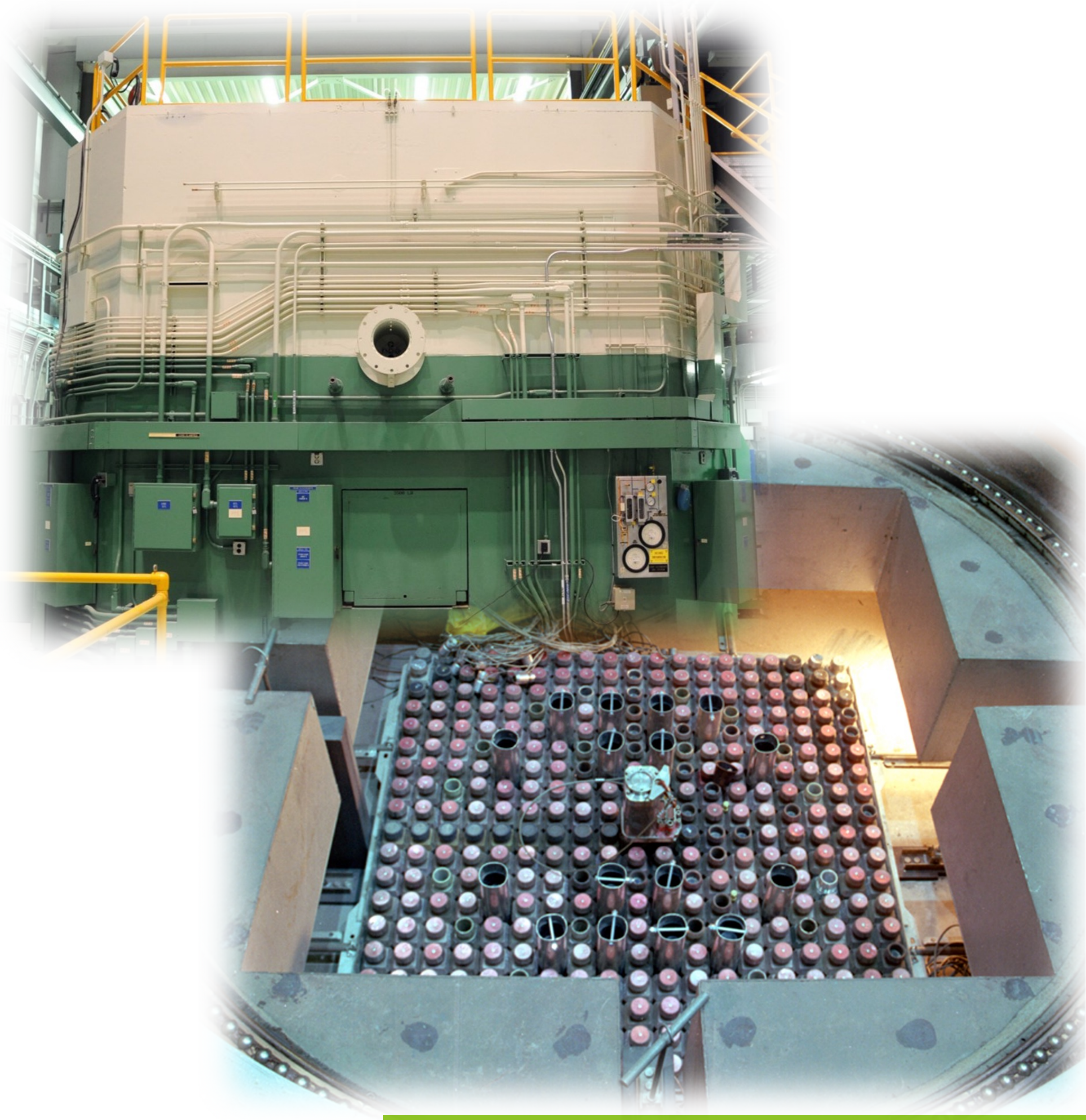
TREAT Reactor

Purpose:

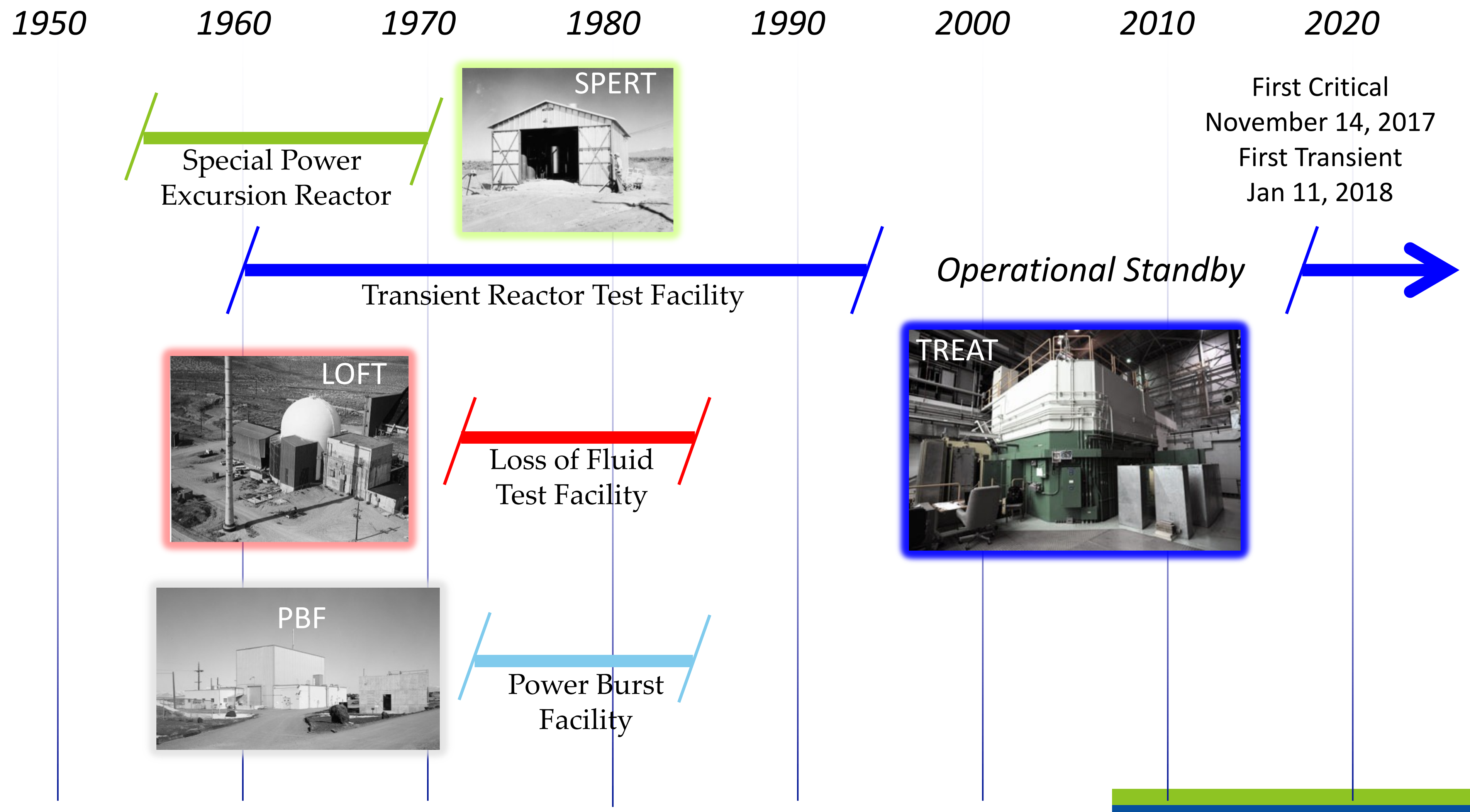
- Demonstrate reactor fuel performance phenomena under extreme (accident) conditions
- Determine safety limits of reactor fuels

Capabilities:

- High-intensity (20 Gigawatts), short-duration (<100 ms) neutron pulses for severe accident testing
- Shaped transients at intermediate powers and times (flexible power shapes up to several minutes)
- Testing capability for static capsules and flowing coolant loops
- Neutron-radiography facility for pre- and post-irradiation imaging
- Neutron "hodoscope" provides real-time imaging of fuel motion during testing
- Air cooled open-core design facilitates instrumentation for experiments

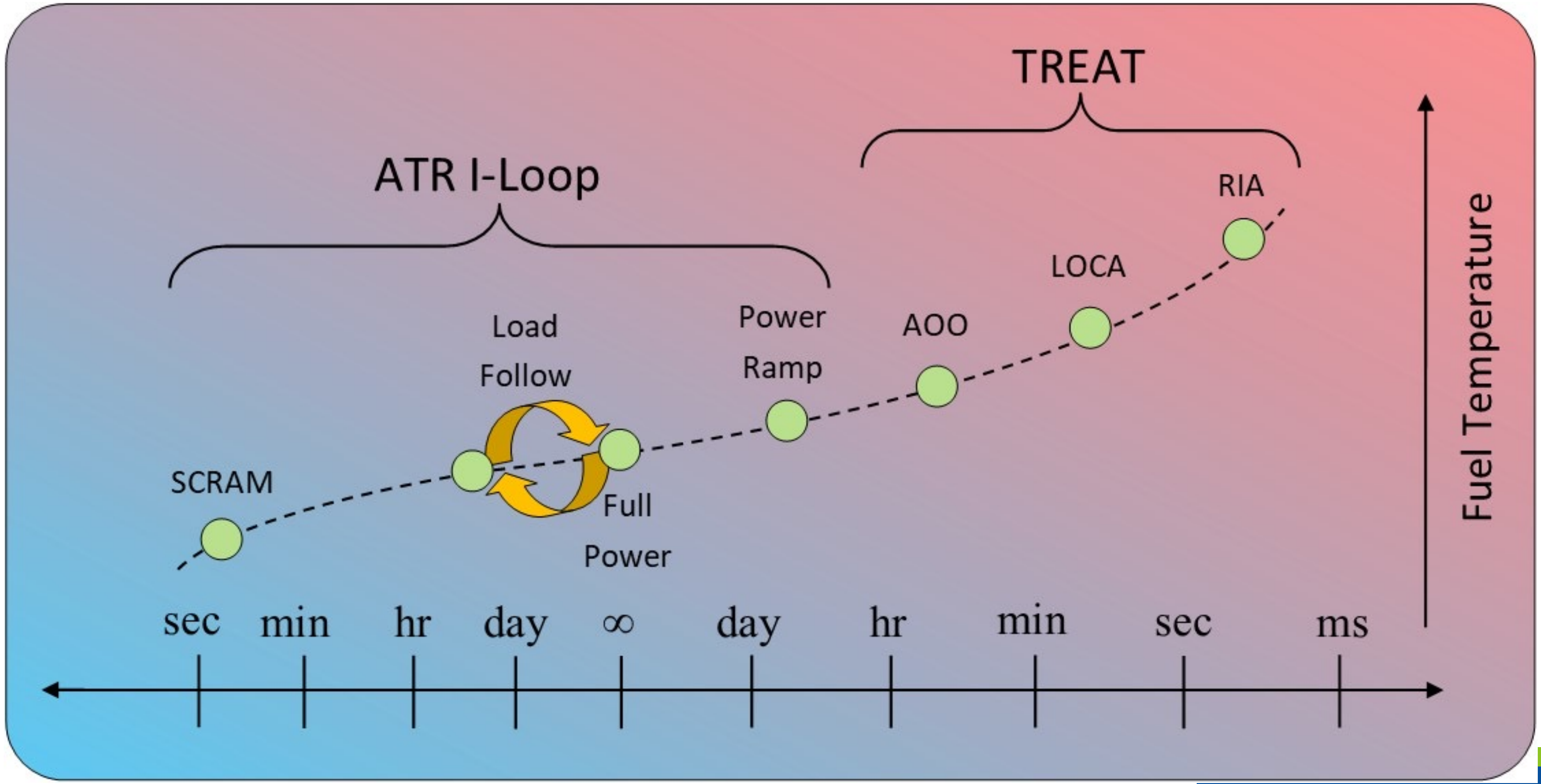


History of Fuel Safety Research at INL

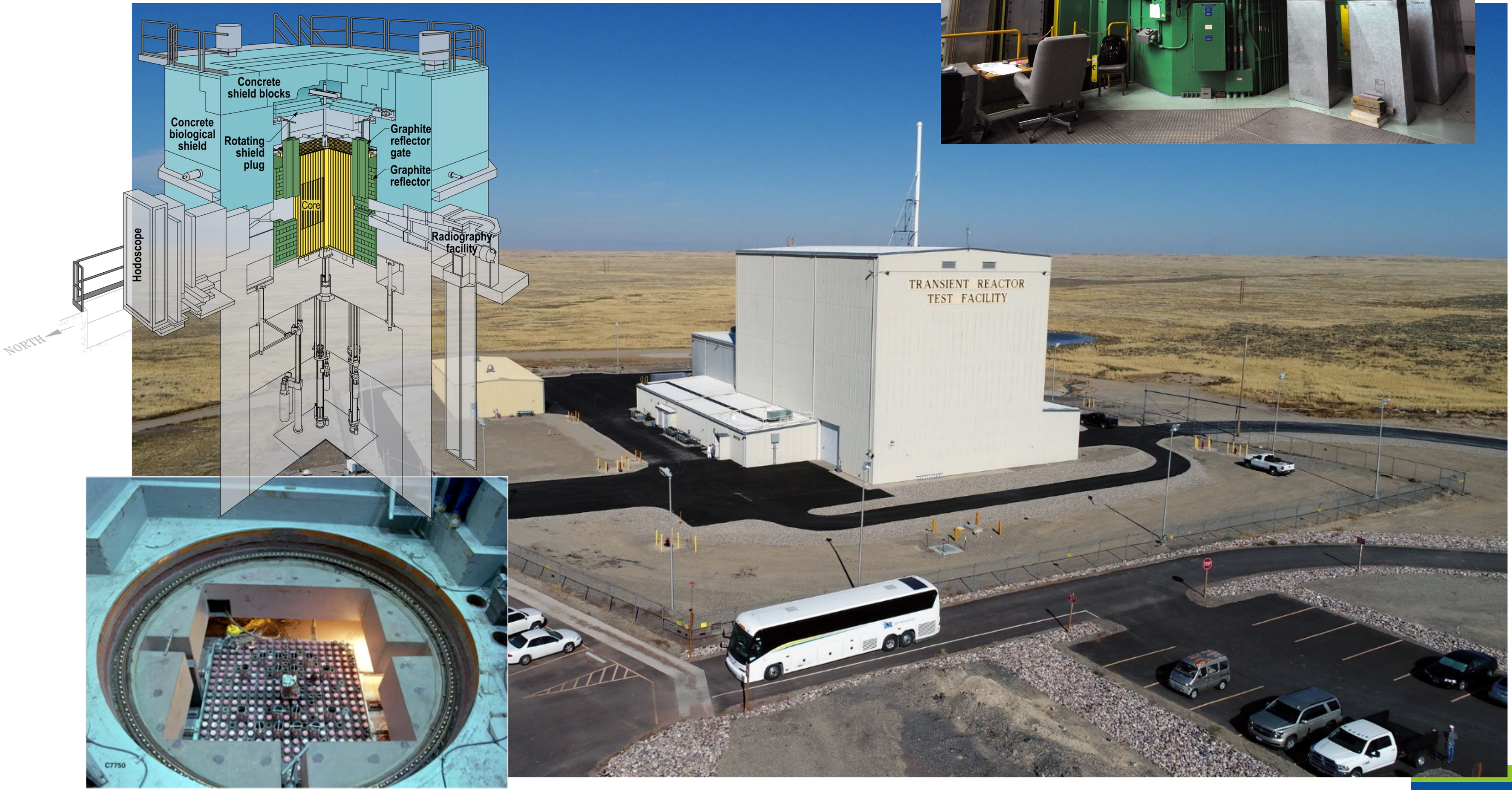


Transient Timescale Domains

- ATR I-Loops and TREAT together cover full range for integral-scale nuclear-heated transient testing needs



Transient Reactor Test Facility (TREAT)



- Up to 120 kW Steady-state power with 20 GW Peak Transient Power
- Core: ~1.2 m high x 2 m. dia.; surrounded by 0.25 m graphite reflector
- 19 x 19 array of 10 x 10-cm. configurable fuel and reflector assemblies
- Fuel: UO_2 dispersed in graphite
- 12 steady-state and 8 transient control rods
- Instantaneous, large negative temperature coefficient (self protecting driver core)
- Co-located at MFC with hot cells and fuel fabrication facilities

MFC Aerial SE to NW

MFC Aerial NW to SE

TREAT Reactor Area

TREAT Reactor and Operating Floor

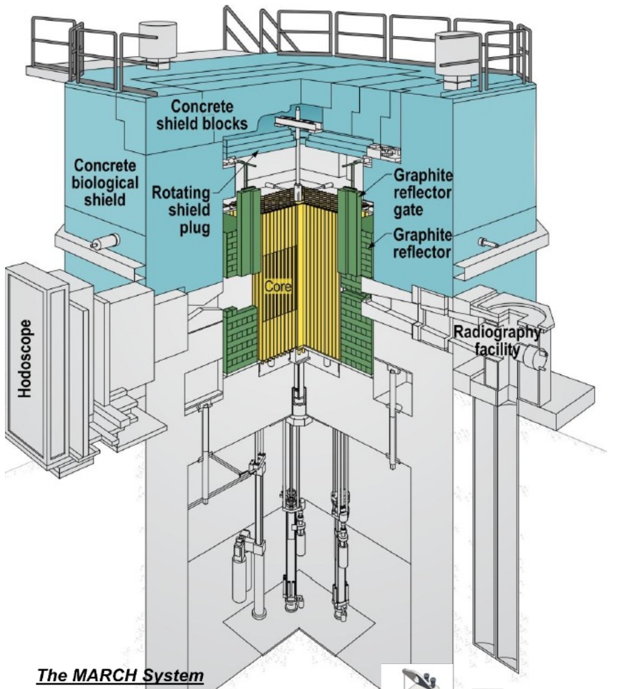
TREAT Experiment Insertion

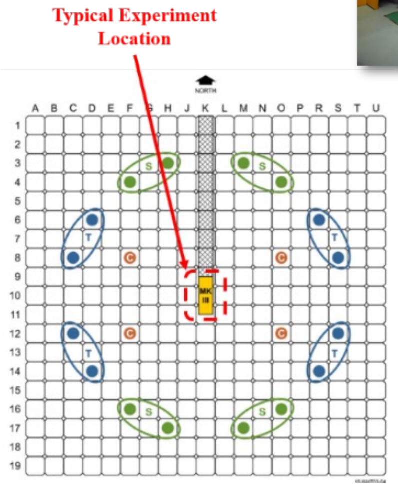
TREAT Control Area

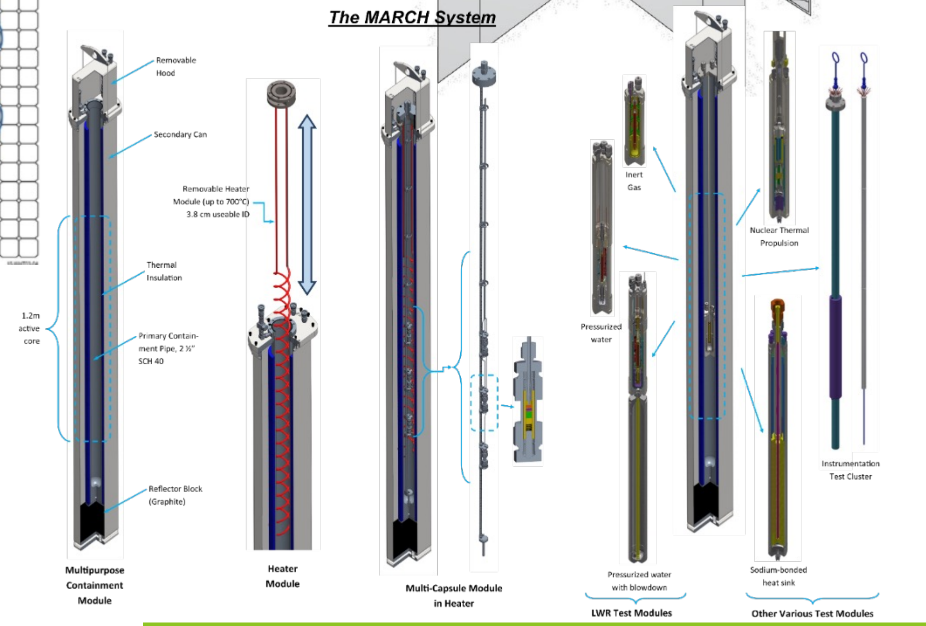
TREAT Control Room

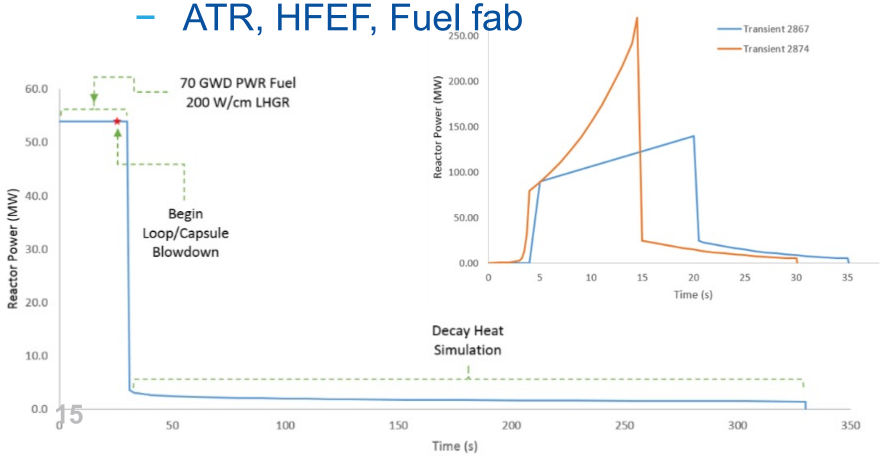
TREAT Features

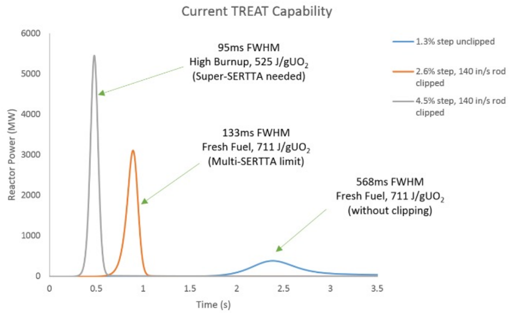
- Zircaloy-clad graphite/fuel blocks comprise core, cooled by air blowers
  - 120 kW steady state, ~20 GW peak in pulse mode
  - Virtually any power history possible within 2500 MJ max core transient energy
  - No reactor pressure vessel, facilitates access for in-core instrumentation
- 4 slots view core center
  - 2 in use for fuel motion monitoring system and neutron radiography
- Experiment design
  - Reactor provides neutrons, experiment vehicle does the rest
  - Safety containment, specimen environment, in-situ instruments
  - Handled outside concrete shield in cask
  - Tests displace a few driver fuel assemblies
- Collocated at INL with other complimentary facilities
  - ATR, HFEF, Fuel fab



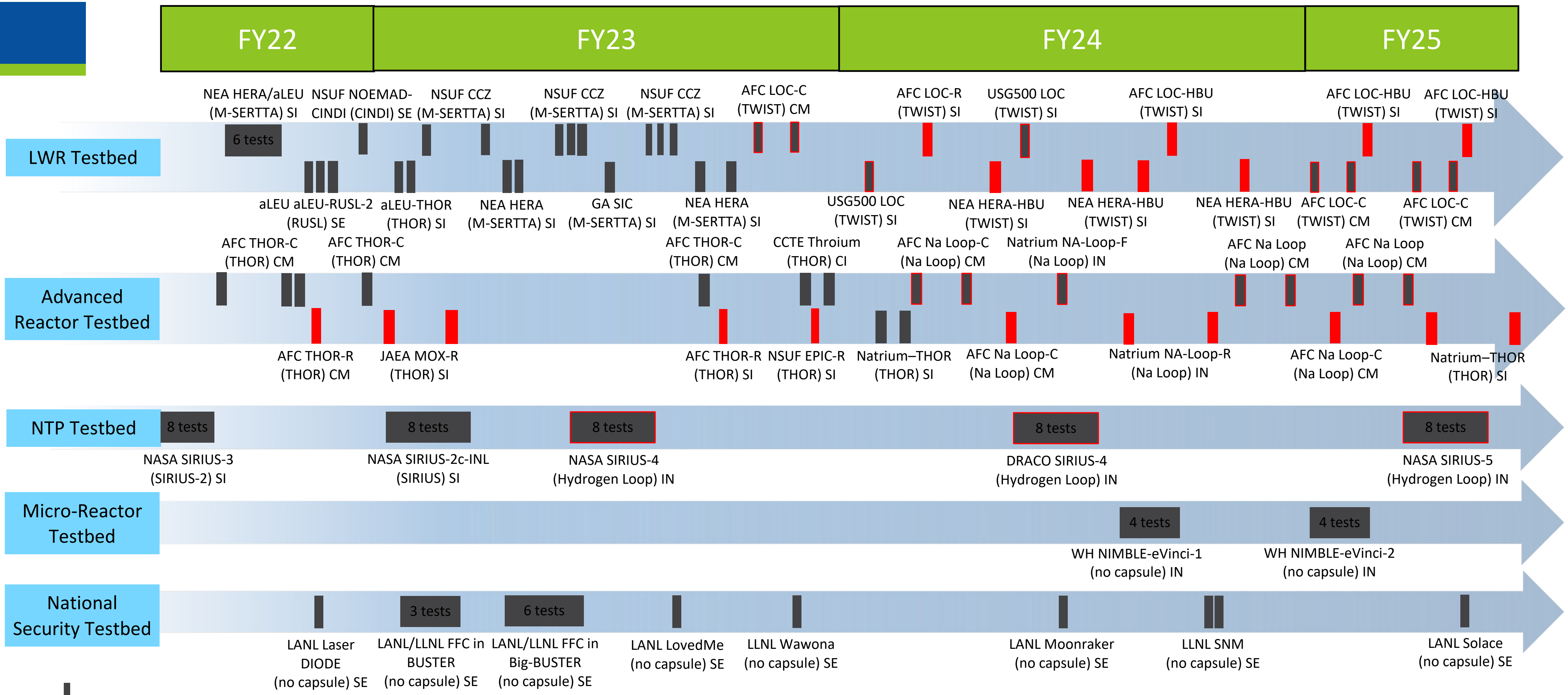








Projected TREAT Utilization



Fresh Fuel Test

Pre-irradiated Test

Labeling:

1. Who the Test is for (AFC, NSUF, aLEU, etc.)
2. Experiment Name (LOC-C, LOC-HBU, THOR-C, etc.)
3. Test Capsule to be used (THOR, TWIST, MARCH-SERTTA, etc.)
4. Type of Experiment (SE, CM, SI, or IN)

Experiment disassembled in TREAT or HFEF

Type of Experiment Key:

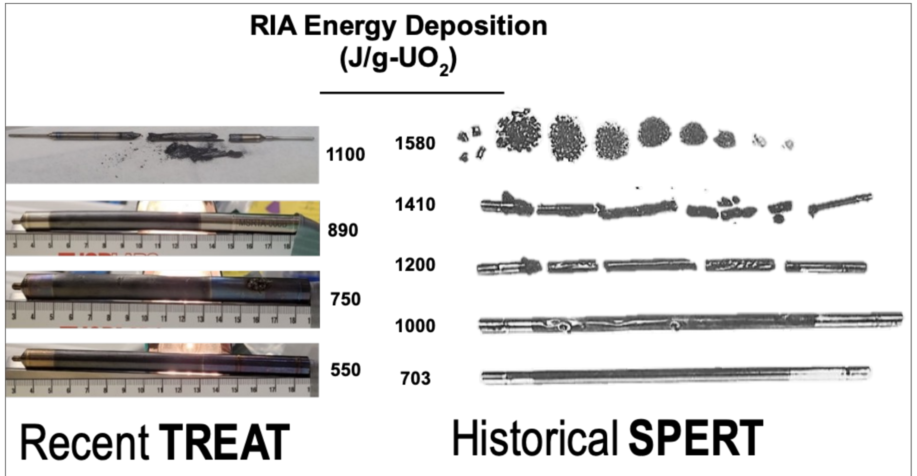
SE	Separate Effects
CM	Commissioning
SI	Semi-Integral Tests
IN	Integral Tests

Typical Experiment Lifecycle

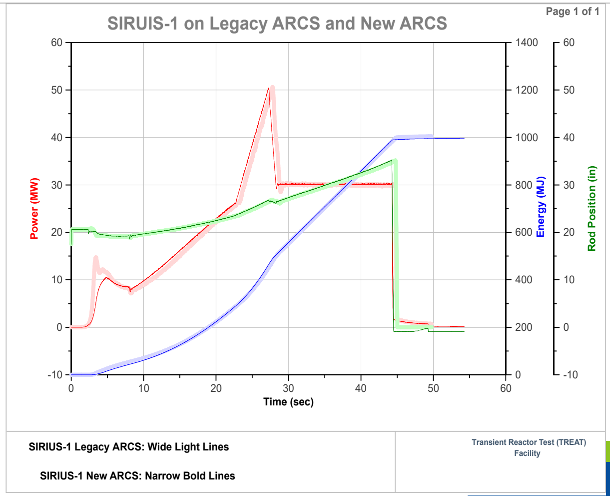
Design ~6 months → **Fabricate ~3-12 months** → **Irradiate** → **PIE ~12 months**

Recent Transient Reactor Test Facility Accomplishments

- **Reactivity Initiated Accident testing**
  - Commissioning test series ATF-RIA-1 and ATF-RIA-R now complete,
  - Demonstrated capability for RIA testing of ATF rod prototypes and previously-irradiated fuel
- **NASA Sirius test series – NTP ramp rates**
  - Sirius 1 test series completed on schedule at the EoFY19
  - Sirius 2-a completed in FY20; Sirius 2b in FY21
  - Hydrogen test loop for Sirius-4 in design process
- **Update to Automatic Reactor Control System (ARCS)**
  - Completed on schedule (as modified for COVID-19 curtailment delay)
  - Replaced home-built 1980s-era hardware and obsolete software
- **Continuing to add to testing capabilities**
  - Collaborating with TerraPower to build and test a flowing sodium test loop



Recent TREAT RIA commissioning experiment results on UO2/Zry rods compared to historical SPERT CDC results



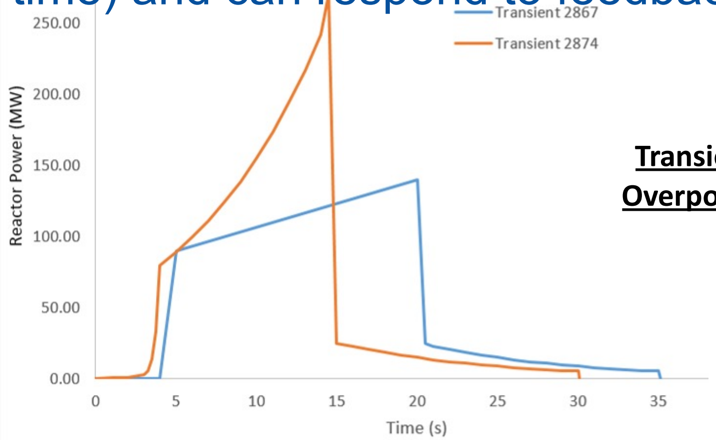
DRIFT-UO_2 capsule ready for insertion into a TREAT experiment vehicle

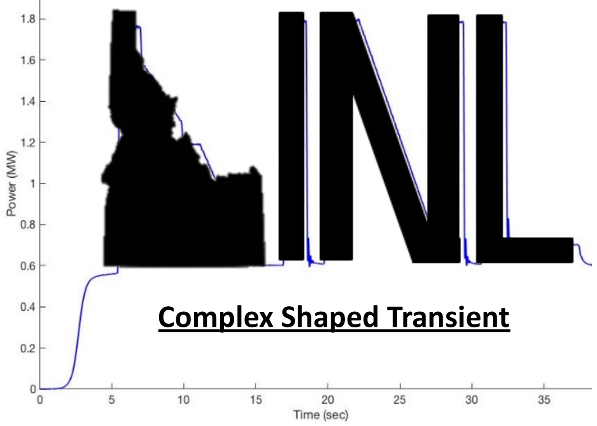
Backup

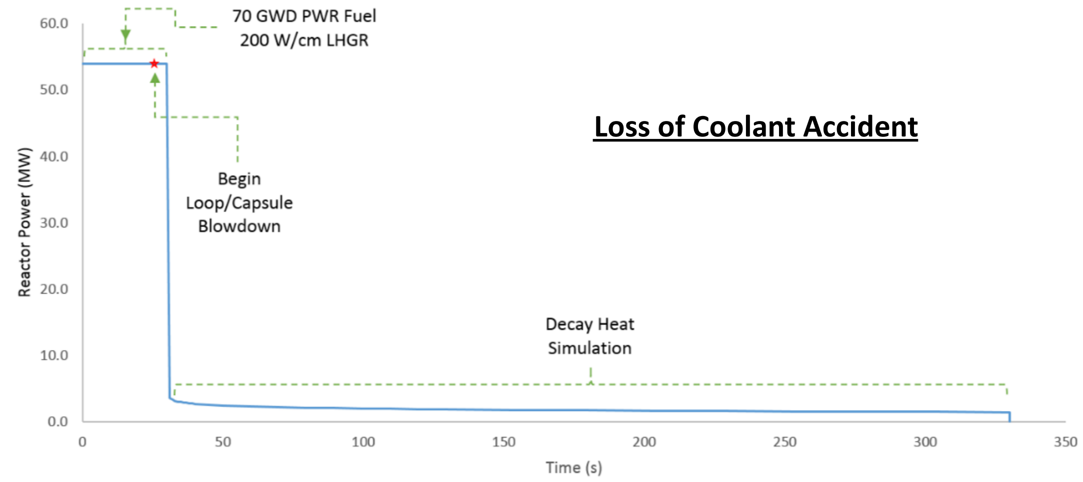
Idaho National Laboratory

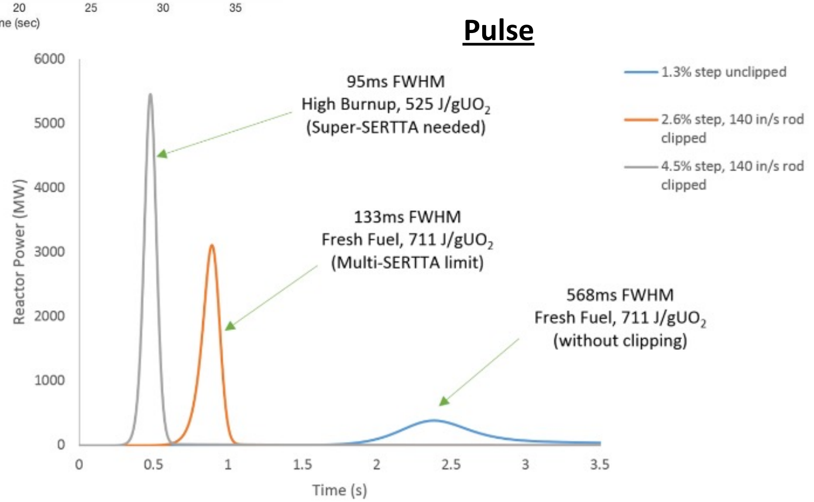
Transient Shaping with ARCS

- TREAT is a *transient* reactor, not only a pulse reactor
- Graphite heat sink, nimble control rod system → flexible power maneuvers
- Automatic Reactor Control System (ARCS) can shape transients (power vs. time) and can respond to feedback from experiment instrumentation









October 5, 2022

Aaron Craft, Ph.D.
Research Scientist &
Nuclear Engineer

Flash Neutron Radiography

Fostering discussions with Alabama A&M

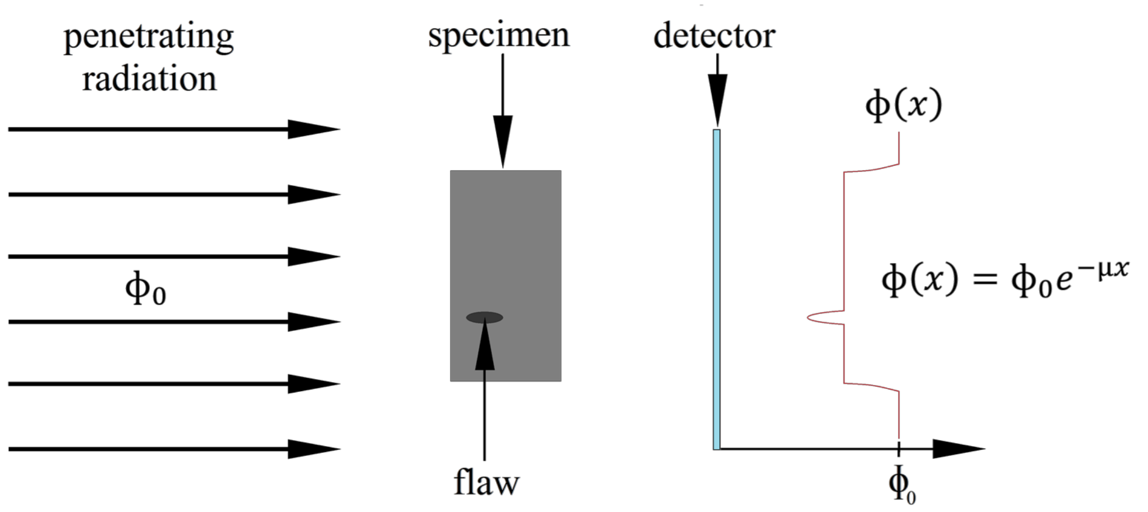
Transient Testing

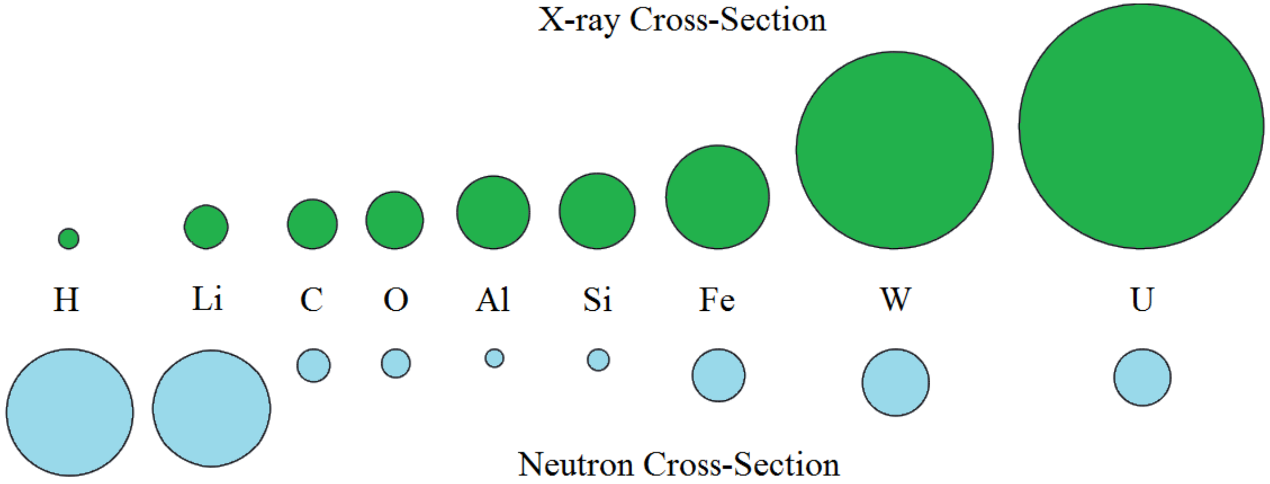
- Determine safety limits prior to implementation.
- Crash testing a car
- Determine performance in off-normal conditions:
  - Rollover accident, impacts

Transient Testing

- Determine safety limits prior to implementation.
- Crash testing **nuclear fuel**
- Determine performance in off-normal conditions:
  - Undercooling and overpower mismatch

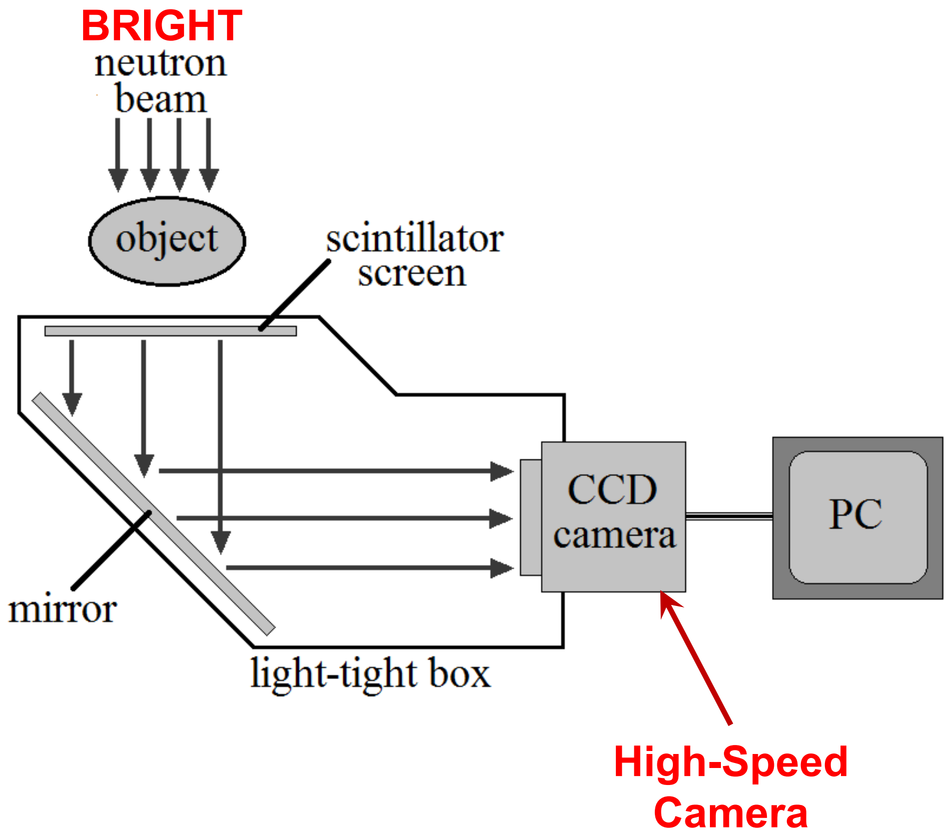
BRIEF Introduction to Neutron Radiography

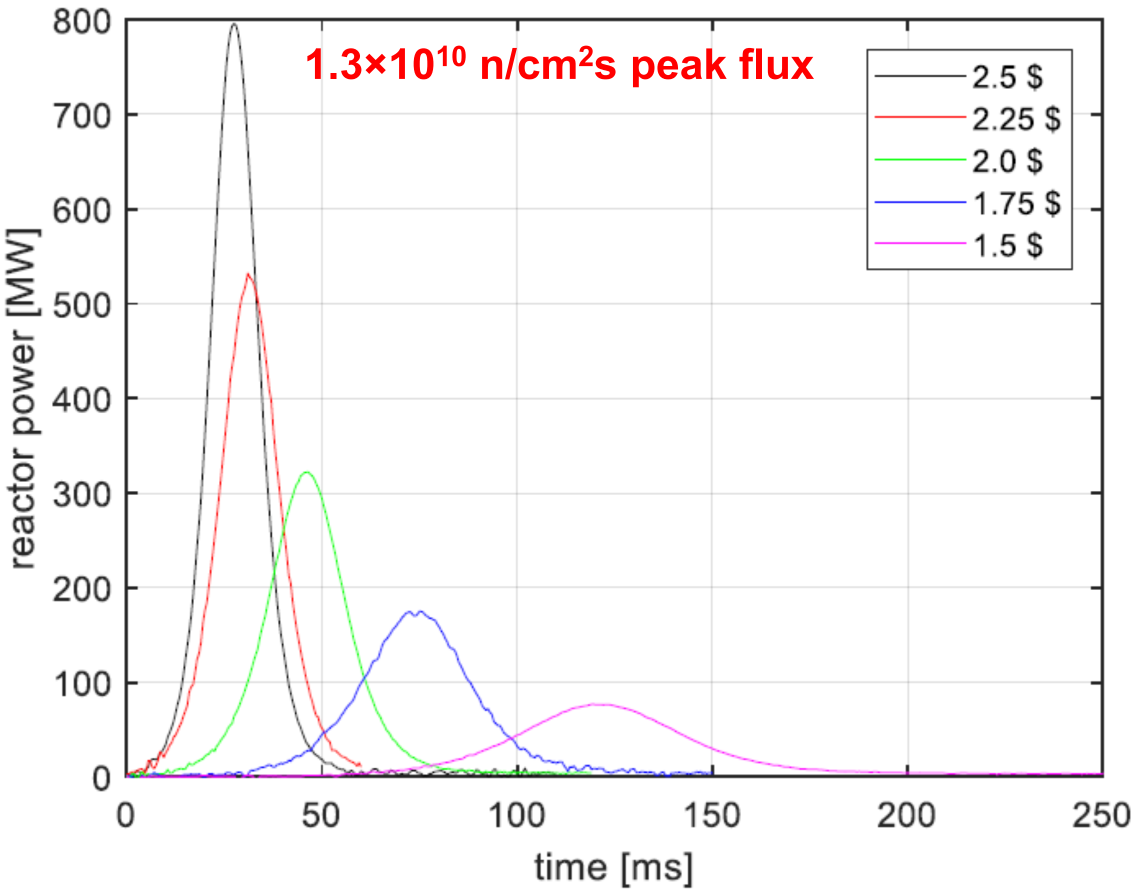




Neutron Radiograph

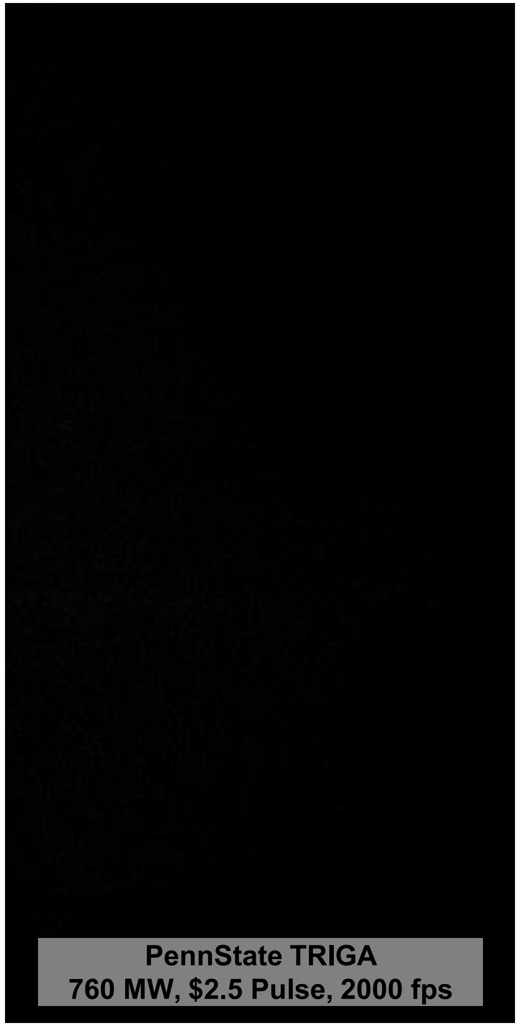
Flash Neutron Radiography

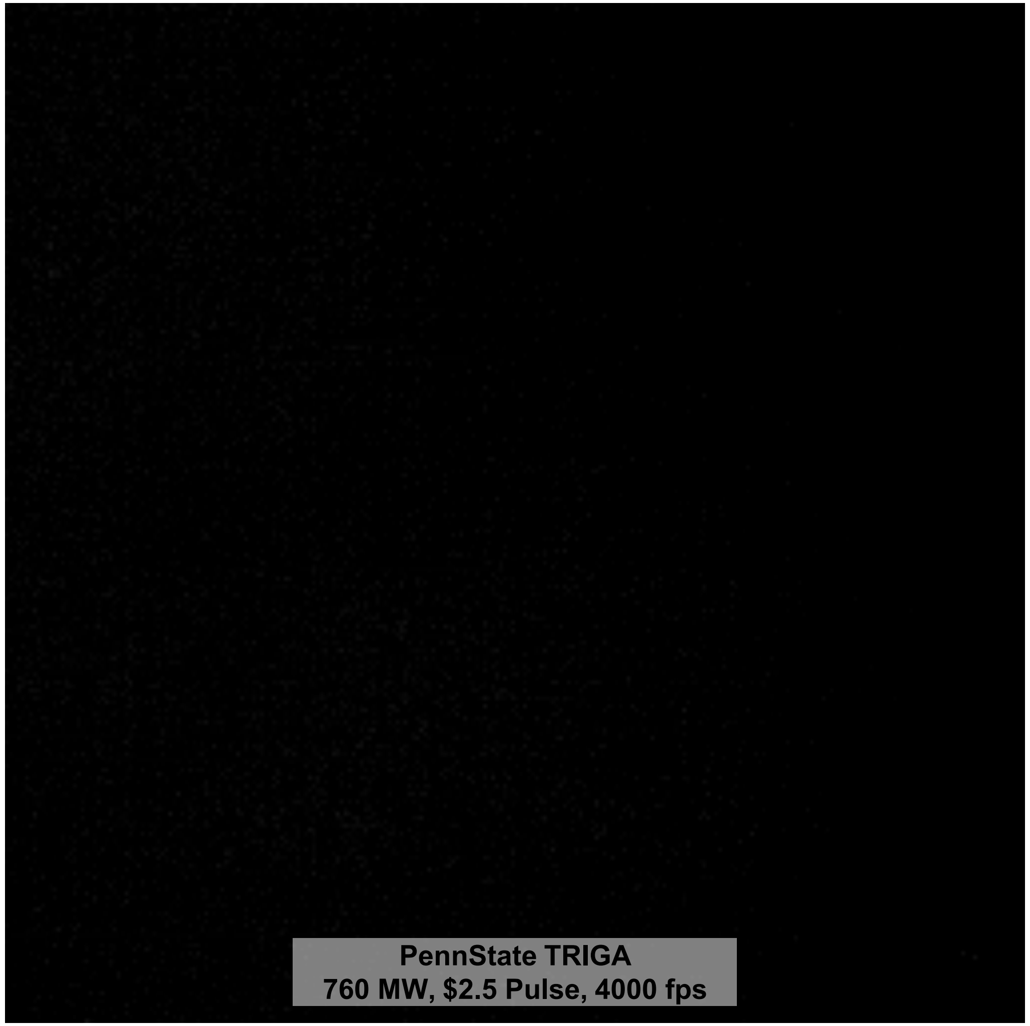


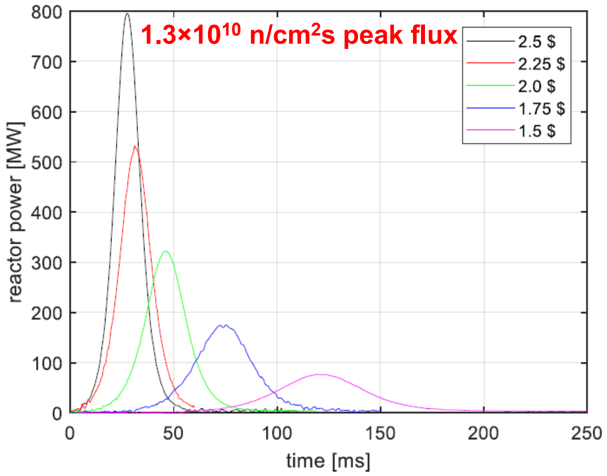


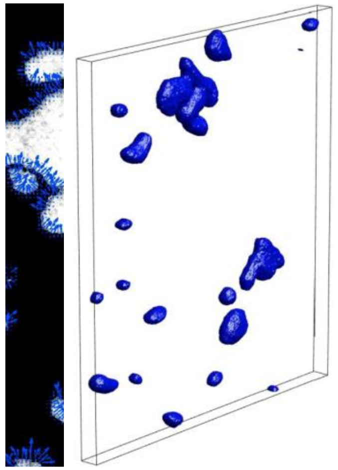
3. Lani, C. and Zboray, R. (2018) “Development of a high frame rate neutron imaging method for two-phase flows.” Nuclear Instruments and Methods, A. In press.
4. Lerche, M., Tremsin, A.S. and Schillinger, B. (2015). “Bright Flash Neutron Radiography at the McClellan Nuclear Research Reactor.” Physics Proceedia 69, 299-303.

Flash Neutron Radiography at Penn State









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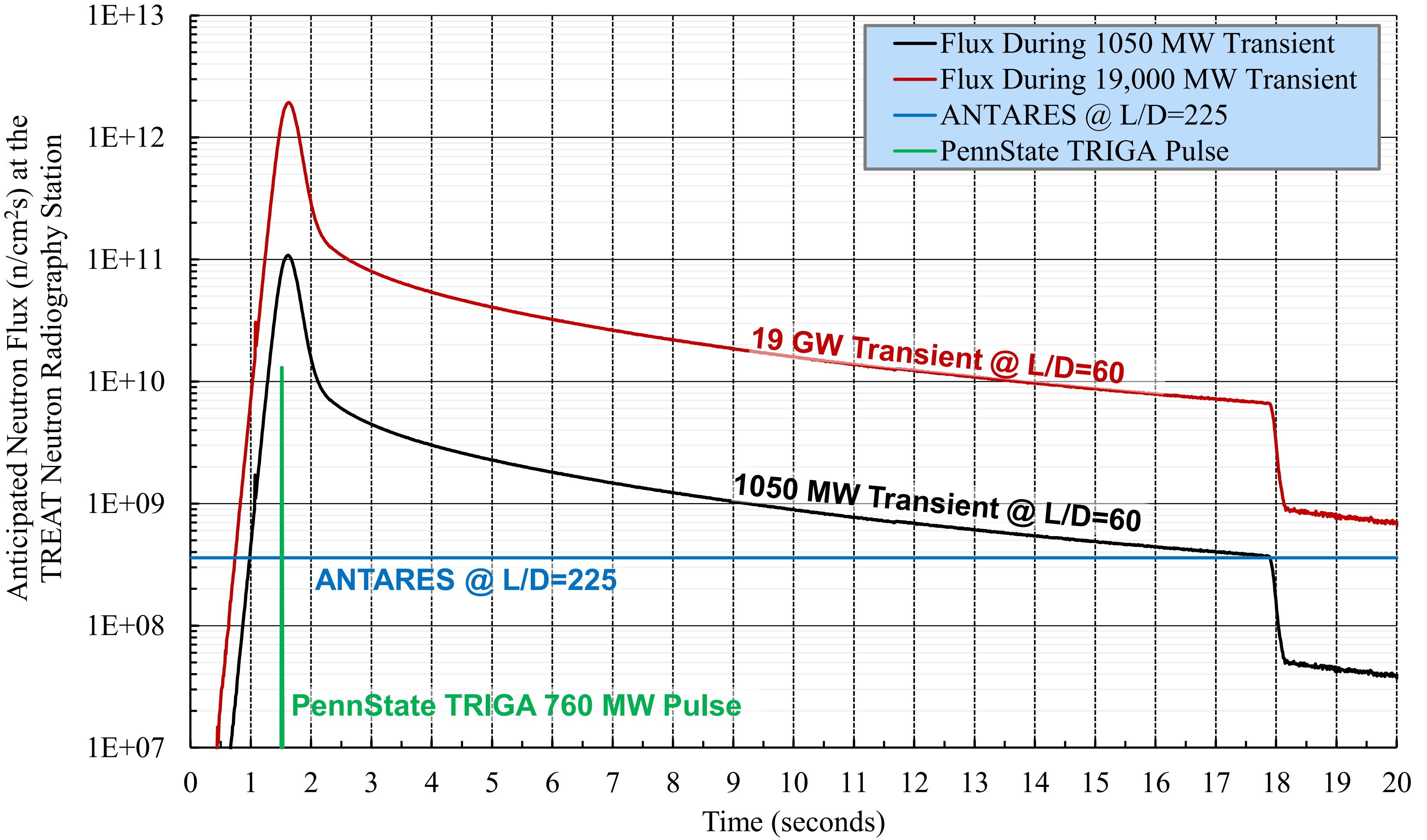
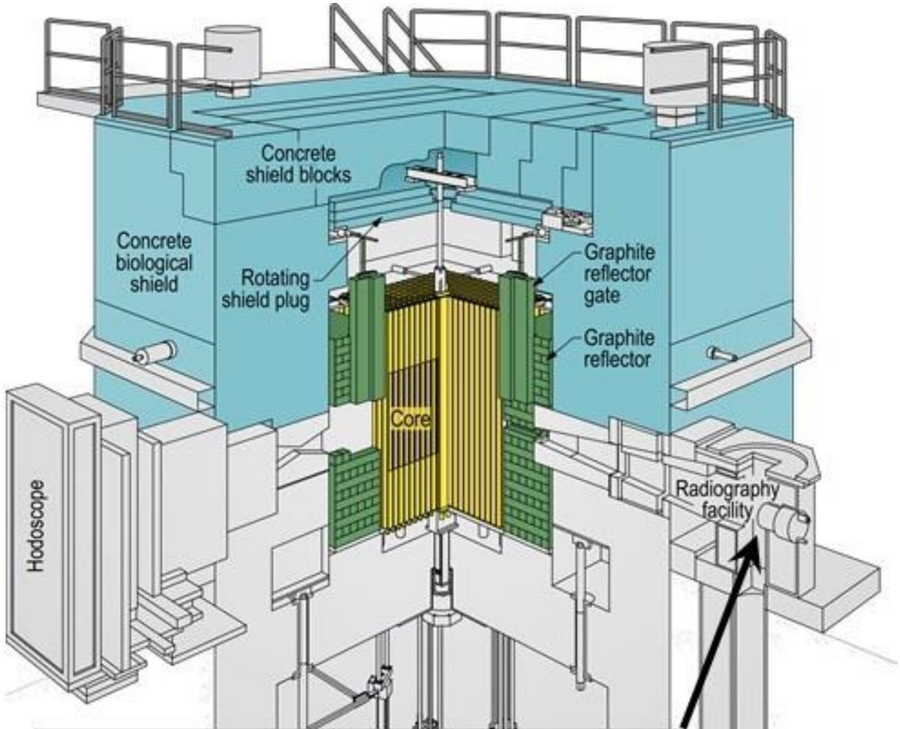
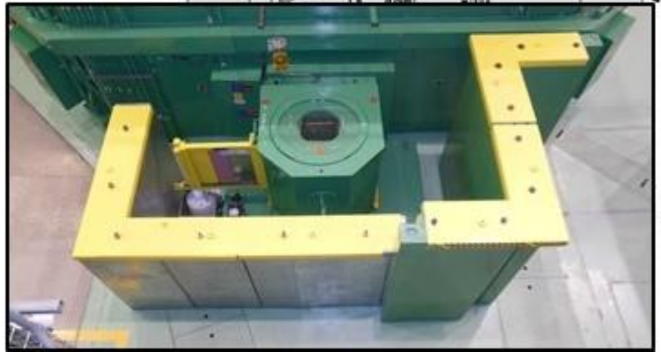
TREAT has the brightest beam in the world!



Install a digital system behind the TREAT NR Station





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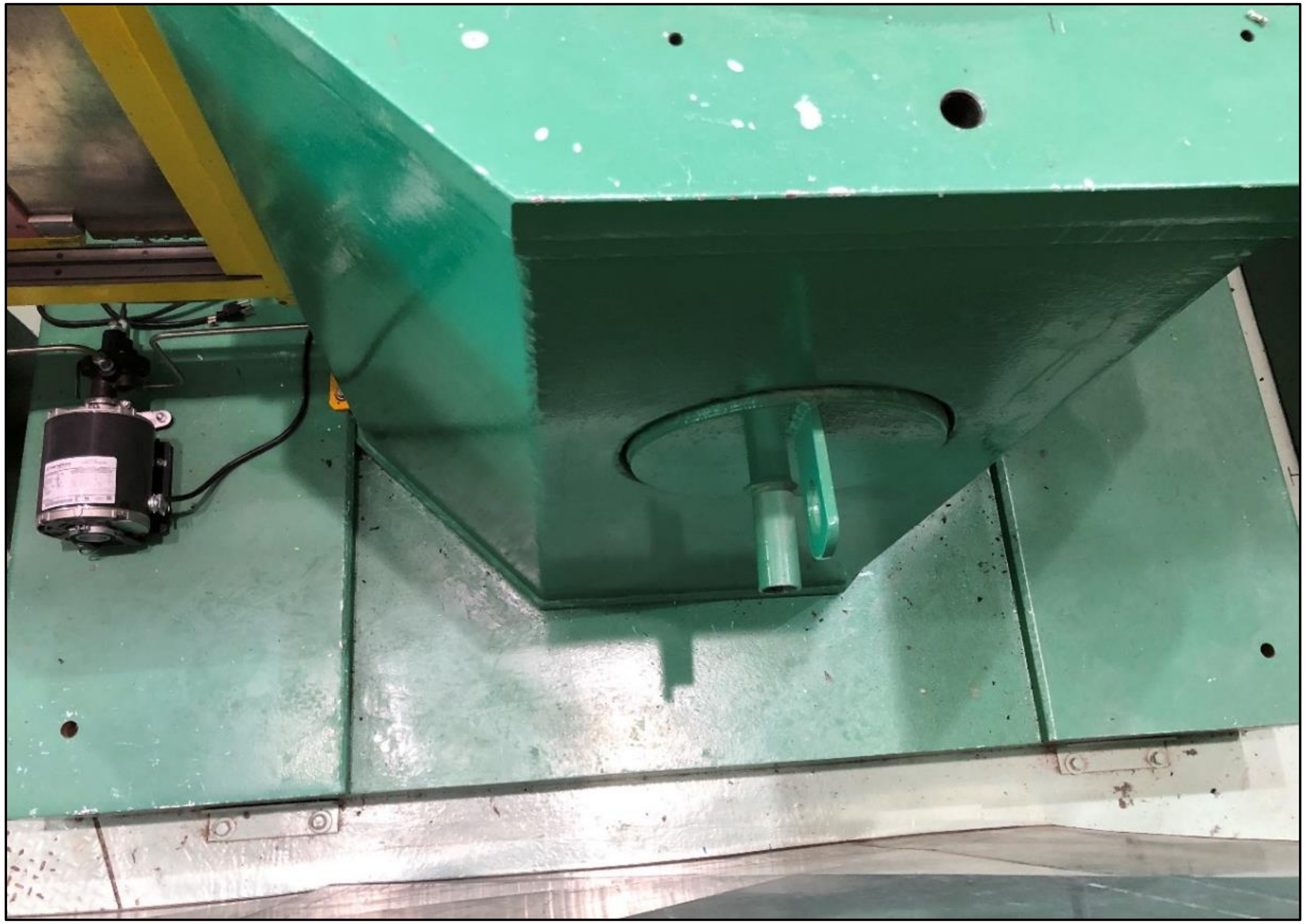
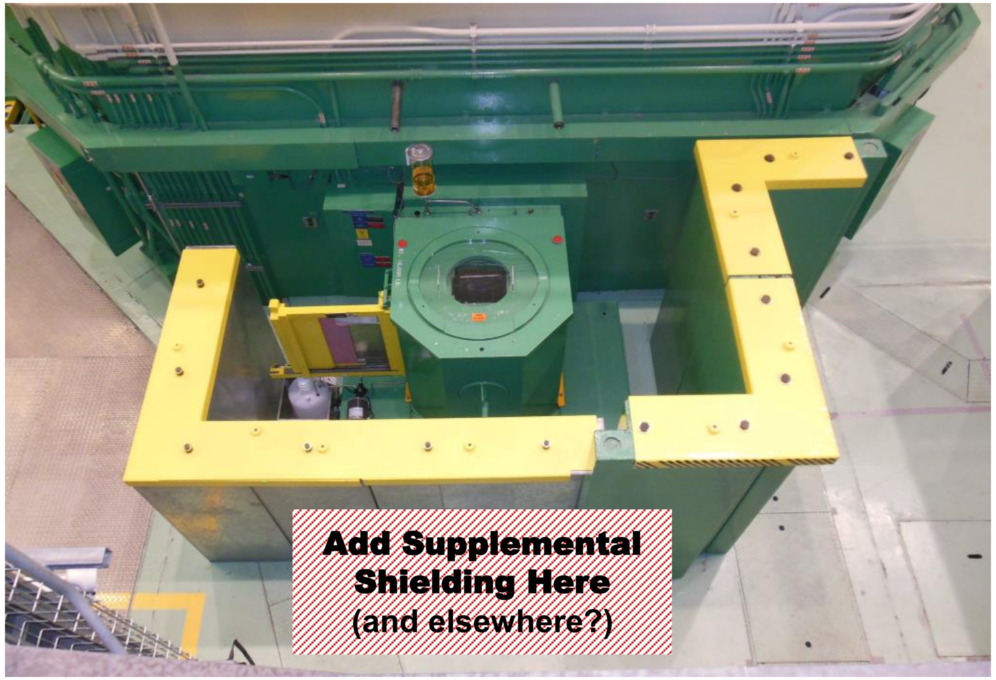
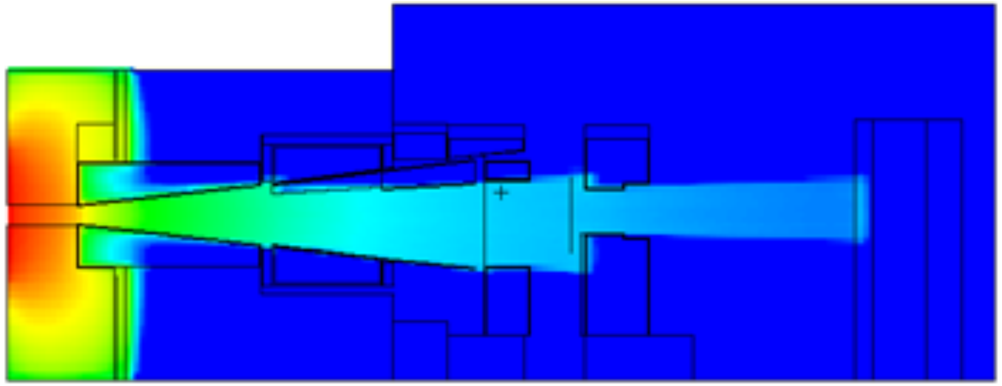
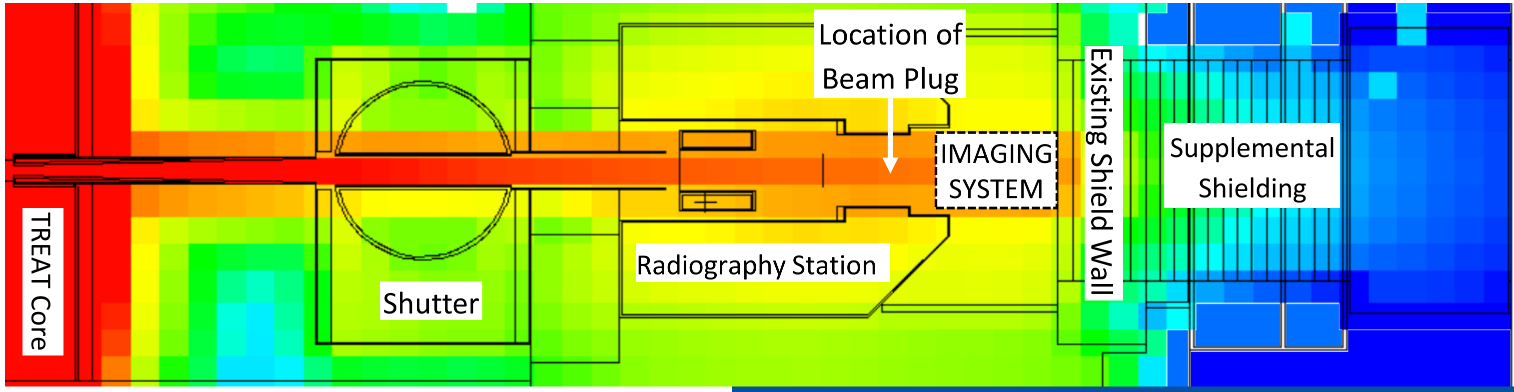


Shutter Open During a Transient – Radiation Shielding Mods

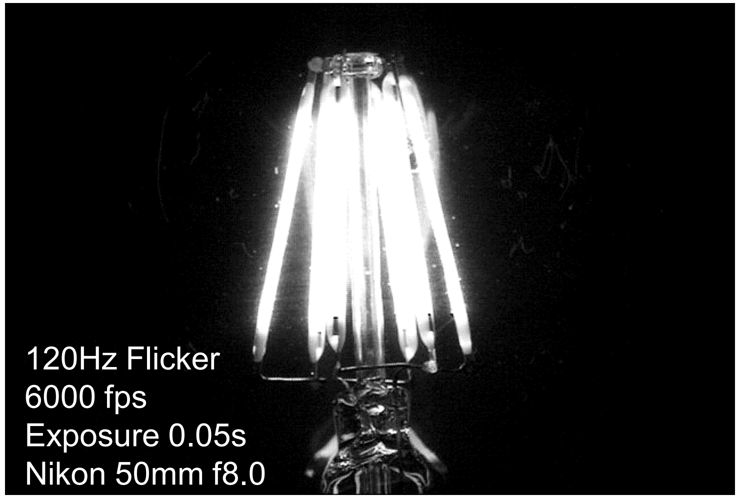


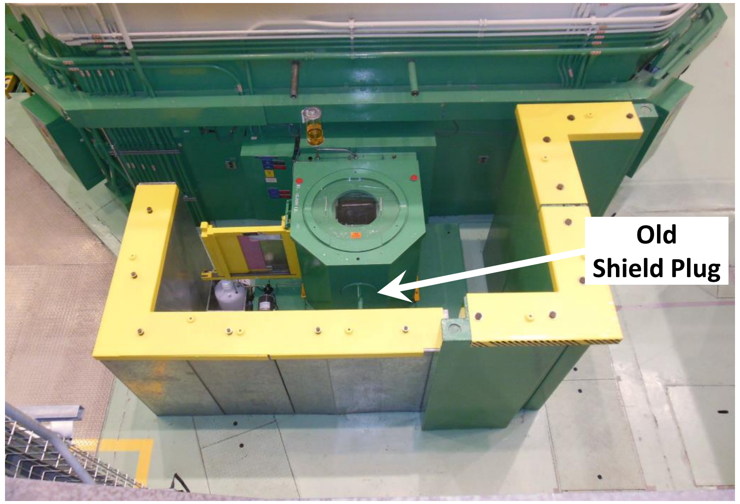
Requires radiation shielding calculations using MCNP



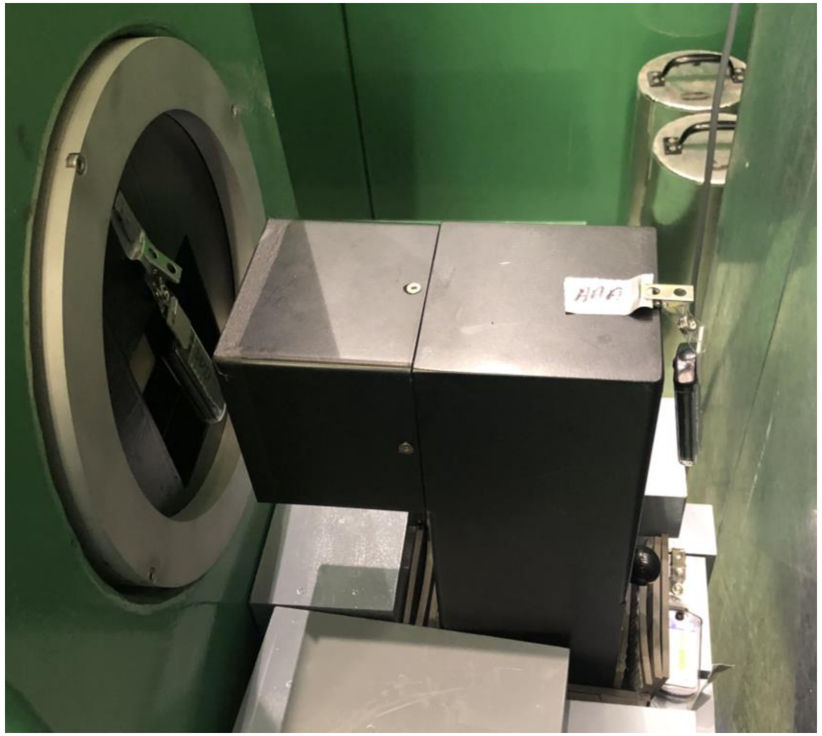


Developing the Hardware





First Measurements



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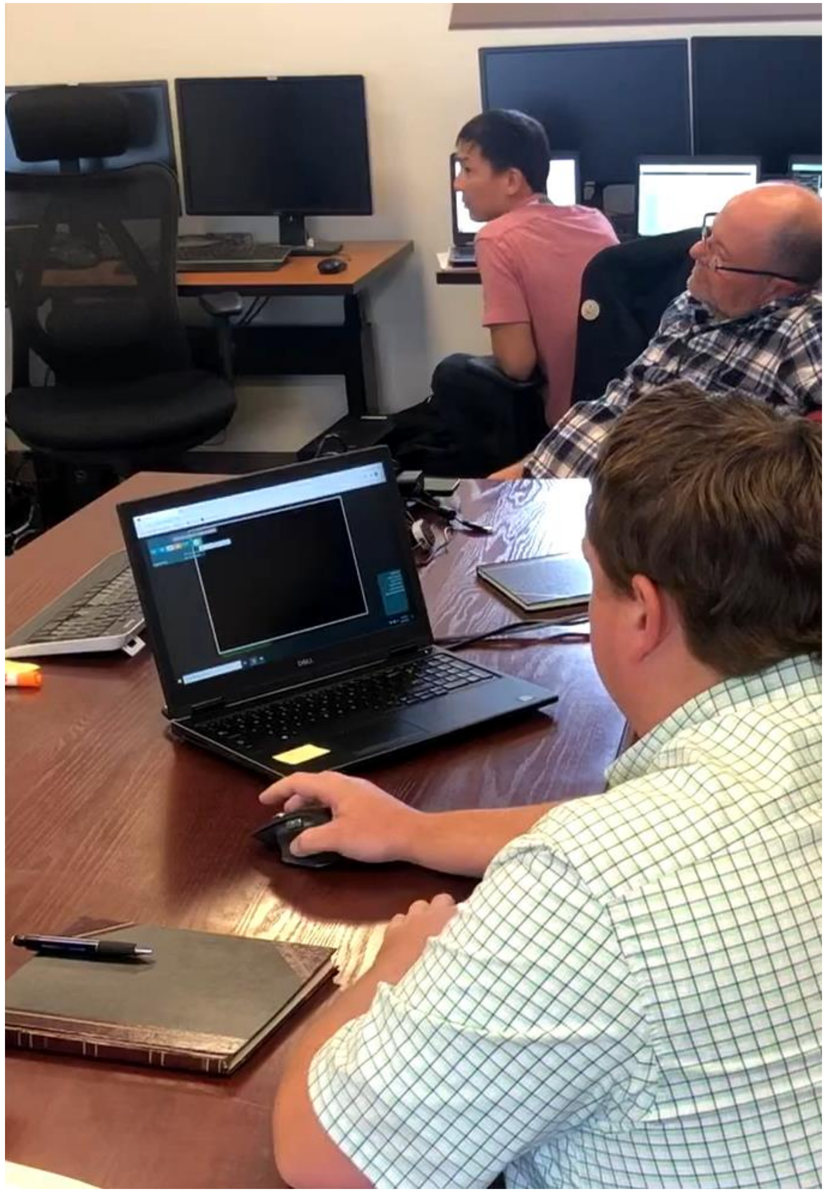

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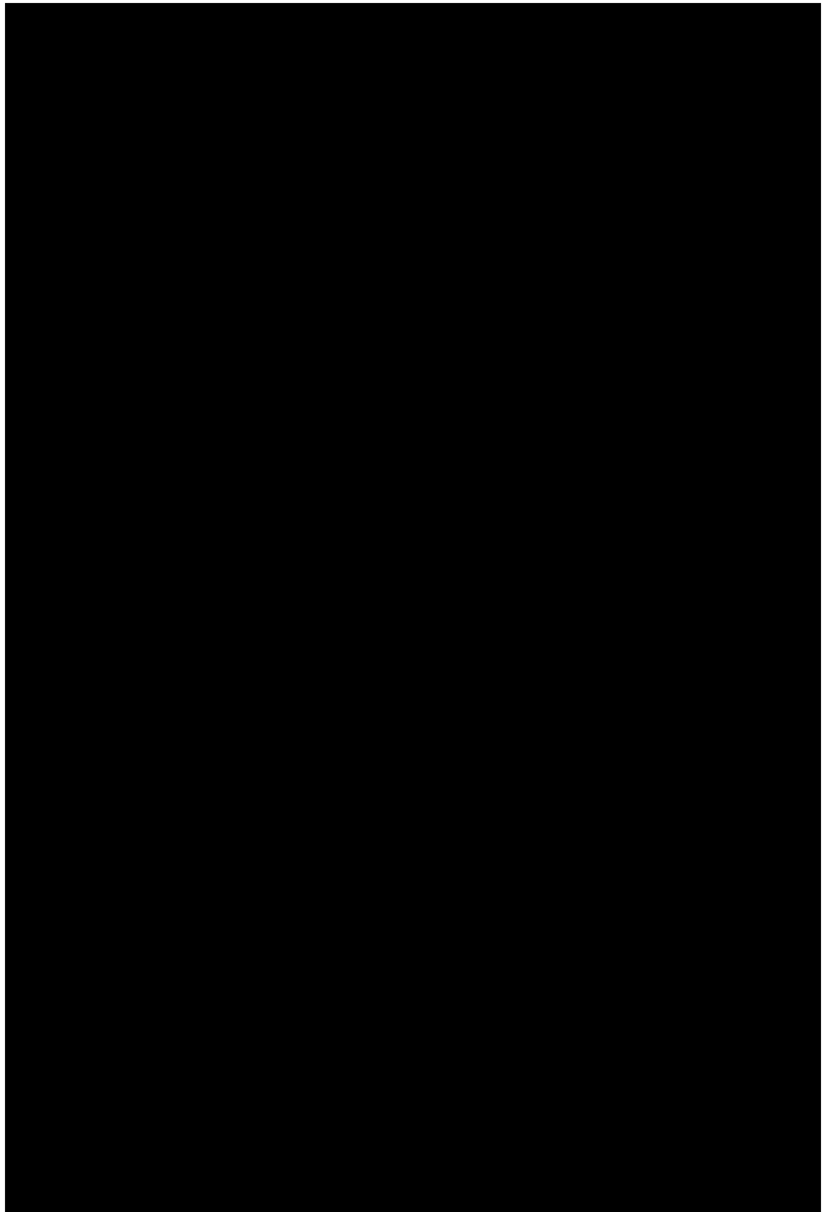

- Acquired during a **7,800 MW** peak transient:
- Neutron beam flux = **7.7×10^{11} $cm^{-2}s^{-1}$**
  - Brightest neutron imaging beamline in the world.
- Possible frame rate of ~30,000 fps
  - Current state of the art is ~4000 fps
- The high-speed neutron imaging system at TREAT <u>enables science that was previously impossible</u>.

- But we **need supplemental radiation shielding**.

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.