TREAT Restart and Transient Testing Program

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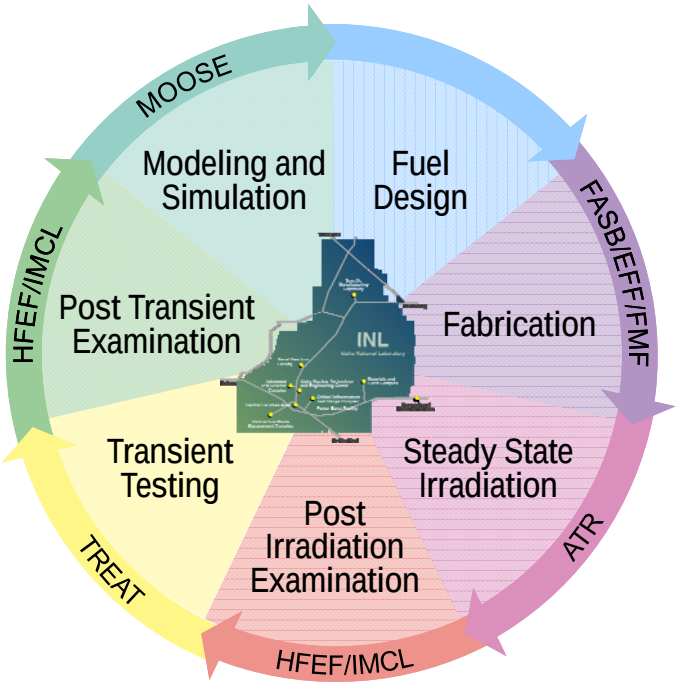
www.inl.gov

Idaho National Laboratory

Why is TREAT so Important?

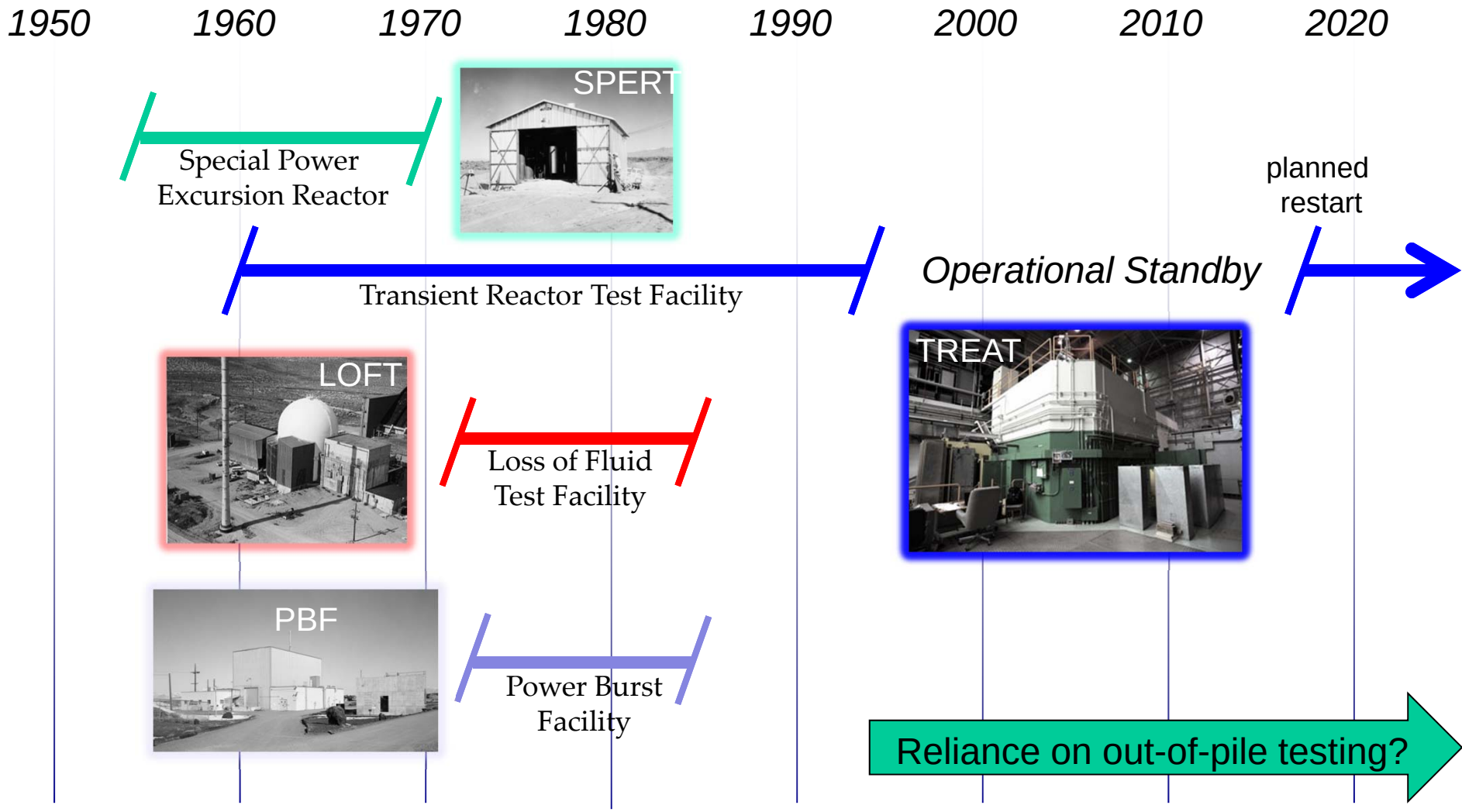
- **Nuclear fuel technology development requires a comprehensive suite of testing infrastructure**
- **This infrastructure deteriorated significantly over the last several decades**
- **DOE is investing heavily in the recovery of the overall capability**



History of Transient Testing at the INL

- **Since its inception as the US *Nuclear Reactor Testing Station* (NRTS) in the 1950's researchers at the INL have been conducting experimental programs to establish the limits of nuclear system performance**
- **These studies were critical to the development, design, and deployment of the nuclear technologies that form the basis of today's nuclear energy industry**

History of Transient Testing in Idaho



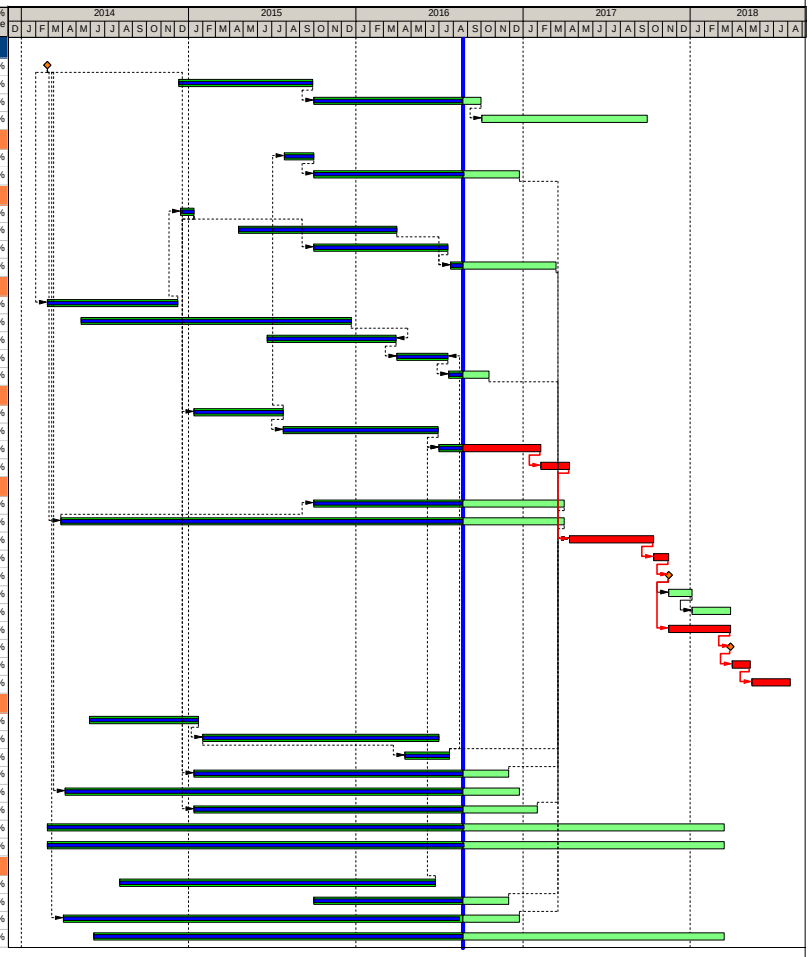
Transient Testing Program Schedule

- **The TREAT Restart schedule is currently driven by the Accident Tolerant Fuels (ATF) program objectives**
  - Insertion of lead test assembly in commercial power reactor by 2022
  - Transient testing must begin before the end of 2018 to support concept screening and safety criteria assessment/development
  - However, the possibility of early reactor restart has opened the opportunity for additional near-term experiments

TREAT Restart Schedule

Resumption of Transient Testing Program (RTTP)

Activity ID	Activity Name	Total Float	Org Dur	Rem Dur	Start	Finish	% Complete
Resumption of Transient Testing Program (RTTP)		0.00d	1149.00d	90.00d	Feb-26-14 A	Aug-07-18	
A1000	TREAT FY 2014 FONSI & Initiation of TREAT Restart		0.00d	0.00d	Feb-26-14 A		100%
A1010	FY15 Milestones		201.00d	0.00d	Dec-11-14 A	Sep-30-15 A	100%
A1030	FY16 Milestones	171.00d	201.00d	23.00d	Oct-01-15 A	Sep-29-16	89%
A1040	FY17 Milestones	170.00d	199.00d	199.00d	Oct-03-16*	Sep-28-17	0%
Fuel Inspections		56.00d	486.00d	71.00d	Jul-28-15 A	Dec-22-16	
A2000	*Perform Fuel Inspections in Storage & Core		61.00d	0.00d	Jul-28-15 A	Sep-30-15 A	100%
A2010	Re-establish Functionality of Fuel & Fuel Storage Systems (#'s 1,2,3,4)	56.00d	218.00d	71.00d	Oct-01-15 A	Dec-22-16	73%
Reactivity Control and Reactor Operations		16.00d	449.00d	111.00d	Dec-15-14 A	Mar-13-17	
A3000	Electrically Reconnect Rod Drives, Restore I&C Systems, PM/CM of Hydraulic/Pnuematic Systems & Initial Rod Drive Testing		160.00d	0.00d	Dec-15-14 A	Jan-12-15 A	100%
A3010	Perform ARCS Software Recovery V&V		173.00d	0.00d	Apr-20-15 A	Mar-31-16 A	100%
A3030	Re-establish Functionality of Reactivity Control Systems (#'s 5,6,7,21,22,23,24)		139.00d	0.00d	Oct-01-15 A	Jul-21-16 A	100%
A3040	Perform Partial Simulation From ARCS, TS&R Rod Drive and I&C Systems Supporting Training	16.00d	127.00d	111.00d	Jul-25-16 A	Mar-13-17	12%
Nuclear Safety and Implementation		93.00d	536.00d	34.00d	Feb-26-14 A	Oct-18-16	
A4000	DSA Initial Update, SER, & Implementation - ESS & Change Pages		159.00d	0.00d	Feb-26-14 A	Dec-08-14 A	100%
A4010	Prepare DSA Full Update for Reactor Operations for DOE Informal Review		314.00d	0.00d	May-12-14 A	Dec-23-15 A	100%
A4020	Informal DOE Review & Comment Resolution of DSA Update for Reactor Operations		151.00d	0.00d	Jun-22-15 A	Mar-29-16 A	100%
A4030	DOE Formal Review & Approval DSA Update for Reactor Operations & Issue SER		52.00d	0.00d	Mar-30-16 A	Jul-20-16 A	100%
A4040	DSA Implementation for Reactor Operations (Including MSA)	93.00d	52.00d	34.00d	Jul-21-16 A	Oct-18-16	34%
Training and Procedures		0.00d	453.90d	127.00d	Jan-12-15 A	Apr-10-17	
A5000	Qualify Nuclear Instrument Technician & Operators for Fuel Inspection & Initial Rod Drive Testing		81.00d	0.00d	Jan-12-15 A	Jul-27-15 A	100%
A5010	Training for Simulated Operations to Include Validation of Existing Training & Procedures & Delta Training		151.00d	0.00d	Jul-28-15 A	Jun-29-16 A	100%
A5020	Simulated Operations	0.00d	120.00d	92.00d	Jun-30-16 A	Feb-07-17	23%
A5040	Operator Examinations & Oral Boards for Provisional Certification of RO & SRO & Startup Plan Training	0.00d	35.00d	35.00d	Feb-08-17	Apr-10-17	0%
Reactor Startup Activities		0.00d	877.00d	193.00d	Mar-27-14 A	Aug-07-18	
A6000	Perform Assessments of TREAT Programs & Processes	5.00d	124.00d	22.00d	Oct-01-15 A	Mar-30-17	59.5%
A6010	Re-establish Functionality of Equip Needed for Reactor Restart (#'s 8,9,10,11,12,13,14,15,16,17,18,20,25)	5.00d	382.00d	22.00d	Mar-27-14 A	Mar-30-17	80%
A6020	Conduct MSA/CRA/RA for Readiness to Resume Reactor Operations	0.00d	103.00d	103.00d	Apr-11-17	Oct-11-17	0%
A6030	Closeout of Readiness Review Findings	0.00d	18.00d	18.00d	Oct-12-17	Nov-13-17	0%
A6040	Aggressive Working Schedule for DOE Startup Authority Approval to Restart TREAT Reactor	0.00d	0.00d	0.00d		Nov-13-17	0%
A6042	Start Up Reactor per TREAT Startup Plan (Aggressive - No Risk Realized)	73.00d	24.00d	24.00d	Nov-14-17	Jan-03-18	0%
A6044	Perform TREAT Core Characterization Physics Testing - Reactor Ready for First Experiment (Aggressive - No Risk Realized)	73.00d	48.00d	48.00d	Jan-04-18	Mar-28-18	0%
A6050	Reactor Restart Risk	0.00d	73.00d	73.00d	Nov-14-17	Mar-29-18	0%
A6060	DOE Startup Authority Approves Resumption of TREAT Reactor Operations / RTTP Complete	0.00d	0.00d	0.00d		Mar-29-18	0%
A6062	Start Up Reactor per TREAT Startup Plan	0.00d	24.00d	24.00d	Apr-02-18	May-10-18	0%
A6064	Perform TREAT Core Characterization Physics Testing - Reactor Ready for First Experiment	0.00d	48.00d	48.00d	May-14-18	Aug-07-18	0%
Balance Of Program		80.00d	922.00d	113.00d	Feb-26-14 A	Mar-15-18	
A7000	Evaluate Fire Protection Actions (Update FHA)		130.00d	0.00d	May-29-14 A	Jan-22-15 A	100%
A7010	Design, Build, & Install Fire Protection Required Facility Modifications		189.00d	0.00d	Feb-02-15 A	Jun-30-16 A	100%
A7020	Update FHA to Reflect Updated Fire Protection Systems		51.00d	0.00d	Apr-18-16 A	Jul-25-16 A	100%
A7030	Re-establish Preventative Maintenance Program	69.00d	385.00d	58.00d	Jan-12-15 A	Nov-30-16	85.5%
A7040	Plan, Design, & Perform Reactor Physics Analysis	322.00d	460.00d	71.00d	Apr-07-14 A	Dec-22-16	87.5%
A7050	Complete System Readiness Determinations	39.00d	415.00d	88.00d	Jan-12-15 A	Jan-31-17	78.5%
A7060	Program Management & Integration	80.00d	922.00d	113.00d	Feb-26-14 A	Mar-15-18	61.5%
A7070	Routine Operations & Maintenance	80.00d	922.00d	113.00d	Feb-26-14 A	Mar-15-18	61.5%
Key Engineering Modifications		80.00d	703.90d	113.00d	Apr-02-14 A	Mar-15-18	
A8000	Mods Required for Start of Simulated Operations		334.00d	0.00d	Aug-04-14 A	Jun-23-16 A	100%
A8010	Re-establish Functionality of Experiment Systems (#'s 19,26,27)	69.00d	381.60d	58.00d	Oct-01-15 A	Nov-30-16	76%
A8020	Mods Required for Startup	56.00d	381.60d	71.00d	Apr-02-14 A	Dec-22-16	87%
A8030	Mods Not Required for Startup - System Health	80.00d	667.00d	113.00d	Jun-09-14 A	Mar-15-18	58.5%



Actual Work
Remaining Work
Critical Remaining Work
Milestone
% Complete

RTTP High Level 8/22/2016

Data Date - Aug-22-16

Prepared Date - Aug-10-16

First Year of Operation

Activity ID	Activity Name	Duration	Start	Finish	Physical % Processors Complete
TREAT Rx Testing and Experiments					
EXP001	Startup Testing	32.00d	Nov-13-17*	Jan-16-18	0%
EXP005	M0 Calibration	18.00d	Jan-17-18	Feb-15-18	0% EXP001
EXP010	Multi-SERTTA Calibration Phase I	8.00d	Feb-19-18	Mar-01-18	0% EXP005
EXP015	Ship Radio Chemistry for Multi-SERTTA Calibration Phase I Samples	41.00d	Mar-05-18	May-14-18	0% EXP010
EXP020	Configure Multi-SERTTA Phase II Vehicle	18.00d	May-15-18	Jun-14-18	0% EXP015
EXP025	Multi-SERTTA Calibration Phase II	12.00d	Jun-18-18	Jul-09-18	0% EXP020
EXP030	Ship Radio Chemistry for Multi-SERTTA Calibration Phase II Samples	30.00d	Jul-10-18	Aug-29-18	0% EXP025
EXP035	Analyze Results and Configure ATF-3-1	16.00d	Aug-30-18	Sep-27-18	0% EXP030
EXP040A	*Develop TREAT Core Temperature Profile Negative Temperature Coefficient	32.00d	Mar-05-18	Apr-26-18	0% EXP010
EXP040B	*Develop Neutron Flux Map of the TREAT Core	32.00d	Apr-30-18	Jun-25-18	0% EXP040A
EXP040C	*Build Transient Library/Characterize Transient Testing Capabilities of TREAT	16.00d	Jun-26-18	Jul-24-18	0% EXP040B
EXP045A	*Perform Neutron Lifetime/Beta Measurements	32.00d	Jul-25-18	Sep-19-18	0% EXP040C
EXP045B	*Perform Neutron Spectrum Characterization	32.00d	Sep-20-18	Nov-14-18	0% EXP045A
EXP050	Complete Transient Testing of ATF-3-1-1	24.00d	Nov-15-18	Jan-07-19	0% EXP045B, EXP
EXP055	Complete Transient Testing of ATF-3-1-2	24.00d	Jan-08-19	Feb-18-19	0% EXP050
EXP060	Complete Transient Testing of ATF-3-1-3	24.00d	Feb-19-19	Apr-01-19	0% EXP055

- Critical Path indicates activities that are conducted in the Reactor
- *Physics testing in TREAT core to support NEAMS Computer model development

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TREAT Experi

FY18

Integrated Reactor Co

Startup Tests

ATF-CAL tests

Reactor Characterization,
Mammoth Validation Tests &
Transient Prescription Development

Potential New Separate
Effects Test Program

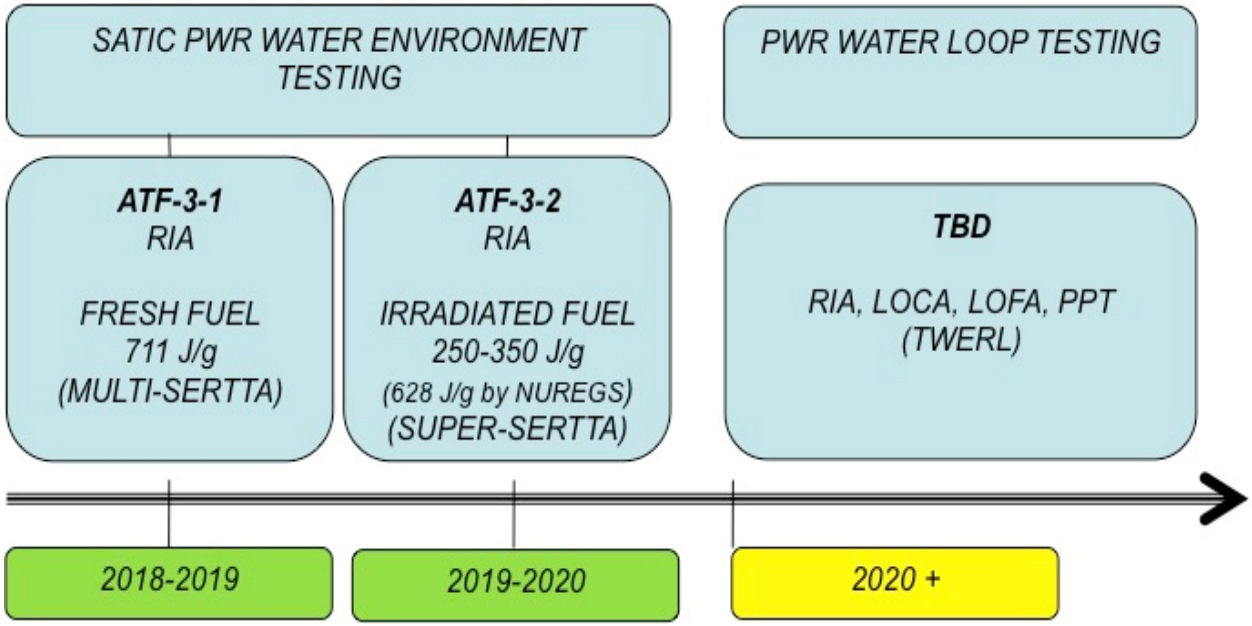
ATF-3 Tests

Transient Testing Program Development

- **The reactor must be complemented by cross-cutting and specific test infrastructure designed for a given experiment type**
  - Experiment vehicle to provide the sample environment of interest
  - Instrumentation to measure the phenomena of interest
  - Infrastructure to assemble the experiment
- **Infrastructure development investment has been prioritized based on current nuclear technology development objectives**
  - Accident Tolerant Fuel (DOE) & LWR Burnup Extension (Industry)
    - Phase I - Static capsules with PWR coolant conditions
    - Phase 2 - Flowing water loop with PWR coolant conditions
  - Microstructural Evolution in Nuclear Materials under Irradiation
    - Capsule based system for small nuclear fuel samples in a controlled environment
  - Fast Reactor Fuel (fuel cycle, new fast test reactor, Gen IV reactor system)
    - Phase I - Static capsules with LMR coolant conditions
    - Phase 2 - Flowing sodium loop with LMR coolant conditions
  - … and more!

Transient Testing for ATF

- ATF-3 will provide DOE and Industry with initial nuclear transient performance screening of accident tolerant fuels concepts under PWR Reactivity Initiated Accident (RIA) conditions.
- PWR Hot Zero Power (HZP) temperature (280° C) and pressure (15.5 MPa) conditions will be initially established around specimens in static environment capsules.
- Under these conditions, a prototypical RIA energy deposition will be delivered. Fresh and Irradiated ATF specimens will be tested in accordance with NUREG RIA energy requirements.



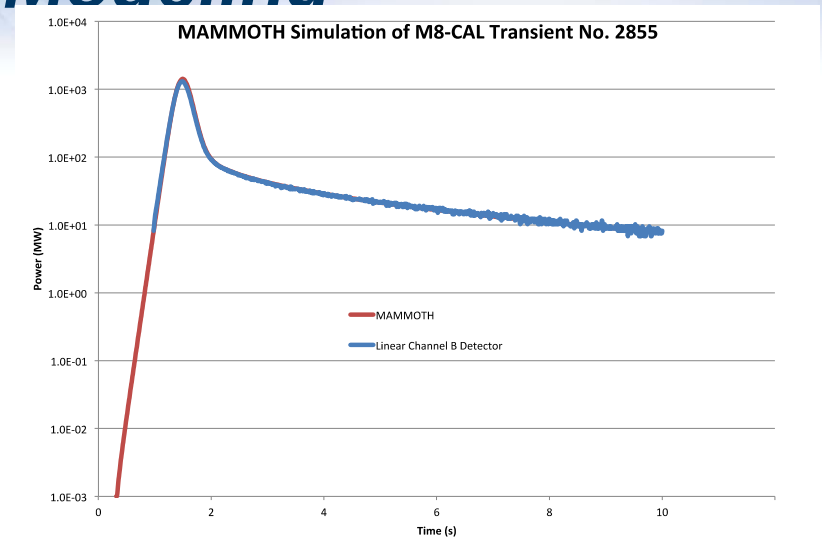
The ATF-3 series of transient tests has motivated / driven the development of the Multi-SERTTA static capsule TREAT Irradiation Vehicle and conceptual designs of the Super-SERTTA capsule and TWERL water loop. Similarly, ATF-3 has determined in-pile instrumentation requirements for ATF-3-1 and ATF-3-2 series and has motivated instrument development activities at INL & industry.

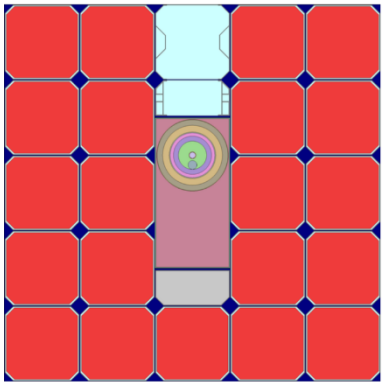
Advanced Reactor Physics Modeling

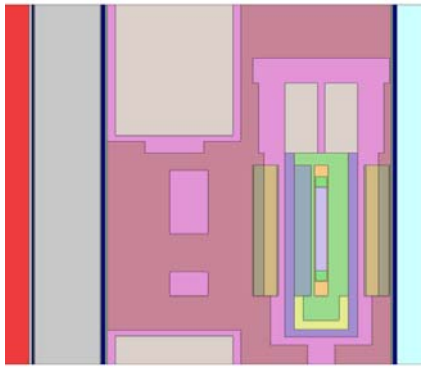
The MAMMOTH Multi-physics reactor analysis software application is built on top of the MOOSE multi-physics framework. For this work, the MAMMOTH package includes *Rattlesnake* for time-dependent neutron transport, *BISON* for fuels performance, and *RELAP-7* for thermal-fluids calculations. These applications co-exist within MAMMOTH and are able to directly share data. For this reason, MAMMOTH is uniquely suited to support time-dependent 3D simulation of TREAT core and experiments.

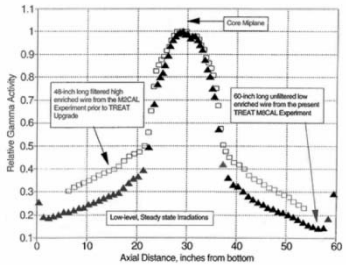
MAMMOTH is intended for use to support TREAT operations (including safety analysis, experiment and instrumentation design). It has been demonstrated to be able to reproduce transient power data from calibration measurements performed in the early 1990s. It is currently being used to support design of the Multi-SERTTA by performing transient simulations that cannot be completed by any other way.

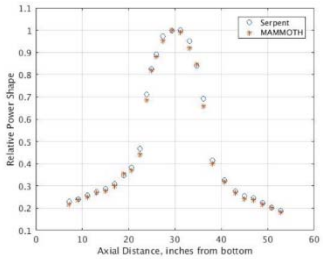
Key to MAMMOTH deployment for various customers will be validation of the code against 3D steady state and transient data. We are coordinating with other stakeholders to ensure that the appropriate measurement campaign will be performed during restart testing





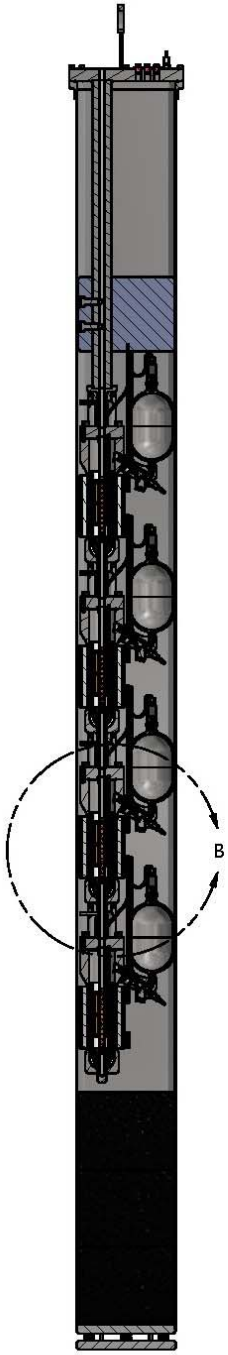


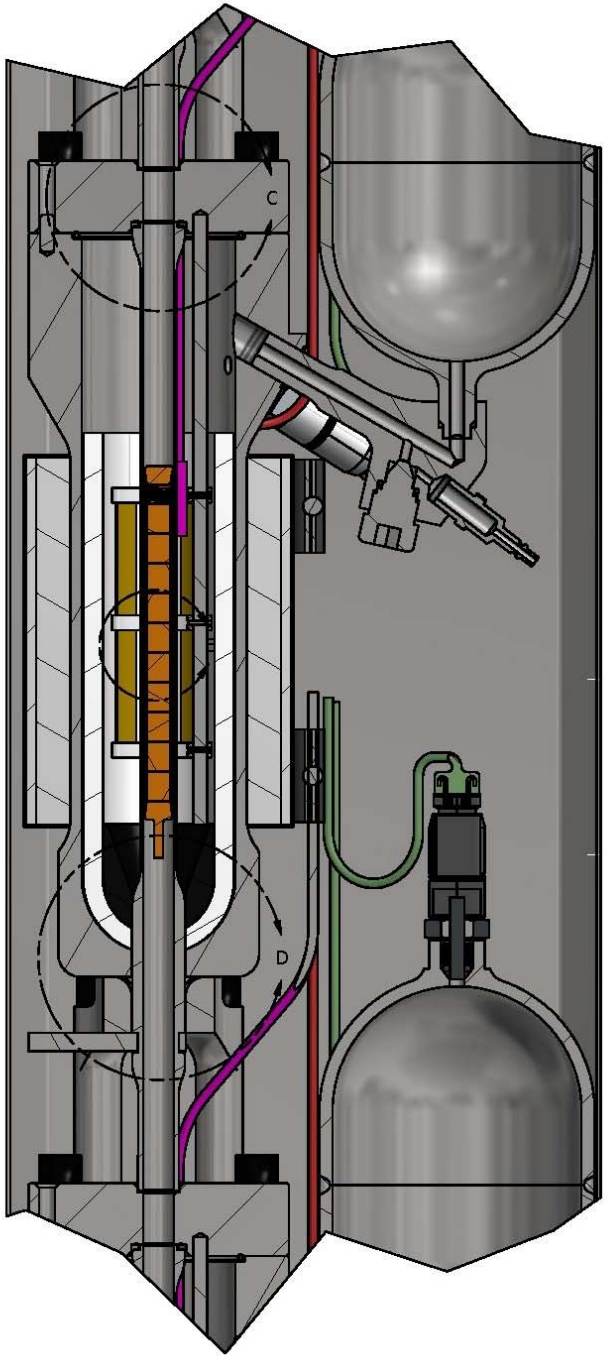




Calibration Vehicle D

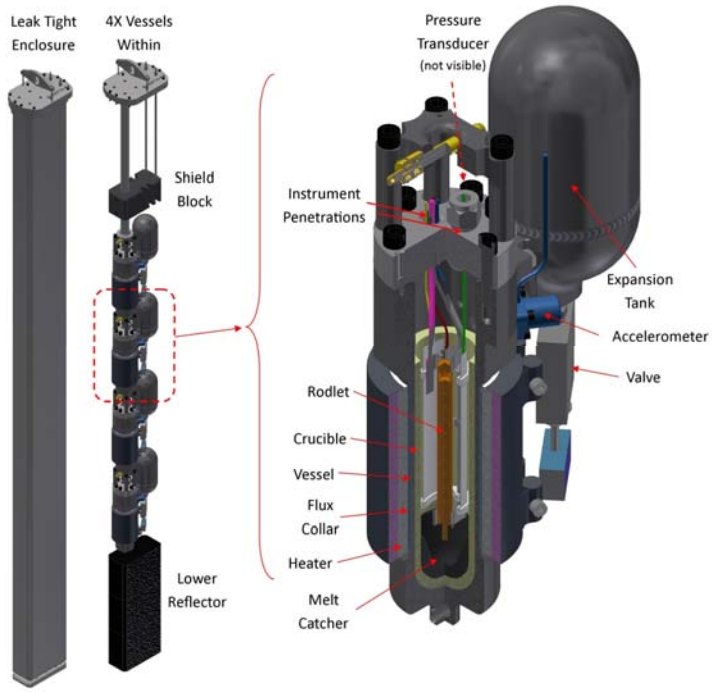
- **Nuclear-equivalent calibrati**
  - Fission wires at steady state (
  - Specimens at steady state (~5
  - Fission wires through planned
- **Dosimeters extracted quick and/or radiochemistry**
  - Drywell needed in CAL vehicle
- **Compute power coupling fa factor (TCF) to show test is**
- **Models indicate that PWR w an issue for historic sodium**
  - Can’t be adequately simulated temperature

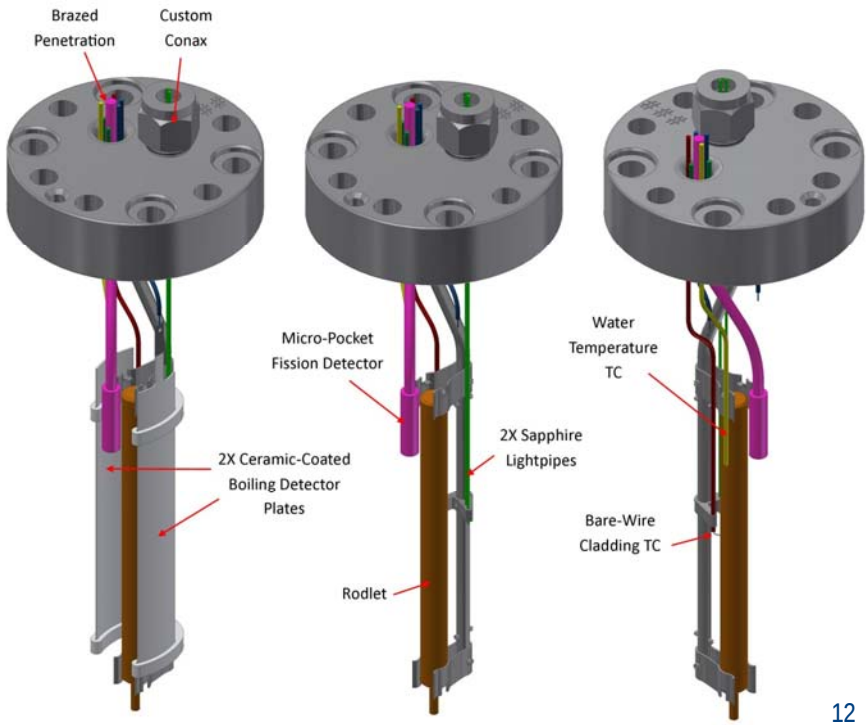




Static Capsule Test Vehicle for ATF

- **Multi-Static Environment Reactor Transient Test Apparatus (Multi-SERTTA) being designed to support initial RIA testing in PWR coolant environment**
- **Device will accommodate up to 4 samples (fresh or pre-irradiated) with instrumentation packages tailored to the experiment objectives**





Instrumentation Package Development

- **Instruments are required to monitor the:**
  - Experiment boundary conditions: Coolant temperature, vessel pressure, boiling
  - Fuel pin conditions: Cladding temperature, cladding elongation, cladding integrity, pin plenum pressure
  - Fuel motion monitoring
- **This requires the adaptation of existing instruments and the development and qualification of new instruments**
- **This is being enabled by several bilateral collaborations between leaders in the field including DOE-CEA, DOE-IRSN, and INL-Halden**
  - For example, IRSN to host a tri-lateral CEA/IRSN/INL meeting on in-pile instrumentation and the fast neutron hodoscope at CABRI in Cadarache in March

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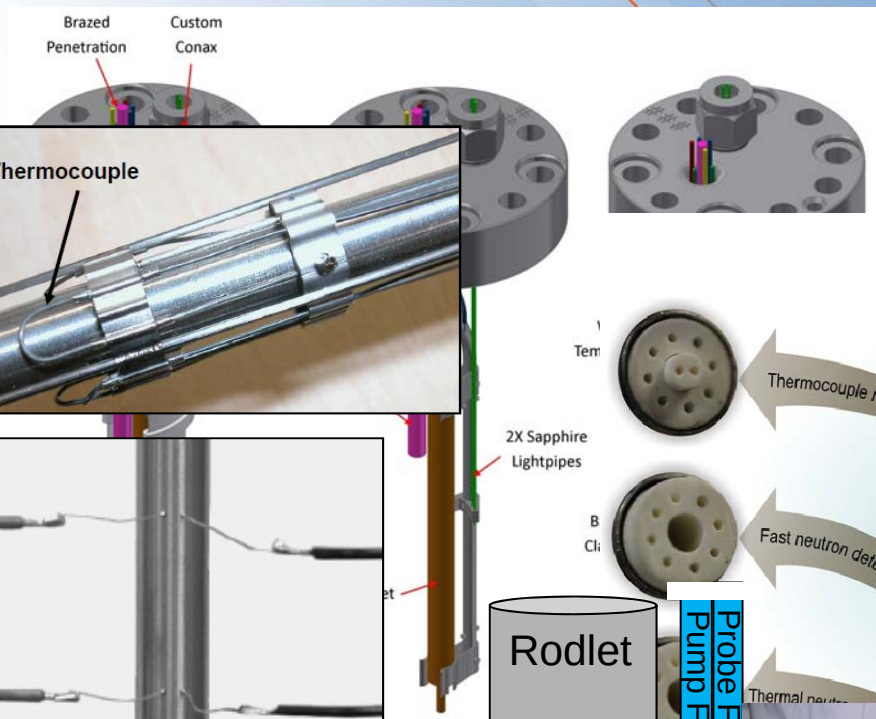

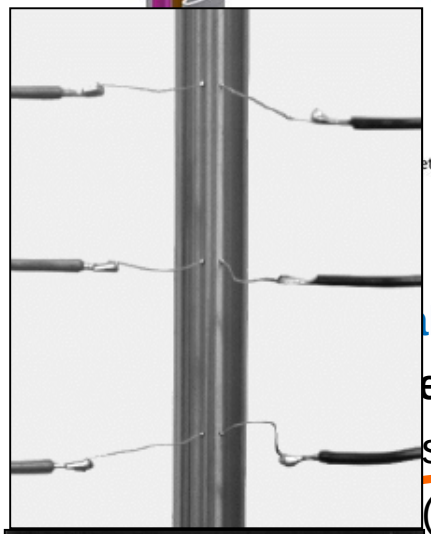

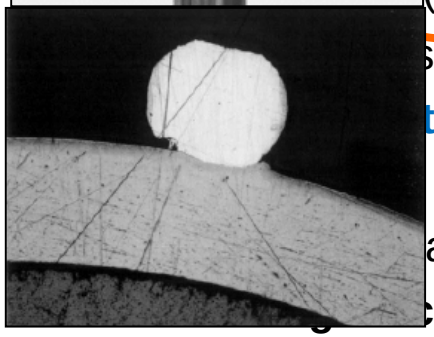

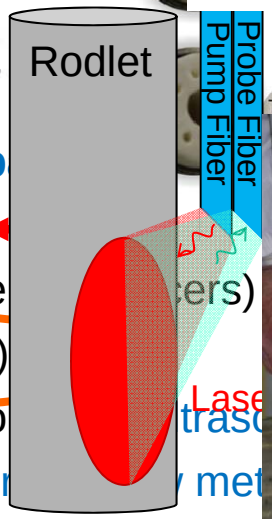

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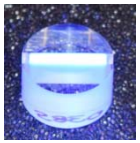
Hodoscope Recovery

The TREAT Fuel Motion Monitoring System (FMMS) is used for measuring the location and movement of fuel during transient tests.

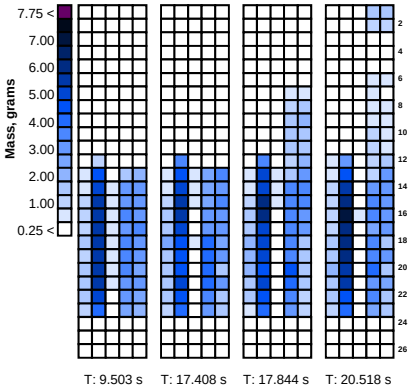
The FMMS employs a concrete front collimator and a steel, 360-slot rear collimator along with an array of fast-neutron detectors to record neutrons originating from fission in a test capsule under irradiation.

The FMMS data acquisition system (DAS) is capable of recording data in 1-ms increments, at rates >400,000 s^{-1}.

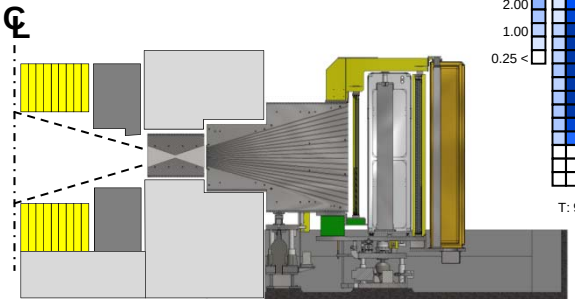
Collectively, the components of this system are referred to as the ***hodoscope***.



Fast-neutron scintillator



Fuel-motion images



Schematic layout of the hodoscope

Refurbishment Status

- **Detector Refurbishment**
  - All scintillator based detectors have been recovered (~99 of 327 detectors are candidates for refurbishment)
  - Scintillator refurbishment techniques developed
  - Identified, tested and selected replacement photomultiplier tube design
  - 16 detectors were assembled to support system level testing
- **Data Acquisition System Design**
  - A 16 channel DAS was designed, constructed, and is being used for system testing. The design is modular and components can be replicated to increase the number of channels.
- **Collimator Assessment**
  - An endoscope was procured to conduct collimator channel inspection (confirm there is no debris)
- **Electro-Mechanical System Recovery**
  - The Hodoscope collimator is maneuvered to optimize field of view for each experiment. The condition of the motor and control system is being assessed as a first step in returning to operation.
- **Hodoscope Modeling and Simulation**
  - Historic Hodoscope drawings were recovered and a 3D solid model was constructed. This model will be coupled to the reactor physics models to estimate signal strength as a function of experiment prescription.
  - Models of the scintillator were developed to study their physical response to estimate device performance and to support data processing software development

Modern M&S Driven Development

- **A world-wide trend toward mechanistic treatment of nuclear fuel safety behavior and risk informed regulation is leading to reassessment of existing safety analysis codes.**
- **Benchmark studies conducted through this prism have revealed significant shortcomings in both the codes/models and the fuel safety criteria.**
- **For example,**
  - RIA safety criteria is based on conservative fail/no-fail data extracted from a diverse set of integral tests (mostly conducted in the 1960's and 70's). All the required information to conduct mechanistic analysis is not available.
  - Benchmark studies conducted on the range of international analysis codes revealed that most phenomenological models are not consistently applied nor do they represent the 'real' behavior (e.g. transient boiling curves)
  - It is proposed that the integral behavior of fuel under these conditions be de-convoluted into a series of separate effects tests that will isolate the phenomena of interest as required to develop and validate new mechanistic models.
  - Specialized instrumentation and testing techniques developed to support these studies will then be applied to integral tests to validate the full function of the codes.

Collaboration

- **Transient testing infrastructure around the world is becoming increasingly limited. Meeting the needs of advanced technology developers will require that all these resources be closely integrated.**
- **The US program has focused on developing collaborative relationships with several key international and industrial partners**
  - CEA-DOE Bilateral Agreement: Transient testing of thermal and fast reactor fuel designs are included in the agreement
  - IRSN-DOE Bilateral Agreement: New agreement established to emphasis transient testing
  - NNC-INL MOU: New agreement to emphasize collaboration between IGR and TREAT
  - JAEA-DOE Bilateral Agreement: Tasks related to transient testing of both thermal and fast reactor fuels have been added to the agreement
  - Halden-INL MOU: New agreement includes collaboration on LOCA testing
  - SCKCEN-INL CRADA: New agreement including development of instrumentation and fuel pin re-fabrication
  - OECD Working Group for Fuel Safety: INL representative added to working group, will likely join the CABRI International Project (administered by WGFS)
  - EPRI Regulatory Technical Advisory Committee (Reg-TAC): INL participation in committee
- **.. and University Partners. Transient testing related university projects include:**
  - Three IRP awards (Wisconsin/Ohio State/Kansas State/Idaho State, Oregon State/Michigan/MIT, and Utah State/New Mexico/Florida)
  - Two NEUP awards (North Carolina State, Kansas State)

Summary

- **Transient testing has played a central role in nuclear technology safety testing for over 60 years.**
- **Resumption of operations at TREAT is underway to continue that tradition and enable the development, design, and deployment of advanced fuel and reactor technology.**
- **The reactor restart schedule has been driven by the Accident Tolerant Fuels program objectives. The INL has committed to having the reactor restarted by the end of 2018. However, it is expected to begin operation as soon as March of 2018.**
- **Development of the irradiation devices and in-pile instrumentation required for the ATF program has been prioritized although infrastructure for a variety of technology types and users is planned.**
- **Broad international collaborations are being established to ensure optimal utilization of the existing safety testing infrastructure worldwide.**

Questions?

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