INL/CON-16-38472-Revision-0

Safety Analysis Challenges With Restart of the Idaho National Laboratory (INL) Transient Reactor Test (TREAT) Facility

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August 2016

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operated by Battelle Energy Alliance

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Prepared for the
U.S. Department of Energy

Under DOE Idaho Operations Office
Contract Unknown

Safety Analysis Challenges With Restart of the Idaho National Laboratory (INL) Transient Reactor Test (TREAT) Facility

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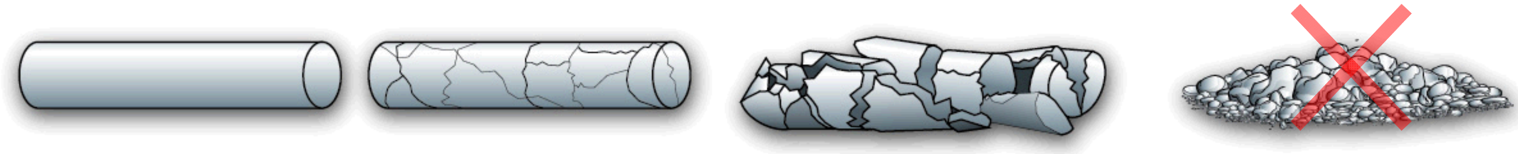
2016 EFCOG NFS Workshop

Summary

- Why Transient Testing?
- TREAT Operations, Design, And Unique Features
- Safety Basis Strategy
- Safety Analysis Challenges
- Safety Analysis Summary
- Conclusions

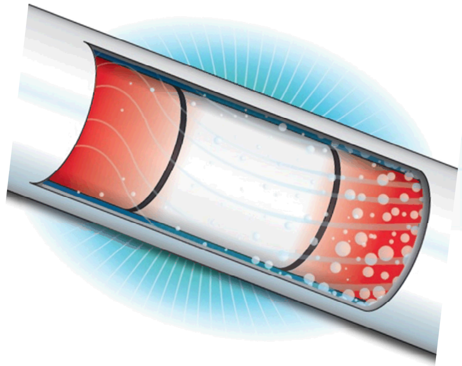
New nuclear fuels development requires transient testing for design development and qualification

Nuclear fuel tends to fracture during use or when exposed to a power burst, it is important for the fuel to retain reasonable structural integrity



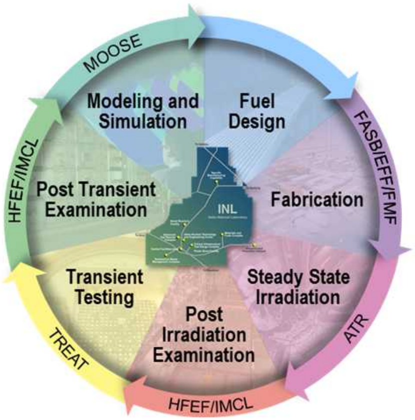
During a transient test, fuel is exposed to a power-to-cooling mismatch, driving the fuel to high temperatures

Transient testing fuel and crash testing cars have a lot in common: ***Design and test for high safety standards***



Programmatic Need for Transient Testing

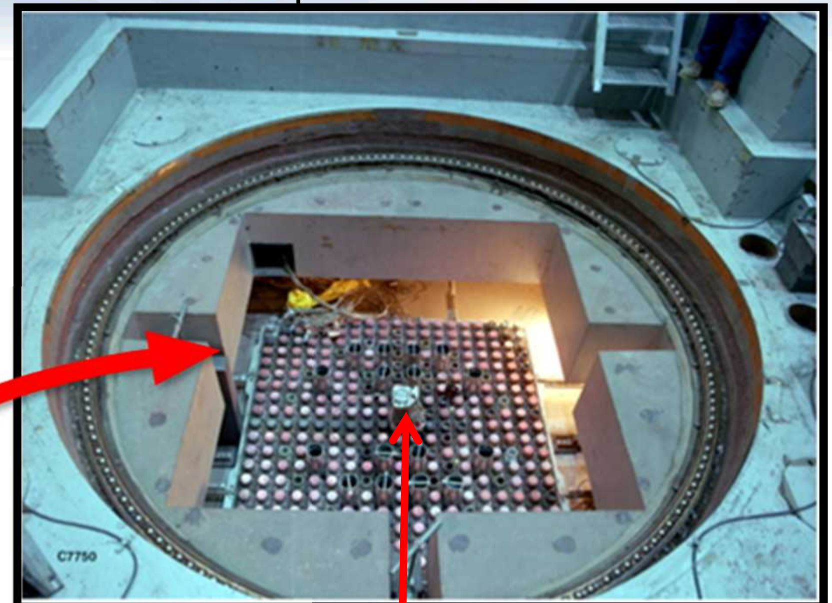
- The mission driver for resuming operations at TREAT is to support the development of new fuel types. Deployment of new fuel systems will require the full suite of qualification testing, including transient testing.
- The schedule is being driven by the Accident Tolerant Fuels (ATF) program.
  - ➢ In order to have a Lead Test Assembly ready for insertion into a commercial reactor by 2022, transient testing is required in 2018.
- Other potential customers, domestic and international, are also showing interest including TerraPower, AREVA, EPRI, CEA, and JAEA.



TREAT Past Ops Summary

- Designed to conduct transient testing of fuels and structural materials.
- Operated from 1959 to 1994.
- Reactor has performed 6604 reactor startups, 2884 transient irradiations.
- Major refurbishment completed in the late 1980's, and upgraded reactor ran from 1989 to 1994.

Top of the Reactor



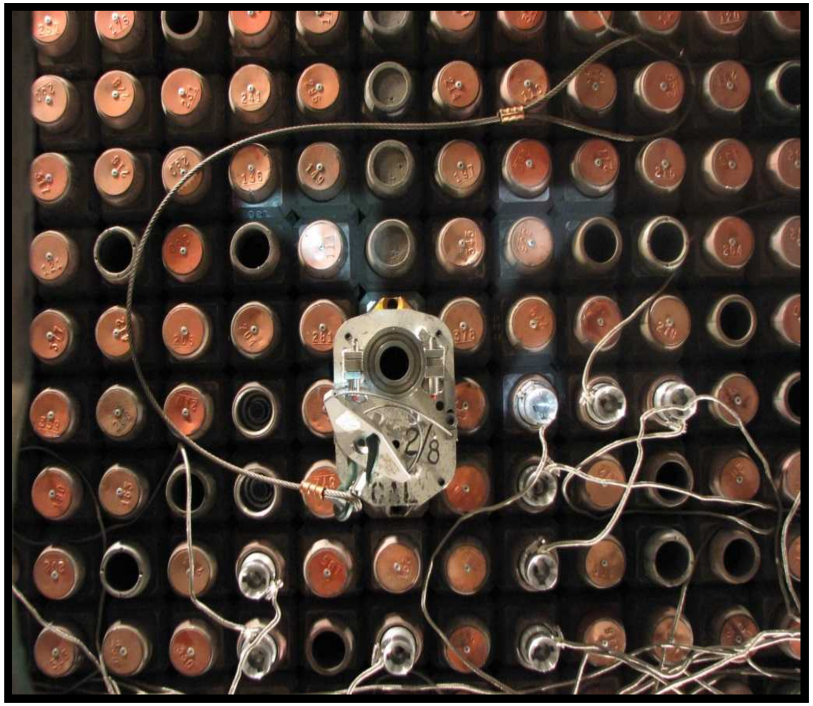
Experiment typically goes here

South View of the Reactor

- Plant left in excellent condition with all required surveillance and maintenance activities performed.
- ***Reactor remains fully fueled and qualified for continued use.***

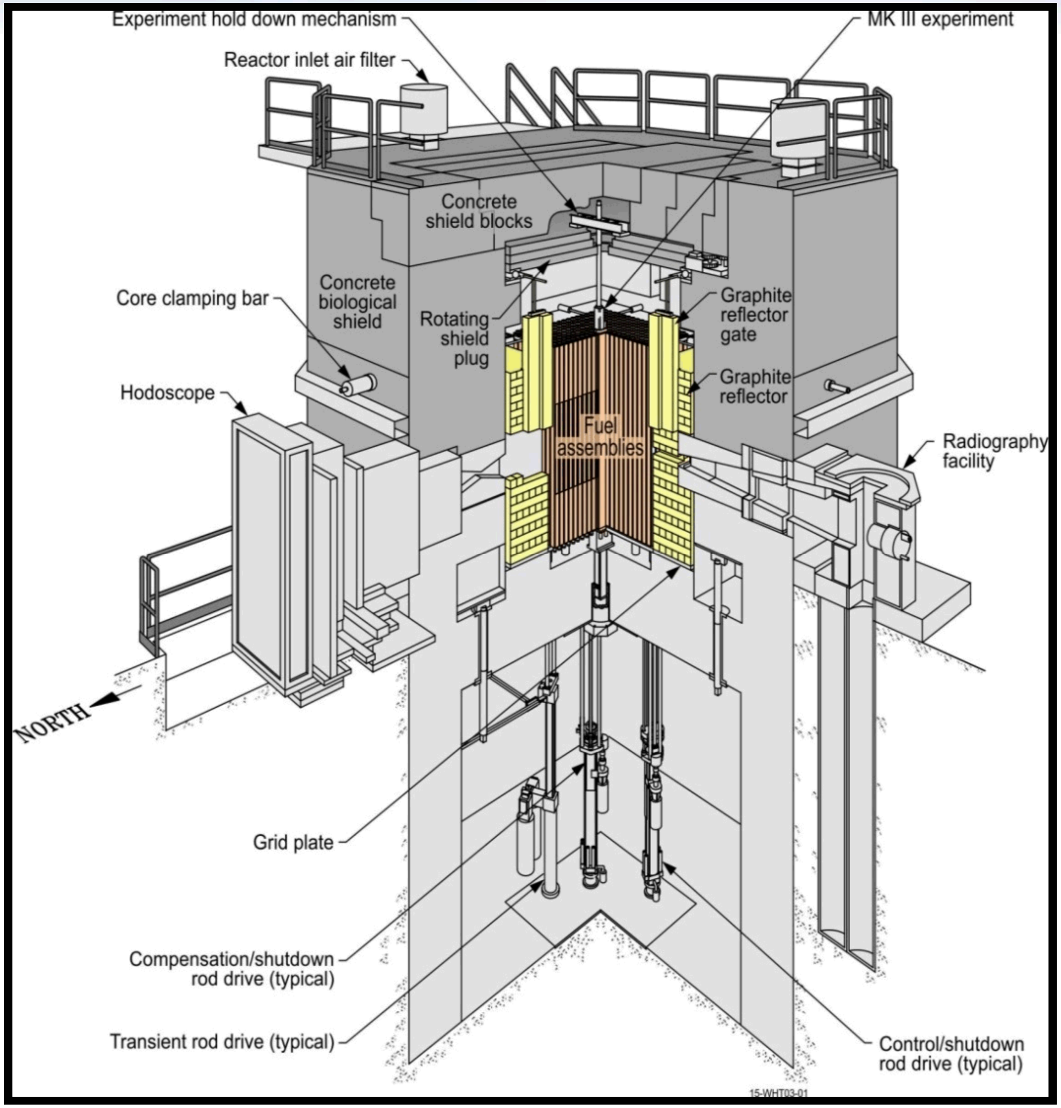
TREAT Design Summary

- **≈18 GW Peak Transient Power (120 kW Steady-state power).**
- Core: 4 ft. high x roughly 6 ft. dia.; surrounded by 2 ft. graphite reflector.
- 19 x 19 array of 4 in. X 4 in. fuel and reflector assemblies.
- Fuel: 0.2 wt.% ***highly enriched UO_2 (HEU) dispersed in graphite,*** LEU conversion work initiated.
- Reactivity Control and Operation:
  - Prompt critical operation – normal mode
  - Three independent Control Rod Drive types
  - Transients initiated from remote Control Room
  - ***Transients performed under computer control.***
- ***High heat-absorption capability provides heat sink for transient heat without cooling dependence.***
- ***Air cooling system has a non-safety-related function – advantageous during steady-state operations or to prepare for next transient.***
- Self-contained experiments.



TREAT Unique Features

- ***No decay heat mitigation actions required:***
  - Walk-away facility
  - Negligible decay heat (No Water!!)
  - Low fission product inventory
  - No emergency cooling or residual heat removal required
  - No emergency power required.
- ***Self-limiting:***
  - Homogeneity of fuel and moderator provides near instantaneous large, negative temperature coefficient safely shuts the reactor down
  - Inherently safe
  - Transient reactivity limited
  - ➢ ***Reactor Trip System is not required to prevent fuel damage.***
- ***Horizontal visual access to core center during operation using slotted assemblies.***



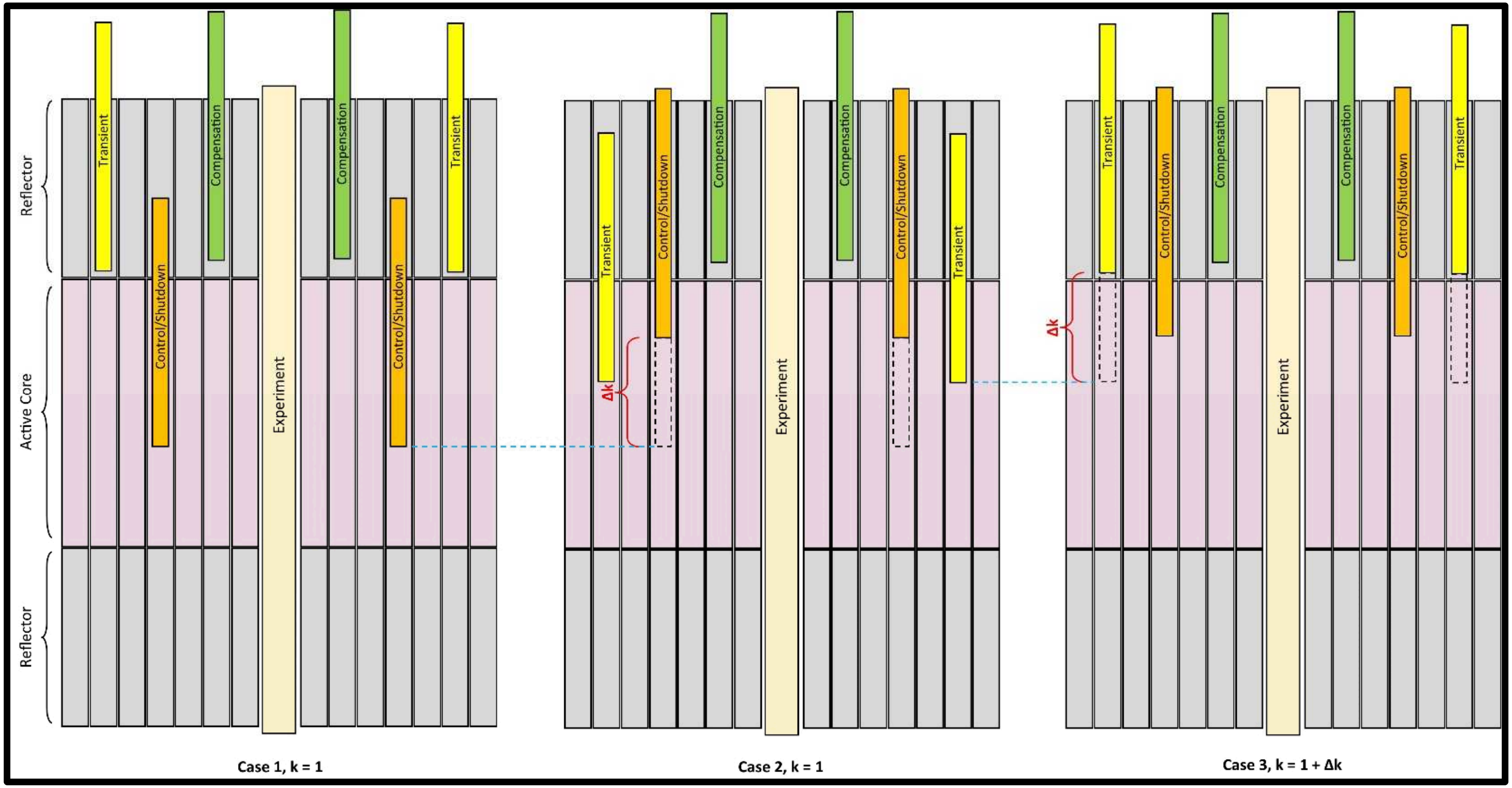
Reactivity Control

- Reactivity control
  - Poison: Steel tubes filled with B_4C
  - Follower: Zr tube filled with graphite
- ***Three independent Control Rod Drive types:***
  - Control/Shutdown - primary means of reactivity control during reactor startup and steady-state operation. Also provides for rapid shutdown.
  - Compensation/Shutdown - compensate for the reactivity worth of an experiment, and provide a fast-acting shutdown capability.
  - Transient - used for high-speed transient control (low-speed during startup and steady-state modes).
- ***Digital computer-based Automatic Reactor Control System (ARCS) – controls transient rods during transient mode (MRCS controls all rods during two other modes).***
- ***Negative temperature coefficient.***

Transient Reactivity Insertion

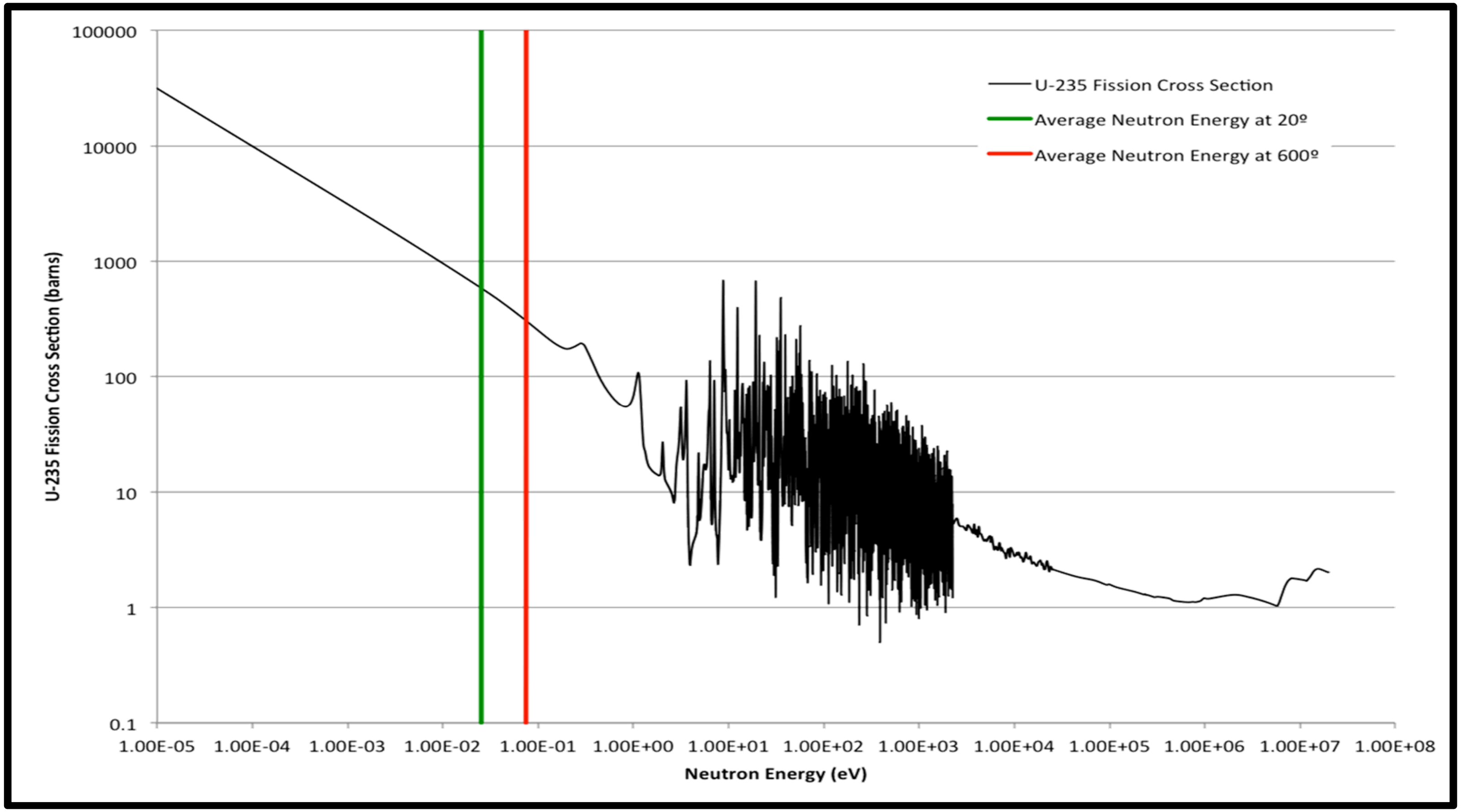
- Case 1: Reactor critical with Control/Shutdown rods.
- Case 2: Control/Shutdown rods withdrawn, Transient Rods “Cocked.”
- Case 3: Transient Rods rapidly withdrawn to provide planned experiment Δk.

➢Technical Specifications require Δk limited so that fuel temp LCS (LSSS) of 600^{o}C is not exceeded.



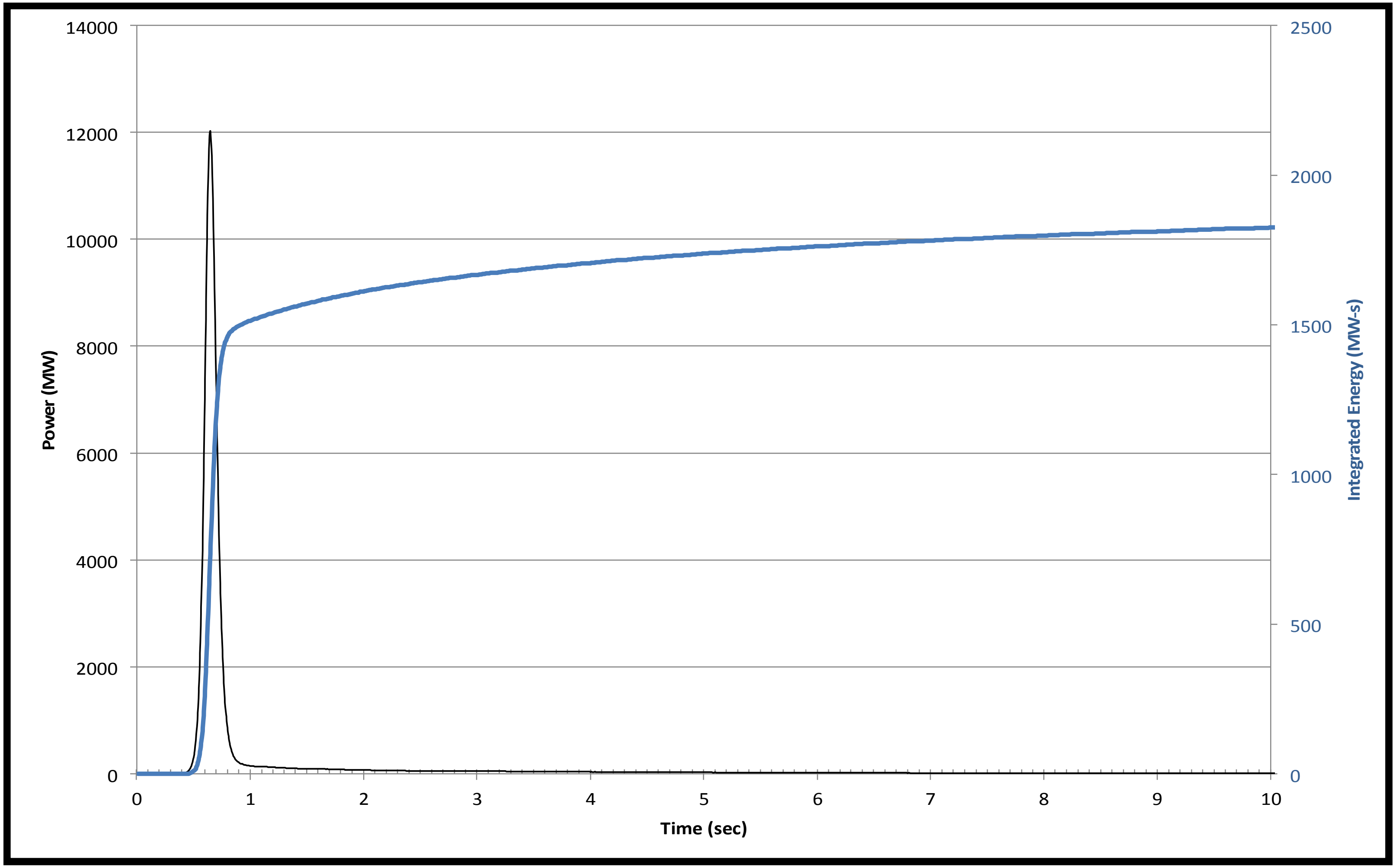
Temp. Coefficient

- ***Negative temperature coefficient of reactivity is mostly due to the shift (increase in neutron energy) of the neutron spectrum as temperature increases***
  - Neutrons slow down to thermal equilibrium with their surroundings.
  - Increase in surrounding temperature increases average neutron energy.
  - Increased energy of the neutrons decreases the probability of fission in U-235.



Reactor Response

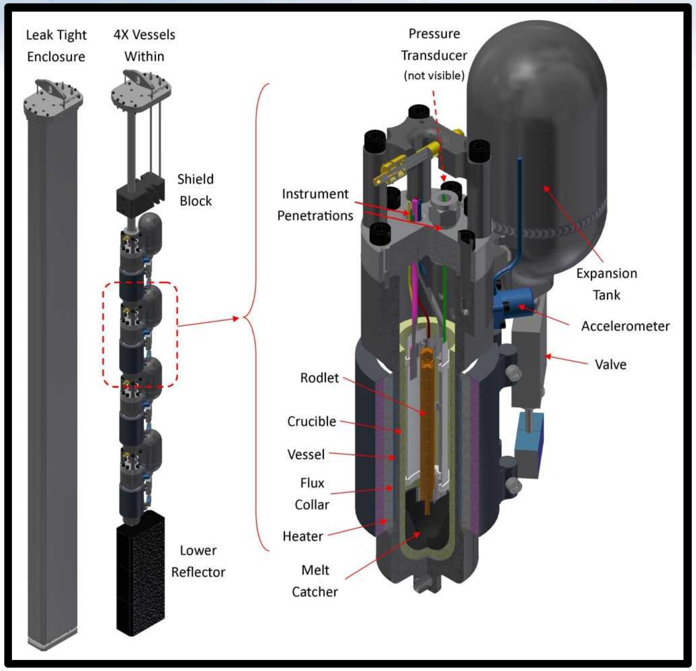
- Rapid reactivity insertion Δk results in rapid power increase.
- Increase in temperature results in rapid negative reactivity insertion from neg temp. coefficient.
- Reactor shuts itself down before exceeding temperature limits.

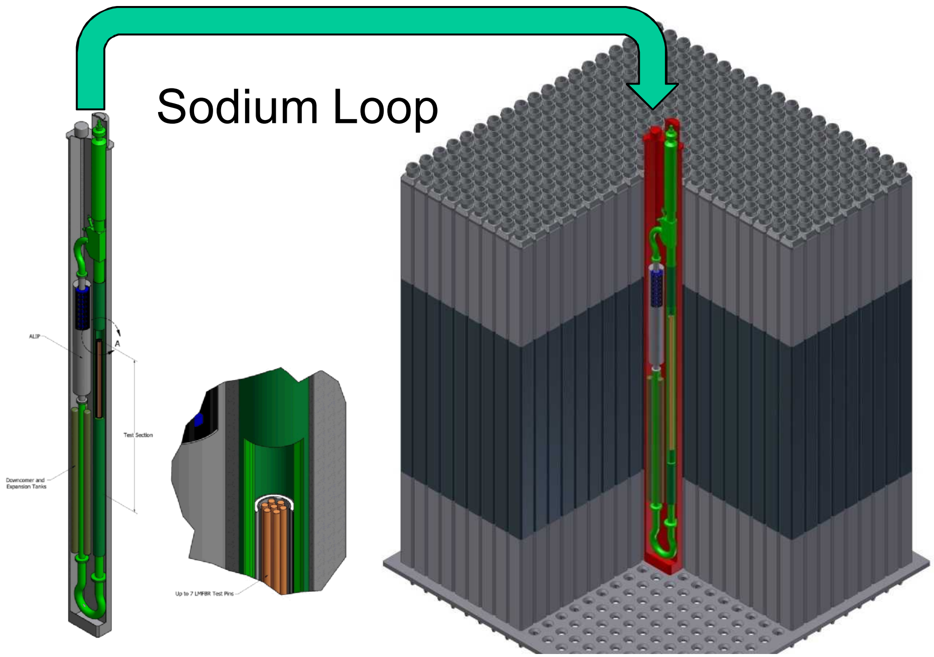


Experiment Vehicles

- Static capsule for dry, water, and sodium environment testing:
  - Static Environment Rodlet Transient Test Apparatus (SERTTA).
- Recirculating water loop:
  - TREAT Water Environment Recirculating Loop (TWERL).
- MK-III sodium loop.
- Devices may be assembled remotely at hot cell facilities and transported to reactor.

ATF Multi-SERTTA Design





- ***Closed system concept minimizes handling and processing risk at reactor site***.
- TREAT core is highly configurable to accommodate different experiment sizes and shapes.
- ***Experiment containment is safety related and a Chapter 16/TS-420 passive design requirement.***
- ***Each experiment is required to have an experiment specific safety analysis (ESA) independently reviewed and approved prior to experiment insertion in TREAT.***

Safety Analysis Challenges

- 10 CFR 830 format and content guidance for reactors requires use of RG 1.70, a format and content guide for commercial power reactors.
- Existing approved FSAR written for an upgraded facility and anticipated future high hazard reactor (Category 1 reactor) and experiment operations.
- Unique design eliminates reliance on traditional reactor Engineered Safety Features, however:
  - Unique pulse-type reactor TREAT operations require administrative controls on insertion of reactivity during experiment transients to prevent exceeding fuel temperature limits. Transients are performed under computer control
  - Perception that the TREAT safety basis should align with NRC research reactor regulatory documents, although designs drastically differ.
- Differing NRC and DOE dispersion and consequence calculation methodologies.
- Reactor based structure, system, or component (SSC) classification conflicts with current DOE SSC classification scheme.
- No approved design for future transient experiment vehicles.
- Conflicting DOE and NRC reactor worker protection guidance.
- Research reactor Technical Specification (TS) requirements differ from DOE Technical Safety Requirements (TSR) guidance.

TREAT Facility Safety Basis Strategy

- ***No one clear regulatory format and content template or guide exists for a pulse-type, air-cooled, graphite—moderated DOE reactor such as TREAT.***
- ***RG 1.70 is designated in 10 CFR 830 as a safe harbor for DOE reactors.***
- Because of significant differences between DOE-owned reactors and NRC-licensed commercial power reactors the following were consulted on a chapter-by-chapter basis to tailor the FSAR content commensurate with a transient test/research reactor such as the TREAT facility:
  - NUREG-1537, "Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors."
  - ANSI/ANS-15.21, "Format and Content for Safety Analysis Reports for Research Reactors."
- Existing FSAR analyses and conclusions were driven by the unexecuted TREAT upgrade core and experiment source term (expected Category 1 reactor), none of which apply to future operations. Therefore:
  - ***FSAR sections revised to remove unexecuted reactor system modifications associated with the TREAT Upgrade Project.***
  - ***Updated accident analysis to reflect current vs. upgraded core.***

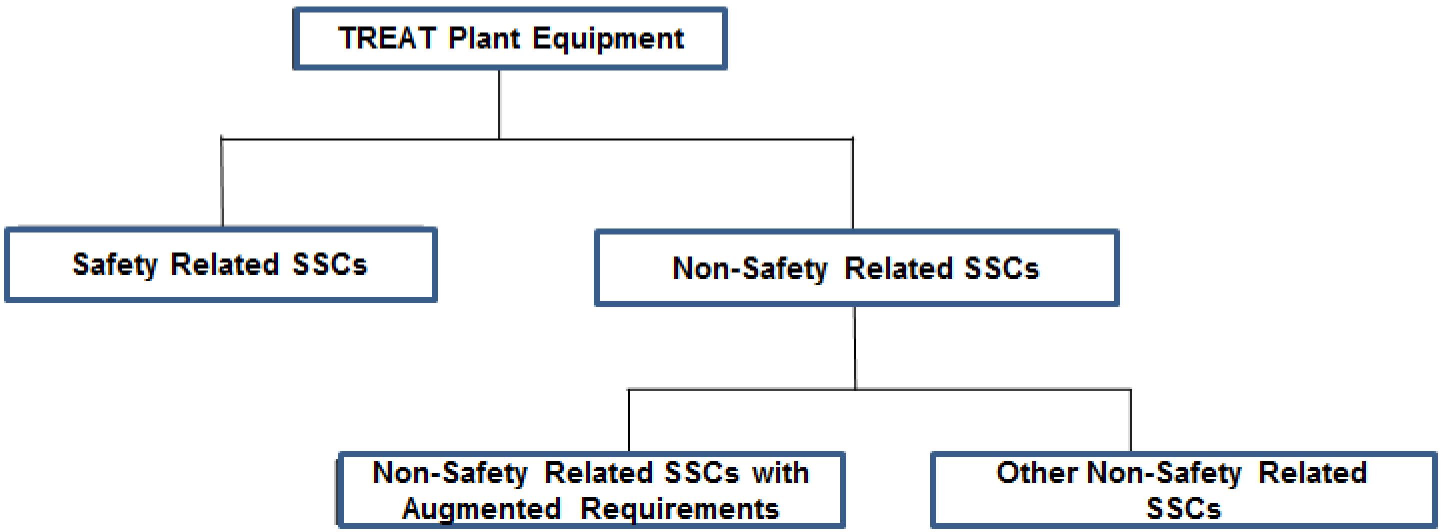
Safety Analysis Summary

- The limiting events selected for analysis include the following:
  - ***Reactivity Insertion Accident (RIA) Design Basis Accident (DBA)***
  - ***Experiment DBA***
  - ***TREAT Maximum Hypothetical Accident (MHA)***
  - Experiment-Handling Accidents
  - Reactor-Fuel-Assembly Handling Accidents
  - Inadvertent Nuclear Criticality
  - System Impact Accidents
  - Reactor-Fuel-Assembly Clad Failure Accidents
  - Loss of Cooling
  - TREAT Facility Fires
  - Natural Phenomenon Events.
- Accidents analyzed assuming current HEU fuel assemblies, and a sodium loop experiment with a preirradiated mixed oxide (MOX) fuel radiological inventory assumed to bound all possible future experiments.

Safety Analysis Summary (continued)

- ***There are no decay heat concerns and neither emergency cooling nor residual heat removal required.***
- ***Limited cumulative energy release results in low fission product inventories, and negligible Zr_3 clad oxidation.***
- ***All credible accident consequences are well within the applicable limits using NRC dispersion methodology, but using INL consequence guidelines.***
- Although not required by DOE methodologies, a hypothesized MHA (reactivity insertion DBA + experiment failure DBA) was analyzed and the consequences are also well within the consequence guidelines.
- Although not required by NRC methodology, collocated worker doses to INL site personnel analyzed and are also well within the consequence guidelines.
- Immediate facility worker doses from credible fuel/experiment handling accidents not calculated. Results assumed unacceptable and immediate worker protected by derived SSCs and TS controls.
- The DOE safety-class or safety-significant SSC classification is NOT used. For TREAT, the methodology from ANSI/ANS-58.14-2001 is used to classify TREAT SSCs as safety-related (SR), non-safety related (NSR), or non-safety-related with augmented requirements (NSR-AR).

Methodology for TREAT SSC Classification



TREAT DBA

- ***The principal restrictions on TREAT facility operations are derived from the RIA DBA (TREAT DBA),*** assumed to occur as follows:
  1. The reactivity available in transient rods is added instantaneously, plus
  2. Credible experiment reactivity effect, added as a coincident step, and
  3. All shutdown rods fail to operate.
- ***The safe shutdown of the TREAT facility is ensured by the reactor's physically inherent strong negative temperature coefficient of reactivity, and not on scram action from the reactor trip system (RTS).***
- ***A three-level administrative approach to reactivity control is established in Chapter 15*:**
  – The first level is to administratively limit core excess reactivity to 8.0%. (TS-LCO)
  – The second level is to limit the reactivity available in the transient rods such that the maximum reactor-fuel temperature would not exceed TS safety limit (TS-SL) fuel temperature of 820^{o}C if all of the reactivity available in transient rods, plus reactivity feedback effects that could be caused by experiment response to the power transient, were added as a step and the power transient was terminated by the negative temperature coefficient only and assuming no scram action (TS-LCO).
    - **This protection is referred to as the *self-limited mode of operation*.**
  – The third level consists of an administrative control on the transient control computer program, such that the TS limiting control setting (TS-LCS) fuel temperature of 600^{o}C will not be exceeded.
- ***These administrative levels of protection limit the potential reactivity available for an assumed maximum credible reactivity insertion DBA with no scram intervention.***

TREAT Experiment DBA

- ***Experiment DBA scenario considers the response of the experiment assembly during accident conditions while it is inserted in the reactor.***
- Initiated by:
  1. Abnormal reactor operating conditions.
  2. Mechanical failure of experimental equipment in the reactor.
- ***The Mechanical Design criteria in FSAR Chapter 10 require that the experiment containment retains its integrity during all normal operation and accident conditions, including the maximum unplanned reactivity addition.***
  - Therefore, no radioactive materials are released to the environment.
  - However, a noncredible, nonmechanistic accident scenario involving a failure of the experimental apparatus during the TREAT DBA is analyzed quantitatively to assess the residual risk of TREAT transient experiment operations.
- ***Conservative design and safety analyses shall document in an ESA how each experiment complies with the mechanical design and safety analyses criteria in FSAR Chapter 10.***

TREAT MHA

- It is assumed that as a result of unspecified circumstances, a nonmechanistic RIA (TREAT DBA) occurs during a transient with an experiment in the core, which results in fuel cladding damage and release of fission products from the TREAT core fuel assemblies, AND damage to the experiment and release of fission products from the experiment fuel.
- ***It is assumed that such a noncredible, nonmechanistic scenario results in a release of 100% of the available core source term, in addition to subsequent fuel melting, and burning of combustibles in the experimental vehicle in the core.***
- Although not required for such a noncredible, hypothesized event, the consequences to the collocated worker at the TREAT control room and the public at the EAB were compared to the consequence guidelines.
- ***The MHA consequences to the collocated worker and the public were shown to approach, but remain below the FSAR consequence guidelines.***
- ***Clearly, engineered safety features are not required for the mitigation of the consequences of the MHA.***

Conclusions

- A unique TREAT specific combination of DOE and NRC commercial and research reactor safety basis format and content guides used to comply with 10 CFR 830.
- FSAR rewritten to focus on current reactor core configuration and to bound future experiments.
- Safe shutdown of TREAT reactor ensured by reactor's physically inherent strong negative temperature coefficient of reactivity, and not on scram action from RTS.
- A three-level administrative approach to reactivity control is established to ensure fuel temperature from RIA DBA does not exceed the TS-SL.
- Analyses using NRC dispersion methodologies for reactors demonstrate that the consequences to the public and collocated workers are well within DOE derived consequence guidelines for all accidents analyzed, including the non-credible TREAT MHA.
- Immediate facility workers protected from credible fuel and experiment handling accidents by derived SSCs and TS controls.
- TREAT SSCs designated as safety-related, non-safety related, or non-safety-related with augmented requirements, and do not use DOE non-reactor classifications.
- TREAT derived Technical Specifications are similar to NRC licensed research reactors and using NRC research reactor requirements per NUREG-1537 and ANSI/ANS-15.1.

Transient Test Program

Enabling World Class Nuclear Energy R&D

Questions?