Transient Reactor Test (TREAT) Experiment Safety Analysis (ESA)

Idaho National Laboratory

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TREAT Experiment Safety Engineering

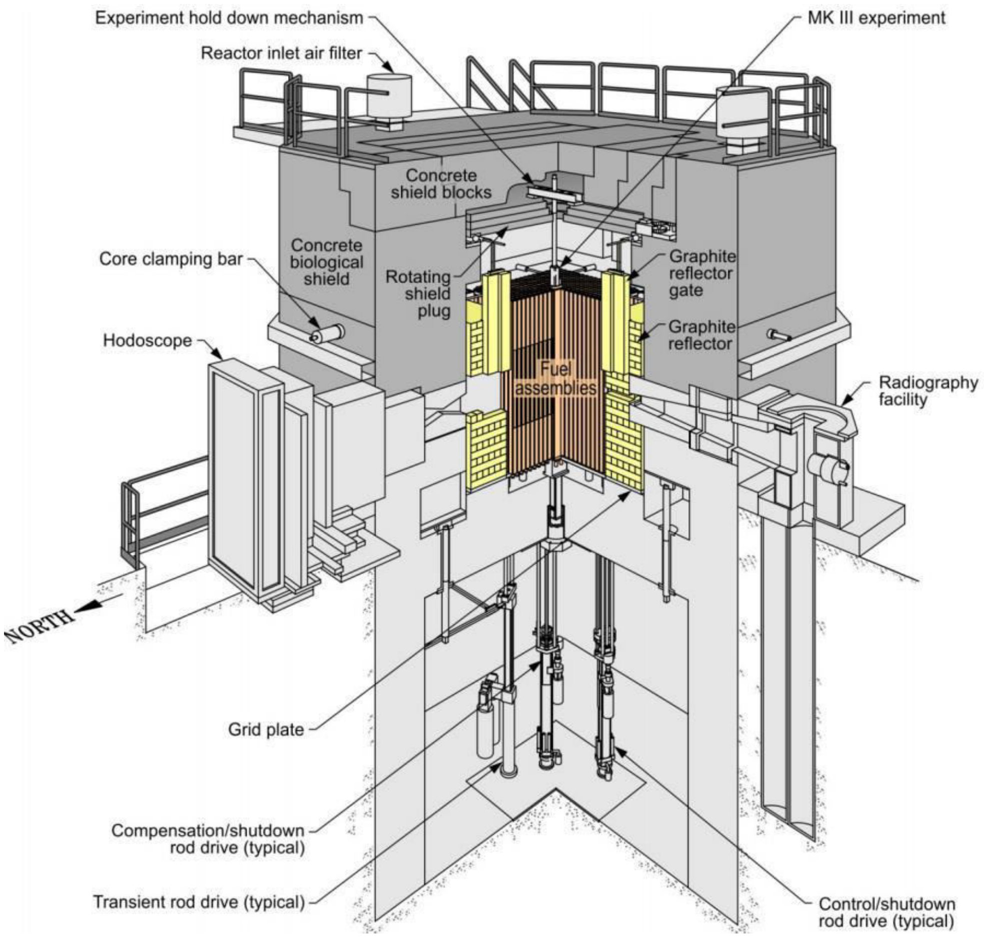
2018 TRTR Conference

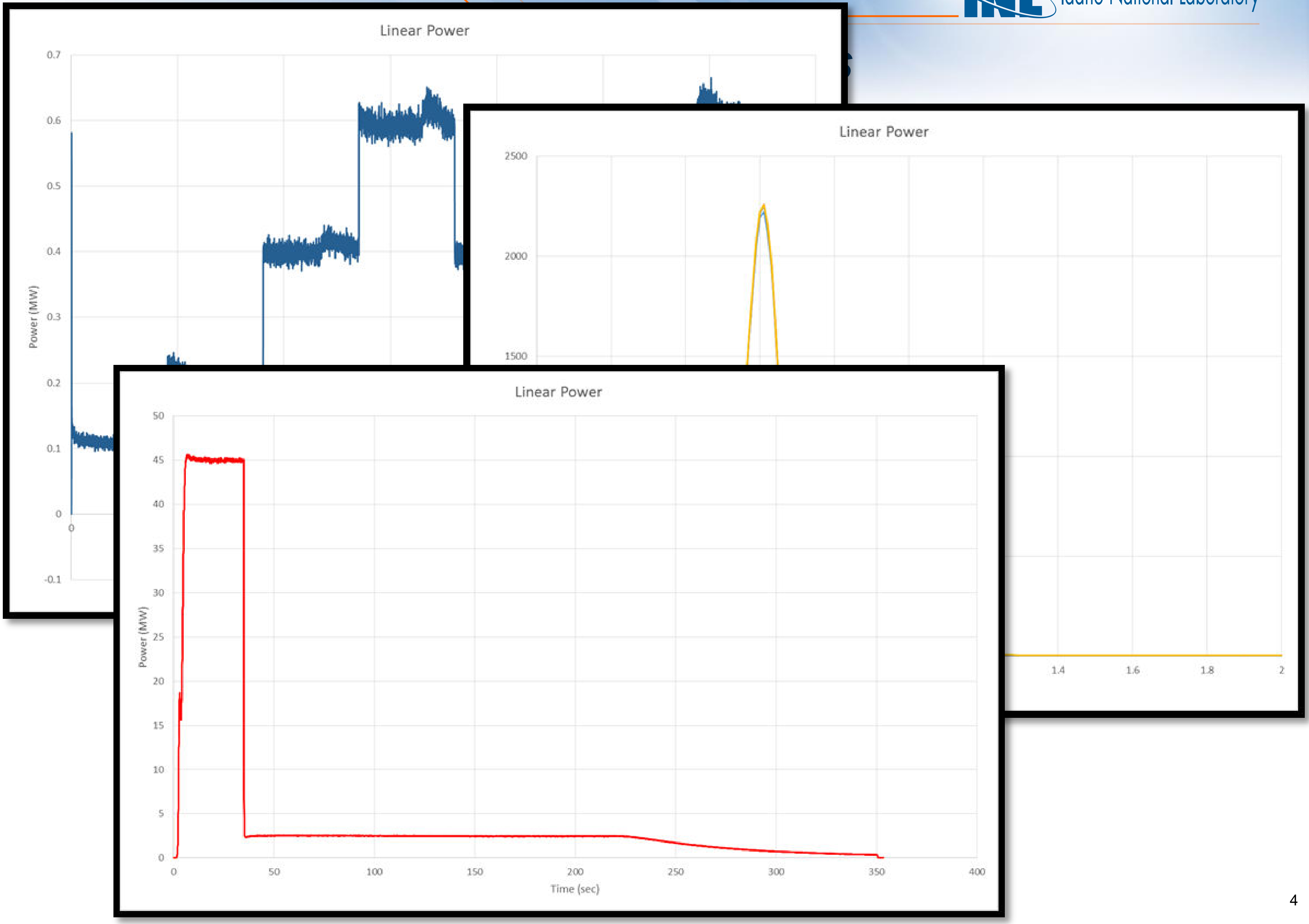
Background of the TREAT

- Located at Idaho National Laboratory (INL)
- Construction began 1958 and concluded in 1959
  - $1.46 million in1959 dollars, $12.5 million 2018 dollars
- Operated 1959 – 1994
  - Performed nearly 3,000 transients
  - Primarily supported testing of Fast Reactor fuels
  - Placed in standby in 1994 with fuel in core
- Restart in 2017 to support accident tolerant fuel (ATF) testing

Background of the TREAT

- Air-cooled, graphite moderated reactor
- 10,000:1 atoms C to atoms U
- Steady state operation 120 kW
- Minimum Period of 0.023 s
- Peak Power of 19,000 MW
- Peak Energy of 2,900 MJ




Linear Power
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
Power (MW)
0
Linear Power
2500
2000
1500
1.4
1.6
1.8
2
Linear Power
50
45
40
35
30
25
20
15
10
5
0
Power (MW)
0
50
100
150
200
250
300
350
400
Time (sec)

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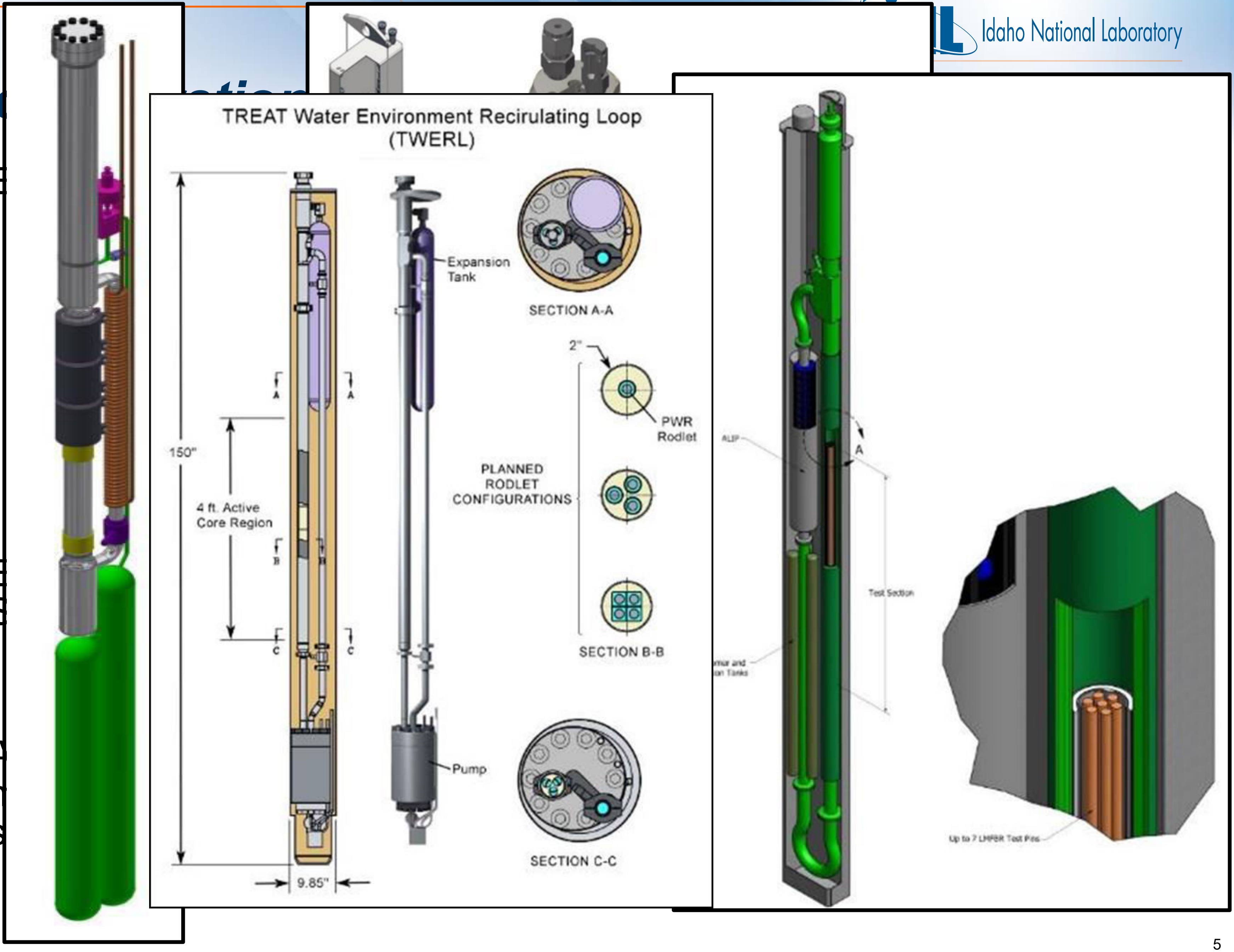


Considerations for ESA Process

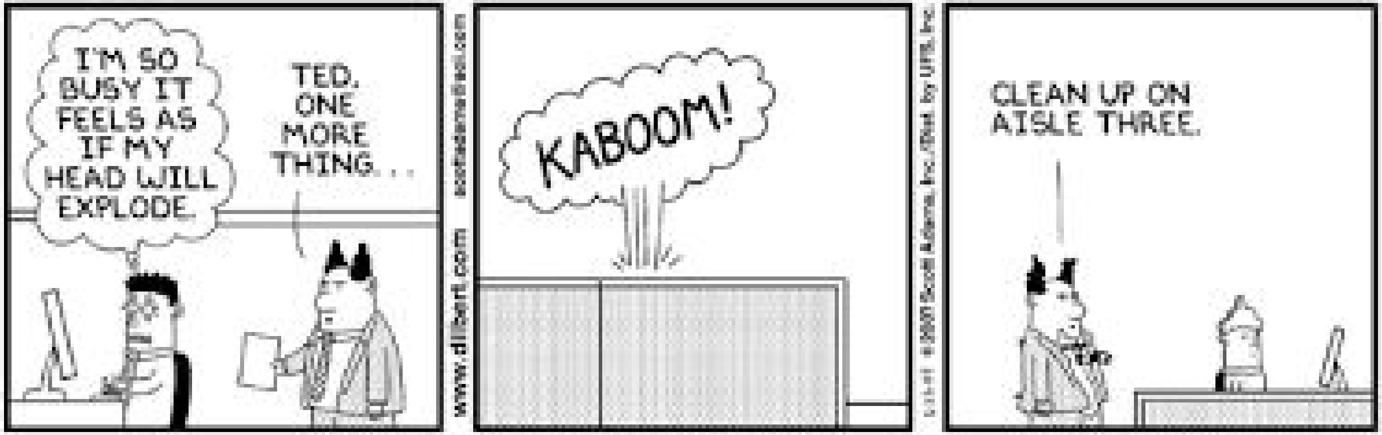
Safety Basis Requirements

- Three TS related to experiments
  - Cannot handle experiments with molten sodium
  - Cannot handle experiments for 24 hours after operation in the reactor
  - An ESA has to be issued addressing SAR-420, Chapter 10.2 design criteria
- Three TS administrative controls (AC)
  - ESA must address SAR Chapter 15 accidents
  - Independent Safety and Operations Review Committee (SORC) review of ESAs is required
  - Experiment must follow INL Quality Assurance (QA) requirements
- SAR-420, 10.2 contains 16 design requirements
- SAR-420, Chapter 15 contains two ESA SAR Commitments
  - Pu content less than 500g
  - Criticality Safety requirements are met

Considerations for ESA Process

Experiment Safety Engineering Group

- Five qualified engineers (when all staff fully qualified)
- Cognizant System Engineer for experiment related equipment and plant systems
  - Casks
  - Experiment Data Acquisition and Control System (E-DACS)
  - Experiment Vehicles
  - Radioactive shipments between facilities
  - Interface between Sponsor/PI and TREAT Operations
  - Experiment support systems



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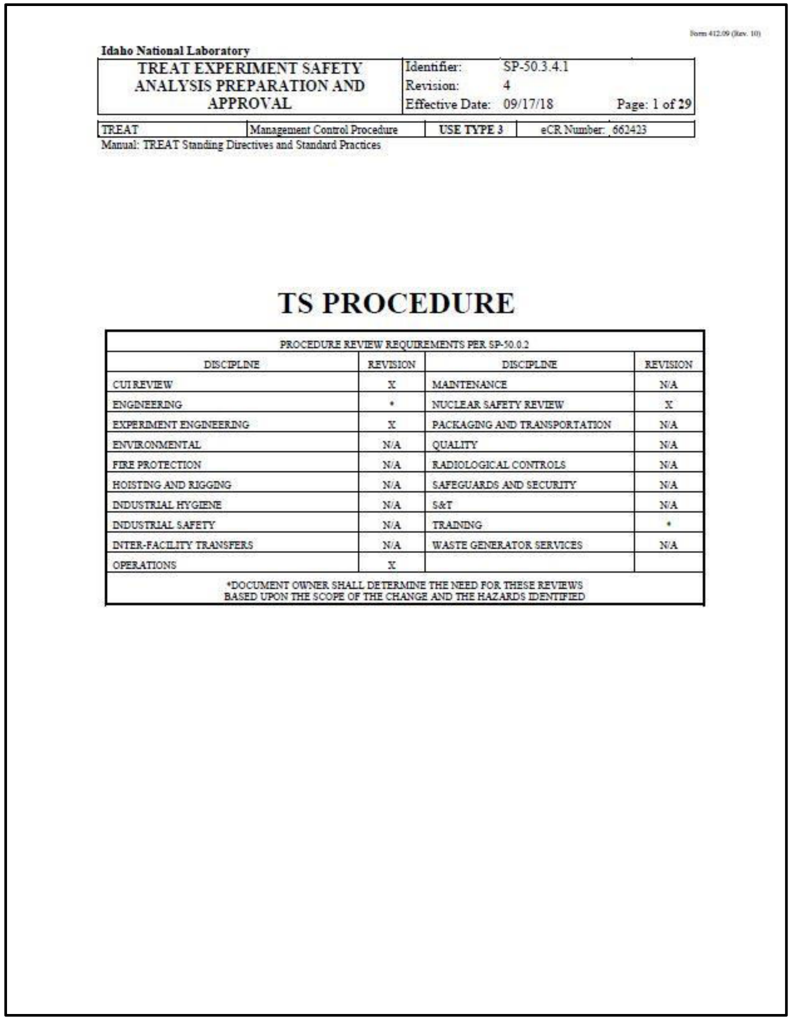
- These considerations dictated that the safety analysis for experiments needs to be robust while still maintaining flexibility and minimizing time to perform the analysis
- Process was developed to perform a two phase approach for the ESA
  - Bounding analysis for the experiment vehicle
  - Specific analysis for the experiment being performed

What is an Experiment?

- EXPERIMENT-Hardware or capsule (excluding devices such as detectors, flux monitoring devices, etc.) that contains test material, subject to evaluation against SAR-420 Section 10.2.3.8 criteria, intended for irradiation in the reactor during STEADY-STATE REACTOR and/or TRANSIENT REACTOR OPERATION. Hardware designed to contain an EXPERIMENT, but not containing test material, is not considered an EXPERIMENT. EXPERIMENTS are of the same type when they are made of the same basic hardware, neutron filter, and experiment fuel, thus having the same reactivity worth and the same effect on the reactor-physics parameters.

Standard Practice (SP)-50.3.4.1

- Procedure used to develop ESAs
- Verifies training requirements for ESA authors and reviewers
- Ensures all ESAs have the same content and formatting
- Ensures demonstration of compliance for all safety basis requirements
- Defines the scope of review for ESA and Experiment Specific Verification Checklist (ESVC)
- Provides guidance on making changes to ESAs
- Provides direction for incorporating safety basis annual updates
- Provides direction for performing ESVC



Form 412.09 (Rev. 10)

Idaho National Laboratory

TREAT EXPERIMENT SAFETY ANALYSIS PREPARATION AND APPROVAL	Identifier: SP-50.3.4.1 Revision: 4 Effective Date: 09/17/18	Page: 1 of 29

TREAT	Management Control Procedure	**USE TYPE 3**	eCR Number: 662423

Manual: TREAT Standing Directives and Standard Practices

TS PROCEDURE

PROCEDURE REVIEW REQUIREMENTS PER SP-50.0.2

DISCIPLINE	REVISION	DISCIPLINE	REVISION
CUI REVIEW	X	MAINTENANCE	N/A
ENGINEERING	*	NUCLEAR SAFETY REVIEW	X
EXPERIMENT ENGINEERING	X	PACKAGING AND TRANSPORTATION	N/A
ENVIRONMENTAL	N/A	QUALITY	N/A
FIRE PROTECTION	N/A	RADIOLOGICAL CONTROLS	N/A
HOISTING AND RIGGING	N/A	SAFEGUARDS AND SECURITY	N/A
INDUSTRIAL HYGIENE	N/A	S&T	N/A
INDUSTRIAL SAFETY	N/A	TRAINING	*
INTER-FACILITY TRANSFERS	N/A	WASTE GENERATOR SERVICES	N/A
OPERATIONS	X		

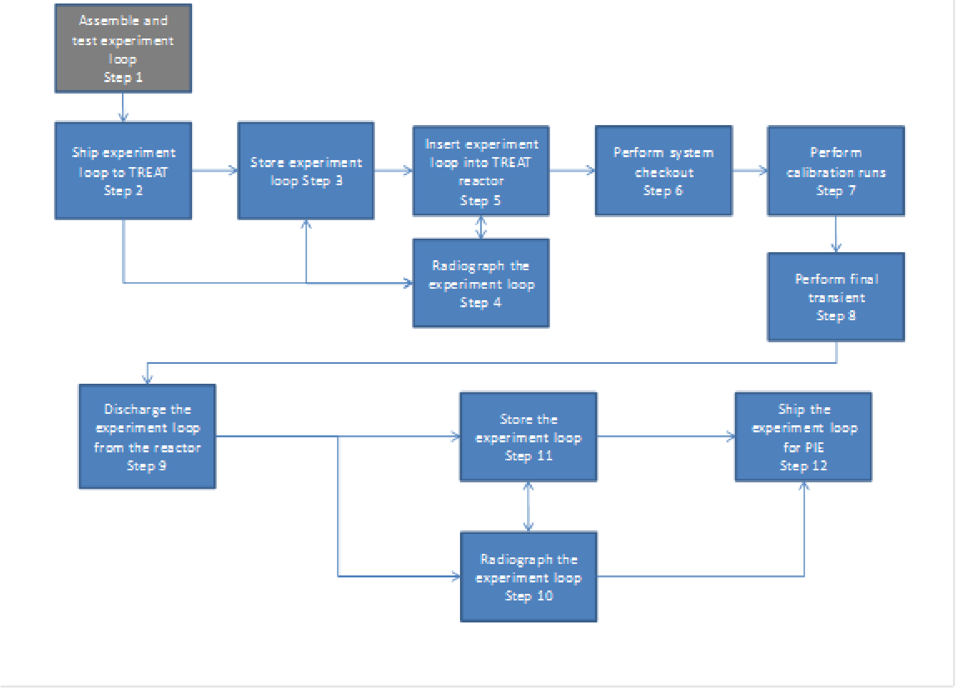
*DOCUMENT OWNER SHALL DETERMINE THE NEED FOR THESE REVIEWS BASED UPON THE SCOPE OF THE CHANGE AND THE HAZARDS IDENTIFIED

ESA Outline

- Scope
- Hazard Categorization
- Description section
  - Step by step description of experiment process
  - Designates controlling procedures
  - Defines potential accidents
- Compliance Section
  - Provides evaluation of experiment hardware against safety basis requirements
  - Documents what controls or analyses are in place to ensure requirement is met
- Accident analysis
  - Ensures accidents identified in Section 3 (description) are analyzed in SAR-420, Chapter 15
  - Verifies that accident consequences are bounded
- Experiment Specific Verification Checklist (Appendix A)

Bounding Analysis

- Written against the test vehicle or hardware (containment)
- Uses separate Neutronics, Thermal, and Structural analyses to evaluate equipment and activities
  - May have additional analyses if required
- Defines operating envelope for experiments contained within the hardware
- Sets safety limits for test operation



Assemble and test experiment loop Step 1

Ship experiment loop to TREAT Step 2

Store experiment loop Step 3

Radiograph the experiment loop Step 4

Insert experiment loop into TREAT reactor Step 5

Perform system checkout Step 6

Perform calibration runs Step 7

Perform final transient Step 8

Discharge the experiment loop from the reactor Step 9

Radiograph the experiment loop Step 10

Store the experiment loop Step 11

Ship the experiment loop for PIE Step 12

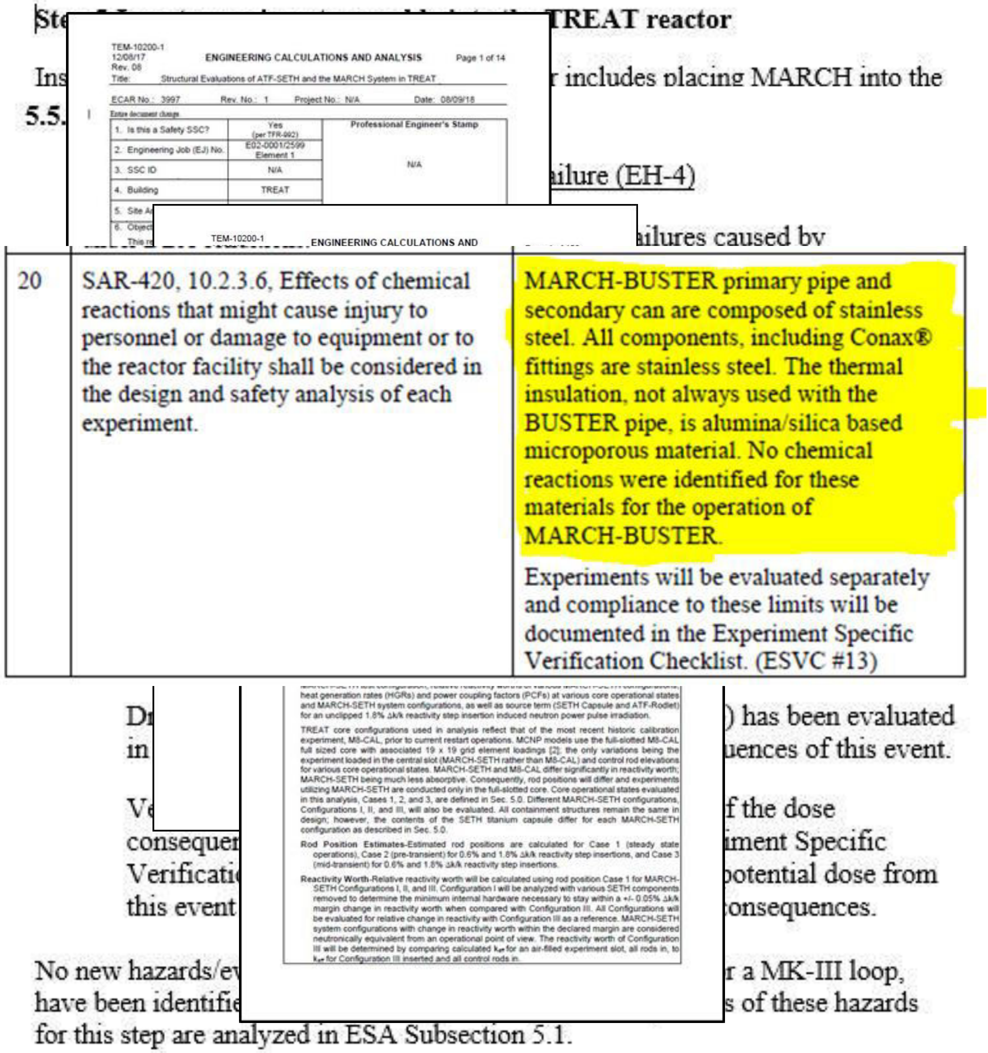
Experiment Process Flow Chart

Bounding Analysis (Cont.)

- Demonstration of Compliance
  - Shows each SAR/TS requirement is met
  - Documents controls that are in place (procedures, setpoints, etc.)
  - Some requirements are test specific
    - Results in a derived requirement that must be verified at a later date
    - Becomes an ESA commitment

- Accident Analysis
  - Evaluates each accident identified against the SAR Chapter 15 accidents
  - Documents that planned operations are bounded
  - Any new accident must be evaluated and added to SAR or parameters must be changed to mitigate the accident

How Does It Work?



Ste TREAT reactor

Ins r includes placing MARCH into the

5.5.

ilure (EH-4)

ilures caused by

TEM-10200-1
12/06/17
Rev. 08

ENGINEERING CALCULATIONS AND ANALYSIS

Page 1 of 14

Title: Structural Evaluations of ATF-SETH and the MARCH System in TREAT

ECAR No.: 3997 Rev. No.: 1 Project No.: N/A Date: 08/09/18

Entire document change

		Professional Engineer's Stamp
1. Is this a Safety SSC?	Yes (per TFR-992)	N/A
2. Engineering Job (EJ) No.	E02-0001/2599 Element 1	
3. SSC ID	N/A	
4. Building	TREAT	
5. Site A		
6. Object		

This re

TEM-10200-1

ENGINEERING CALCULATIONS AND

20	SAR-420, 10.2.3.6, Effects of chemical reactions that might cause injury to personnel or damage to equipment or to the reactor facility shall be considered in the design and safety analysis of each experiment.	MARCH-BUSTER primary pipe and secondary can are composed of stainless steel. All components, including Conax® fittings are stainless steel. The thermal insulation, not always used with the BUSTER pipe, is alumina/silica based microporous material. No chemical reactions were identified for these materials for the operation of MARCH-BUSTER. Experiments will be evaluated separately and compliance to these limits will be documented in the Experiment Specific Verification Checklist. (ESVC #13)

heat generation rates (HGRs) and power coupling factors (PCFs) at various core operational states and MARCH-SETH system configurations, as well as source term (SETH Capsule and ATF-Rodlet) for an unclipped 1.8% Δk/k reactivity step insertion induced neutron power pulse irradiation.

TREAT core configurations used in analysis reflect that of the most recent historic calibration experiment, M8-CAL, prior to current restart operations. MCNP models use the full-slotted M8-CAL full sized core with associated 19 x 19 grid element loadings [2]; the only variations being the experiment loaded in the central slot (MARCH-SETH rather than M8-CAL) and control rod elevations for various core operational states. MARCH-SETH and M8-CAL differ significantly in reactivity worth; MARCH-SETH being much less absorptive. Consequently, rod positions will differ and experiments utilizing MARCH-SETH are conducted only in the full-slotted core. Core operational states evaluated in this analysis, Cases 1, 2, and 3, are defined in Sec. 5.0. Different MARCH-SETH configurations, Configurations I, II, and III, will also be evaluated. All containment structures remain the same in design; however, the contents of the SETH titanium capsule differ for each MARCH-SETH configuration as described in Sec. 5.0.

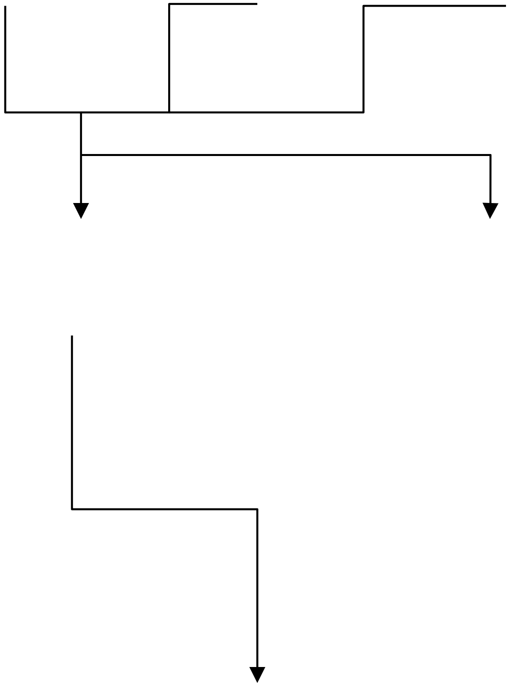
Rod Position Estimates-Estimated rod positions are calculated for Case 1 (steady state operations), Case 2 (pre-transient) for 0.6% and 1.8% Δk/k reactivity step insertions, and Case 3 (mid-transient) for 0.6% and 1.8% Δk/k reactivity step insertions.

Reactivity Worth-Relative reactivity worth will be calculated using rod position Case 1 for MARCH-SETH Configurations I, II, and III. Configuration I will be analyzed with various SETH components removed to determine the minimum internal hardware necessary to stay within a +/- 0.05% Δk/k margin change in reactivity worth when compared with Configuration III. All Configurations will be evaluated for relative change in reactivity with Configuration III as a reference. MARCH-SETH system configurations with change in reactivity worth within the declared margin are considered neutronically equivalent from an operational point of view. The reactivity worth of Configuration III will be determined by comparing calculated k_{eff} for an air-filled experiment slot, all rods in, to k_{eff} for Configuration III inserted and all control rods in.

Dr) has been evaluated
in uences of this event.

V f the dose
consequen ment Specific
Verificati potential dose from
this event consequences.

No new hazards/ev r a MK-III loop,
have been identifie s of these hazards
for this step are analyzed in ESA Subsection 5.1.



Bounding Analysis (Cont.)

- ESA Reviews
  - Peer review
    - Verification of technical content
    - Verification of derived requirements (App. A)
    - Concurrence with conclusion of ESA
  - Reactor Engineering review
    - Verification of consistency with reactor loading and operating requirements
  - Nuclear Facility Manager Review
    - Verification that safety basis requirements are adequately addressed and that conclusions support experiment operation
  - SORC Review
    - Independent review of the conclusions and technical basis for adherence to TREAT Safety Basis requirements
  - Other reviews as required by scope

ESVC

- Used to evaluate an experiment or group of experiments for compliance to the safety basis
- Limited to those requirements that require specimen information or operating parameters to evaluate
- Typically requires thermal and neutronic analysis
  - These analyses also perform any programmatic evaluations
  - Structural is only required for containment
  - ESVC ensures assumptions of the structural analysis are met
- If the bounding analysis does not allow the planned operation, one of the following must happen:
  - The experiment must be modified to be within the bounding analysis
    - Change the specimen
    - Change the operating parameters
  - Modify the bounding analysis and update the ESA
  - Modify the experiment hardware

How Does It Work? (Pt. 2)

Table 1. ESA Commitments for MARCH Experiments.

Requirement	Compliance
A dose consequence evaluation has been performed to show the experiment(s) is bounded by SAR-420, Chapter 15 accidents previously analyzed. (Compliance 4 and 16)	This requirement is verified by the Experiment Specific Verification Checklist prior to experiment insertion into the TREAT.

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EXPERIMENTS OPERATED IN MARCH-BUSTER	Identifier:	TREAT-ESA-002	
	Revision:	2	
	Effective Date:	10/09/18	Page: 69 of 76

Appendix A

Experiment Specific Verification Checklist

13. The effects of chemical reactions in the specimens that might cause injury to personnel or damage to equipment or to the reactor facility have been considered and do not create a hazard for personnel or equipment for the planned operation (Compliance 20).

    Discussion: The SETH capsule contains only a fuel pellet with Zircaloy cladding surrounded by Helium encased in a titanium capsule. None of these components have known chemical reactions with one another that could harm personnel or equipment.

Verification document(s) Reference Drawings

capsule will be filled with inert gas at room temperature/pressure pre-transient conditions for more-pragmatic separate effects testing. These specimens will be irradiated in order to commission capabilities, identify performance phenomena, and establish baseline behaviors of these "state-of-the-art" specimens in the SETH environment for comparison to future tests. The presently-addressed SETH-based irradiations are considered the first in a broader ATF safety research and irradiation program. Figure 2, taken from PLN-5523 (Reference 3), shows an overview of the SETH capsule planned for these initial ATF irradiations.

Of particular interest in this analysis are temperatures of materials to ensure integrity of containment structures (documented in the structural analysis), prevent melting, and calculate internal pressures due to the increased temperatures. Conditions are evaluated during a time limited steady state operation and under planned and unplanned transient events. Results from this analysis are used to further evaluate structures in the structural analysis.

Test Holder (MARCH-SETH) system as described in PLN-5523 [1]. The MARCH irradiation vehicle system consists of a primary containment structure that can accommodate a variety of specialized low activation modules designed to expedite specimen post-irradiation examination (PIE). The primary containment structure design, the Broad Use Specimen Transient Experiment Rig (BUSTER), and the SETH module designed for ATF specimen testing make up the combined MARCH system for this analysis. Calculations include rod position estimates, reactivity worth of the MARCH-SETH test configuration, relative reactivity worths of various MARCH-SETH configurations, heat generation rates (HGRs) and power coupling factors (PCFs) at various core operational states and MARCH-SETH system configurations, as well as source term (SETH Capsule and ATF-Rodlet) for an unclipped 1.8% Δk/k reactivity step insertion induced neutron power pulse irradiation.

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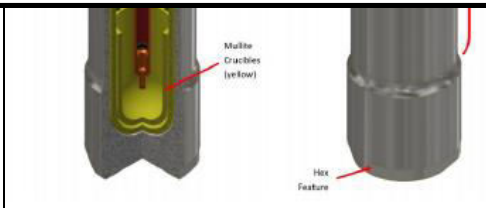

gure 7. Example SETH Capsule.

Appendix A

What About Things That Are Not Experiments?

- SP-50.3.4.3
  - Parallel process for hazards analysis
  - Uses same compliance matrix as ESA
    - Some items that only apply to experiments are excluded by the procedure
  - Documentation requirements are reduced
    - Technical Evaluation
    - Operating Test Plan
    - Other referenceable document
  - Can use Appendix A if using hardware with an existing ESA

Summary

- TREAT has limited staff to perform experiments
- Modifications to test programs are likely to happen to ensure test objectives are met
- Test vehicles must be able to operate under a broad range of transient conditions
- ESA process must be robust but allow for changes with minimum effort
- Two step process adopted
  - Bounding on hardware
  - Experiment specific for each experiment or group of experiment
- Similar process for non-experiment operations

Questions