Coordination of Efforts Between Restart, Experimentation and Modeling for the Transient Test Reactor

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TREAT – The Transient Test Reactor Facility
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TREAT’s mission is to deliver transient energy deposition to a target or targets inside experiment rigs.

FIG. 5. Plot of TREAT reactor power and energy for hypothetical RIA-type transient resulting in 1400-MJ pulse with a 72-msec FWHM capable of depositing 1200 kJ of energy per kg of fuel (290 cal/g).

1.21 Gigawatts
TREAT Modeling and Simulation

• The INL multi-physics modeling team is supposed to model such experiments in next generation experiment series!
First Experiments

Static Environment Rodlet Transient Test Apparatus (SERTTA)

- General purpose devices without forced convection
- Pre-pressurized and electrically heated
  - Liquid water up to PWR condition (320°C 16 MPa)
  - Inert gas or steam
  - Liquid sodium
- Two SERTTAs are under development
  - 4X capsule “Multi-SERTTA”
  - 1X capsule “Super-SERTTA”
- At present MAMMOTH is the only means available to assess the transient performance of these capsules.
**Multi-SERTTA**

- Best for smaller scale specimens and four-for-one testing (concept screening)
- Planned to be the first new test to be used in restarted TREAT
TREAT Water Environment Recirculating Loop

First forced-flow experiment configuration

Pump on bottom design conceptually, but not complete

Test train is modular:
- One rod in a flow tube for highly instrumented test trains
- Up to three rods in individual flow tubes for concurrent testing
- Four-rod bundle test-specific instrument designs

Detailed design concept underway for a single-rod test train only (for ATF-2)

New design was described in a recent internal report, but no detailed drawings yet available

Further TWERL design work currently unfunded
How TREAT works

- Three sets of control rods:
  - Safety – fully out for transient
  - Compensation – partially inserted to set critical state pre-transient
  - Transient – partially inserted for desired delta-\(k\), then rapidly fully withdrawn

- Core is 100 ppm highly enriched uranium – very little resonance absorption.

- As core heats, a shift in the thermal Maxwellian takes the core back to a new critical state; eventually rods are driven in to shut down.

- Temperature distributions (and thus feedback) are spatially distributed.
How MAMMOTH Works

- MAMMOTH has been built using the MOOSE framework (Multi-physics Object Oriented Simulation Environment)
- MOOSE allows implicit, strong, and loose coupling of MOOSE animal solutions
- MAMMOTH is the MOOSE-based multi-physics reactor analysis tool.
- At present, TREAT core simulation efforts rely on BISON (fuel performance), Rattlesnake (time-dependent neutron transport) and MAMMOTH. LWR-type pin experiments are being evaluated using RELAP-7 as well.

- Note that MAMMOTH is a single executable code with multiple personalities all co-existing.
- All codes are based on FEM – MOOSE routines perform all solutions.
- All data from all codes is available to the solver(s) used.
- Nothing like this exists elsewhere – MAMMOTH is earth-shaking.
MAMMOTH Fuel Physics Coupling Process

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BISON provides thermal feedback and densities to MAMMOTH for cross-section generation and clad temperatures for RELAP.

RELAP7 provides temps and densities for BISON and MAMMOTH.

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BISON provides mod. temp, clad temp, and T, p to RELAP7.
MAMMOTH Fuel Physics Coupling Process

- **RELAP7** supplies power to the fuel in **BISON**
- **MAMMOTH** provides isotopic distribution (including fission gas components) and damage to **MARMOT**
- **Rattlesnake** supplies power to the fuel in **BISON**
- **MAMMOTH** provides cross-sections to **Rattlesnake** for transport calculation
- **BISON** provides thermal feedback and densities to **MAMMOTH** for cross-section generation and clad temperatures for **RELAP7**
- **MARMOT** passes “science-based” predictive properties to **BISON**
- **BISON** provides temperatures, gradients, and stresses to **MARMOT**
- **RELAP7** provides temps and densities for **BISON** and **MAMMOTH**
- **MAMMOTH** passes isotopic data to **MARMOT**
- **MARMOT** passes “science-based” predictive properties to **BISON**
- **Moderator T, ρ**
- **Clad Temp**
- **Mod. Temp**
- **Isotopes**
- **X-sections**

**All of this in a single solve!**
**Coupled Physics in MAMMOTH**

Temperature (K) ↑
- Reactivity increase (boron removal) between 0.01 and 0.1s
- Reactivity decrease is due to temperature feedback

Thermal Flux ➔
Stakeholder Needs

- Stakeholders refers to the parties with near team interest in TREAT modeling and simulation
  - Restart and operations
    - Reduce operational costs through rigorous pre-experiment analysis
    - Provide more margin for experiments
  - Experiment design
    - Simulation of transients prior to reactor insertion
    - Understanding spatial variations and spectral changes
  - Instrumentation
    - Needs identification
    - Estimate of flux magnitudes and spectra inside and outside core
  - Benchmark Development
    - Support for ongoing NEUP and IRP benchmark development
    - Evaluation for historic transient configurations
  - Department of Energy
    - Nuclear Engineering Advance Modeling and Simulation (NEAMS) investments
    - Understanding of core behavior in licensing review
Modeling and Simulation Needs

- Validation, validation, validation.
- User feedback
- Theoretical improvements
- Did I mention validation?
  - neutronics
  - fuel performance
  - thermal fluids
  - coupled behaviors
- Validation is a circular process
  - We are currently helping to design experiments and vessels
  - Data from those experiments will:
    - Validate the computational simulation or indicate shortcomings that must be addressed.
    - Identify instrumentation deficiencies or new needs
    - Highlight areas for improvement for PIE (methods, equipment, materials)
  - Following experiments will gain from these experiences.
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Learning to Walk

- This analogy is not all that far off the mark
- TREAT has been idle for 22 years
- We’re going to start off crawling first!
- The first tests to be performed in TREAT will be to reproduce the last set of measurements performed in TREAT – the M8 Series Power Calibration Experiment (M8CAL), 1990-1993.
- These measurements will be performed with existing equipment
  - No additional detectors
  - No additional flux/fission wires
  - Existing data acquisition system DAS and Automatic Reactor Control System (ARCS)
  - Wires and foils in test position will be gamma scanned and surveyed for FP inventory
- DOE-ID wants INL to demonstrate that we can reproduce historical data before resuming operations
Historical Approach for TREAT Calibration

- Steady state – calibration of detectors with experiments to calculate power coupling factor
  1. Heat balance measurements (calorimetry) were used to determine steady state power at one or more flux levels.
  2. A sample fuel rod(s) was placed within TREAT, and a steady-state test was performed for a set amount of time. The test rig was then removed and the number of fissions/sec/gm determined by destructive analytical chemistry techniques or gamma scan.
  3. Fission wires of uranium alloy were irradiated at steady state and also assayed to obtain burnup data.

- Transient operation – determination of transient coupling correction
  4. TREAT would be operated in transient mode with a second set of fission wires with the planned transient.
  5. Estimation of core power during transient, coupling to experiment in steady state, and transient correction factor.

- Finally the test rig was placed in the test volume within TREAT and the prescribed transient test was performed.
- This process could take a week or more.
Is Modeling and Simulation Even Needed?

- Operations has pointed out (more than once) that they don’t need new advanced M&S to restart.
  - True, they can perform operations in exactly the same fashion as was done historically
  - Inefficient, time consuming, limited accuracy, but it worked:
    - 6,604 reactor startups
    - 2,885 transient irradiations
  - No predictive capabilities on fuel performance
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• The truth is operations doesn’t need advanced M&S, but does want these capabilities.
  – Reduce a week’s worth of pre-transient testing to perhaps a day.
  – Better quantify the behavior of the full core to reduce conservatisms
  – Tools for experiment, experiment vessel and instrumentation design
  – Increased throughput, better science coming out of measurements.

• DOE want the most bang for the buck on future TREAT operations
  – Increase throughput
  – Better utilization of reactor
  – Improved materials performance knowledge
  – Validation of single- and multi-physics methods
Moving Forward on Advanced Modeling and Simulation

- Development of methods to handle cross section challenges
  - 3D effects – base cross sections generated using Serpent 2
  - Strong neutron streaming in hodoscope slot
    - Direction-dependent diffusion coefficients using Larsen-Trahan method added to Rattlesnake
  - Strong absorption near control rods
    - Superhomogenization correction
    - Also corrects for vertical leakage through air channels.
Moving Forward on Advanced Modeling and Simulation

- Successful modeling of historical transients from M8CAL measurements with slotted core and in-core calibration vehicle.
  - transient power measurements
  - fission wires
Planning for Validation Measurements

- Measurements to support validation from Feb – Nov 2018 (~130 working days)
  1. Develop Neutron Flux Map of the TREAT Core
     - Flux wires in strategic locations (x, y and z)
     - Fission wires together with flux wires
     - Strategy for wire insertion, removal, tracking, counting
  2. Characterize Neutron Spectrum (steady state)
     - Core center/experiment location
     - Performed as a function of temperature
     - Activation of foils with and without filters
     - Use procedure for flux unfolding and code comparison using techniques developed in ATR in 2011-2014
     - Temperature measurements
  3. Develop TREAT Core Temperature Profile/Negative Temperature Coefficient
     - Non-trivial – only clad temperature is readily measured
     - Thermocouple or infrared, other?
  4. Perform Neutron Lifetime and Beta Measurement
     - Noise techniques
     - Oscillation
  5. Evaluate new detector technologies (in-core and ex-core)
Planning for Validation Measurements

- For wires and foils, post-irradiation counting will be performed (betas and gamma)
- TREAT currently has no in-house facilities.
- Counting labs are available at the Advanced Test Reactor (20 min. drive) and at the Materials and Fuels Complex (>5 min. drive)
  - Unfortunately, both facilities are being heavily utilized
  - Measurements should be made within 24 hours
- Justification for new counting facilities at TREAT
  - Budget is available
  - Decisions need to be made soon!
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- February 2018 is just around the corner and much remains to be done by all parties!
TREAT Team Leads

- Dan Wachs – Transient Testing Lead
- Bruce Nielson – Program Manager
- Rob O’Brien – ATF-3 Principle Investigator
- Andy Beasley – ATF-3 Experiment Manager
- Heng-Ban, Troy Unruh, Darrell Knudson, Josh Daw, Kurt Davis – Instrumentation
- Nick Woolstenhulme – Test Vehicle Design & Analysis Lead, SERTTA Lead Engineer
- Greg Housley – TWERL Lead Engineer
- Clint Baker – Hot Cell Prep. and Assembly Engineer, Sodium Loop Lead Engineer
- Lance Hone, Nathan Jerred – Engineering and Prototyping Support
- John Bess, Connie Hill, Jorge Navarro, Vishal Patel, Cliff Davis – MCNP Neutronics
- Colby Jensen, Cliff Davis – Thermal Analysis
- Spencer Snow – Structural Analysis
- Jim Parry, Lee Nelson, Doug Gerstner – TREAT Operation Interfaces
- Mark DeHart – Multi-physics Methods Development
Questions?