Q7 MEETING SUMMARY

"Computational and Experimental Benchmarking for Transient Fuel Testing"

FY 2017 NE-IRP

Bi-annual Meeting

MEETING ATTENDEES

AREVA
- John Strumpell

Argonne National Laboratory
- Changho Lee
- Heather Connaway
- Dimitrios Kontogeorgakos
- Arthur Wright
- Jordi Roglans-Ribas

Hill & Associates
- David Hill

Idaho National Laboratory
- Mark DeHart
- John Bess
- Doug Burns
- Colby Jensen
- Nic Woolstenhulme
- Jim Parry
- Josh Daw
- Dan Wachs

Massachusetts Institute of Technology
- Lin-Wen Hu
- David Carpenter
- Kaichao Sun

Oak Ridge National Laboratory
- David Pointer

Oregon State University
- Wade Marcum
- Brian Woods
- Dan LaBrier
- Tommy Moore
- Emory Brown
- Yikuan Yan

TerraPower, LLC
- Mike Steer
- Kevan Weaver

University of Michigan
- Tom Downar
- Volkan Seker
- Haining Zhou
- Hunter Smith
- Bill Martin
- Ethan Pachek
- Eshed Magali

University of Wisconsin
- Michael Corradini

Day 1

1 GREETINGS (HUSSEIN KHALIL)

Hussein welcomes us all to Argonne. Wishes us all a successful few days of meeting and collaboration. He pointed out that Argonne has quite the history with TREAT, having built and run it for many years, so they are all excited to see it being restarted.

2 LOGISTICS (CHANGHO LEE)

The location of the bathroom, the exit path for emergencies, and the breakout session rooms were shown. Informal dinner signup for tonight at Gordon Biersch in the break room. Tours of APS and ATLAS available for signup as well. Wireless internet connection is available through the guest portal. He is very happy to be hosting the meeting at Argonne.

3 GOALS OF MEETING (WADE MARCUM)

IRP group has grown to incorporate new members. Everyone introduced themselves in a roundtable manner. Revisit task goals and show the high-level objectives of the IRP. Touch on Tuesday agenda for task updates. (Note: Michael Corradini to participate via phone call to provide updates). Expects a very informal discussion on Wednesday from industry partners to gauge how project can best be utilized beyond current scope.

4 UPDATE ON TREAT RESTART (DAN WACHS, NIC WOOLSTENHULME)

Status of Transient Testing Capabilities – Dan Wachs

Fuel Safety research

The objective is to help industry describe how fuel systems respond to relevant transients (operational/off normal, integrated by multi-scale M&S). Treat is an instrument to provide nuclear/sample environment and characterization. Possible transients include pulses, continuous power/flat top, power ramps, etc. Able to run, contracting with DOE, done before November first experiment to benchmark codes (small pulses). -Early march. 75-80ms pulse

Instrumentation include traditional PIE, modern 3D neutron tomography. In-situ: high speed instrument for P/T/deformation etc. fast neutrons: Hodoscope for real time fuel motion

monitoring. November timeline for core characterization, then DOE review. M8CAL in core now.

Experiment Design Preparations – Nic Woolstenhulme

2500 MJ energy deposited in the core is the current limit. The vehicle is 3.87 m in length and 25 cm in diameter. 4 slots in the core center are available, generally only 2 in use. Transient shaping: (treat not a pulse reactor).

Steady State: 120KW core power, specimen power coupling, isotope build-in for follow-on test, neutron radiography.

Flattop transient: flattop is greater than 120KW, are considered transient.

LOCA decay simulation: fission heat to provide internal heat generation. Transient rod oscillations to simulate BWR void power instability.

When operated in pulse mode, it has a long period. Step insertion 4.5% Δk/k, release 2500MJ in~0.5s. Step insertion can follow a flattop transient; rod "clipping" narrower pulses. Higher capacity vehicles needed for < 100ms FWHM.

Enhanced clipping viable for narrower pulses- better simulation of LWR HZP RIA drove high burnup LWR fuel to regulation limits in 46ms FWHM. Current LDRD project addressing enhanced clipping design.

Experiment design status: Multi-SERTTA nearly complete to support ATF-3-1 fresh fuel baseline testing. MARCH vehicle recently funded under LDRD ready in 2019. RETINA video-capable vehicle & Super-SERTTA planned for ATF-3-2 (pre-irradiated specimens) funding pending, design starting 2018. TWERL water loop still planned. Design not likely to be concurrent with the IRP. Sodium capsules and loop very much in the plan.

Multi-SERTTA CAL recently designed. Will precede ATF-3-1 transient. Steady state, transient PCF, steady state PCF. First of a kind CAL vehicle/ transient for TREAT.

MARCH small sample, brief irradiation, and low activation hardware materials. PIE can happen within weeks of test. Simplified post-test shipment. Ditches baggage of high-pressure & liquid-coolant to emphasize cost-effective separate-effects or screening test. Heater module capable of 700C. Ease in instrument penetrations. Accepts fuel from TEM disc to 15cm rodlet. Reduced cost of irradiation, broadly applicable experiment envelope mostly reusable.

RETINA & Super-SERTTA briefly introduced. Future Engineering-scale test capabilities: PWR loop TWERL/Sodium capsules and loop capabilities to be reestablished.

5 UPDATE ON INL MODELING AND SIMULATION (MARK DEHART)

Current efforts to benchmark M8CAL measurements from early 1990s. Development of methods to handle cross section challenges including 3d effects, strong neutron streaming in air channels and hodoscope slot. There is confidence in core simulation modeling. Able to reproduce experiment location physics using MAMMOTH. MAMMOTH provides more accurate answer but is not QA'd. MAMMOTH is used to help design and fine tune experiments, while QA'd codes are used for developing the safety envelope. Success modeling of historical transients from M8CAL using MAMMOTH. Trouble modeling fission wires (~10 to 30 % error). These are steady state measurements. PCF and TCF historically used to determine coupling factors. Discussion of the methodology of historic effective pin power calculations. Using pin and wire coupling factors, the effective power a pin will see is determined. Heat balance performed prior to transients. Thermal equilibrium took about 6 to 7 hours. Historic calibration approach described using fission wires and fuel pins. After calibration, the experiment would be placed in and run for a steady state before transient testing. Using correction factor from proper Q value and other corrections, error is reduced significantly (less than 5%). Data quality is not appropriate for a full validation, missing critical data. Confidence in methods exists, but validation of this experiment is not possible. TREAT will provide capability of full validation within a year. Lots of measurements will be taken to support this. Goal to have MAMMOTH as QA to be able to use for safety analysis and design.

6 UPDATE ON UW- LED IRP PROJECT (MICHAEL CORRADINI)

Begun end 0f 2014 (6 moths from finish). Working on in-situ real-time transient instrumentation. Being done in 4 task items. To do testing at TRIGA reactor for various detectors.

Task1. George Imel working with TREAT folks for MPFD

Task2. George Imel developing cross calibration technique for fission chamber calibration

KSU. Evolve Hornyak button designs. Mainly through geometry to reduce S-N ratio. Filling silicon trenches (10s of microns wide) with paraffin.

Trying to develop a transient experiment in-pile at UW TRIGA reactor. 500C ramp up over couple of minutes to ~1200C.

Task 2c. Ohio State University is tasked with innovative fiber optic temperature sensors for use in nuclear environment. Looking at long term survival. Also, looking at sapphire fiber to 1500-1600 C. Minutes to hours of silica fibers up to 1000C. Long term (days) up to 800C.

Developing diamond thermistor. Wanting to go to 1500 C with very fast temperature response time. Current prototype is slightly large. Can be shrunk from appx 3mL volume time to 1mL. Large challenges with material joining. Electron beam welding is improving nickel wire welding to diamond. INL developing HTIR thermocouple for slow response but high accuracy probe.

Task 3 and 4. Out of pile testing has begun with selected sensors (ongoing spring and summer). Safety case is developed to present to reactor safety committee for review and approval.

MPFD going into MITR. Lin-Wen Hu requesting results for in-pile testing of MPFD at KSU (done at end of March).

7 OVERVIEW OF OSU- LED IRP PROJECT (WADE MARCUM)

Objective of IRP introduced for all tasks (task 1 neutronics, task 2.1 sodium loop recovery, task 2.2 Trace/RELAP modeling and out of pile facility, task 3 instrumentation.)

Task status introduced. Task1 on schedule. Task 2 sodium benchmark met difficulties. Water loop modeling done, facility under construction, slightly behind schedule. Task 3

Timeline introduced. Deliverables due to DOE, no big delay on schedule.

8 TASK 1 PROGRESS OVERVIEW (TOM DOWNAR)

Purpose is to develop a benchmark. Using SERPENT, MCNP, OPENMC, PARCS, and PROTEUS. Steady state benchmark is completed and submitted. Minimum Critical and M8CAL separated into two documents. M8CAL steady state will be in transient report. Minimum Critical was shown to be very slightly supercritical. Iterations on steady state work have increased confidence in the solution. Transient work will consist of one burst and one shaped. There have been two candidate problems identified for each type. Monte Carlo calculations on M8CAL are looking good so far. PROTEUS work at ANL already showing

good results as well. CMFD showing dramatic improvements in run time. Serpent and PROTEUS showing good agreement as well. Does the code handling all of the contaminants or is it just representing this as a macro cross section?

SERPENT carries all of these throughout the calculations

PARCS results good for all but M8CAL. Use of quasi-diffusion methods has been implemented in PARCS and the method is shown to work, just need to apply it M8CAL. TRMM simulation initial modeling underway. COMSOL has been used to model the exact temperature fluctuation of the TREAT reactor during reactivity insertions. Coupling OPENMC and COMSOL is a possible next step.

9 TASK 2.1 PROGRESS OVERVIEW (BRIAN WOODS)

Review of overall goal. Pick one of the historic TREAT sodium loop and do benchmark with STAR-CCM+ and NEK5000. Last spring/summer 2016, down selected to HOP1-6A. Currently in preliminary modeling phase for STAR and NEK. Solid models developed from historic drawings. January 2017: meeting to do an initial scoping preliminary analysis with STAR model prior to NEK5000 model. Tommy Moore to be in ORNL summer of this year to wrap up STAR model and begin process on NEK5000 model with hands on help with Dave Pointer.

10 TASK 2.2 PROGRESS OVERVIEW (DAN LABRIER)

Timeline, a little bit behind. TRTL delivered to OSU on 4/24, photo shown. DAS/PLC wiring complete. Pre-conditioning heater installed. Pulse heater fabricating in progress. Shakedown: utilities to be installed in this week. Define flow loop operation tests and benchmarking test. Conduct operation test, expected to begin in mid-June. Will take 4-6 weeks. TRACE and RELAP modeling will be presented. Next steps briefly introduced.

46ms, 90ms, flux vs. time is of interest.

11 TASK 3 PROGRESS OVERVIEW (LIN-WEN HU)

In-reactor instrumentation tests performed on the selected instruments for eventual use in TREAT. Testing scheduled to happen in July at the MIT reactor. Report of the results to follow. Instead of using OSU reactor, the second portion of the project will be tested in TREAT due

to the restart being ahead of schedule. 100 kW operation at MIT reactor allows for the lid to be open which will allow for the test thimble to be moved around easily. Sample matrix includes fission wires, activation wires, self-powered detectors, micro-pocket fission detectors, ion chambers, and fission chambers. Do the self-powered detectors have a response time that can be used to control the reactor?

Possible for gamma powered, but not neutron powered.

Description of the dummy element to be put into MITR provided. Sensors are being delivered currently. Static measurements, slow positive transients, and fast negative transients are planned. The instruments are academic in nature but will hopefully prove to work and replace older accepted instrumentation as an upgrade.

12 TREAT CONVERSION

Develop a LEU fuel design that will maintain reactor test performance relative to the existing HEU. Develop a LEU fuel fabrication process that can consistently produce high quality fuel elements. Test block testing campaign is progressing. 2x2 block are close, then scale up to 4x4 blocks. Concerns exist about over committing to any LEU conversion strategy before more analysis can be conducted. Possible strategies include manufacturing multiple cores worth of fuel to deal with oxidation if no cladding is in the refuel. Issues with that strategy involve long term storage of fuel blocks and shuffling/replacing blocks can lead to premature damage of blocks.

13 TASK 2.1 UPDATE (TOMMY MOORE)

Currently at 2.1.6 and 2.1.7.

January model: What did Terra-Power want to know? The physics around the fuel pin. With the wire wrap, a sensitivity study should be done to determine how much thermal effects on the pin will change the model. Fluid model was constructed from solid model of HOP1-6A. Have three working meshes (1mm base size cell. 3.1 million total cells for coarse SS mesh). Has ‘unofficial’ sodium temperature data from Mike Steer. Not currently in model since it is a steady state model.

Flow measurements from original documentation claims that the instruments have low certainty and system code. Conversation around the table seems confident that flow will be

fully developed regardless of the attachment “wedge” at the bottom. Current model’s goal is to show that a single channel model in NEK5000 will faithfully reproduce the channel results from benchmark. Nik asks if we can model “distributed strainers (large holes)” in future sodium loops. Can it be made so that Safety features like this can have credit taken for them. Tommy, start with Idelcheck. Next step is to add temp profile.

Woods question. Sensitivity study for turbulence? At top end of flow rates, no secondary flow structures are expected to evolve. Possibility to infer location of thermocouple if it is in well mixed region. If not well mixed, reliability is completely suspect. Grounded junction TCs.

14 TASK 2.2 UPDATE (DAN LABRIER)

Introduce TRTL team.

As of last November, TRTL frame being welded up and lab space being created. No loss of time since then. Time will be made up this summer now that facility is in-house.

Electrical system upgrade has taken place. Projecting walkthrough of software and its capability by June. Walked through control room set up. Still waiting on preconditioning heaters and instrument/heater pass-through.

Wade Marcum mentioned to Nik that the pass-through for instrumentation has been one of the largest physical challenges. At TREAT, cask is the limiting factor for experiment size. TWERL was max size possible.

All leads to question, beyond IRP, what role can TRTL play in providing information for water vehicles in TREAT.

Benchmark tests: SS unheated. SS heated, Unsteady heated. Plan on doing “low and slow” transients to get comfortable results without worrying of burying out heater prematurely.

Outlined short, intermediate, and long term goals for TRTL group to make progress towards Task completion.

Nik: time not well spent on worrying about what TWERL needs from a prototyping perspective. Purpose, from OSU’s perspective is to “map” challenges and experience for loop shake down and operation for help with future TREAT water loop. Nik suggests 46 millisecond pulse that represents max TREAT capability. 90ms TREAT current prompt-pulse fast-clip and one more (unstated) for test matrix similarity between TRTL and TREAT. Nik

will follow up on getting heat-flux vs time profiles for “most impactful” additional test matrix additions in TRTL.

15 EMORY BROWN BREAKOUT SESSION

Main focus of work has been on the problem description report. Waiting on as built drawings before finishing TRACE model. What happens if there is a azimuthal flux bias due to the 6 heaters?

> Will not be able to be resolved in a lump parameter code

Heaters are of interest to INL due to the full pressure capabilities. Might be implementable in a future flowing loop beyond the scope of this IRP. What is the axial effects of the flowing gas on the internal of the heater?

> Seems that faster gas flow makes the best result.

Discussion of applications regarding CHF determination for a fast transient. Are there any inertial effects going to come into play during these transients? Does the length of the transient cause any effects?

> Some lagging effects due to thermal inertia. May just be a result of the boundary condition however.

As pulse width decreases the onset of boiling may occur quicker. Fuel changes over time in a core. Is burnup or aging of fuel going to be a consideration in this work?

> Surface conditions can be a major player in how the boiling works. Needs to be considered going forward.

In-pile vs. out of pile experiments can be very different for this work. Possible post-doc work related to in-pile testing like out of pile work. From an AREVA point of view they are in support of this work but also cautious about making statements that contradict operational knowledge. Consider a Freon loop in-pile with see-through material. Better we understand this the better our reactors will be.

16 YIKUAN YAN

Raised question we can actually reach the point at which homogeneous nucleation would occur. No, the tempature would need to be too high, and you would just burst your rod.

Day 2

17 TASK 2 UPDATE (WADE MARCUM)

Start with presentation by Tommy Moore. Mike, David, Tommy, Wade had informal working group meeting in January to make progress on task 2.1. Developed geometry and STAR model from HOP1-6A model. Discusses practicality of porous baffles for modeling.

Task 2.2 Started off with discussion of TRTL status from Dan LaBrier and had discussion with Nik to decide what boundary conditions are desirable to apply that overlap between TRTL shakedown and TREAT needs. TRACE and RELAP models on hold until TRTL model moves beyond conceptual design. Emory and Yikuan presented scientific questions related to engineering scope of project for individual Ph.D work. Action items with respect to the heaters to be followed up on.

18 TASK 3 UPDATE (DAVID CARPENTER)

What tests to run in TREAT?

Lots of discussion on the testing plan, data from these tests, and what sort of tests will be run related to this IRP (putting in MIT thimble instrumentation). Run one test without the thimble and re run with thimble to confirm BC and to add confidence to the data from the initial testing performed for TREAT.

May also be information from these tests that are important to the conversion effort (repeating similar tests for benchmarking purposes). How will the test plan come to fruition?

May be several people interested in the same tests, how will these separate plans become a single test plan? Jim will be putting this together.

Only existing instruments are required for the restart of TREAT. Testing of new instruments to assist in future work in TREAT.

19 TASK 1 UPDATE (TOM DOWNAR)

Talked about steady state benchmarks. Questions about using off critical system. Good feedback from Heather and Demetrios. Biggest issue SL-beta scattering data in endF8.

Requires some thought over next several months. 400pcm effect from sensitivity study. M8CAL – Uncertainties are still larger than wanted. Good PROTEUS agreement with MCNP CMFD speedup (x6) makes it much more viable. Some limits on size of problems for MCNP. Need feedback. Burst 2864 for benchmark tests. Largest power and heterogeneity.

20 TASK 1 STAKEHOLDER OUTCOMES (JOHN BESS)

On schedule. End game is to get steady state documentation to international community for peer review. Successful Minimum Critical Core benchmark specifications. Good progress on development of existing and advanced methods. Risk to lab funding is a concern to success of Task 1 (Submission of SS and Transient Benchmarks to IRPhEP).

Nik has concerns with task 1…

> Be thinking about partial recovery strategies to account for possible funding issues. Plan for risk mitigation. Relies on programmatic support (which are sensitive to funding). If funding is not there, US will relinquish IRPhEP, and benchmark will not be internationally vetted, but will be stand alone, internal document.

Transient #2874 and #2864 were identified as prime candidates in the M8CAL experiments.

Uncertainty of the unknown with regards to old data using old instruments. “Bad” data from old tests are informative for development of benchmark tests and future LEU conversion. Drive knowledge on sensitivity in system. Marcum suggests creating a whitepaper on this topic to start this process. Will add significant value to the overall IRP.

Final thoughts: model of the benchmark is more important that the data. Future experiments might reduce experimental uncertainties but defining the benchmark is the final. Increased collaboration of Labs/universities has been very beneficial.

Tom Downar comment: Improved modeling capabilities has increased transparency of uncertainty quantification between labs and universities.

21 TASK 2 STAKEHOLDER OUTCOMES (NIC WOOLSTENHULME)

Observations: CFD model built for HOP 1-6A test in a historic Mk-II loop. Problem description report complete. Previously behind schedule mostly recovered.

Water loop slightly delay but recoverable. TRTL parts mostly on site. A turtle picture is shown as a joke. Expect to see the new heater performance.

22 TASK 3 STAKEHOLDER OUTCOMES (COLBY HENSEN)

Core instrumentation development. Subtask modified. Perform initial benchmarking evaluation. Perspective on instrumentation selection. In core flux and fluence (spectral, temporal, spatial), temperature. Measurement uncertainty quantification and comparison. Instrumentation benchmark evaluation in TREAT. What task to run? Recreate transient performed in MITR, repeat historical transients performed in M8-CAL, include other shaped transient, effect of dysprosium filter (move test article axially in M8-CAL). MITR test are well poised this summer. Modification to change testing from OSTR to TREAT.

23 ADVISORY BOARD DISCUSSION

- John Strumpell
  - Position same from last meeting, interesting work being performed.
- David Hill
  - What is the process to perform meaningful work in this work setting (IRP) with the constraints of funding.
  - Linking 3 tasks together and to the outside world.
  - Success in being relevant to the restart of TREAT.
- Kevin Weaver
  - Task 3
    - Likes idea of advanced instrumentation.
    - Bigger picture – needs to be done for TREAT.
    - Provides less uncertainty.
    - These instruments could be beneficial commercial (fast reactors).
    - Keep moving this forward so that these benefits aren't lost on possible future benefits.
- Dan Wachs
  - Time to think about closure points for the project to really showcase what the IRP accomplished.
  - Show that the IRP led to something better than what could have been accomplished on their own.

    - Showing success in this IRP can show the benefit of this style of collaboration for future work.
    - Commends the great collaboration occurring in this IRP.
    - Be ready to advertise.
- Wade Marcum
    - Show the synergy across all of the tasks.
    - Next meeting will be different since the Wisconsin IRP will be completed. Have delegates from their IRP provide information on their cap.
    - Appreciate all of the feedback provided by the stakeholders and others.
    - This program has provided a great opportunity for this work to take place.
    - Next meeting looking like end of October early November in Corvallis at OSU.
- Ken Kellar
    - Agrees with Dan.
    - Impressed by TH meeting.
    - Likes how the precise tasks can be made out of a broad project.
    - Cool that we get to model such interesting work (basically a new reactor).
    - Looks like we are heading in the direction of a new test reactor which could lead to lots of creativity leading forward.
- Tom Downar
    - Tying everything together could be the hard part of this project.
    - Thanks Wade for his leadership on this IRP.
    - Wade agrees and is optimistic that it can be done with lots of collaboration.
- Wade Marcum
    - Thanks to Changho Lee for hosting us and meeting adjourned.