Colby Jensen

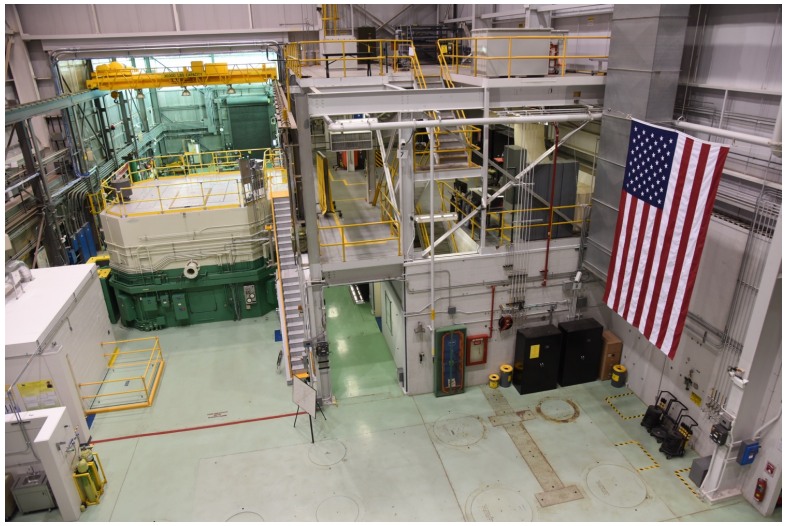
GAIN-EPRI-NEI Sensor Technologies for Advanced Reactors Virtual Workshop

October 13, 2020

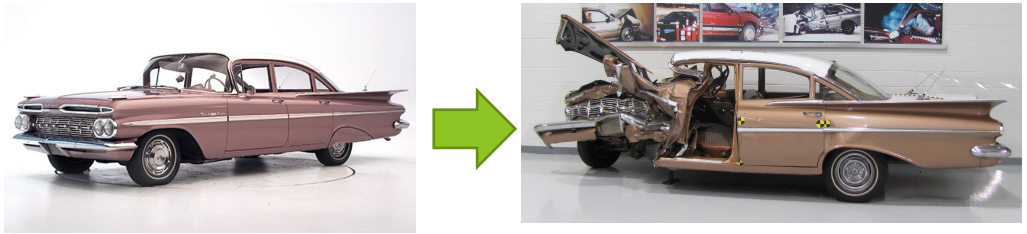
The success story of integrating advanced, real-time instrumentation in TREAT Experiments

Idaho National Laboratory

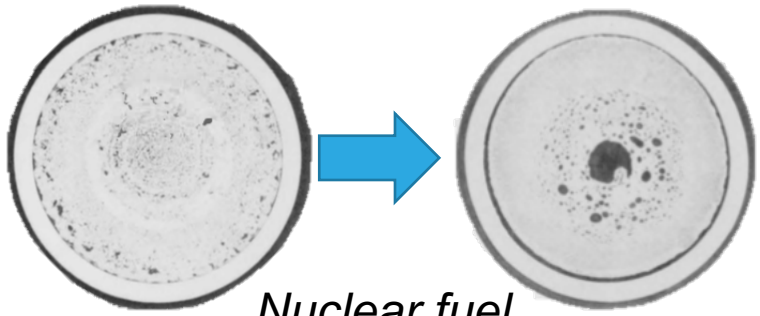
Background



- The Transient Test Reactor (TREAT) Facility was successfully restarted in 2017, last operations in 1994.
- Fills R&D capability gap for evaluating transient behaviors of nuclear fuels and materials – basically car-crash testing for nuclear fuels
- Running experiments since spring 2018 – actively designing many experiments
- Key features of TREAT testing:
  - Diverse environments and applications
  - Up to extreme environments – not long exposures
  - Rapid throughput – dozens experiments/year
  - Data intensive objectives – instrument-heavy experiments



Pre *Post*



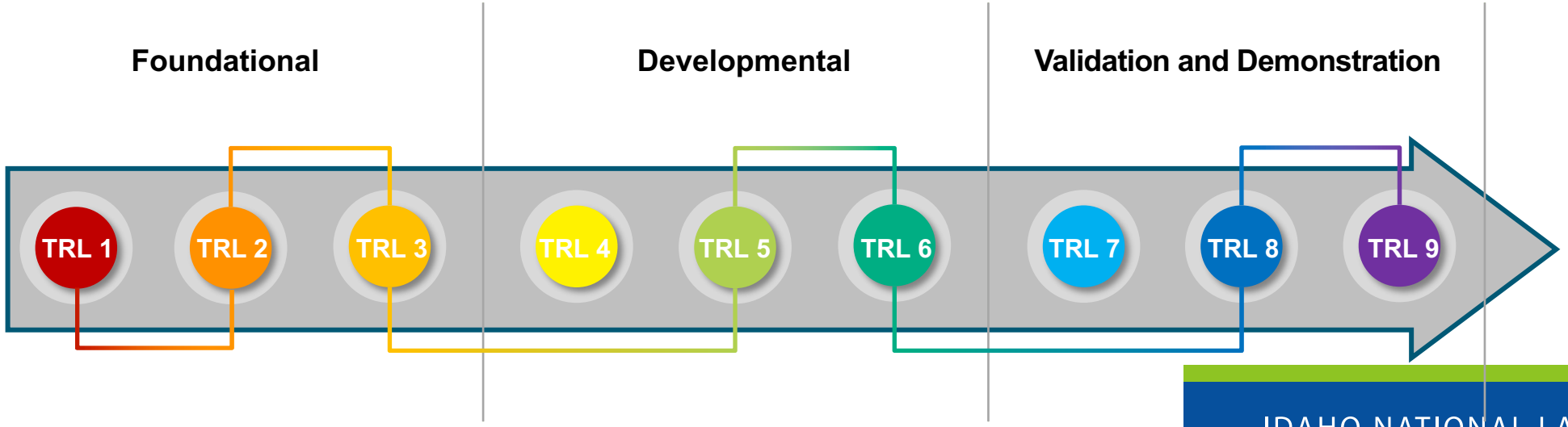
Nuclear fuel

"Valley of Death" for *In-Pile* Sensor Success

Experiment Deployment → Requires Customer Engagement!

Innovative Sensor Development (Lab Bench)

Sensor Integration in Nuclear Systems (In-Reactor)



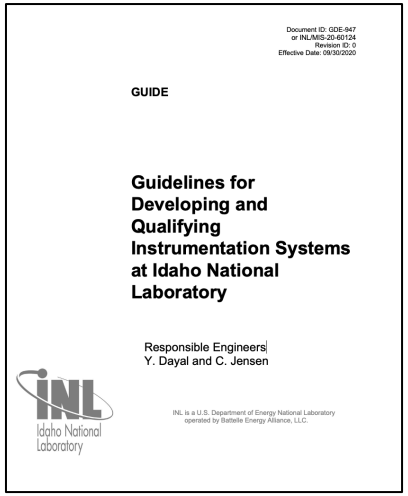
Considerations for Introducing Sensors into Experiments (*not complete*)

- Considerations
  - Introducing a sensor into a design can be an expensive engineering effort
    - "Building a car around a delicate hair-like piece of glass"
    - Needs to start early – can build flexibility into some things
  - Modeling tools used to prioritize data opportunities and model-informed integration via pre-test design and post-test interpretation activities
  - Use experiments to aid in qualifying sensors for future experiments
- Safety
  - Typically not an enhanced risk for experiments – designs typically "bake in" safety related instrumentation
  - Not safety but ALARA - feedthroughs do increase chance of leaks
- Programmatic
  - Sensor does not capture data desired
  - Sensor provides "bad" data
  - Interferes with other experiment objectives – influence on thing to be measured. E.g. thermocouple

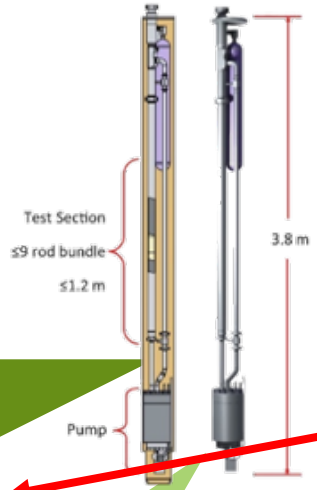
Evel Knievel attempt to jump over Snake River Canyon, 1974

3 Instrument Qualification Focus Areas "*Deployment Bridge*"

Qualification: science-based approach to show an instrument will operate in established limits for its intended purpose

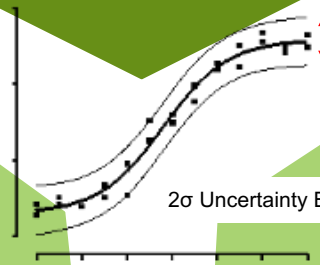


Experimental Device Integration (mechanical/ logistical)



- Geometry
- Feedthroughs
- Connectors
- Leads

Adequate definition = GOAL!



In-Pile Characterization & Testing

- Flux/fluence
- Electromagnetic environment
- Facility integration

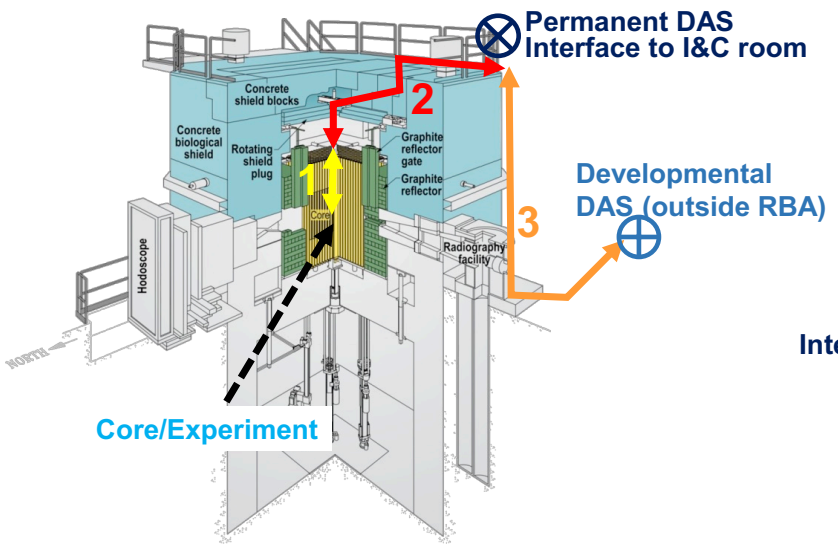
Out-of-Pile Characterization & Testing

- Temperature/Pressure
- Coolants
  - Chemistry/Flow
- Transient response

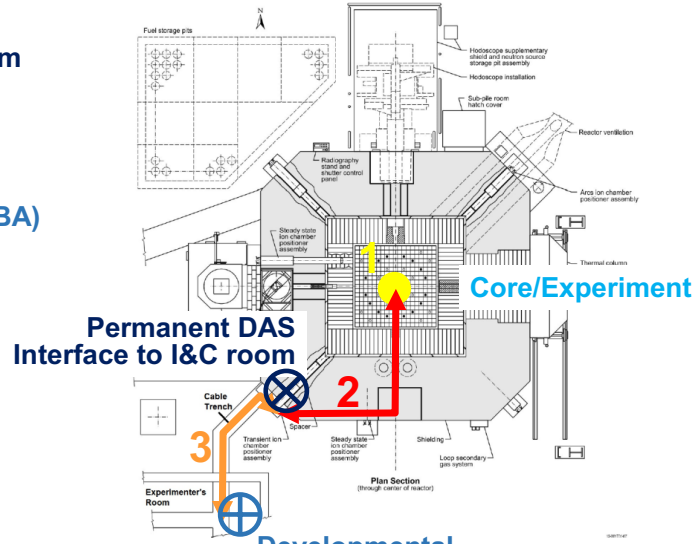
In-Pile Testing at the TREAT Facility

- Key strategy at TREAT is to reduce the cost of in-pile testing of instruments at TREAT and minimize burden of overall logistics
  - Since facility restart – instruments have been tested in every transient possible
  - Experiments include significant emphasis on required and opportunity instruments
  - Great place to evaluate neutron + gamma effects and/or stimuli

TREAT Cutaway View



TREAT Plan View

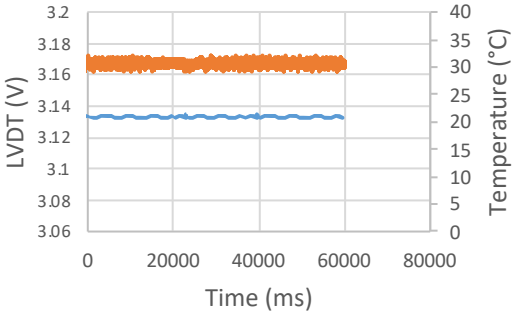


Number	Segment Length (m)
1	1.5
2	10
3	11

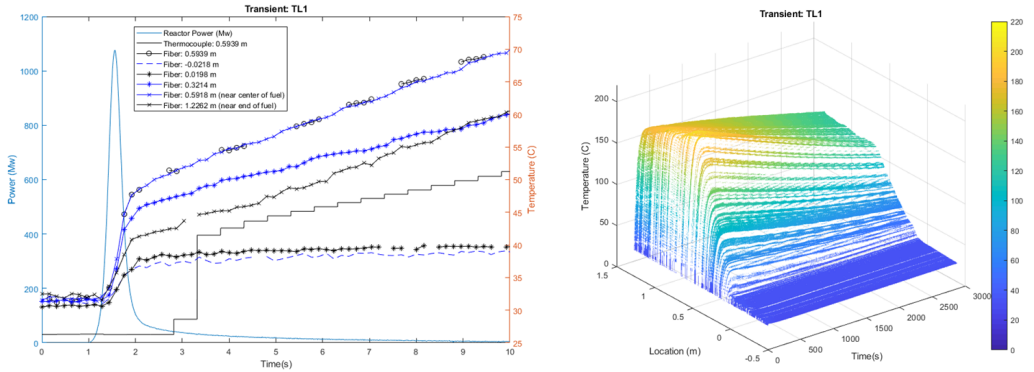
Top View of TREAT core with instruments inserted

In-Pile Evaluation Examples

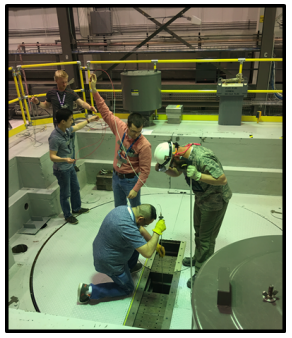
- 15+ sensors irradiated in irradiation effects tests (outside of experiments – along for the ride) since restart – some in dozens of transients



In-pile evaluation of LVDT response to TREAT flux

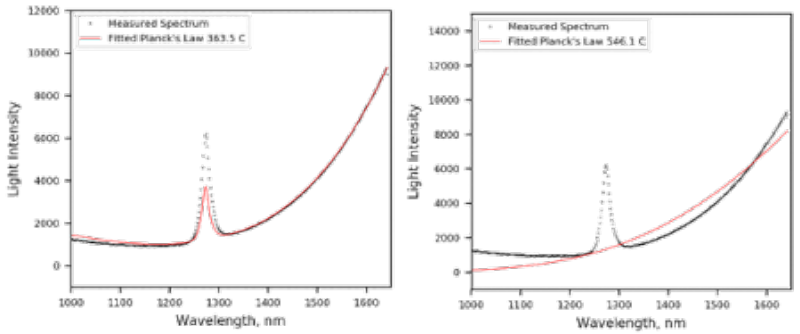


Distributed temperature sensor (fiber) measurement during TL-1 Transient



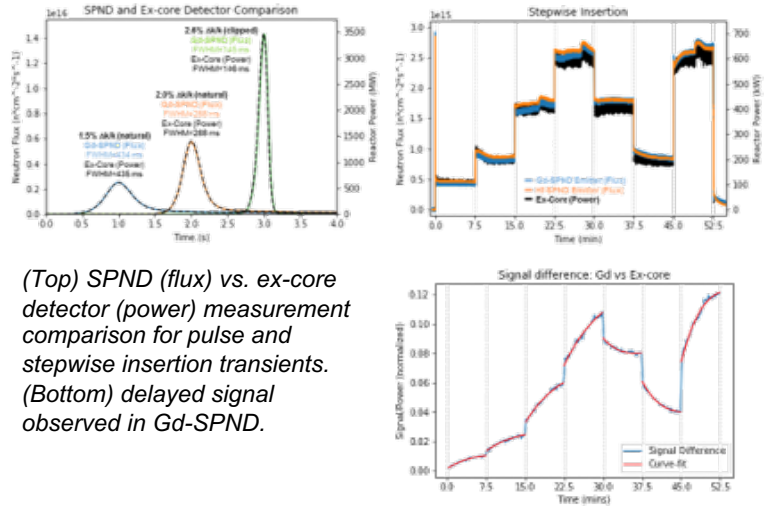
Routine insertion/ removal of advanced instruments

Experiment DAS cabinet to support instrument testing at the TREAT facility



(a) **(b)**

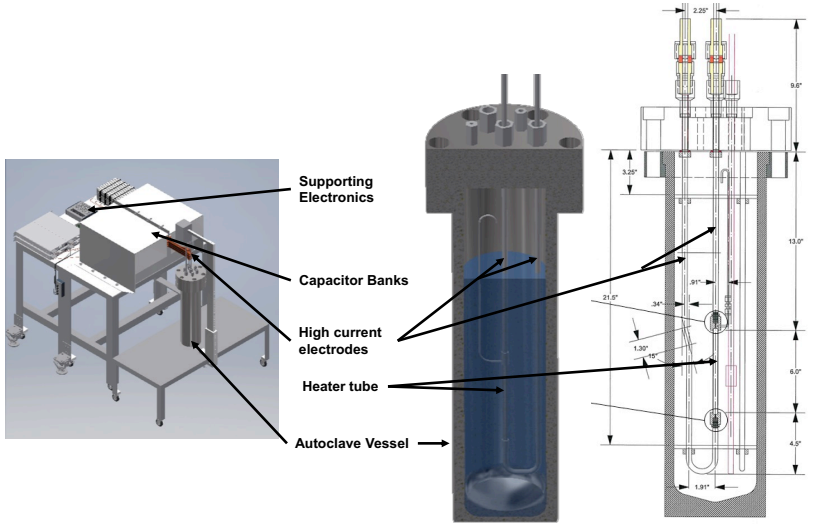
IR pyrometer evaluation with experimentally data fitted with (a) and without (b) the radiation induced emission compensation



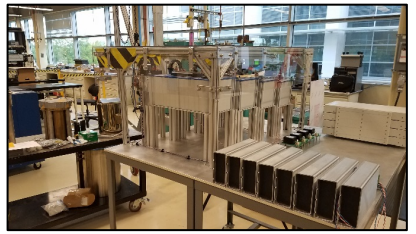
(Top) SPND (flux) vs. ex-core detector (power) measurement comparison for pulse and stepwise insertion transients. (Bottom) delayed signal observed in Gd-SPND.

Out-of-Pile Characterization

- Preferred approach to evaluate effects of physics obtainable ex-reactor
- Thermal and thermal hydraulic evaluations dominate prioritization for experiments
  - Utilize a variety of furnaces
  - High pressure water autoclaves
  - Flowing pressurized water loop at university (OSU) and a new facility at INL
  - Building TREAT device companion test beds
    - Equivalent LOCA device, sodium testing facilities
    - Incorporate other environments as needed
  - Examples on next slides…
  - Non thermal hydraulic facilities include gamma irradiation facilities, cyclic mechanical loading, etc.



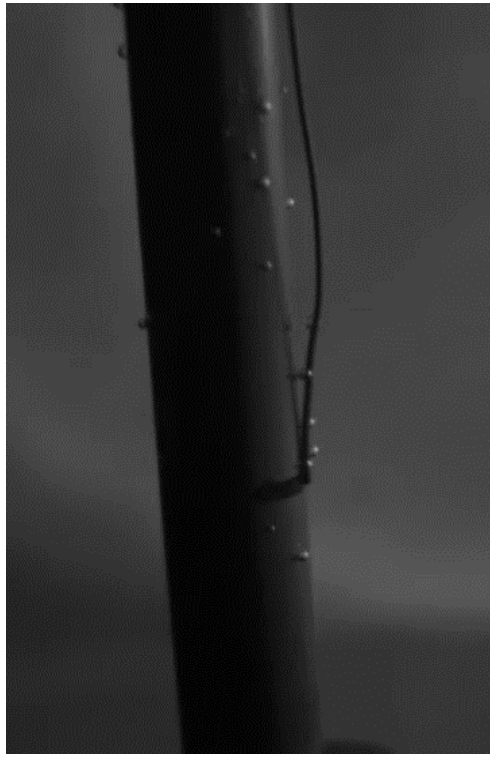
New pulsed power system coupled with PWR water autoclave

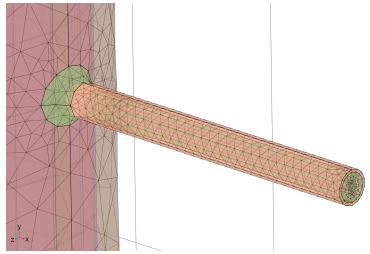


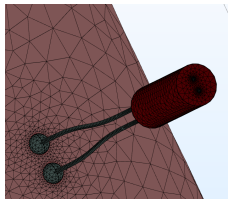
High temperature displacement sensor evaluation station constructed in FY18 – used routinely

Out-of-Pile Thermal-Hydraulic Characterization

- Example of transient boiling system



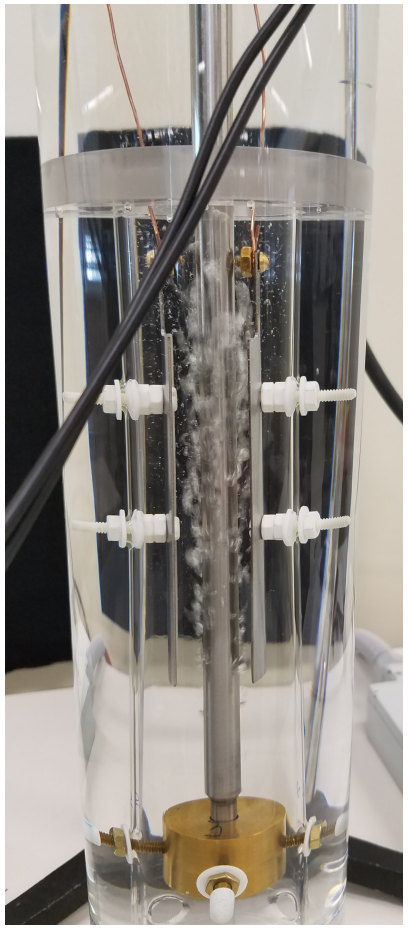


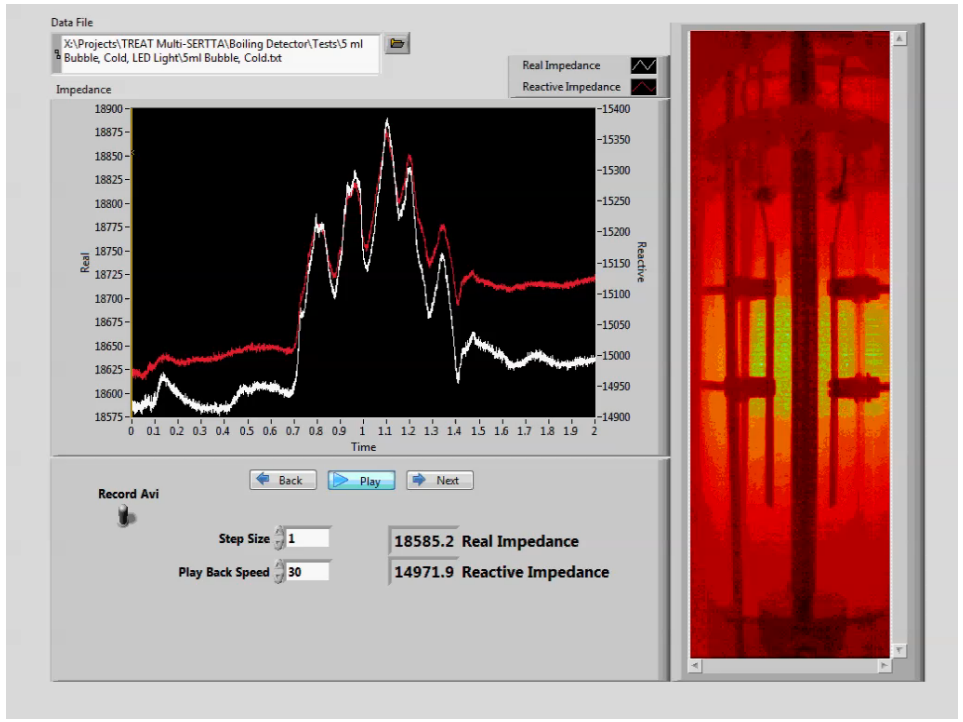


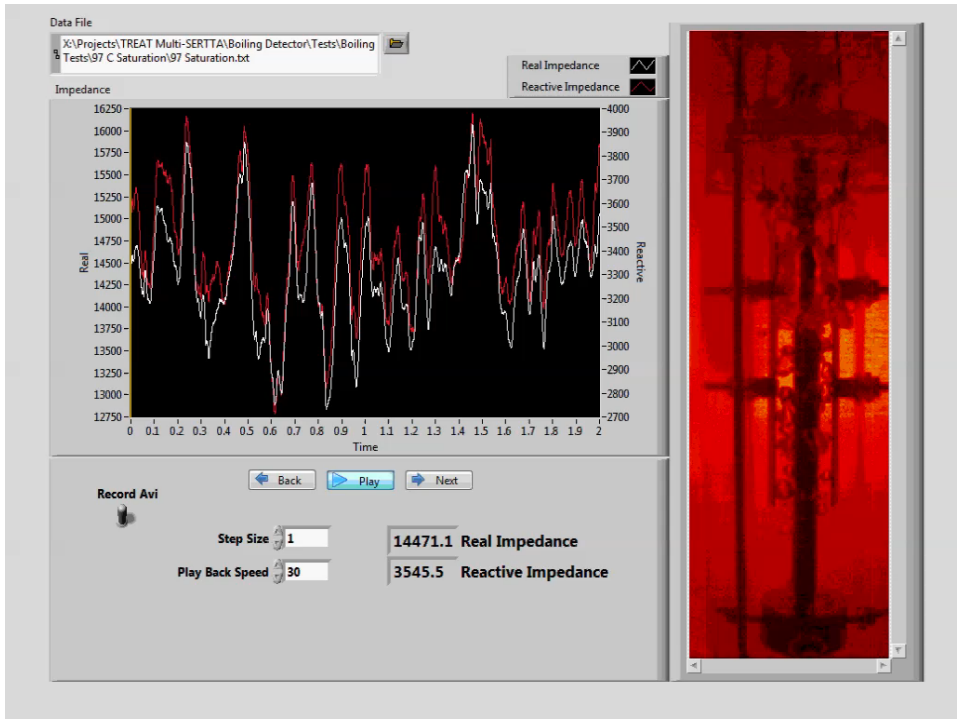
Thermocouple characterization via experiment and modeling

Out-of-Pile Performance Characterization

- Example of boiling detector using visualization capability

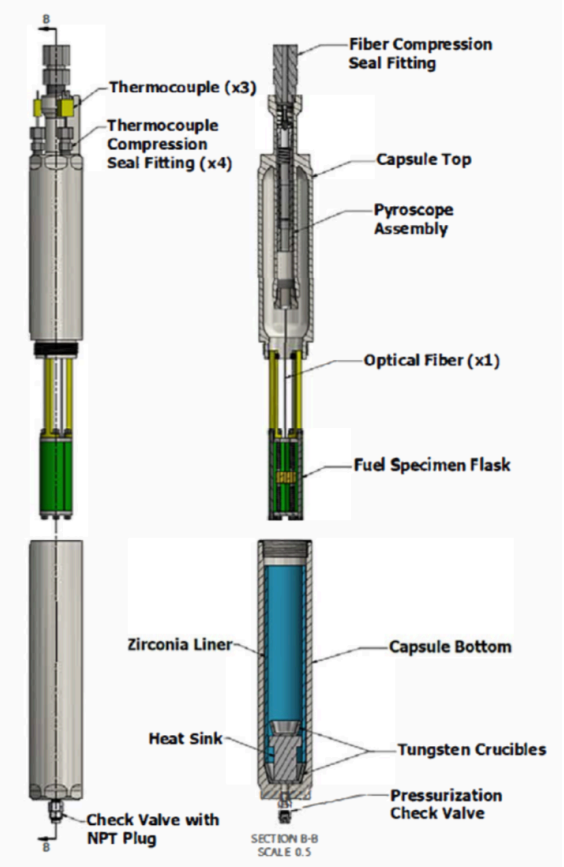




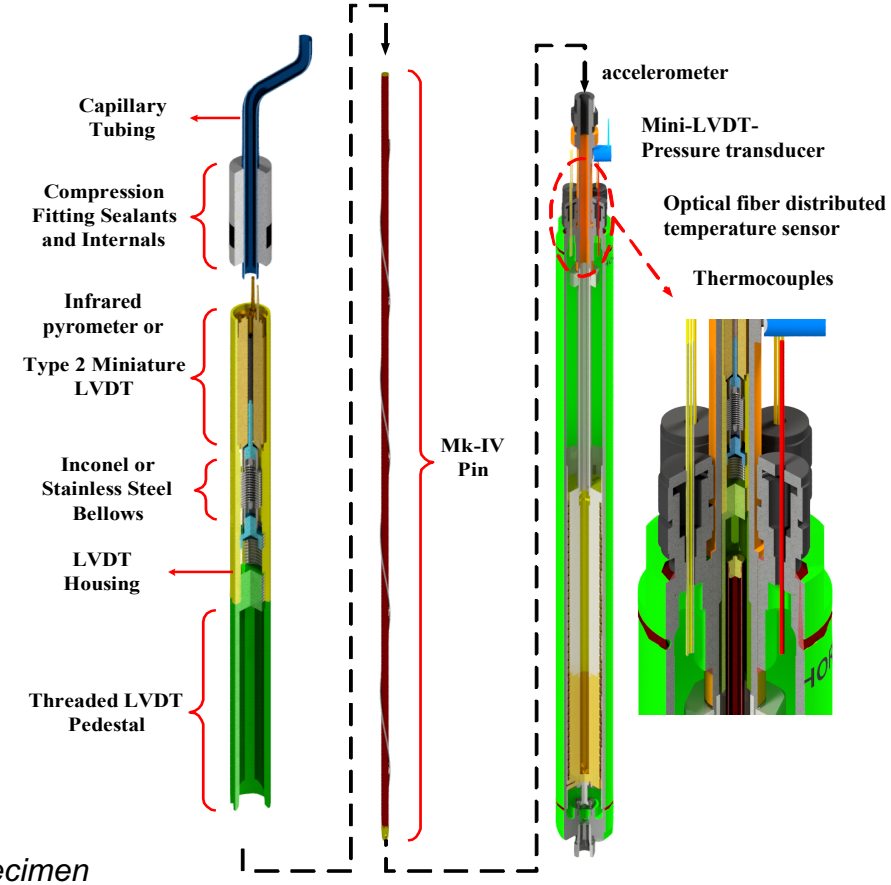


Mechanical Integration

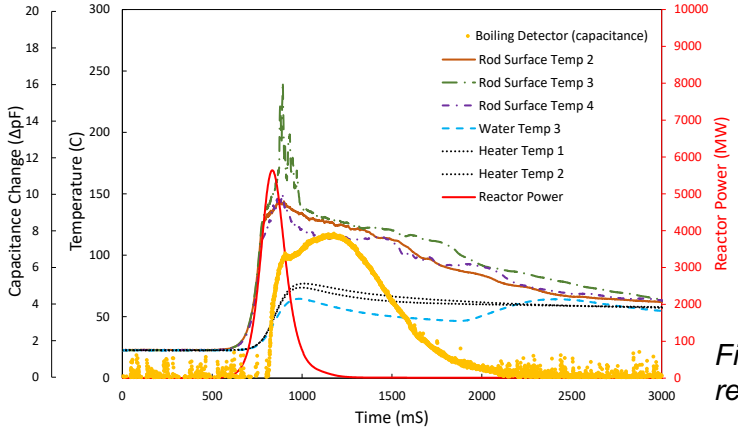
- Examples of SIRIUS, THOR, SERTTA – *see video*



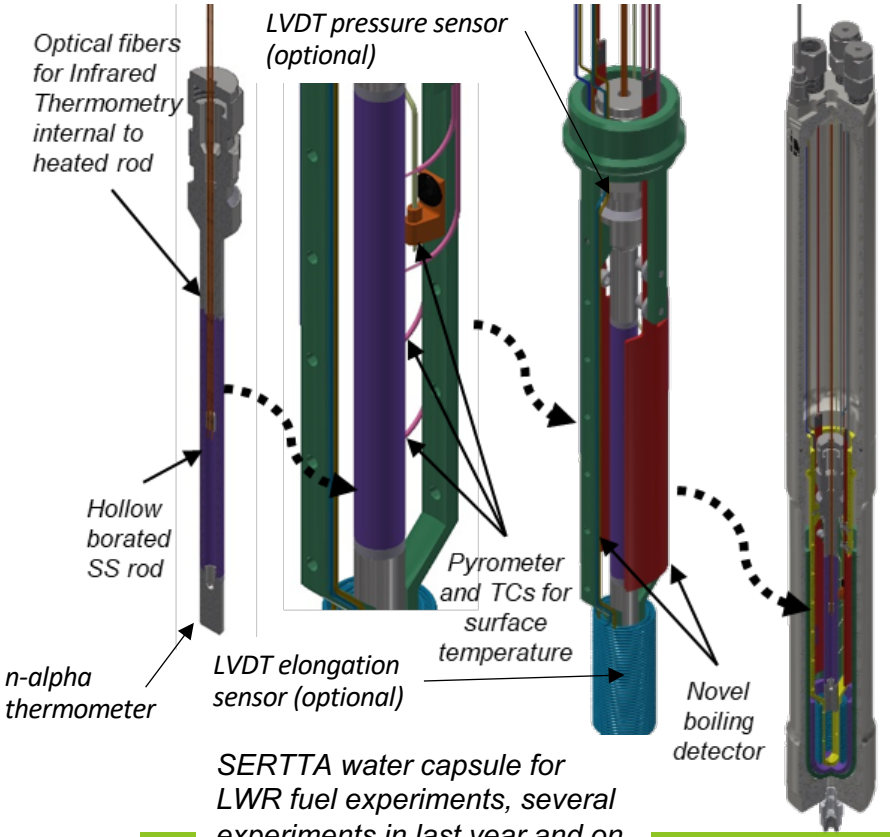
SIRIUS capsule for very high temperature specimen monitoring, several experiments to date



THOR capsule for liquid metal environment testing planned for several tests in next few years



First SERTTA results in 2019



SERTTA water capsule for LWR fuel experiments, several experiments in last year and on

Summary and Conclusions

- TREAT is restarted and running experiments regularly relying on a wide range of in-pile sensors – unique in all respects
  - Experiments cover a range of environments and conditions relevant to systems level applications – especially for in-core environments
  - Several success stories ranging from LWR to space reactor applications – dozens of distinct sensor types tested in the core in ~2.5 years – many more planned – a lot to do!
    - Experiments nearing maturity for SFR and misc. microreactor technologies
- End-use characterization is key component of device qualification needed to reduce risk in deployment
  - Requires careful mechanical integration, detailed out-of-pile thermal-hydraulic evaluations, and in-pile irradiation effects characterization
- Fuels and materials experiments provide unique opportunities to evaluate sensor performance in an integral fashion – actively and rapidly building strong qualification basis for many sensors for many applications
  - Specific irradiation effects experiments are still needed in many cases
  - Experienced staff are invaluable to making in-pile applications successful
- Always happy to talk about your application and needs