U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Clean. Reliable. Nuclear.

Spent Fuel and Waste Science and Technology (SFWST)

Dry Storage of Commercial SNF Thermal Analysis

David Richmond

PNNL-SA-149171

NWTRB Fall 2019 Board Meeting
Alexandria, VA
November 19, 2019

Outline

- Historical Context
- Thermal Modeling Phenomena Identification and Ranking Table (PIRT)
- Current Work
  - High Burnup Demonstration Research Project Cask (HBU Demo)
  - Boiling Water Reactor (BWR) Dry Cask Simulator (DCS)
  - MAGNASTOR Heat Load Sensitivity
- Future
  - Transient Modeling
  - Horizontal Dry Cask Simulator

Historically, thermal design was not fully integrated

- Fuel temperature limits were not tightly controlled
- Large amounts of margin to thermal limits at normal operating conditions
- Operations are primarily concerned with offloading large numbers of old fuel assemblies
- It is useful and expedient to bias high temperatures

Thermal design is now fully integrated

- Operations require loading higher decay heats
- As loaded (non design basis) conditions are analyzed routinely
- Aging management is critical
- Best estimate calculations are needed for integrated decision making

Phenomena Identification and Ranking Table Schedule

- PIRT Deliberation Meeting
  - October 22-24
  - Sam Durbin (SNL)
  - Chris Bajwa (NRC)
  - Jim Fort (PNNL)
  - Victor Figueroa (SNL)
- Initial Report Draft
  - January 2020
- Finalize and publish PIRT Report
  - Summer 2020

Scenarios

- Storage Bolted
  - TN-40
- Storage Vertical Ventilated
  - MAGNASTOR
  - HI-STORM
- Storage Horizontal Ventilated
  - NUHOMS
- Short Term Operations
- Transportation




Phenomena/Models/Parameters

- **Geometry**
  - General sizing and tolerances
  - Gap thickness
- **Boundary Conds**
  - Ambient air temp
  - Wind vector
  - Ground temperature and ground/pad thermal resistance
  - Atmospheric pressure
  - Insolation
  - Pool/cooling jacket temperature
  - Fluid pressurization (vacuum for short term operations)

- **Material Prop. and Source Term**
  - Solid properties (including temperature dependence)
  - Fluid properties (equations of state)
  - Surface radiative properties
  - Decay heat

- **Physics Eqns**
  - External (ventilation air) convection
    - Flow, turbulence, heat transfer
    - Boundary correlation
  - Internal thermal-fluid modeling
    - Explicit (pin-by-pin CFD)
    - Subchannel code
    - K-effective (porous media)
  - Thermal radiation
  - Gap heat transfer model
  - Contact conductance

- **Numerical Soln**
  - Space discretization (mesh)
  - Time discretization

- **Other**
  - Materials degradation
  - Phase change
  - Cask interactions
  - Individual modeler variability

Phenomena Identification and Ranking Table Process

- Knowledge (Low – Medium – High):
  - Is the state of the art acceptable/ready to be used for best estimate plus uncertainty?
- Importance/Sensitivity (Low – Medium – High):
  - Is the figure of merit (temperature) sensitive to this?
- Opportunity (Yes – No):
  - Do we recommend prioritizing a reduction in uncertainty?

		Importance H	Importance M	Importance L
Knowledge Level	H			
	M	*		
	L	*	*	

* Additional insight is recommended

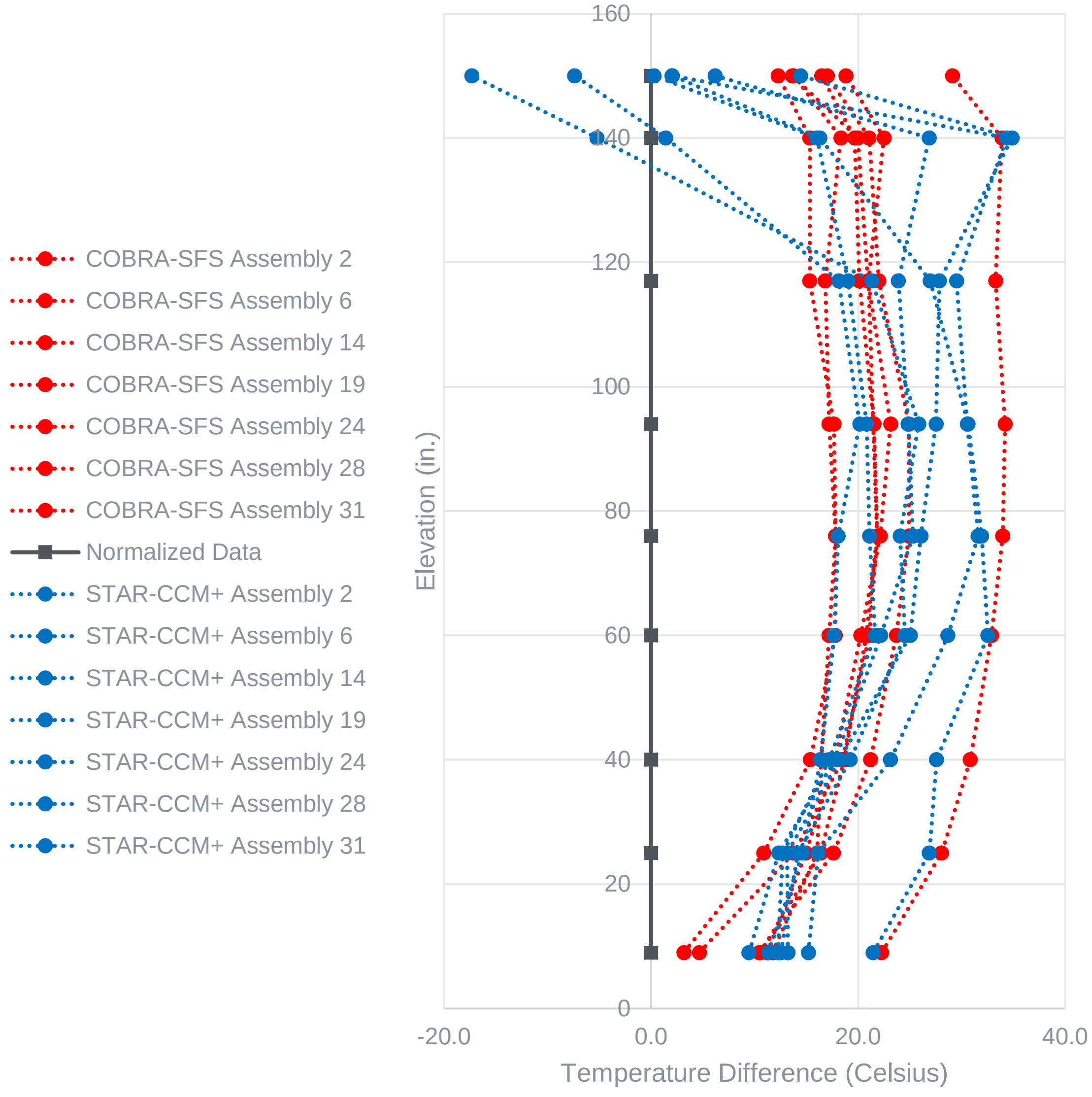
Thermal analysis can support many evaluations

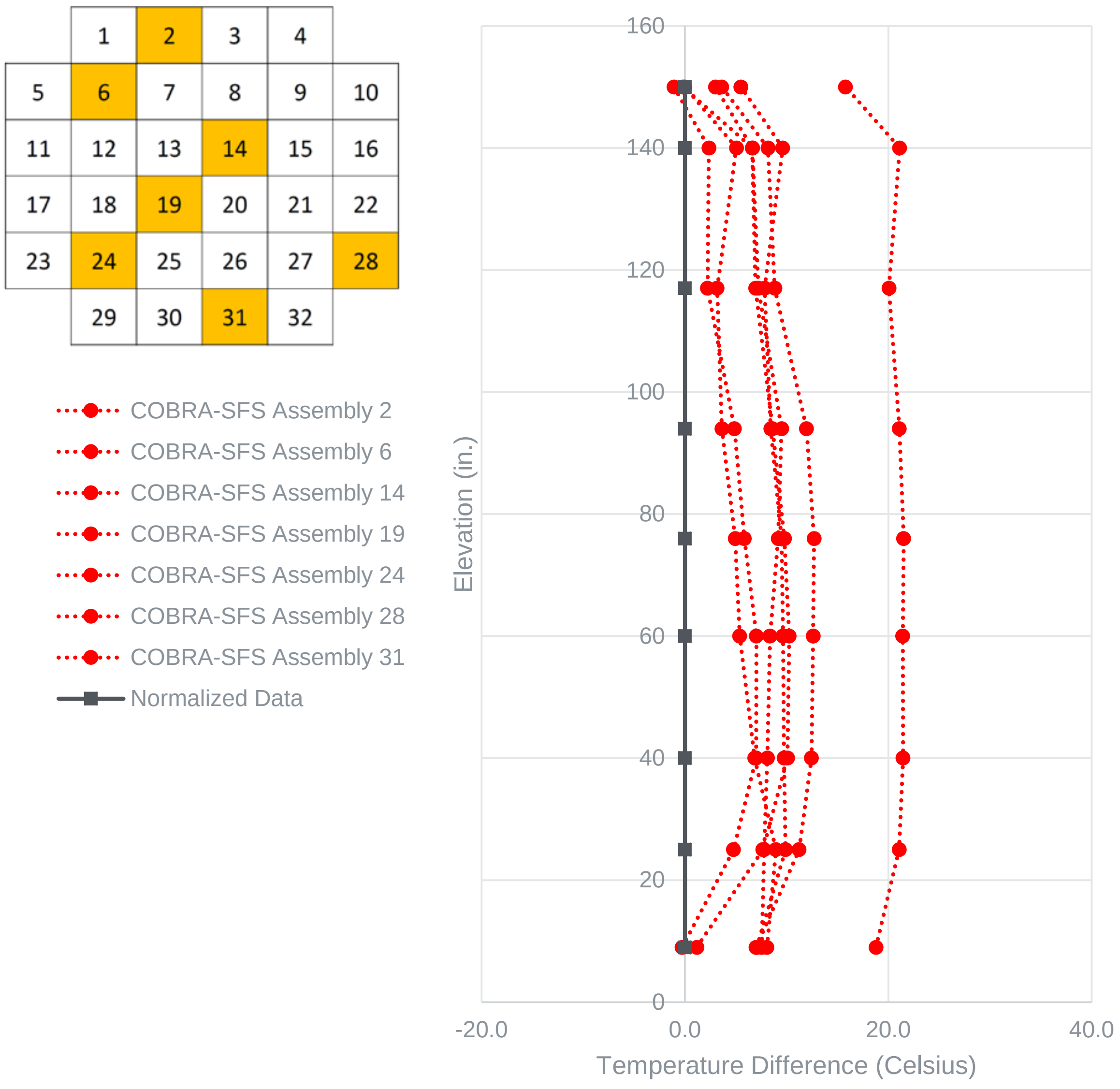
- Total Clad Metrics
  - Percent Surface Area
  - Average Clad Temperatures
- Fuel Performance Calculations
  - Axial Temperature Profile
  - Load Specific
- Canister Temperature Maps
  - Temperature at residual stress zones

The HBU Demo Cask provides unique operational data

- Steady state modeling is complete
- Initial transient modeling is complete
  - Loading
  - Drying
  - Pad

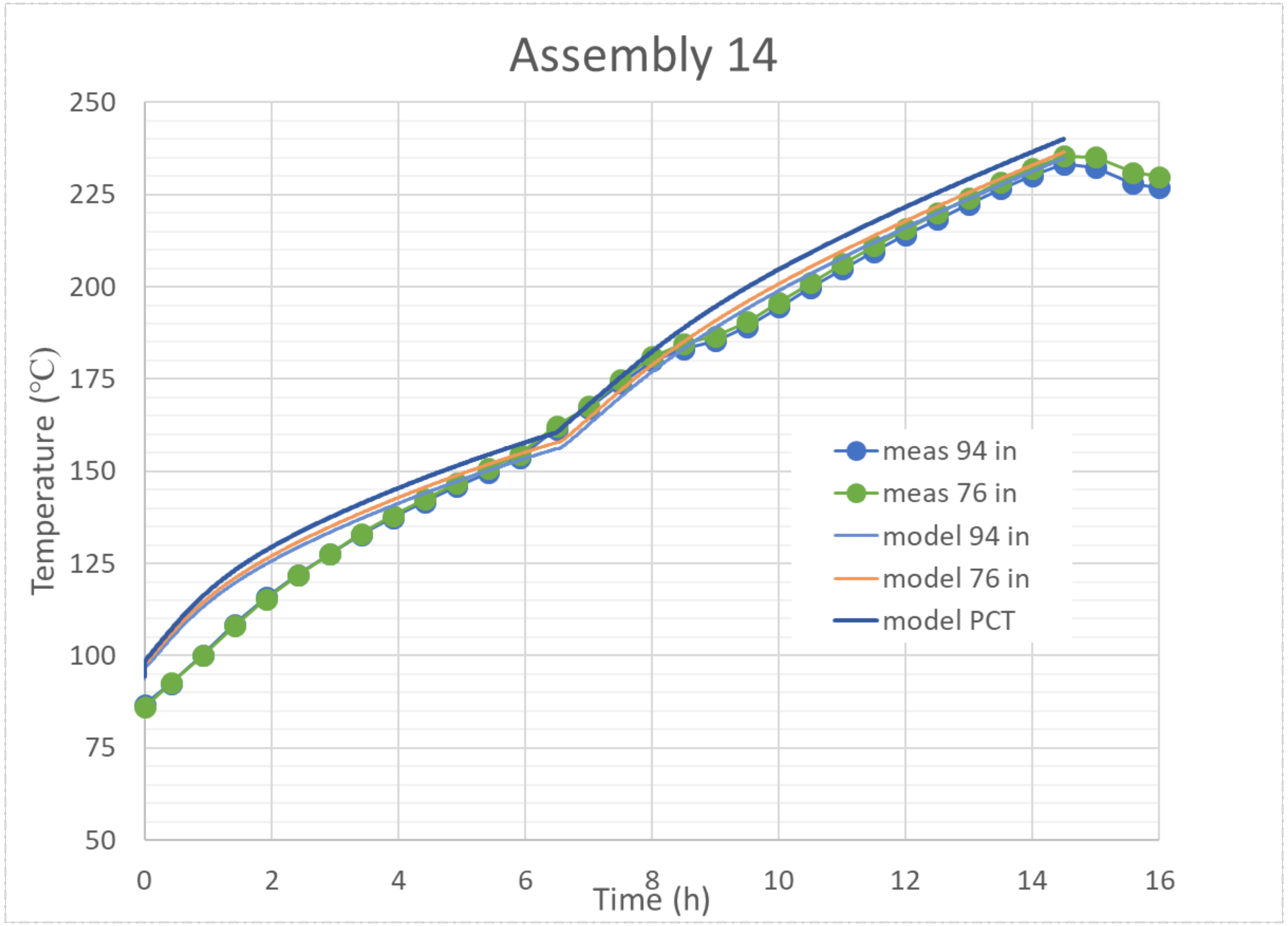
High accuracy inputs are critical to high accuracy predictions (FSAR gap vs. 0.1 inch)



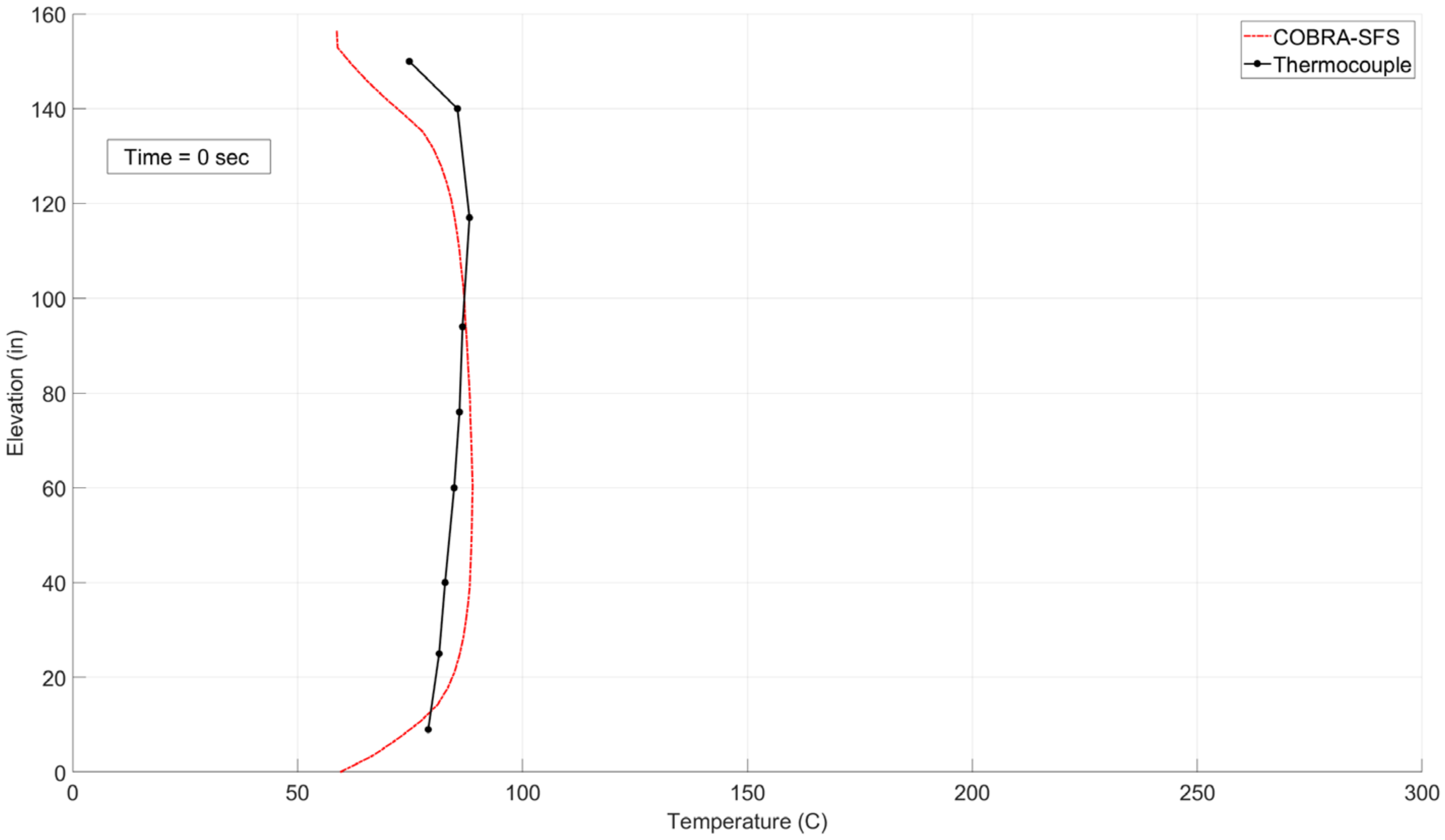


STAR-CCM+ Transient Results

	1	2	3	4	
5	6	7	8	9	10
11	12	13	14	15	16
17	18	19	20	21	22
23	24	25	26	27	28
	29	30	31	32	

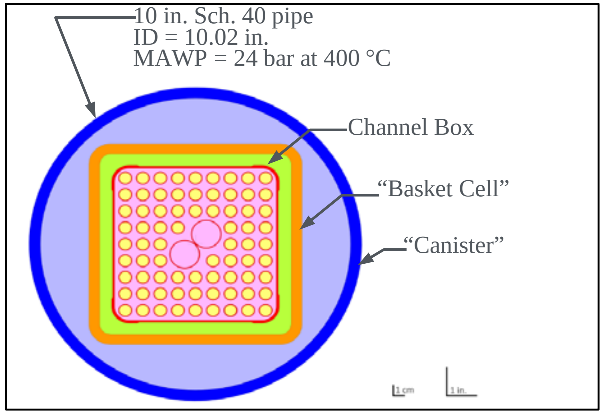


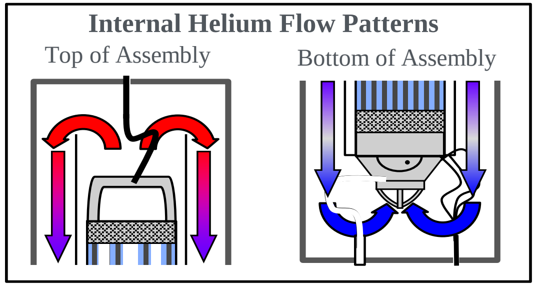
COBRA-SFS Transient Assembly 14 Thermocouple

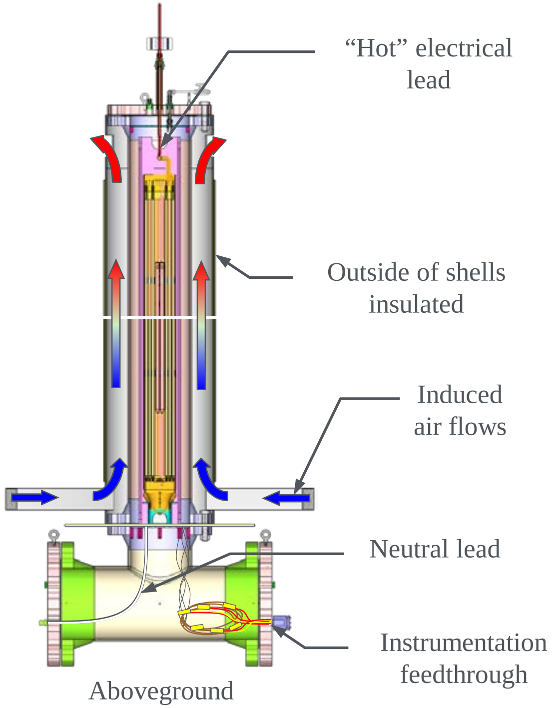


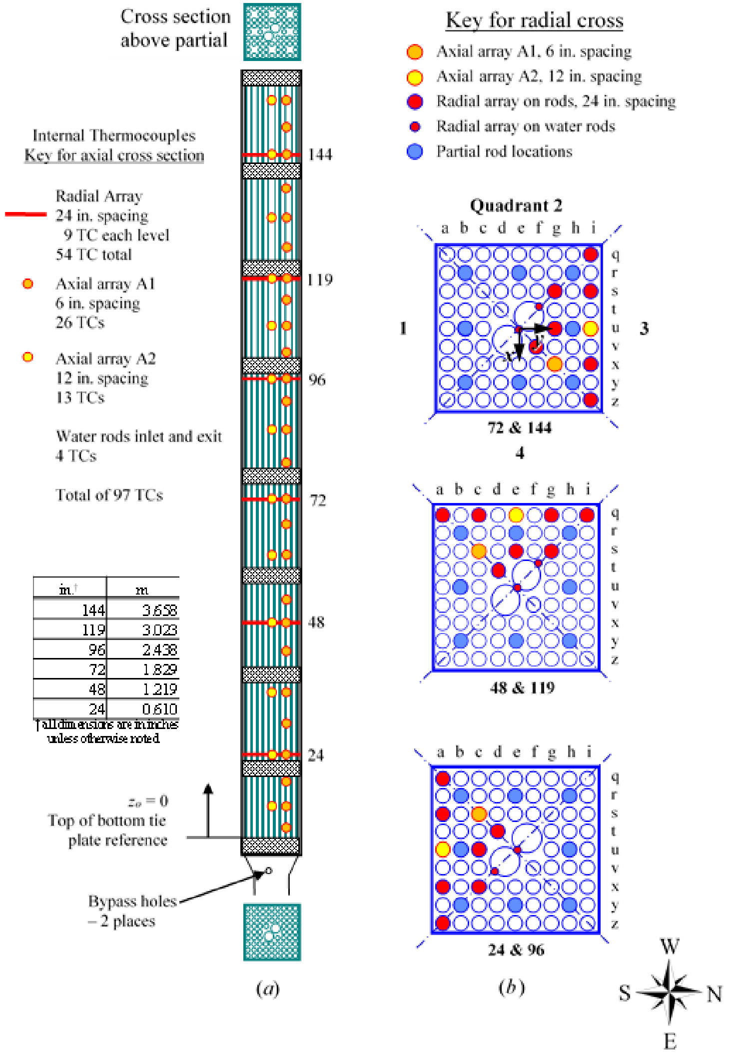
The BWR DCS adds a well controlled test to our validation library

- Removes the variability of the demo cask
- Confirms ability to model vertical canister systems

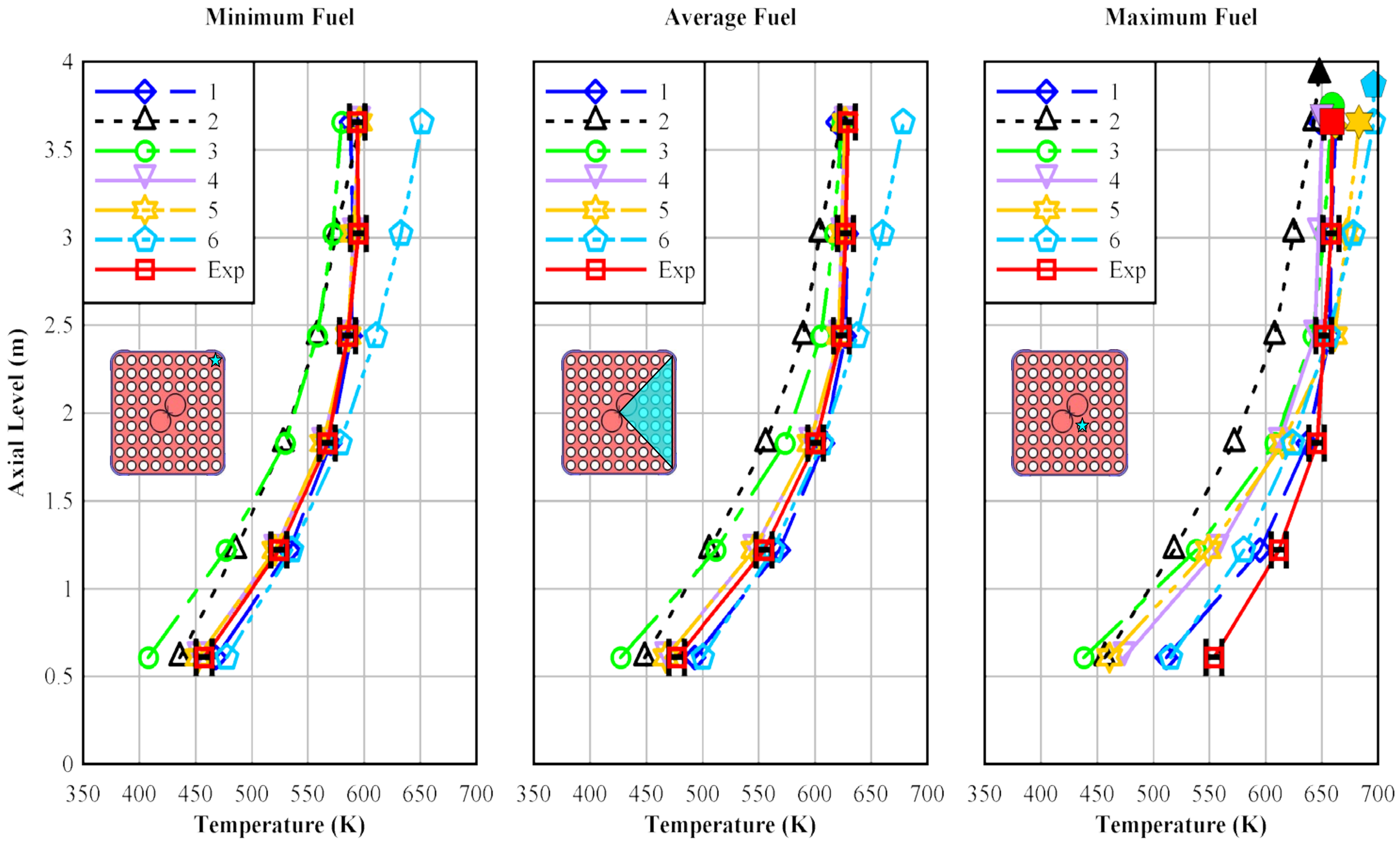








5 kW 800 kPa

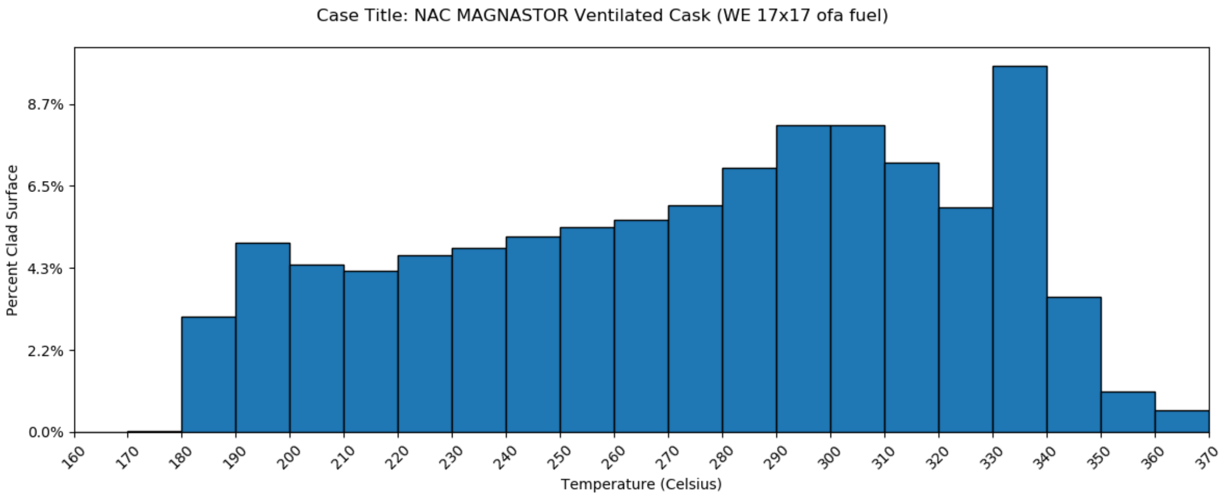


Minimum Fuel
Average Fuel
Maximum Fuel
1
2
3
4
5
6
Exp
Axial Level (m)
Temperature (K)
0
0.5
1
1.5
2
2.5
3
3.5
4
350
400
450
500
550
600
650
700

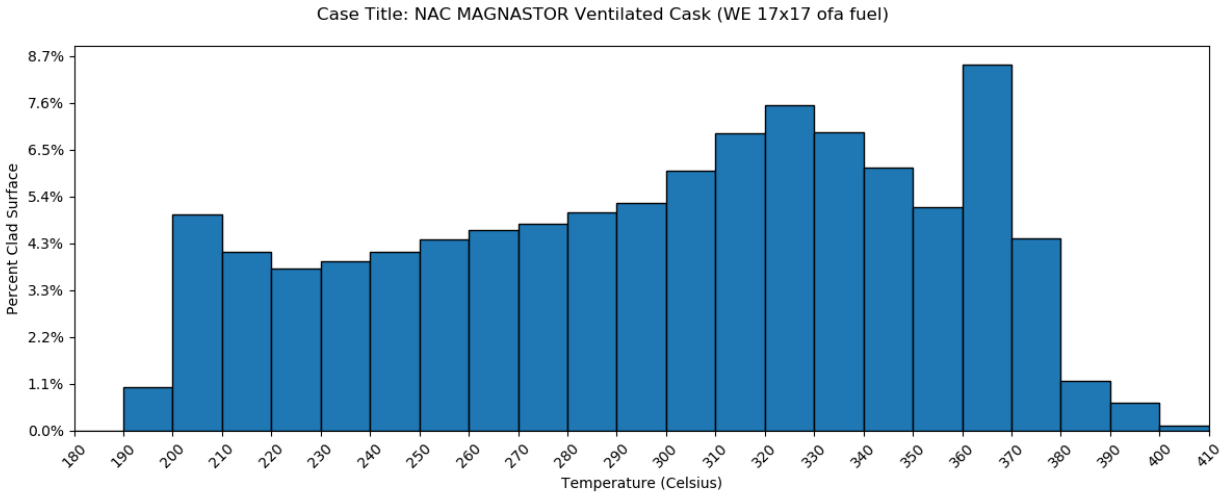
Fuel performance is not expected to change as heat loads increase

Case Name	Description	Max Assembly Heat load (kW)	Total System Heat Load (kW)	Peak Cladding Temperature (°C)	% Cladding Above 350°C
Conservative Base Case	Duke Energy estimate for actual load	0.969	29.5	314.0	0.0
3-Zone Design Basis	3-zone preferential design loading	1.200	35.5	356.2	1.0
4-Zone Design Basis	4-Zone preferential design loading	1.800	35.5	369.9	1.7
Case Five	Scaled 3-zone Design Basis	1.416	41.9	403.0	26.0
Case Six	Scaled 4-Zone Design Basis	2.034	40.1	403.2	20.1

4 Zone Design Basis vs Regulatory Peak Temperature



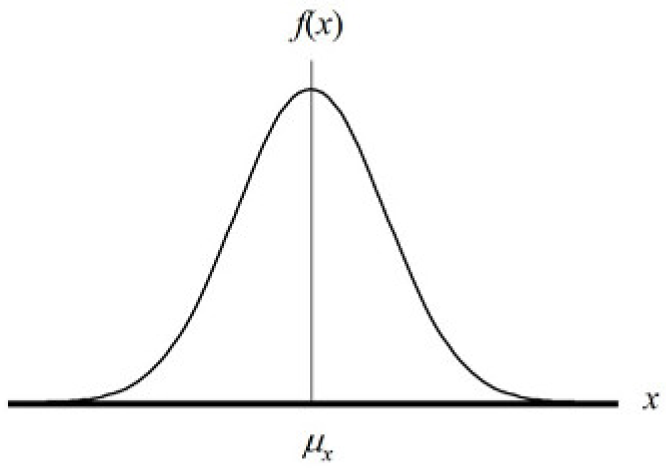
Design Basis



Regulatory Limit

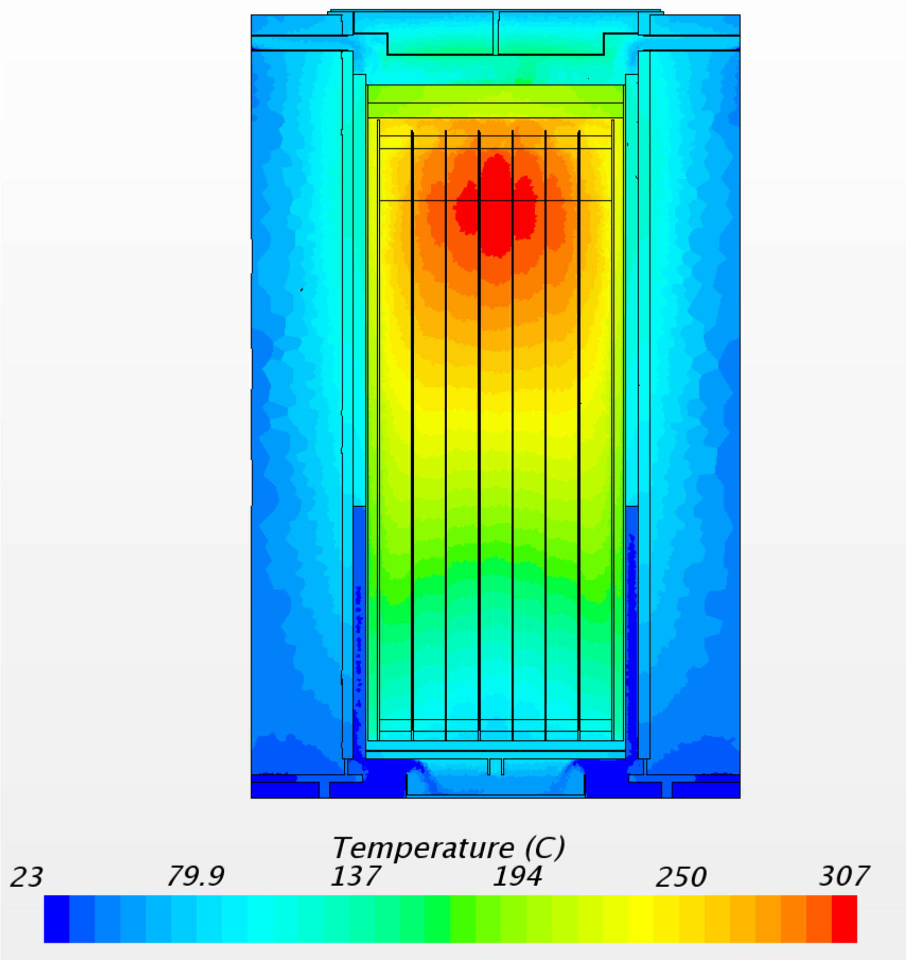
Careful uncertainty analysis will enable decision making

- Best Estimate Plus Uncertainty (BEPU)
  - Common in other safety significant analyses
  - 95-95 confidence
- COBRA-SFS and other speedy methods enable uncertainty analysis
  - Approximately 50 times the speed of STAR-CCM+ with less hardware



Future work will focus on methodology development and validation

- Transcient Modeling
  - HBU Demo Cask
- BWR assemblies
  - Dry Cask Simulator
- Horizontal Systems
  - Dry Cask Simulator
- Larger Thermal experiments
  - Next Generation Simulator
- Operational Systems
  - HBU Demo Cask

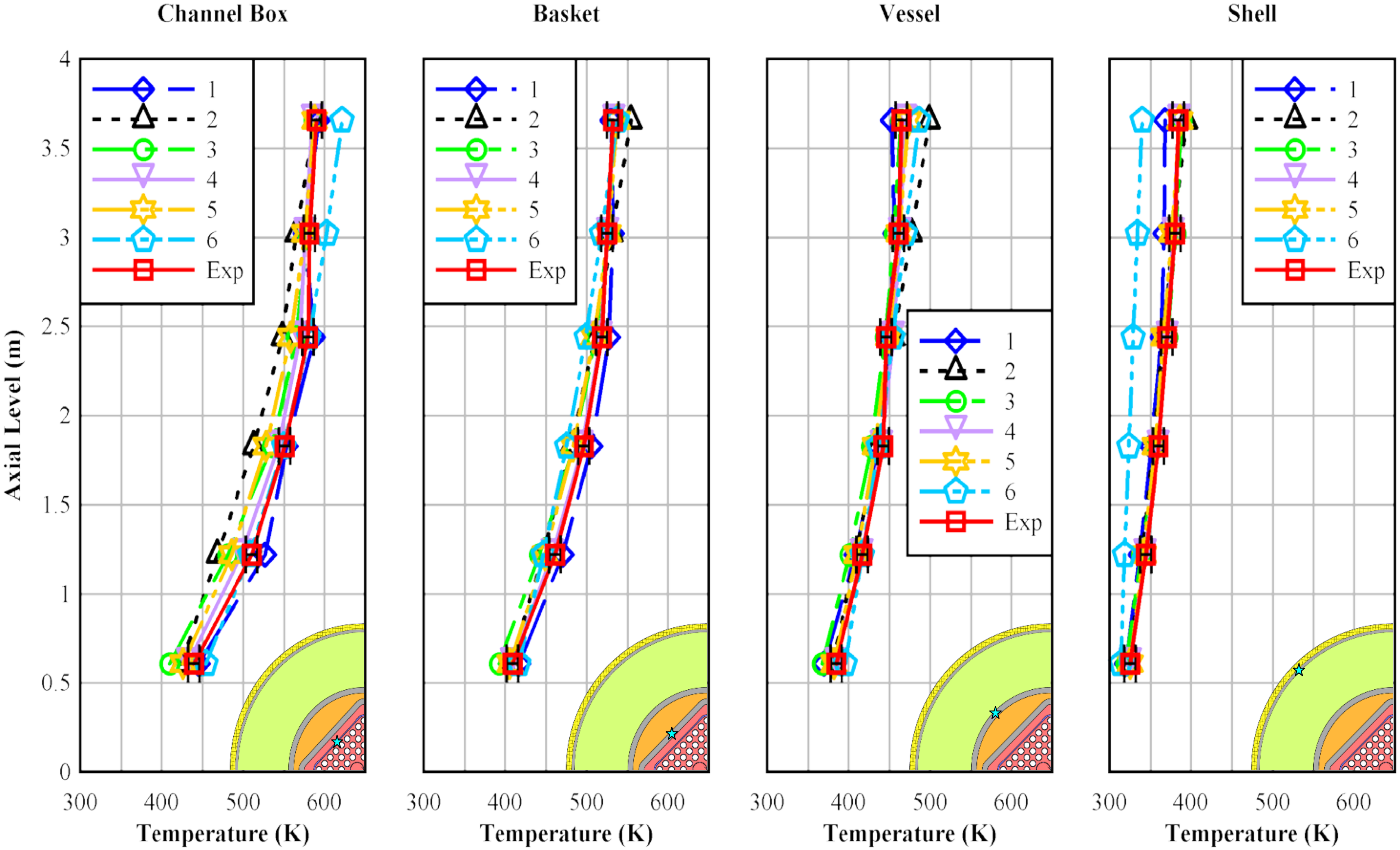


Questions?

Clean. **Reliable. Nuclear.**

- PNNL-28915, Thermal Modeling of the TN-32B Cask for the High Burnup Spent Fuel Data Project
- PNNL-29058, High-Burnup Demonstration: Thermal Modeling of TN-32B Vacuum Drying and ISFSI Transients
- Durbin, S.G. and E.R. Lindgren, “Thermal-Hydraulic Experiments Using A Dry Cask Simulator,” NUREG/CR-7250, U.S. Nuclear Regulatory Commission, Washington, DC, October 2018.
- PNNL-28424, Modeling of the Boiling Water Reactor Dry Cask Simulator
- L.E. Herranz, F. Feria, J. Penalva, M. LLoret, M. Galbán, J. Benavides, and G. Jiménez, Pulido, R.J.M., E.R. Lindgren, S.G. Durbin, A. Zigh, J. Solis, S.R. Suffield, D.J. Richmond, J.A. Fort, "Modeling Validation Exercises Using the Dry Cask Simulator," SAND2019-6079R, Sandia National Laboratories, Albuquerque, NM, May 2019.
- PNNL-28864, Thermal Analysis of High Decay Heat Loading Strategies in the MAGNASTOR System
- Lindgren, E.R., S.G. Durbin, R.J.M. Pulido, and A. Salazar, “Update on the Thermal Hydraulic Investigations of a Horizontal Dry Cask Simulator,” SAND2019-11688R, Sandia National Laboratories, Albuquerque, NM, September 2019.

5 kW 800 kPa



Channel Box
Basket
Vessel
Shell
Axial Level (m)
Temperature (K)
1
2
3
4
5
6
Exp
0
0.5
1
1.5
2
2.5
3
3.5
4
300
400
500
600

PIRT top priorities for reducing uncertainty and/or bias

- Short Term Operations
  - Most operational limitations are driven by loading and drying temperature limits
- Decay Heat
  - Highly accurate methodology exists but may not be implemented by all utilities
- Ambient Temperature
  - Site specific and load specific data can be used with high confidence

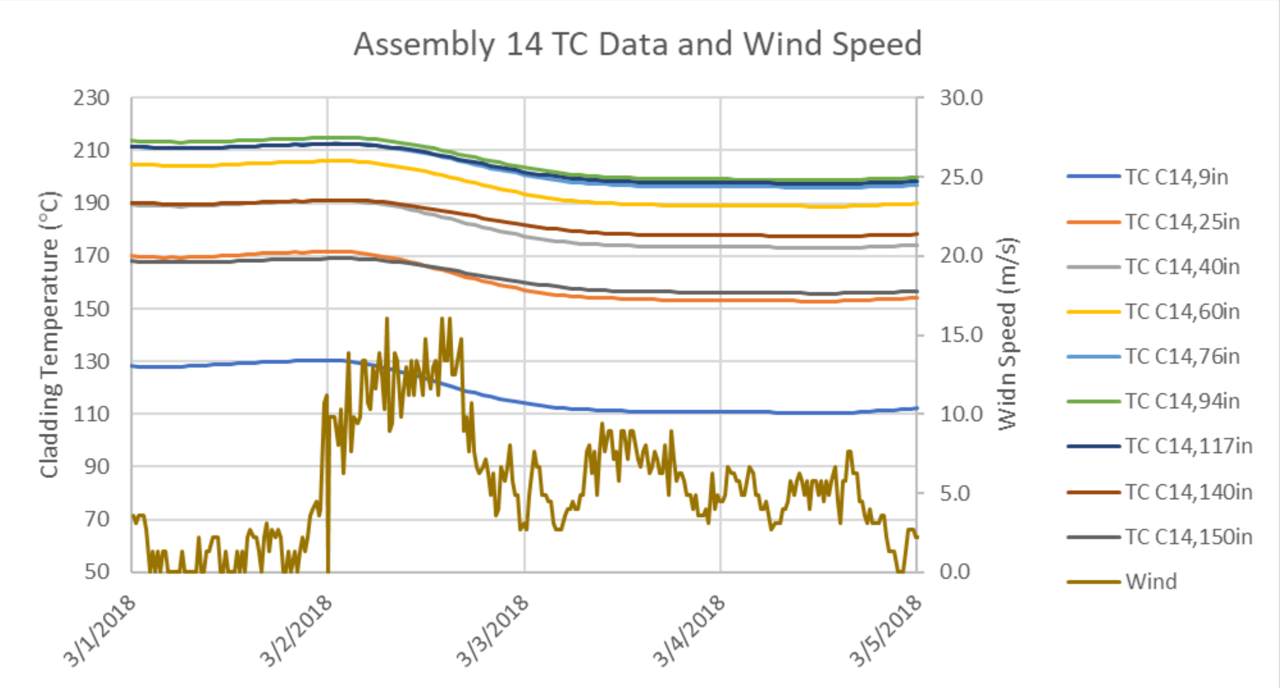
Example Pad Transient Case

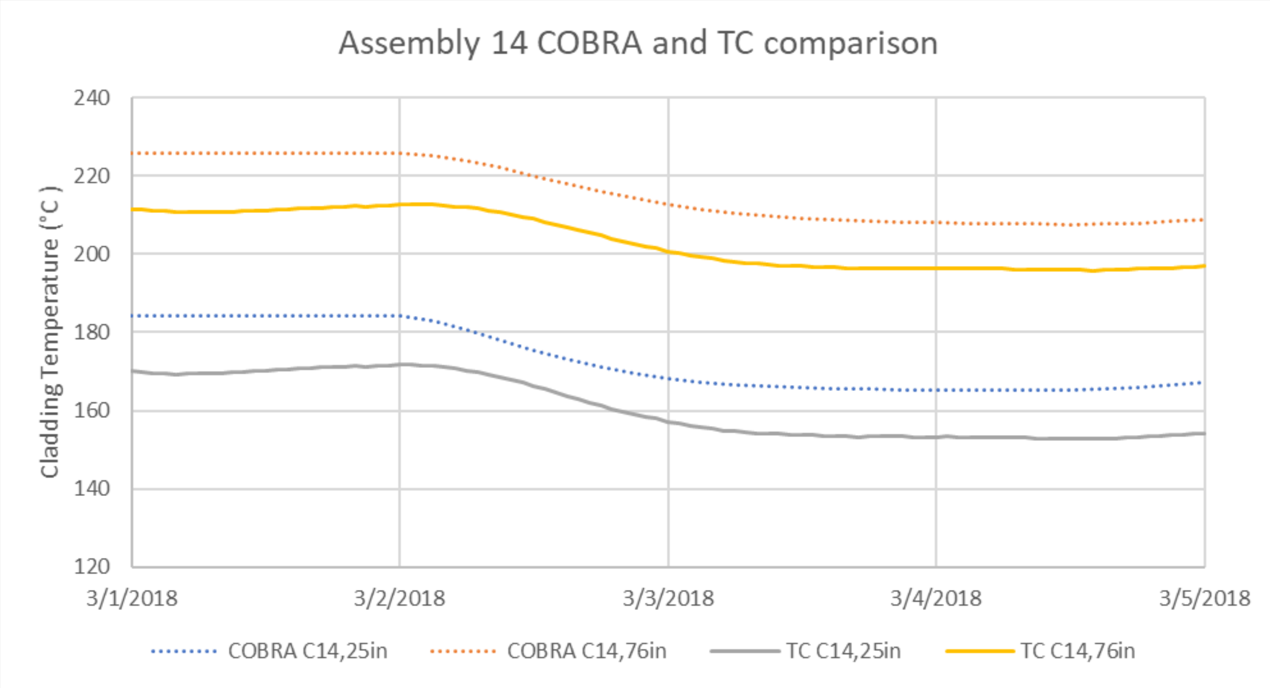
Measured Data

- Wind data from local airport
- Ambient temperature on site

Model Compared to TC Measurements

- BC modified to include wind speed
- Model gives good agreement





Wind data from NOAA Local Climatological Data set, Louisa County's Freeman Field Airport (WBAN:03715).

COBRA-SFS Transient Results