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Assess the Impact of Prototypic High Burnup Operating Conditions on Fuel Fragmentation Relocation and Dispersal Susceptibility

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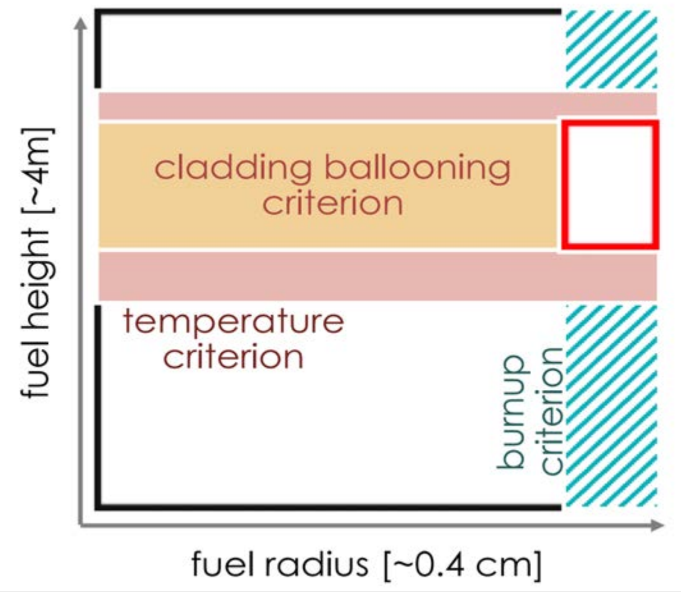
NEAMS
Nuclear Energy Advanced Modeling and Simulation

Objective

- **Characterize the ranges of operating conditions being experienced by high burnup rods and quantify FFRD susceptibility**

Ranges of operating conditions → Ranges of fuel performance → Transient and thermal-hydraulic analyses → Susceptibility to FFRD

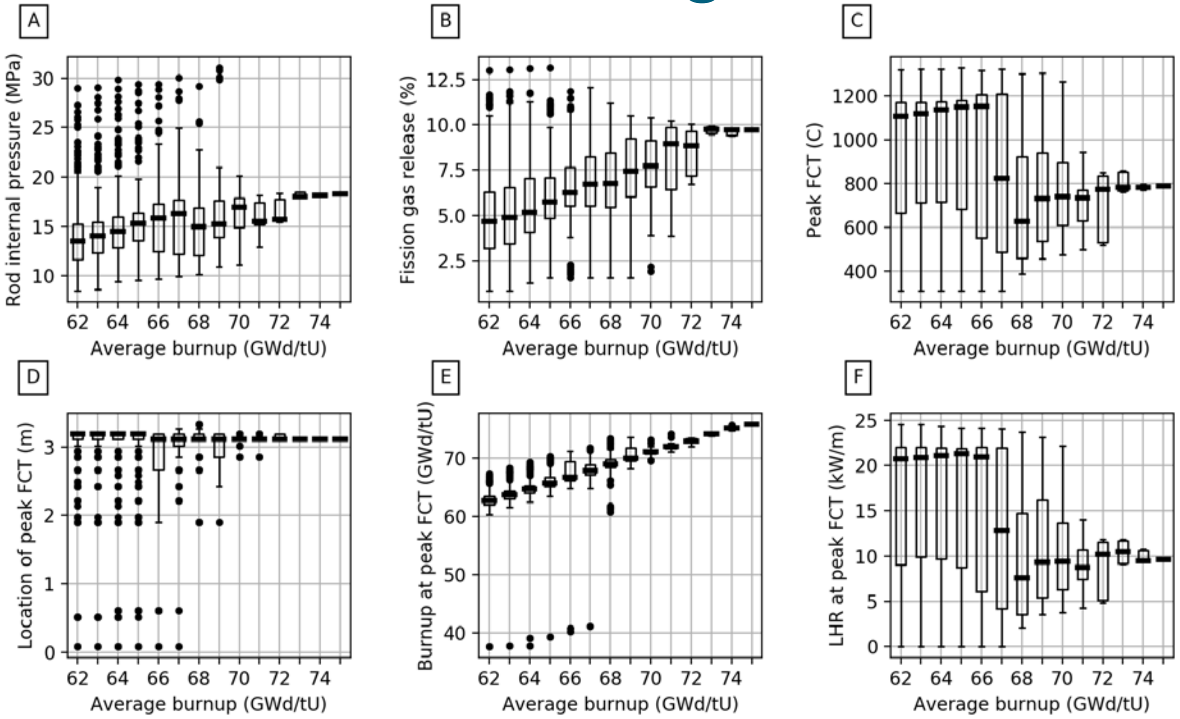
- **VERA - identify operating conditions**
  - Burnups
  - Linear heat rates (LHRs)
  - Peaking factors
- **BISON – critical fuel performance behaviors**
  - Fuel centerline temperatures (FCTs)
  - Rod internal pressures (RIPs)
  - Fission gas release (FGR)

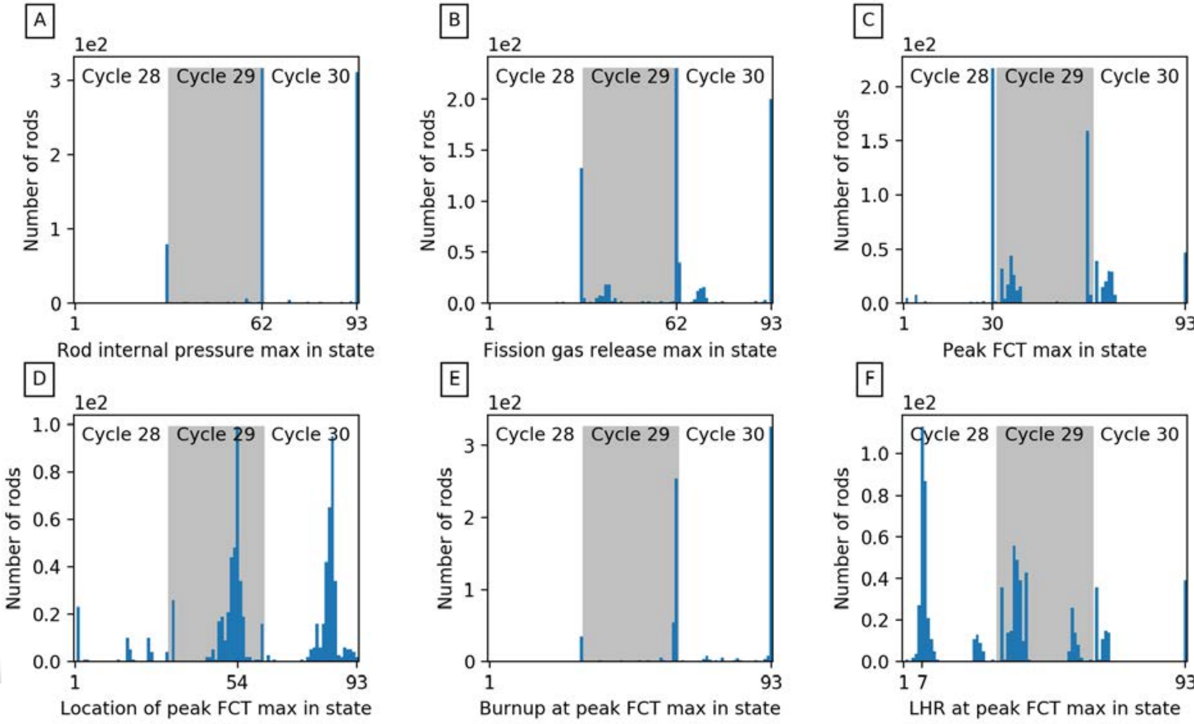


Capps et al. Nuclear Engineering and Design 2021

BISON – Critical Fuel Performance Behaviors

- **Critical fuel performance parameters increase as burnup increases**
- **Peak fuel centerline temperature located at ~3.15-3.25m**
- **FFRD limiting event occurs at end of cycle**





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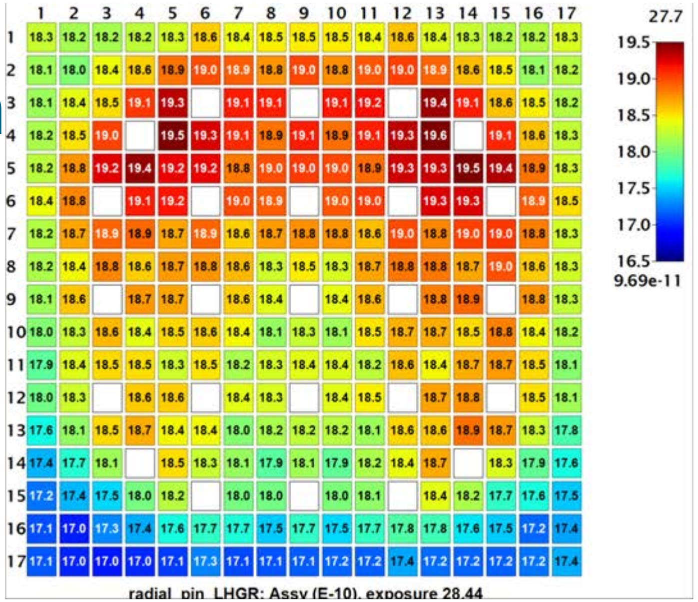
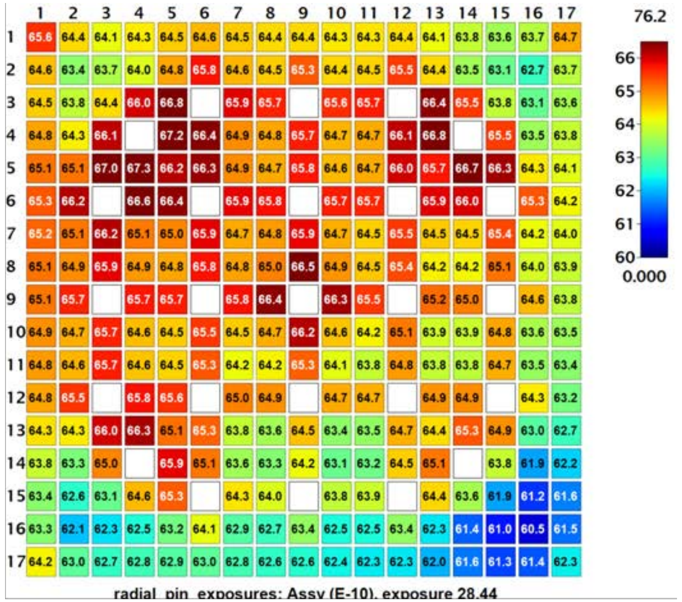
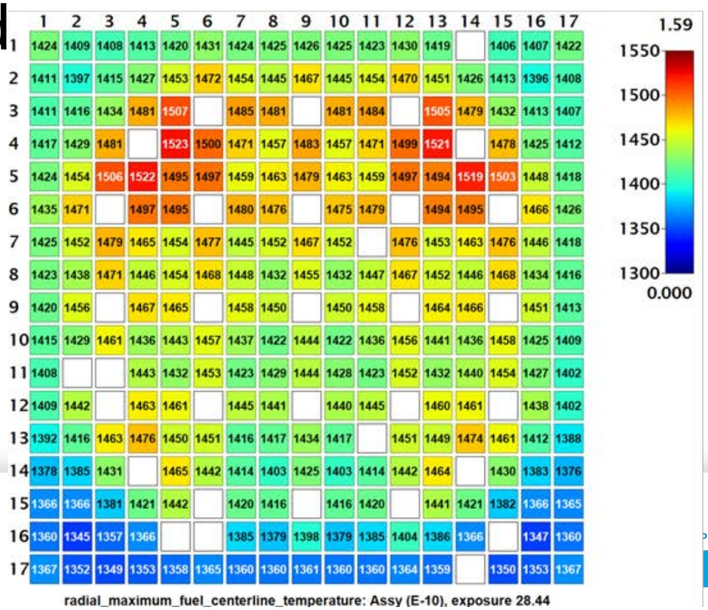
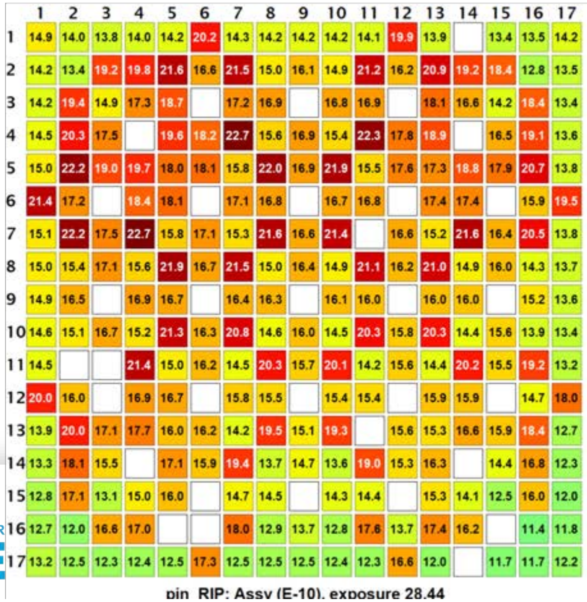
BISON – Critical Fuel Performance Behaviors

- **Fuel performance depends on location in the core and assembly**
- **Burnup and LHR gradients observed**
  - Translates to temperature and rod internal pressures
- **Important to capture pin-by-pin resolution**



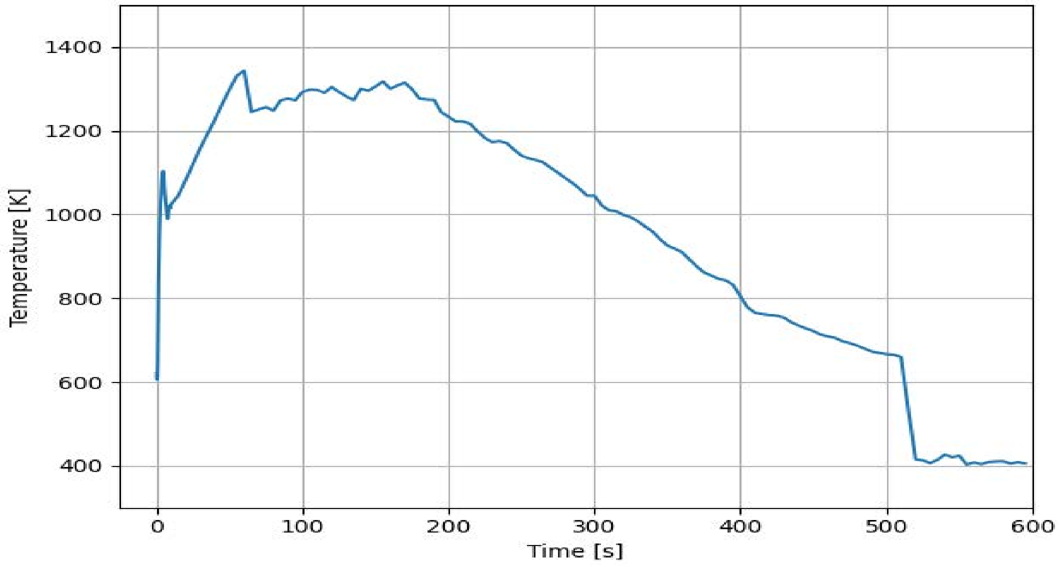




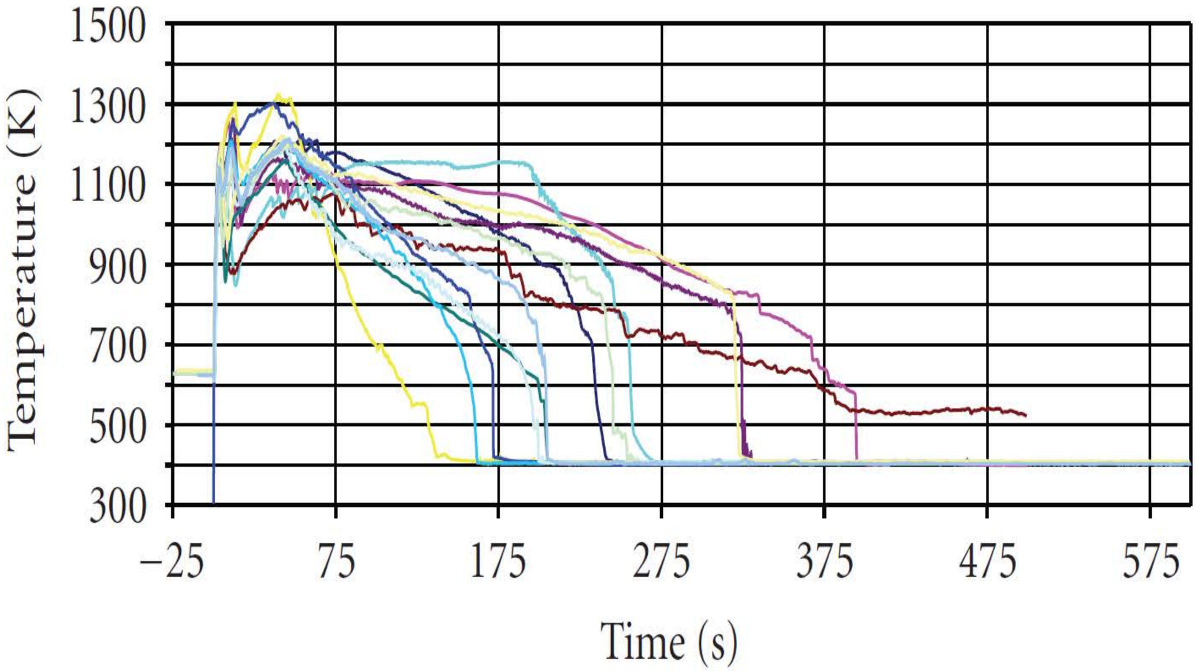


Thermal Hydraulic Model and Benchmark

TRACE



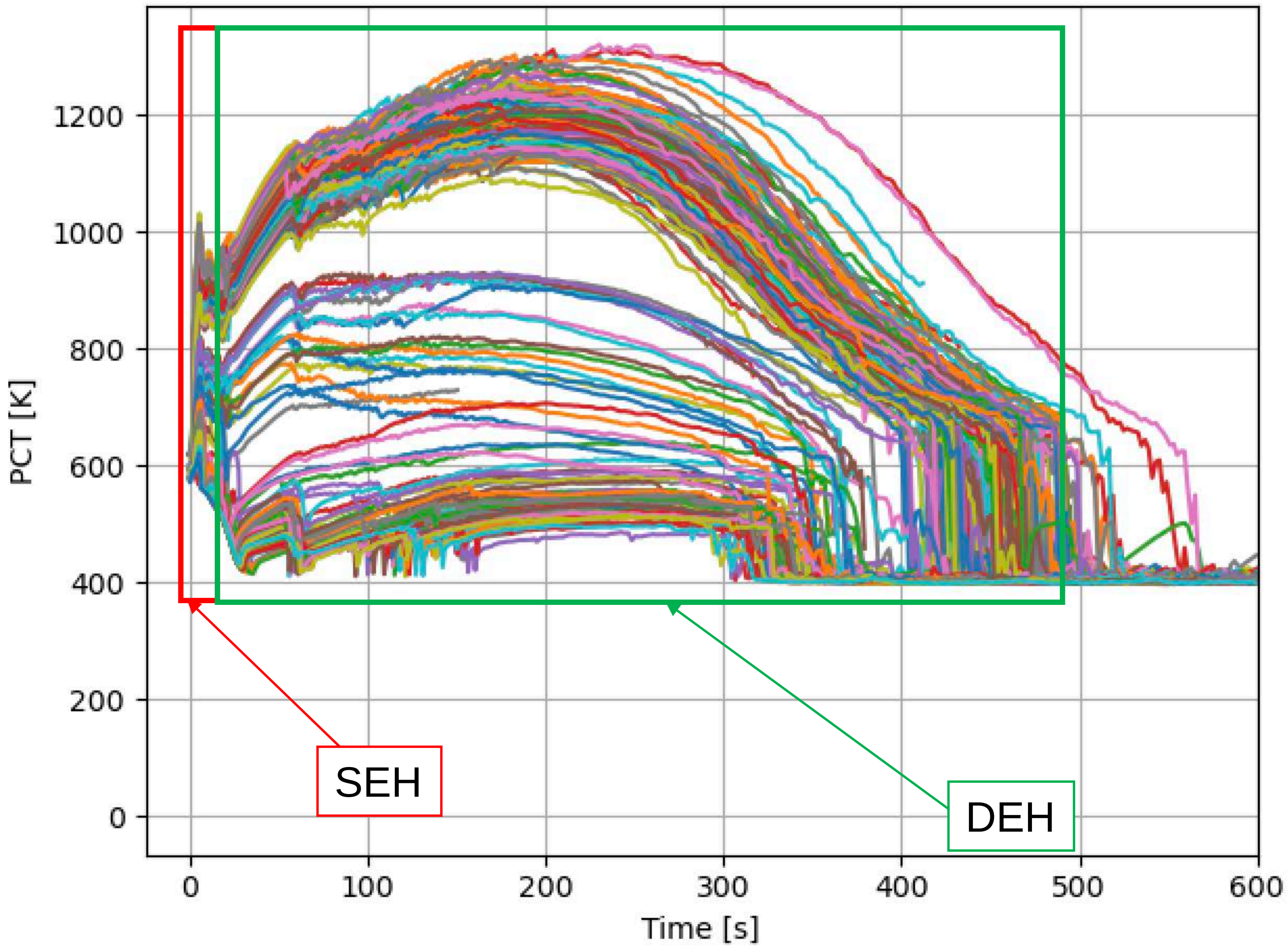
BEMUSE Participants

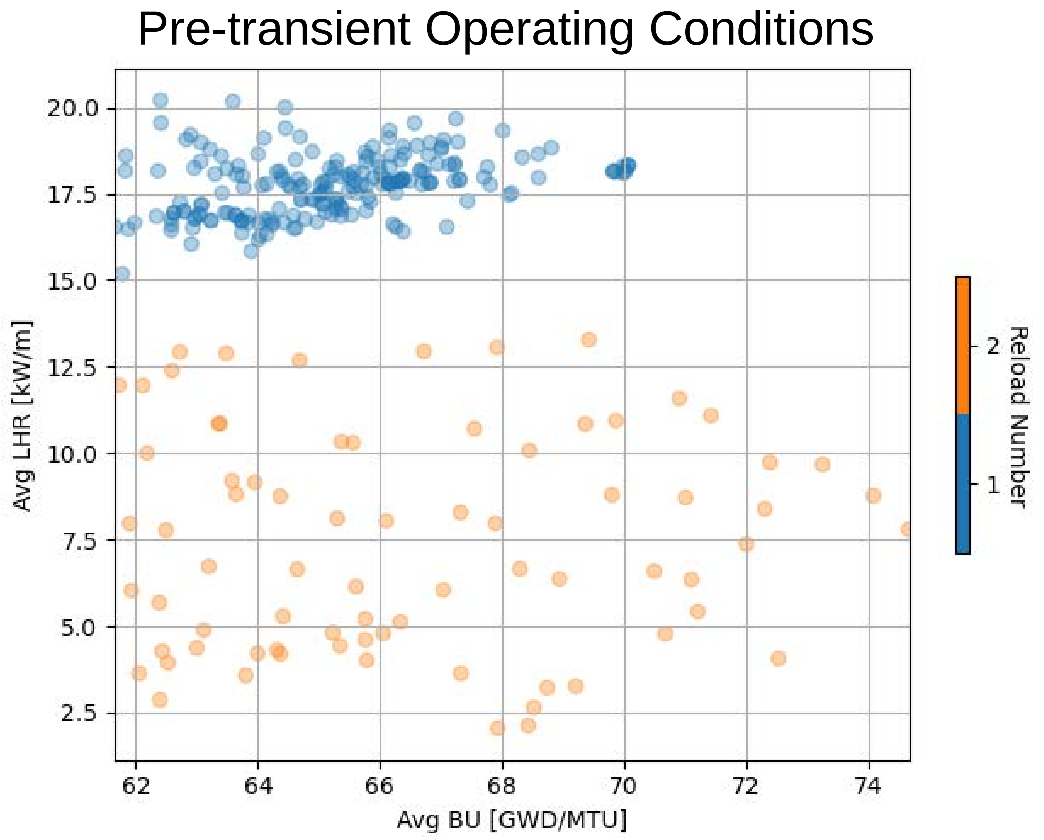


- **TRACE model based on the BEMUSE International Benchmark**
- **Benchmarked initial conditions to BISON steady state conditions**

Transient TH LOCA Results for HBu Fuel Rods

- Analyzed 281 HBu rods in TRACE based on steady state results
  - Representative of core wide response

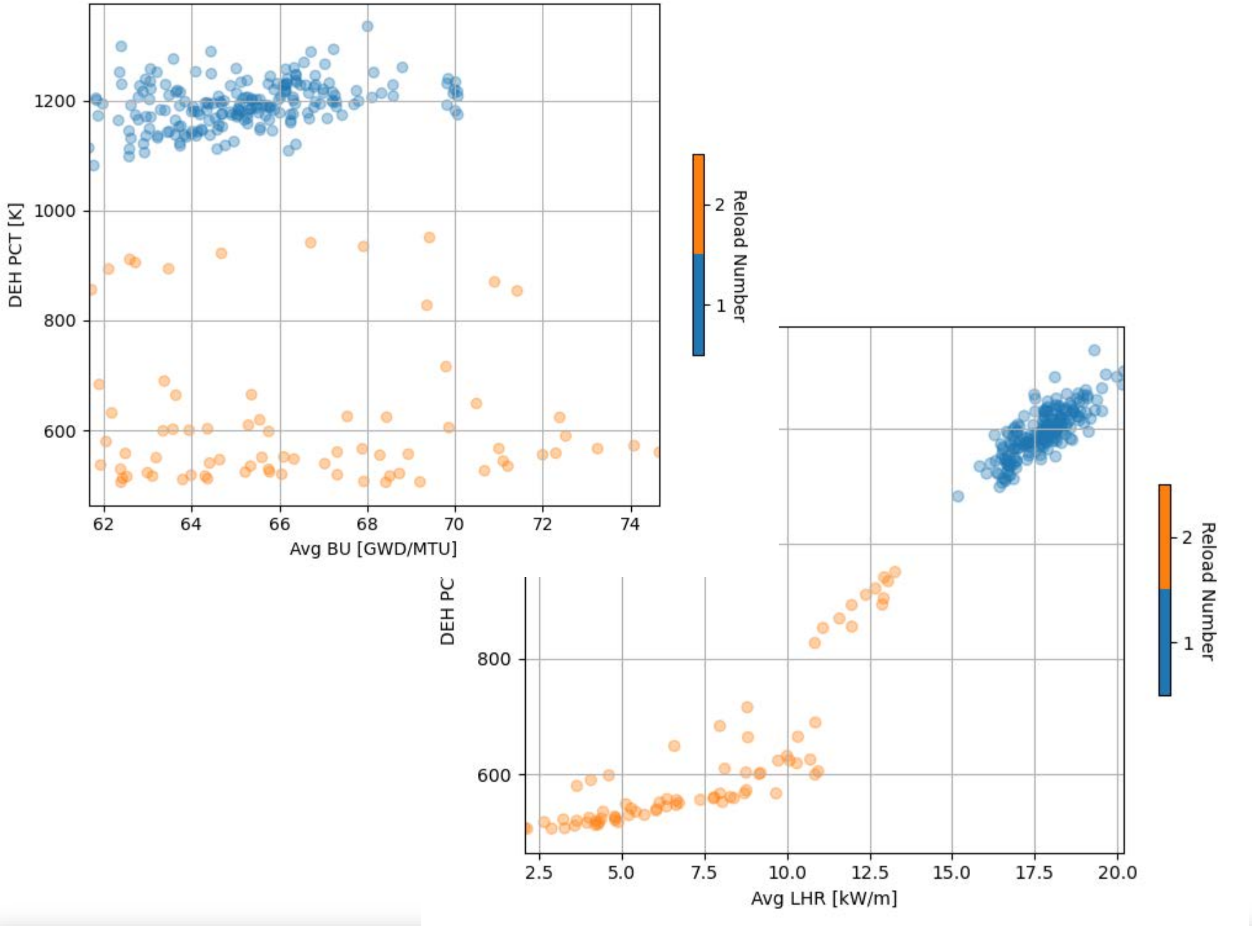




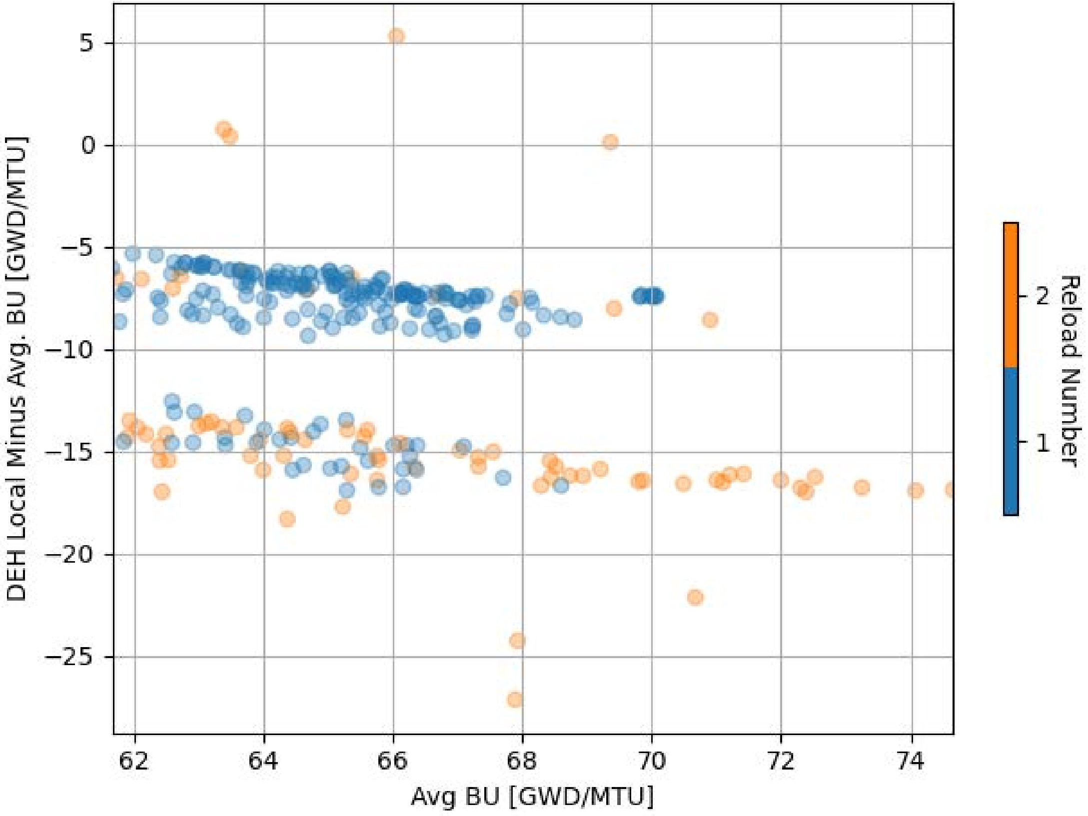
SEH – Stored Energy Heatup
DEH – Decay Energy Heatup

Transient Thermal Hydraulic Behavior

Cladding Temperature Dependencies



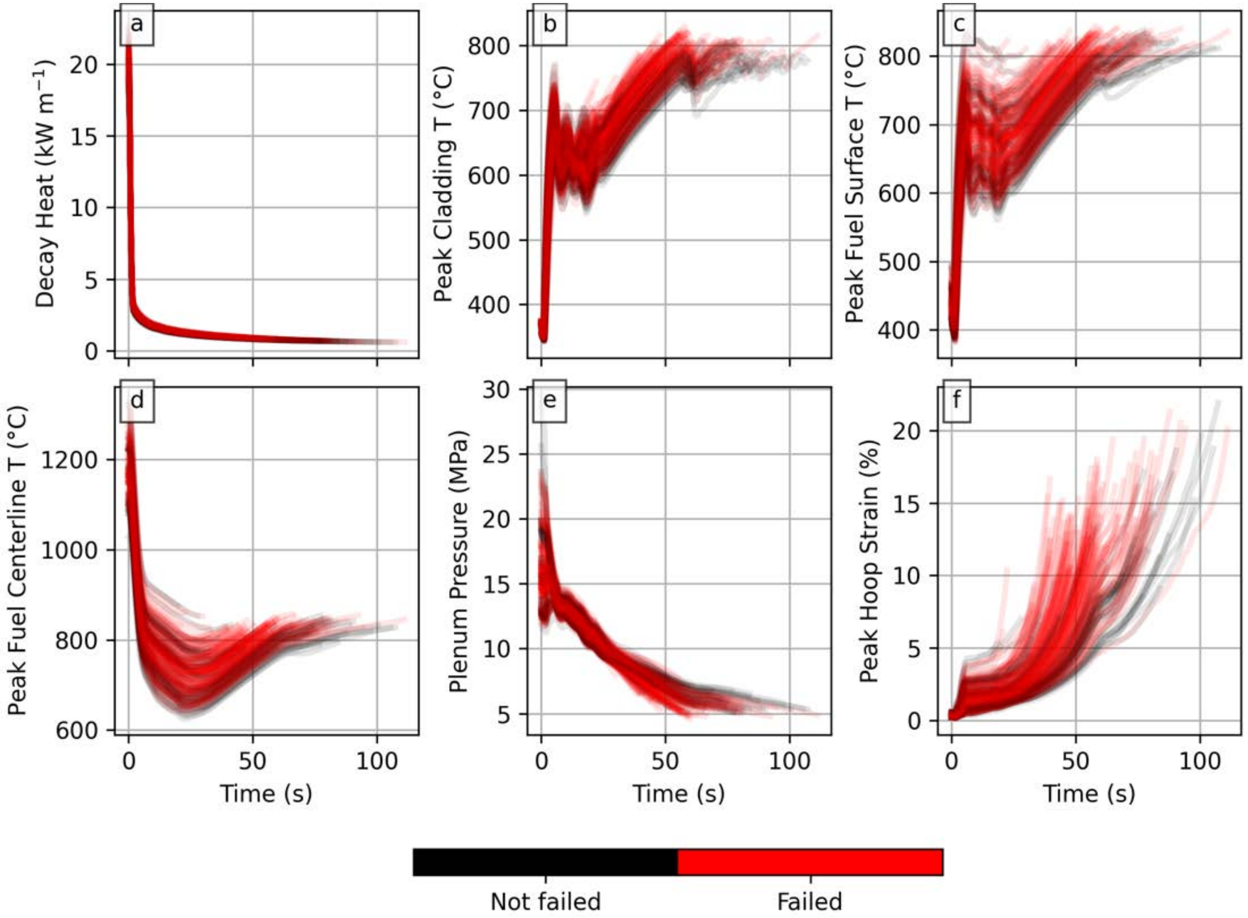
Local Burnup at PCT Axial Location

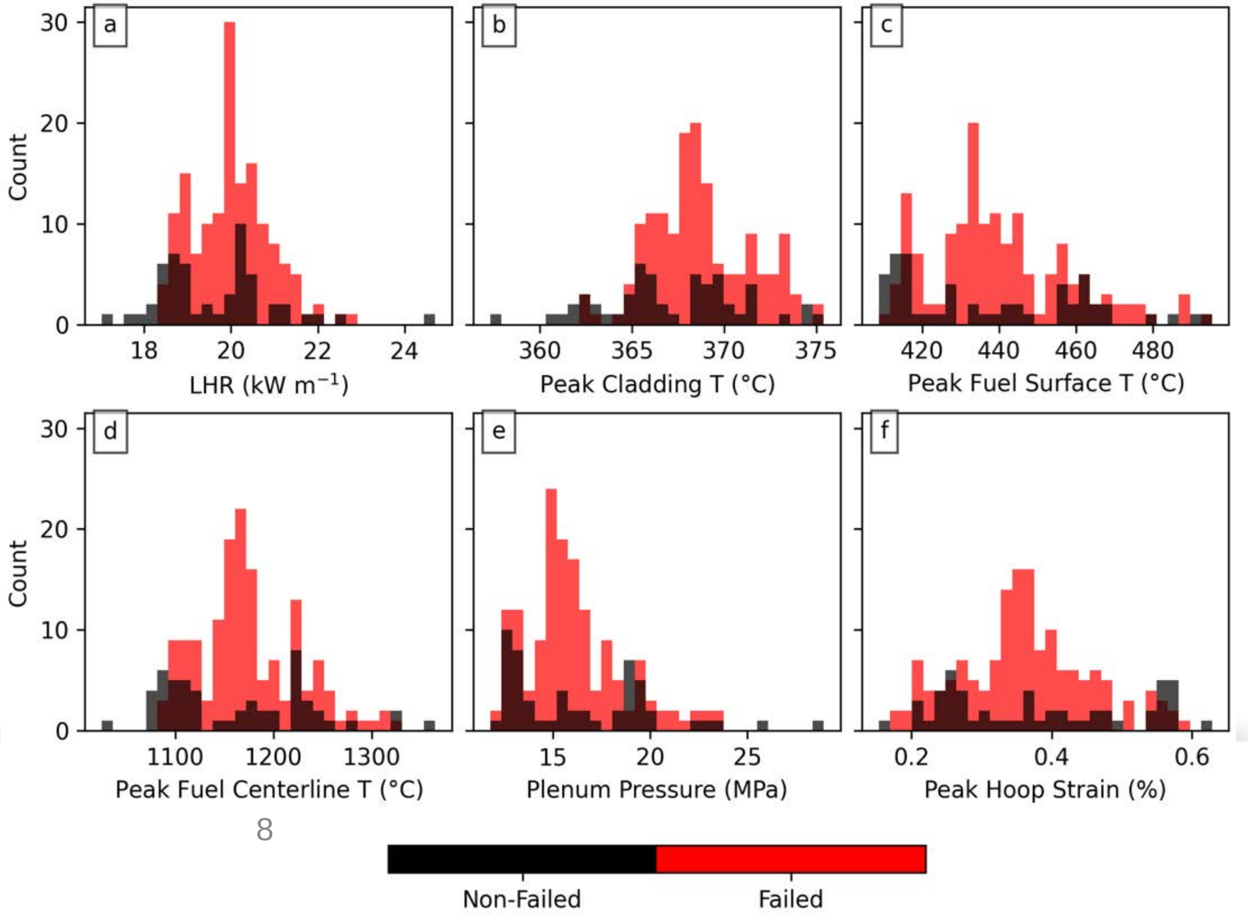


Transient Fuel Performance Analysis

- **Most rods on the interior of the core failed**
  - **Critical Parameters:** LHR and Rod Internal Pressure
- **No twice burned rods failed using any criteria**

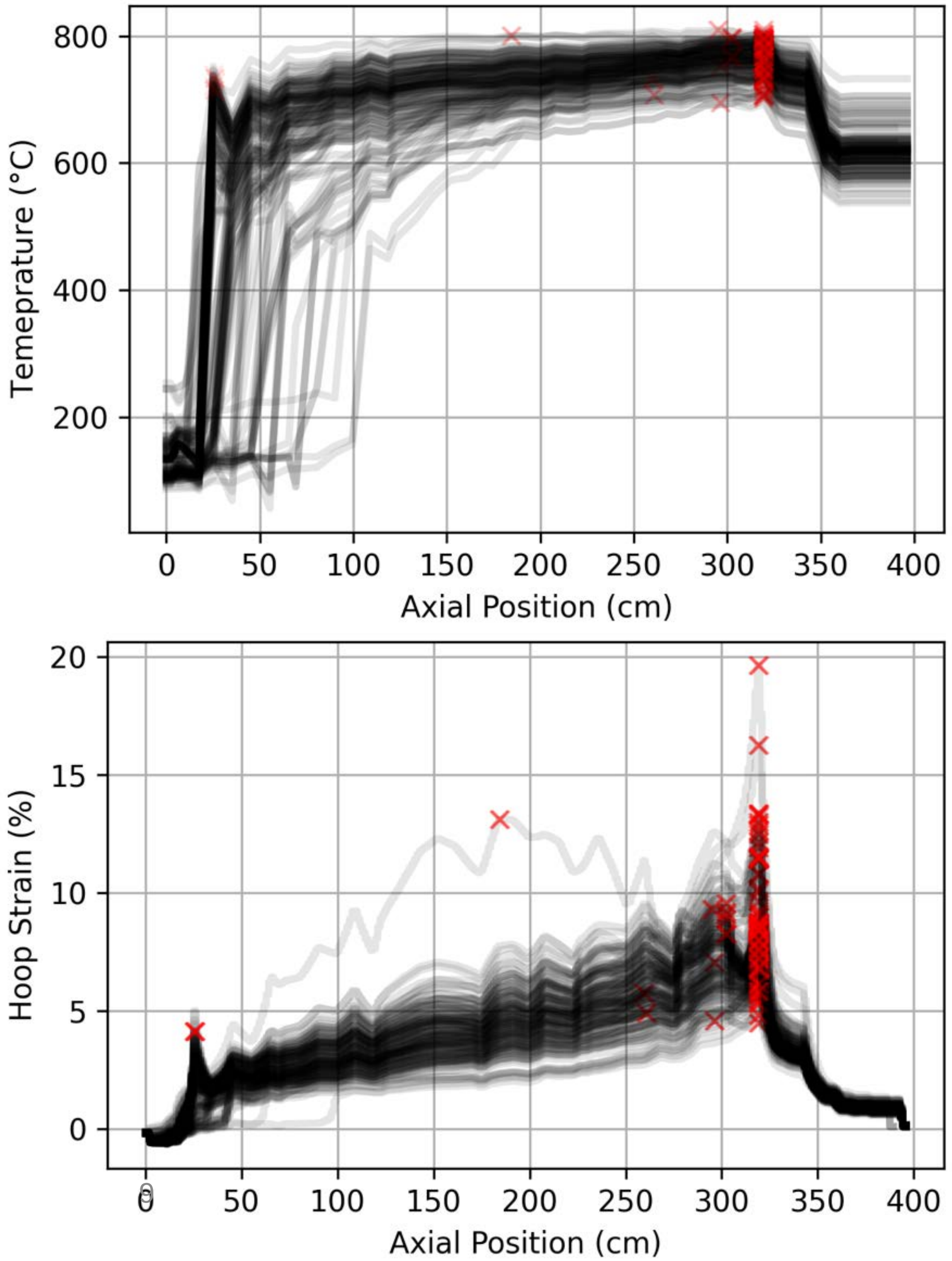
tFGR not modeled and cladding creep model not applicable





Transient Fuel Performance Analysis

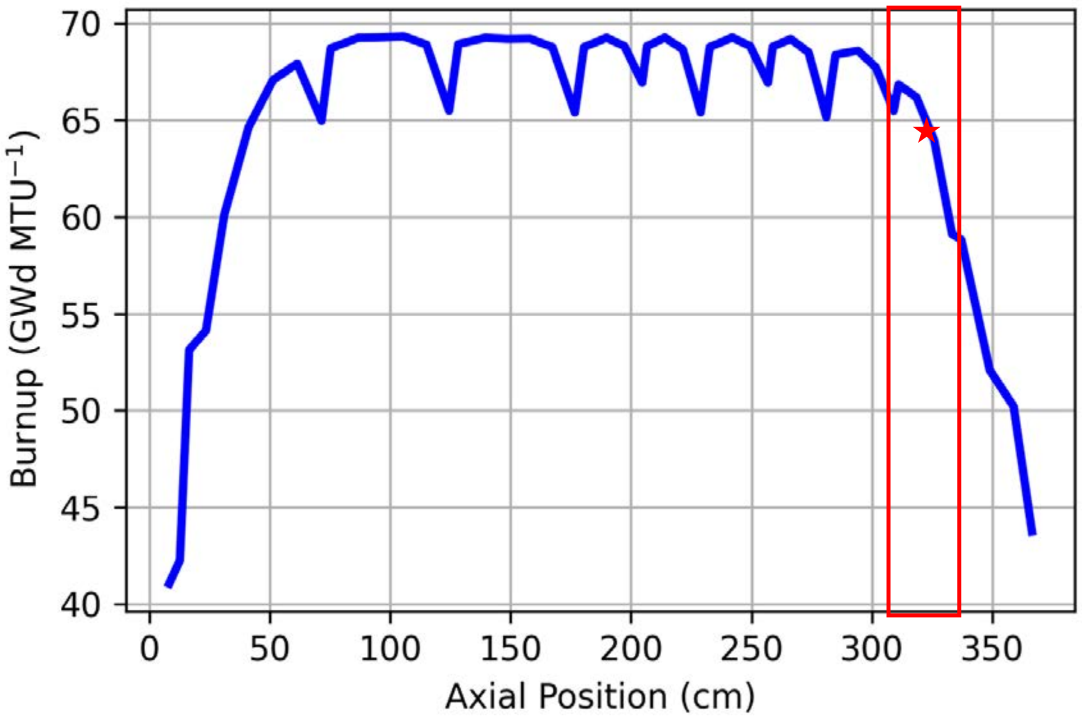
- **Fuel rod failure occurs at the top of the rod - ~3.19-3.2m**
- **Quench front started at time of failure**
- **Grid-spacers and mixing vanes locally suppress deformation**
  - Not explicitly modeled
- **Double ballooning not impossible but unlikely**
- **Assumptions**
  - tFGR not modeled
  - Assembly structural features not explicitly model



Determining FFRD Susceptibility

- Determine Cladding Rupture Susceptibility
  - Evaluate cladding deformation during transient
  - Determine if, when, and where burst occurs

- Determine Fuel Susceptibility to Relocation and Dispersal
  - Evaluate fuel pulverization against Turnbull pulverization threshold
  - Determine cladding balloon geometry
  - Estimate relocation and packing fraction
  - Evaluate rupture opening

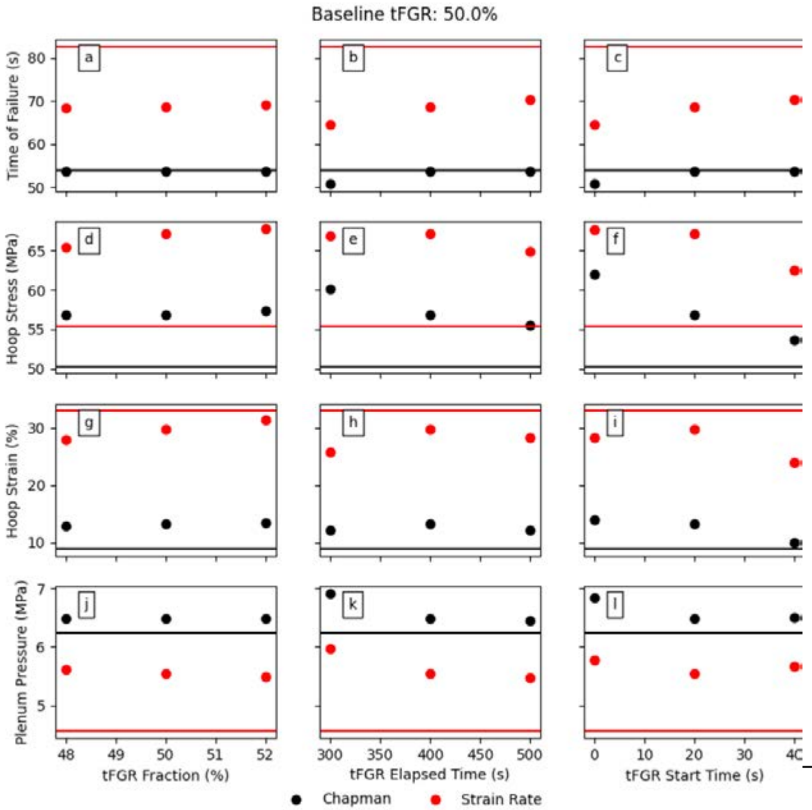


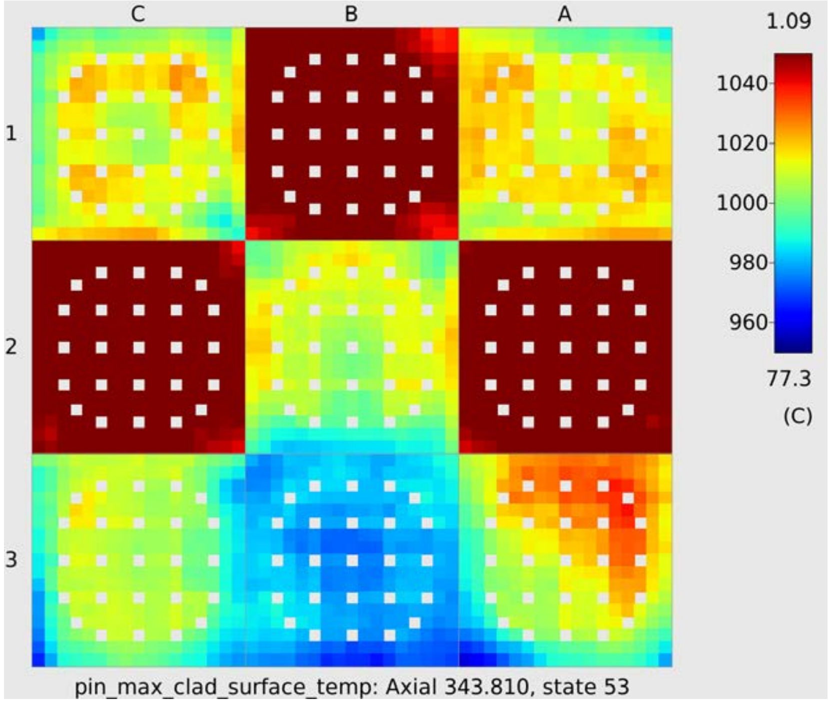
	NRC RIL 1 mm	NRC RIL 2 mm	Turnbull
Average fuel susceptible to FFRD per failed rod (kg)	0.048	0.060	0.018
Total fuel susceptible to FFRD simulated rods (kg)	7.35	9.18	2.72
Total fuel susceptible to FFRD in full core (kg)	330.9	413.7	122.4
Margin of Error (kg)	±53.7	±67.1	±19.9

- Key Assumptions
  - Assembly structural features mitigate additional FFRD
  - Double ballooning and burst was not considered
  - Mass below rupture was considered susceptible to dispersal – per RIL definition

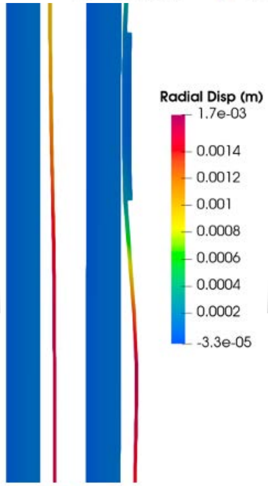
Addressing Modeling Assumptions

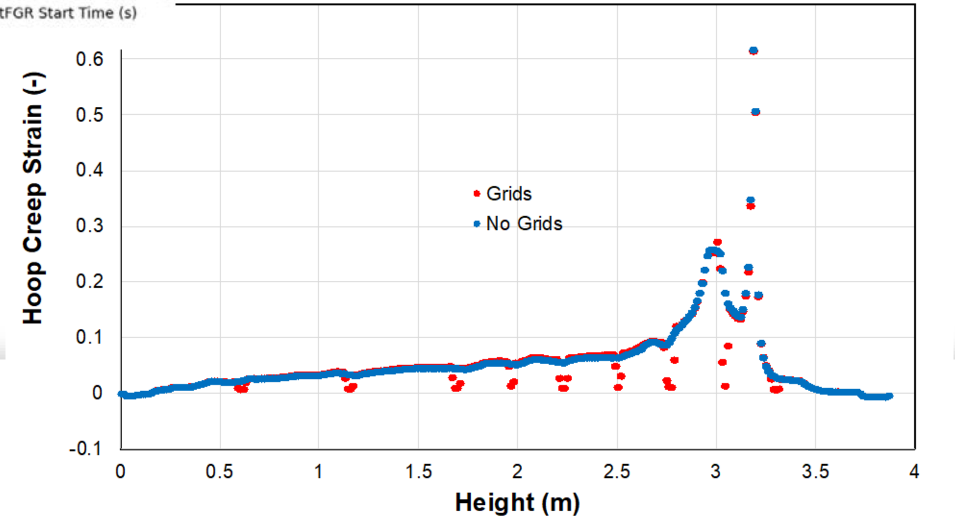
- **Quantify transient uncertainties**
  - Impact of pin-by-pin thermal hydraulics
  - Assess tFGR impact on cladding rupture
  - Evaluate the impact of assembly structural features on cladding deformation





- **Identify core design optimization strategies to limit FFRD**





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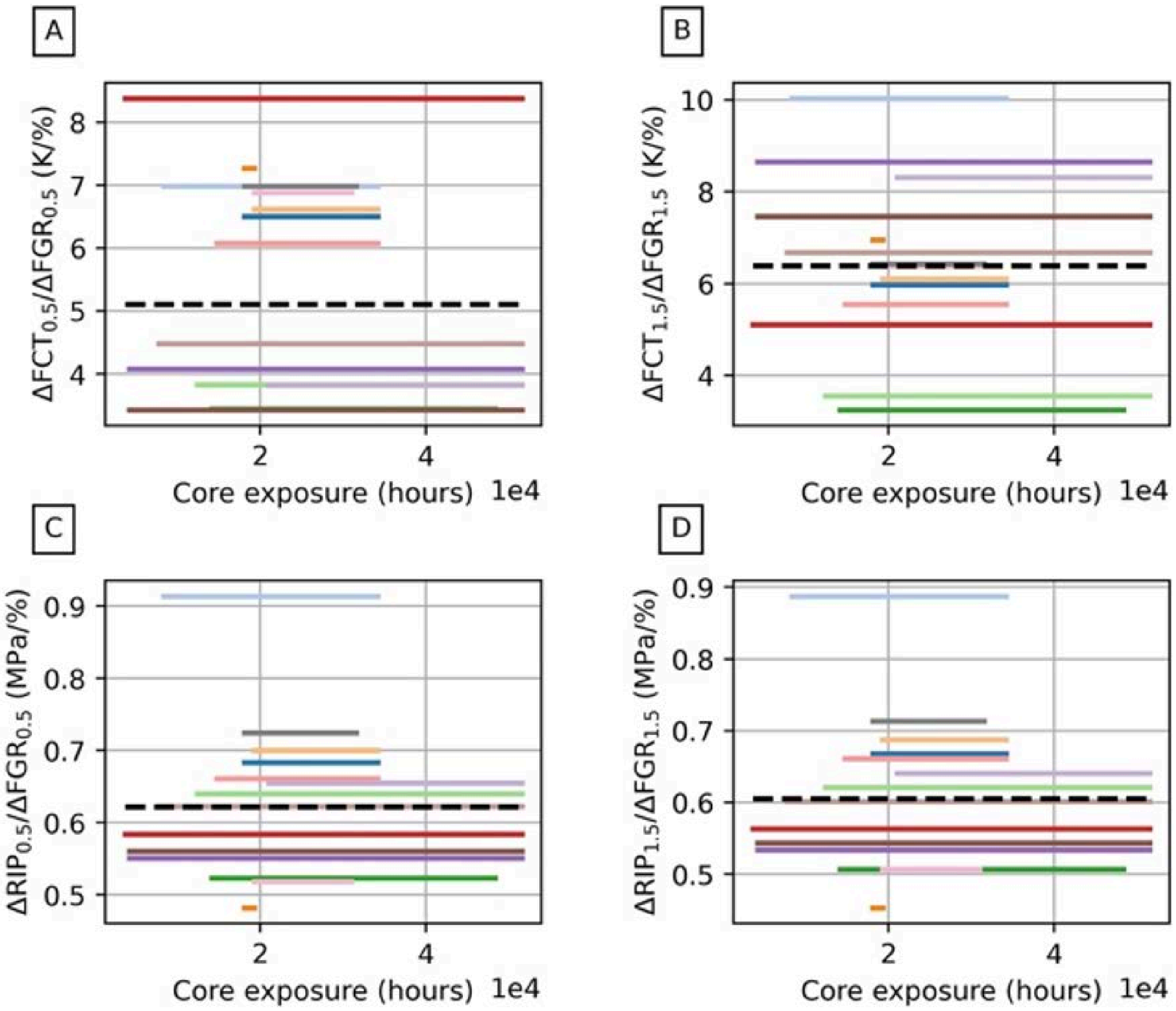
Questions?

Critical Fuel Performance Behaviors - Uncertainties



- **Assessed the impact of steady state FGR on rod internal pressure and fuel temperature**
  - Selected 16 rods
  - Arbitrary increased and decreased FGR
- **Rod Internal Pressure**
  - Max effect – 1% FGR = 0.9 MPa
- **Fuel Centerline Temperature**
  - Max effect – 1% FGR = 10 ^{o}C

Process for Determining FFRD Susceptibility