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Results from FALCON Benchmark RIA Cases

Industry-NRC RIA Workshop

San Diego, CA

March 24, 2009

Discussion Topics

- Updates since last meeting
  - Goals
  - Action Items
- Sample Results
  - HBO cases
  - RepNa-3
- Key Findings

Goals of Benchmark Study

- Compare results from the same sample problems to identify and rectify differences in FALCON and FRAPTRAN responses

- Review cladding failure models used in FALCON and FRAPTRAN to predict PCMI failure during RIA loading conditions

Action Items Resulting from Meeting

- Investigation of Fuel-Cladding Gap Differences

Task	Status
Run FALCON for the base calculation to get initial gap and rerun with HBO-1	completed
ANATECH provide our gaps used in the FALCON old runs to PNNL	completed
PNNL with ANATECH (PIE) initial gap sizes HBO-1	on going
Provide the cladding strains for the old FALCON runs	completed

- Investigation of fuel expansion differences

Task	Status
PNNL to evaluate gap reopening behavior	on going
PNNL to re-run HBO-1 with Option 1 (old method)	completed
ANATECH to provide information to support FALCON thermal expansion during RIA (behavior of cracked pellet)	on going

Action Items Resulting from Meeting

- Heat transfer coefficients

Task	Status
Review clad to coolant heat transfer coefficients	on-going
Investigate the use of T.C. data vs. Na heat transfer model for RepNa3	completed
ANATECH provide Na sodium heat transfer coefficient model	tbd
Run FALCON with same boundary conditions as FRAPTRAN	completed

- Other issues

Task	Status
ANATECH and PPNL run HBO-5 hot case to failure	completed
ANATECH and PNNL W 17x17 case to failure	completed
Review initial yield stress differences	effect of the fast-fluence assumed in original FALCON run
ANATECH to review initial clad axial elongation values in FALCON to see what's causing the high value	code input option
Propose an analysis to evaluate pulse width effects	on going

Changes Made to FALCON Inputs

- Power profiles modified to match FRAPTRAN input
- Initial gap thickness reduced to match FRAPTRAN input
- Fast fluence adjusted to match initial cladding yield stress
- Inputs to axial growth model corrected
- An attempt made to run FALCON with same boundary conditions as FRAPTRAN
  - Some modification to heat transfer coefficient for HBO cases
  - Cladding surface temperature input for RepNa-3 case

Sample Problems used in Comparison

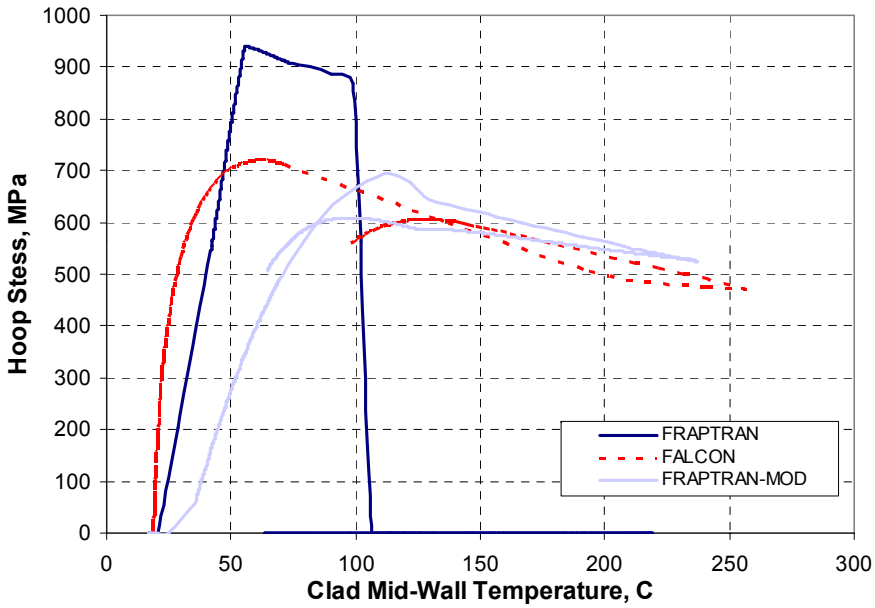
Test Case	Burnup	Oxide Thickness	Pulse Width	Injected Enthalpy	Failure Enthalpy
HBO-1	50 GWd/MTU	43 μm	~4 ms	73 cal/g	60 cal/g
HBO-5	44 GWd/MTU	60 μm	~4 ms	80 cal/g	77 cal/g
HBO-6	49 GWd/MTU	30 μm	~4 ms	85 cal/g	n/a
RepNa-3	64 GWd/MTU	40 μm	9.5 ms	120 cal/g	n/a

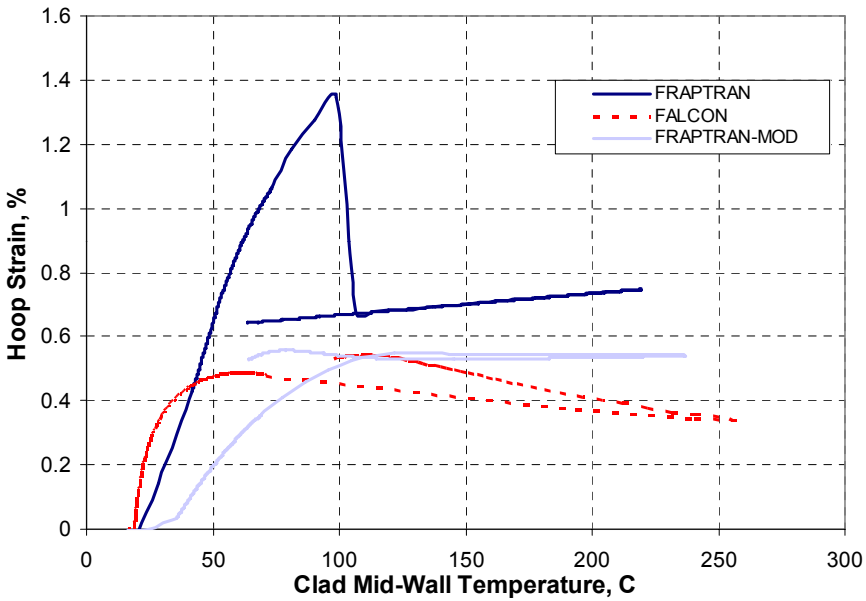
- Other Cases
  - HBO-5 hot conditions
  - Westinghouse 17x17 case
  - Base irradiation of HBO-1 and HBO-5

Sample

Results

HBO-1 Comparison





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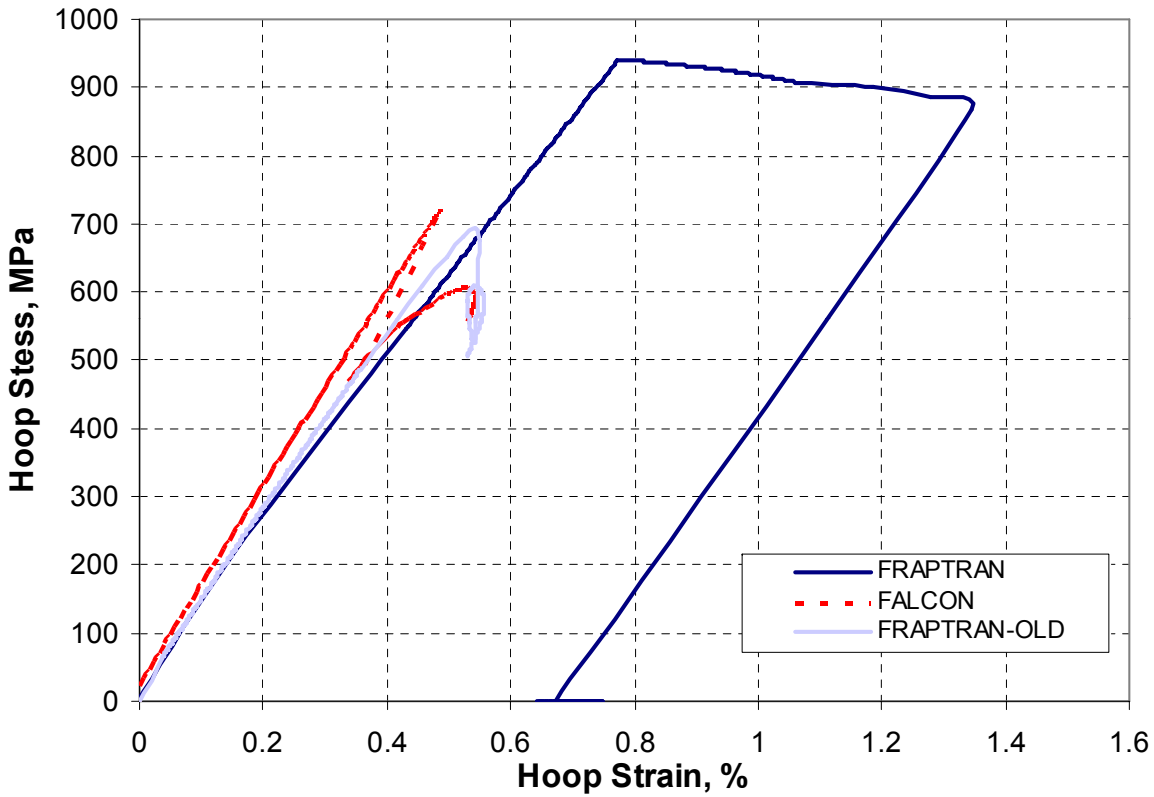
HBO-1 Comparison



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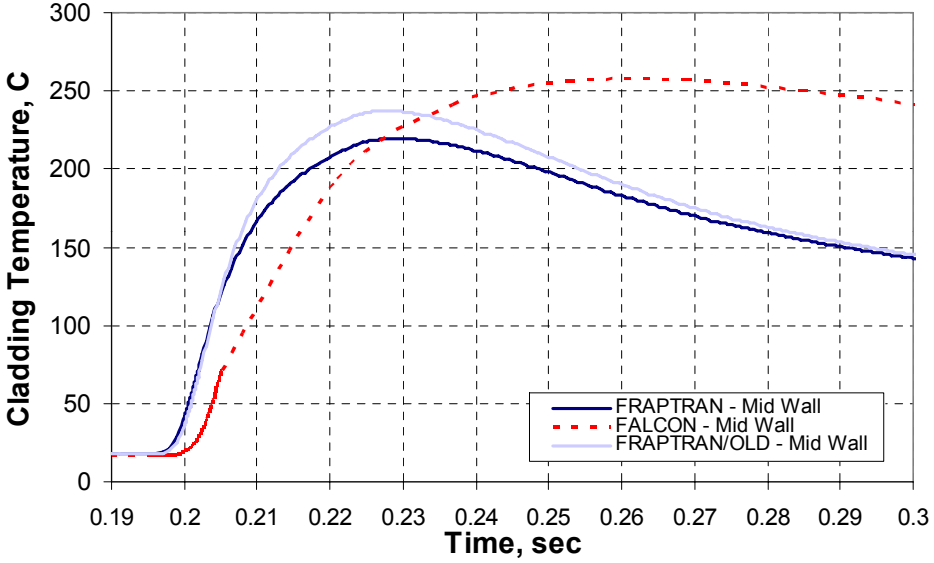
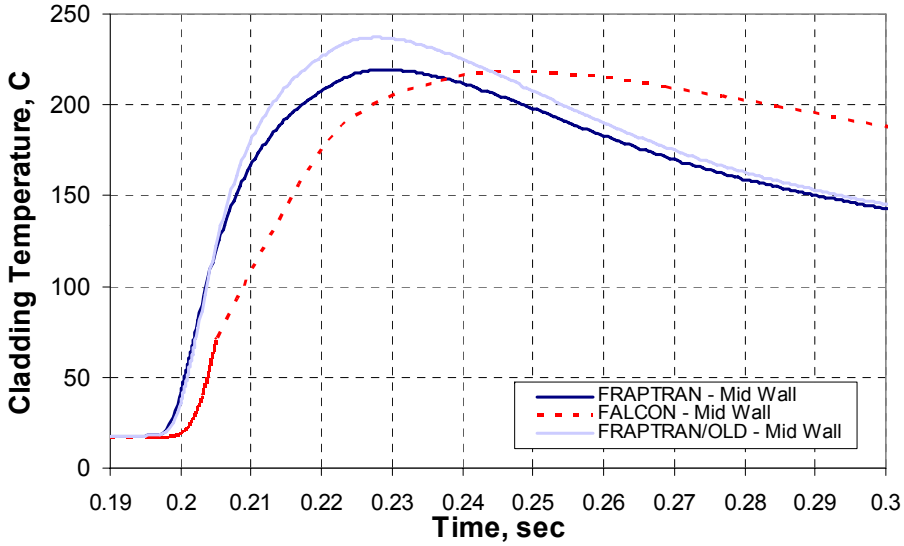
HBO-1 Comparison: Adjusted Thermal Boundary Condition



HBO-1



HBO-1 adjusted

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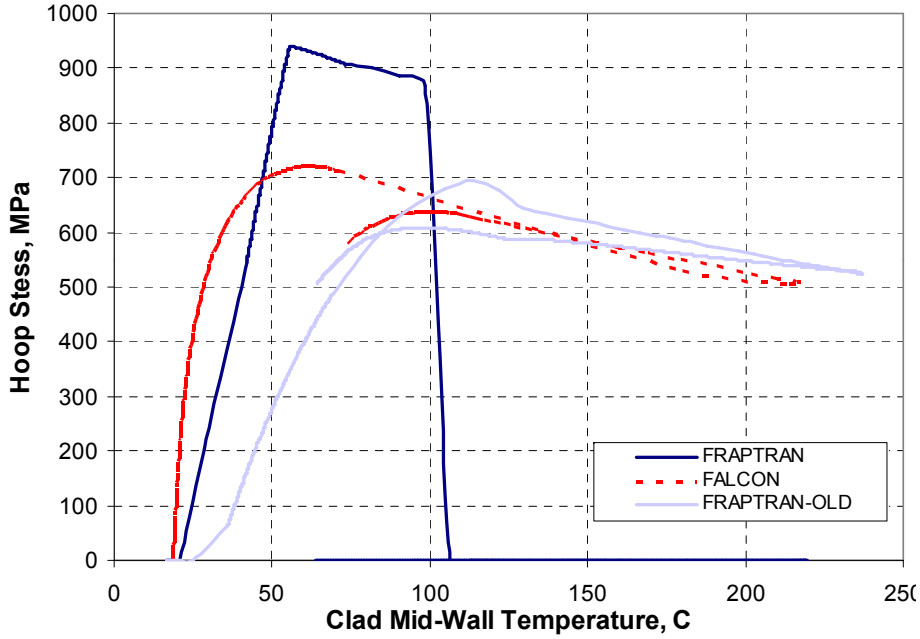
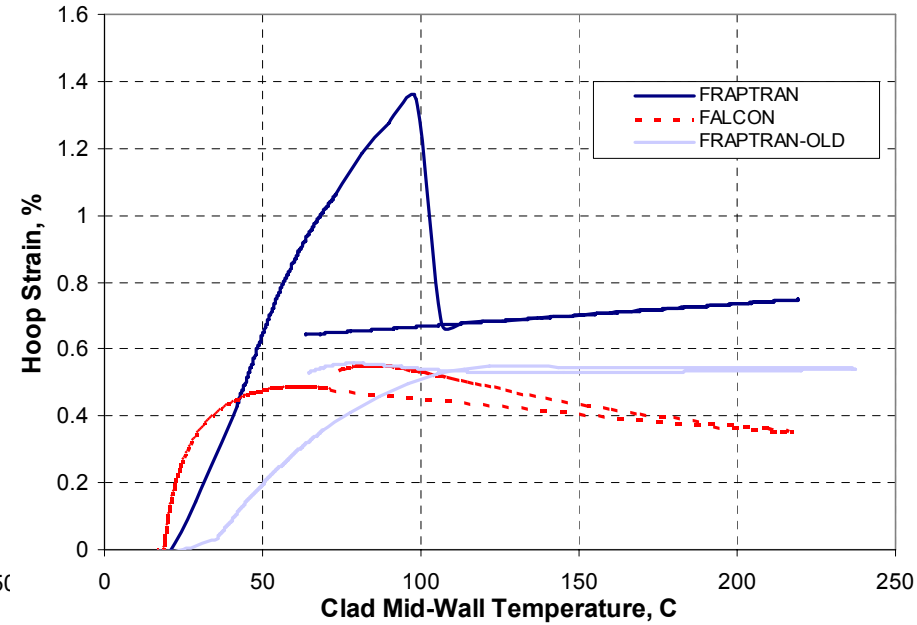
HBO-1 Comparison: Adjusted Thermal Boundary Condition





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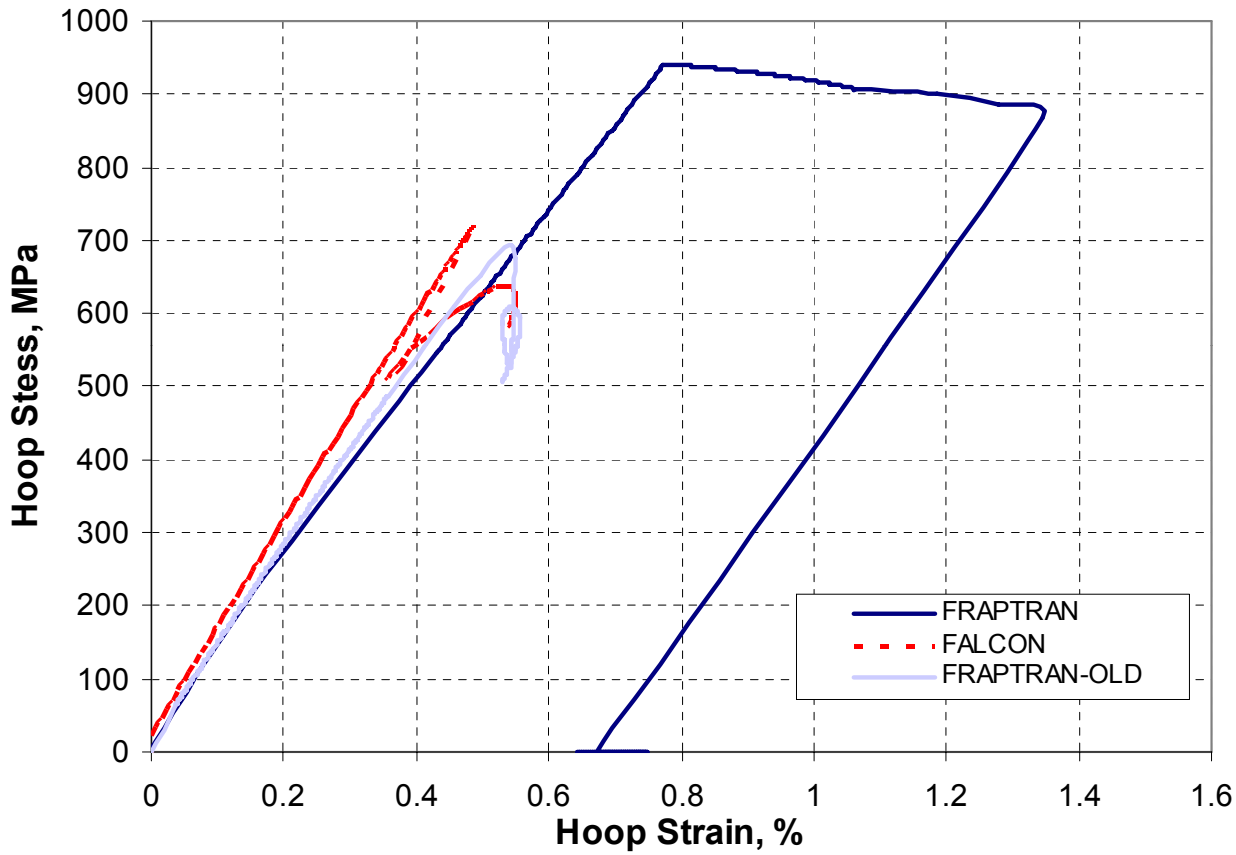

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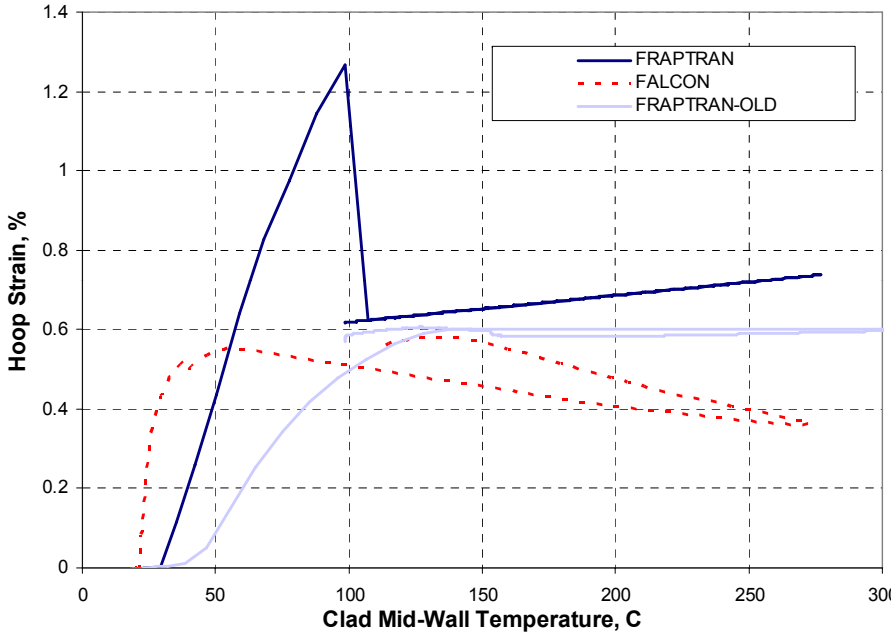
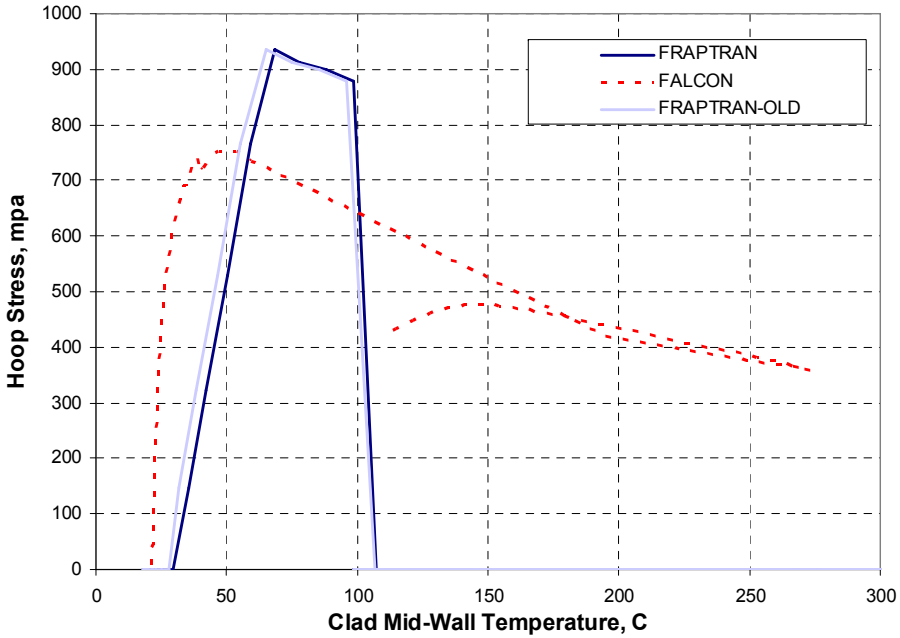
HBO-5 Comparison: Cold Conditions





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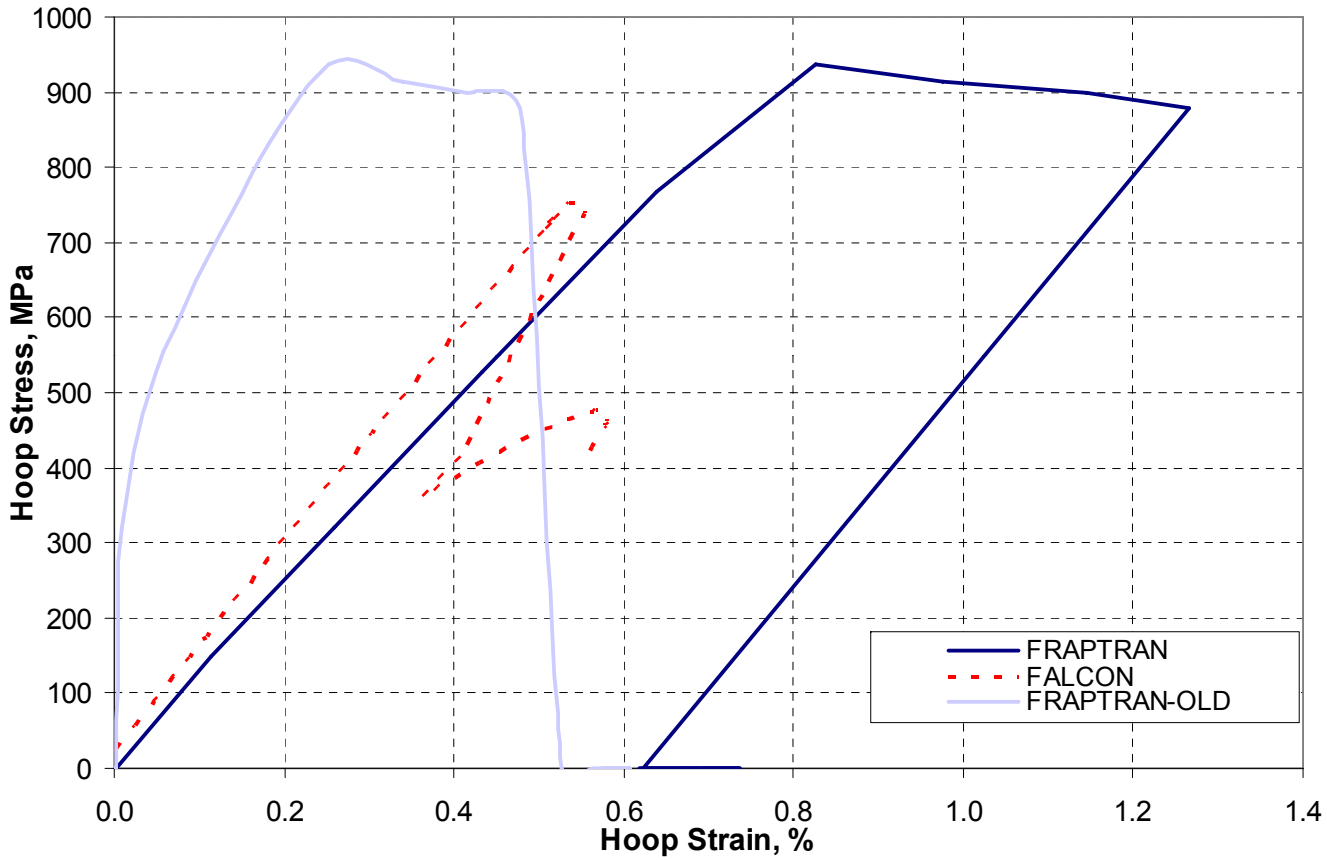

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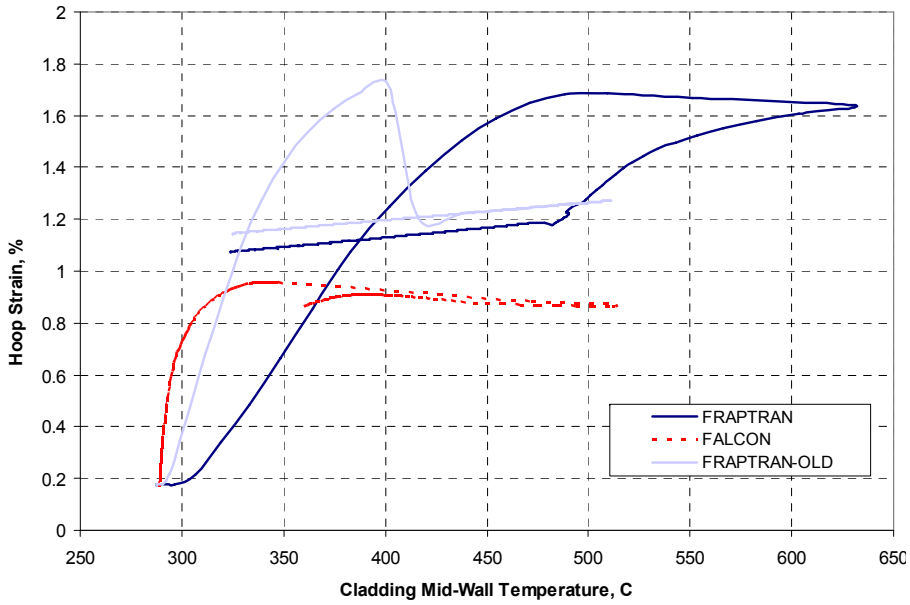
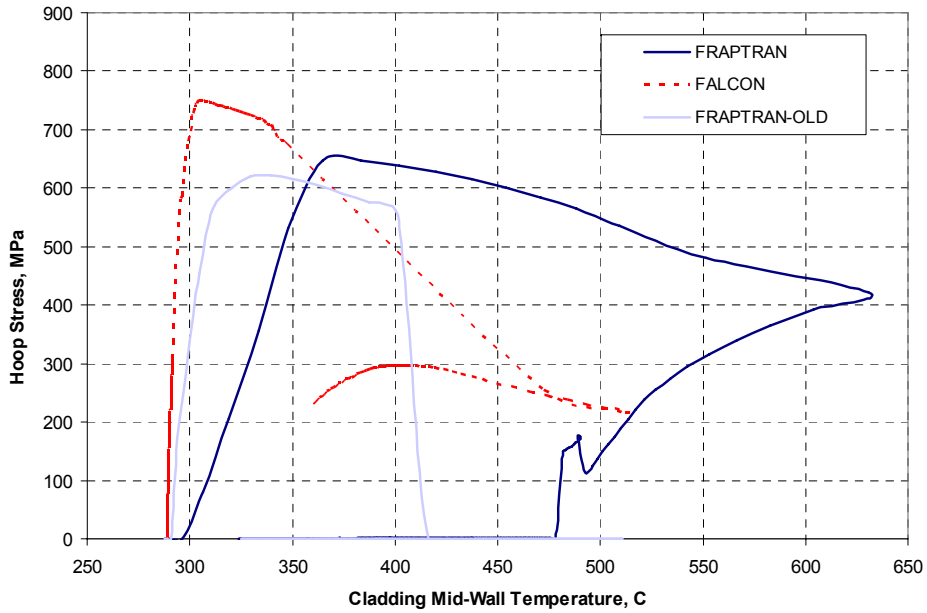
HBO-5 Comparison: Hot Conditions





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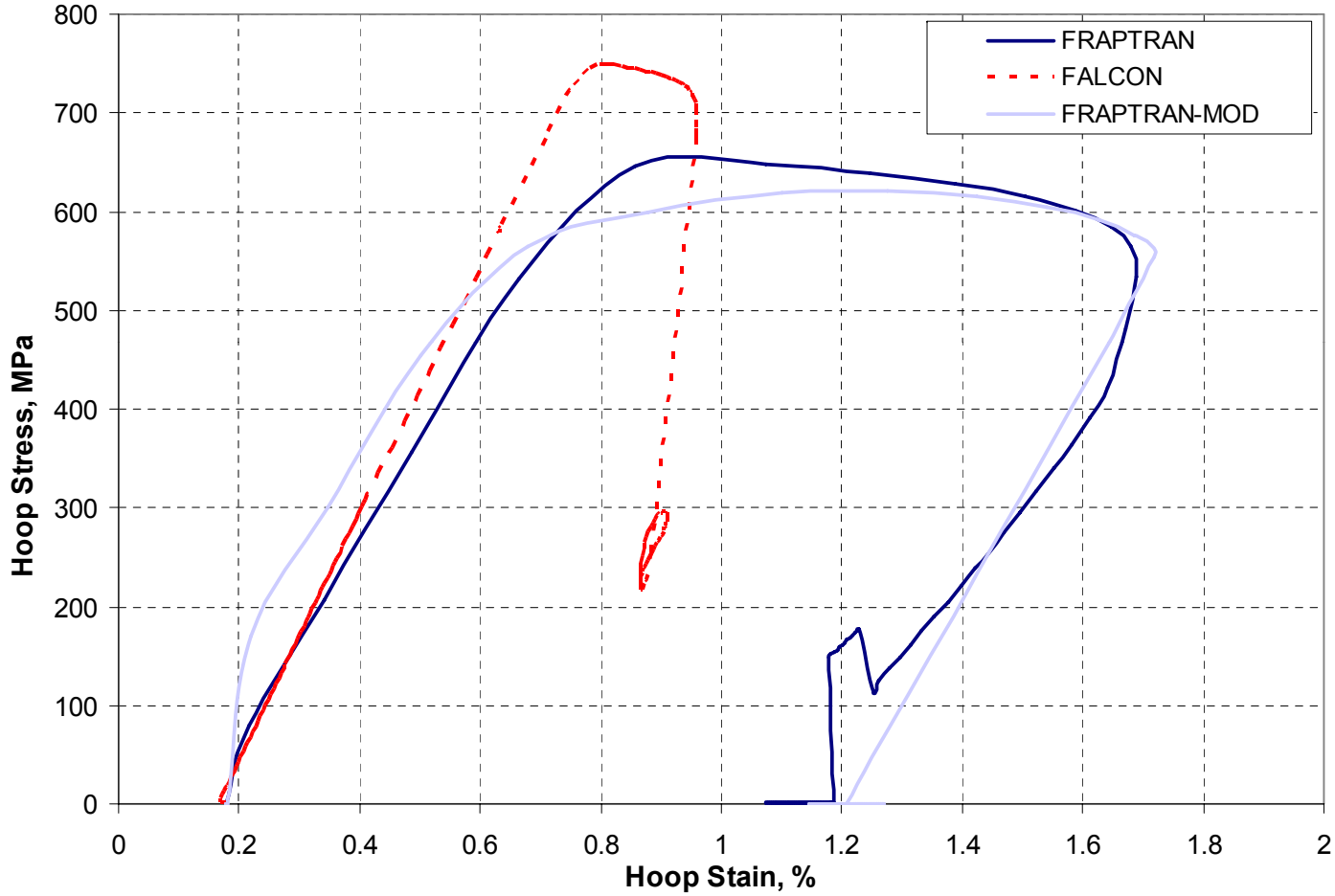

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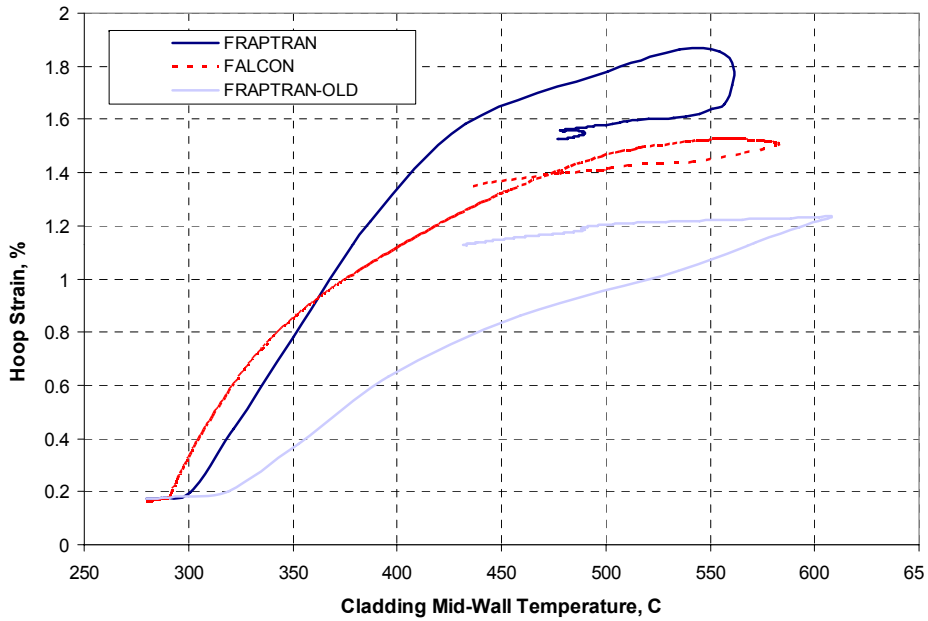
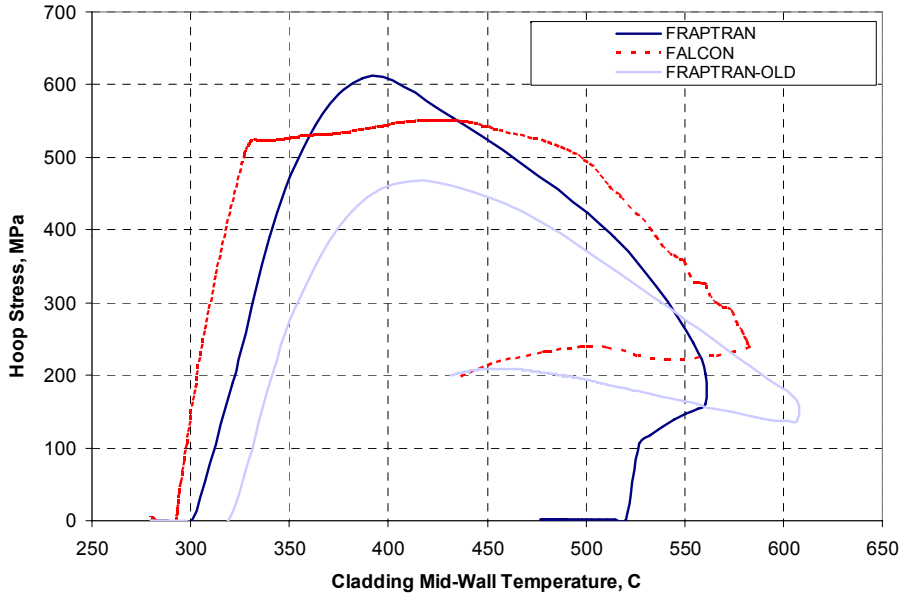
RepNa-3 Comparison:





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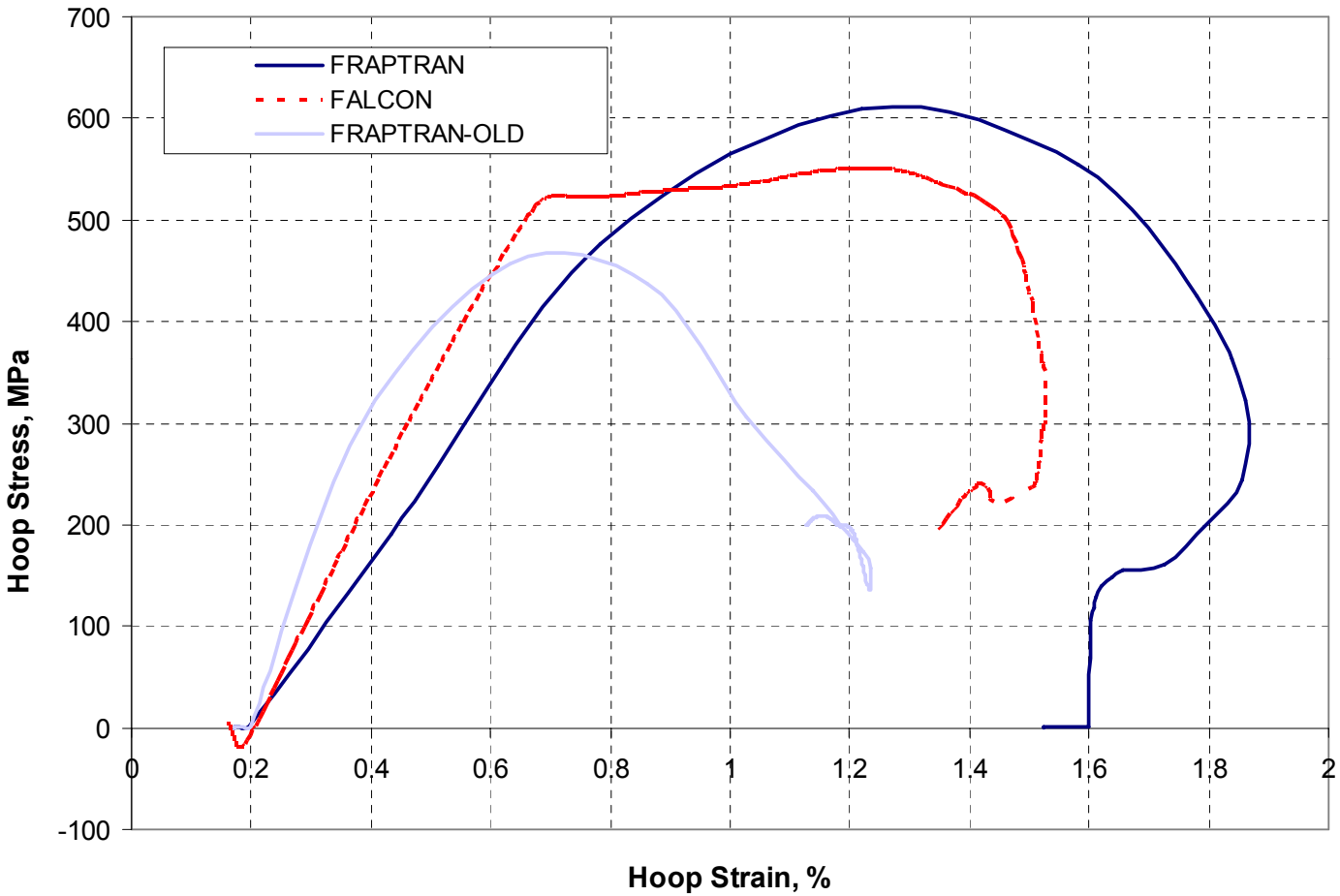

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Analyses Results

Test Case	O/C Ratio	FALCON Stress (Mpa)	FALCON Strain (%)	SED (MJ/M3)	CSED (MJ/M3)	Enthalpy (cal/g)	FRAPTRAN Stress (Mpa)	FRAPTRAN Strain (%)	FRAPTRAN Failure Enthalpy (cal/g)	Failure Enthalpy (cal/g)
HBO-1 (F)	0.08	721	0.5	4.3	8.5	73	941 (694)	1.3 (0.55)	71.9	60
HBO-1 (O)	0.08	979	0.8	7.5	8.5	72				
HBO-5 (F)	0.075	754	0.58	4.9	9	79	936 (766)	1.3 (.61)	72.1	77
HBO-5 (O)	0.075	985	0.83	8.5	9	81				
HBO-5 (Hot)	0.075	749	0.96	6.5	20	96	647 (620)	1.69 (1.7)		
HBO-5 (Hot to failure)	0.075	675	2.1	20	20	184				
HBO-6 (F)	0.04	835	0.66	6	12	83	924 (744)	0.61 (0.68)	83.5	n/a
HBO-6 (O)	0.04	991	0.88	9.3	12	84				
RepNa-3 (F)	0.07	543	1.5	13	17	134	609 (457)	1.8 (1.2)	106.3	n/a
RepNa-3 (O)	0.07	575	1.5	15.4	17	137				
W 17x17		893	1.3	19	14	118	589	1.6		

(F) = FRAPTRAN Input

(O) = FALCON Original Input

(number) = Old FRAPTRAN Method of Pellet Expansion

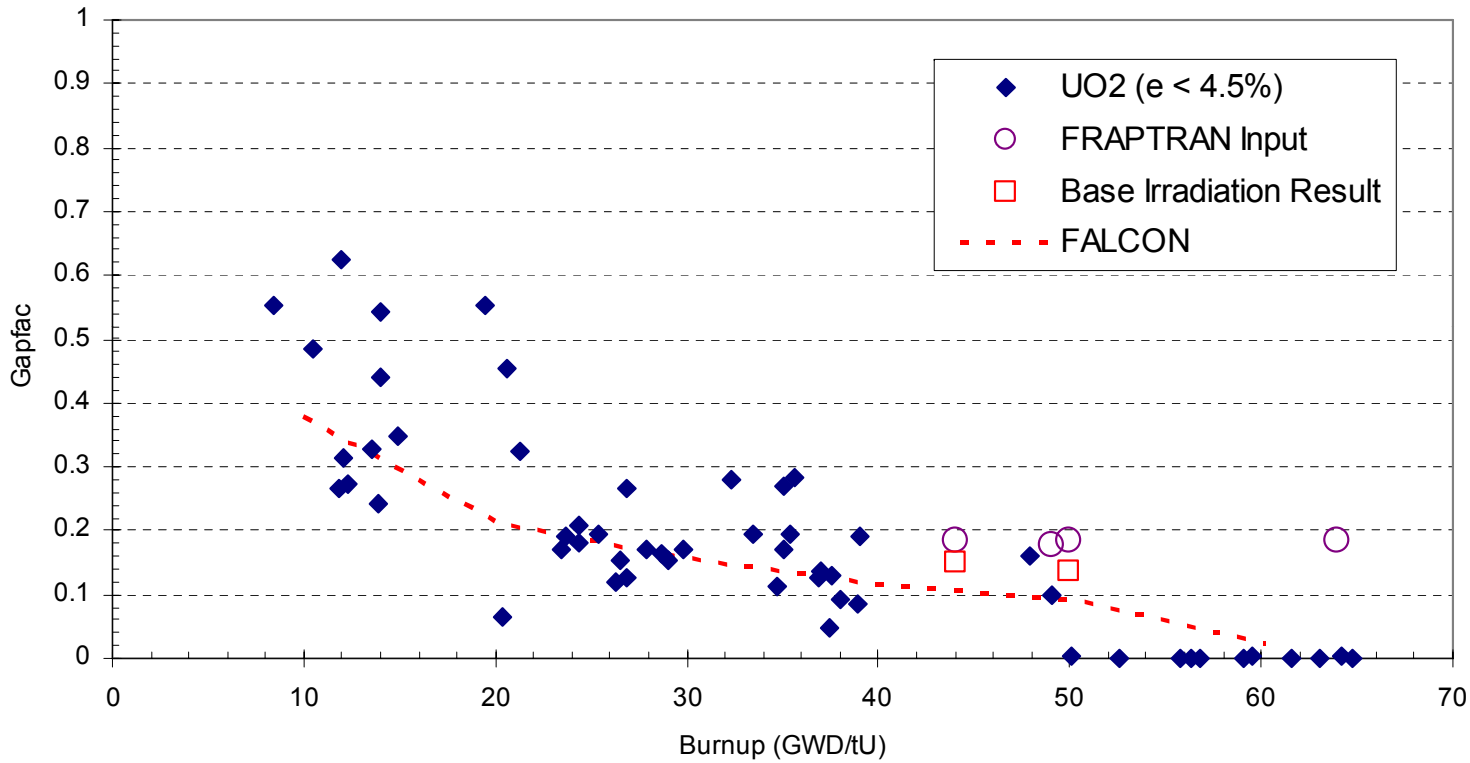
Key Points Identified from Comparisons

- Shell model behavior vs. average pellet expansion
- Steady State vs. transient heat conduction across the cladding
- Thermal performance of codes similar
- Old method of pellet expansion in FRAPTRAN yields similar results to FALCON

Shell Model Behavior vs. Average Pellet Expansion

- Shell model results in higher strains at the expense of incorrect pellet behavior after heat conduction begins
- Alternative requires an assumption about the initial gap size
  - Smaller initial gap = larger strains
- How to define gap in high burnup fuel?
  - Concentric gap as calculated by FRAPCON or FALCON from steady state modeling is artifact
  - Actual gap is redistributed into pellet cracks
- Does shape of the temperature distribution across the pellet during pulse effect gap closure/fuel compliance?

Modeled Fuel-Cladding Gap as a Function of Fuel Burnup



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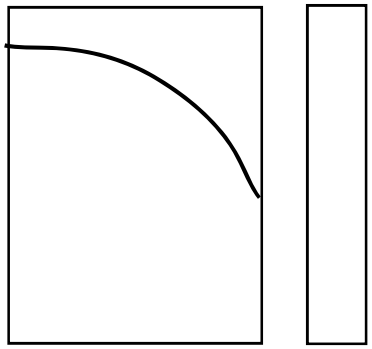
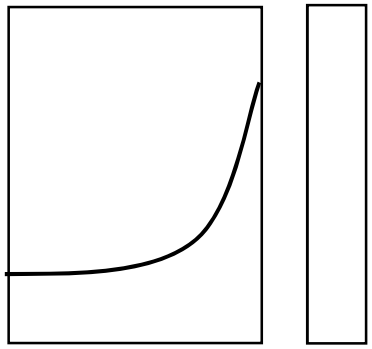
Things to Consider in Selecting the Fuel-Cladding Gap for High Burnup Fuel

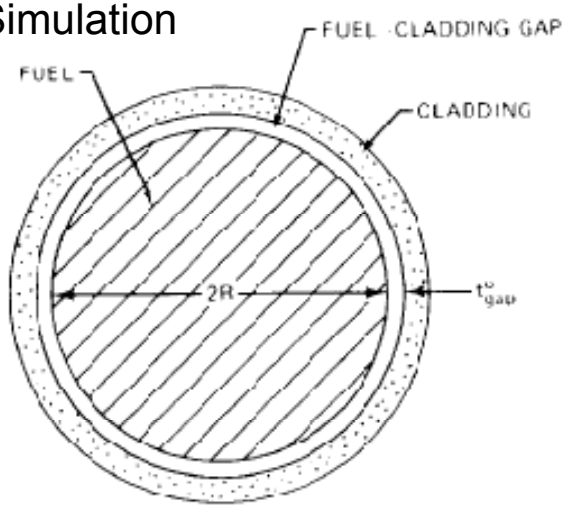


Normal temperature distribution across pellet

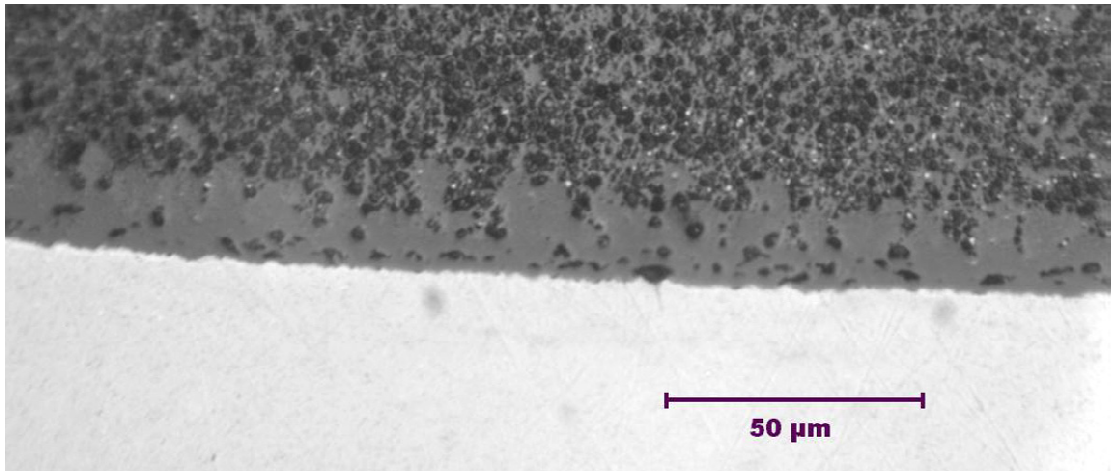


Temperature distribution across pellet during the initial phase of RIA event

Analytical Simulation



Actual Condition



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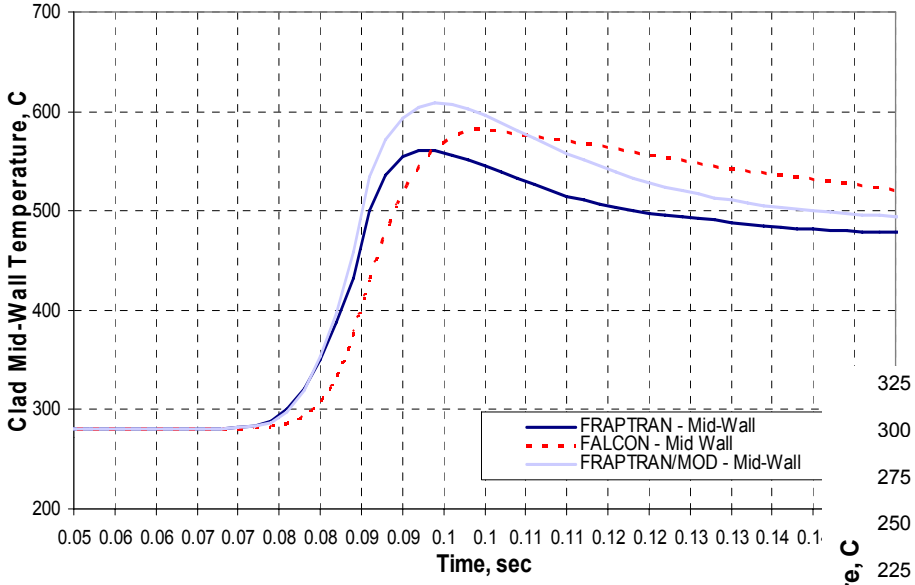
Steady State vs. Transient Heat Conduction Across the Cladding

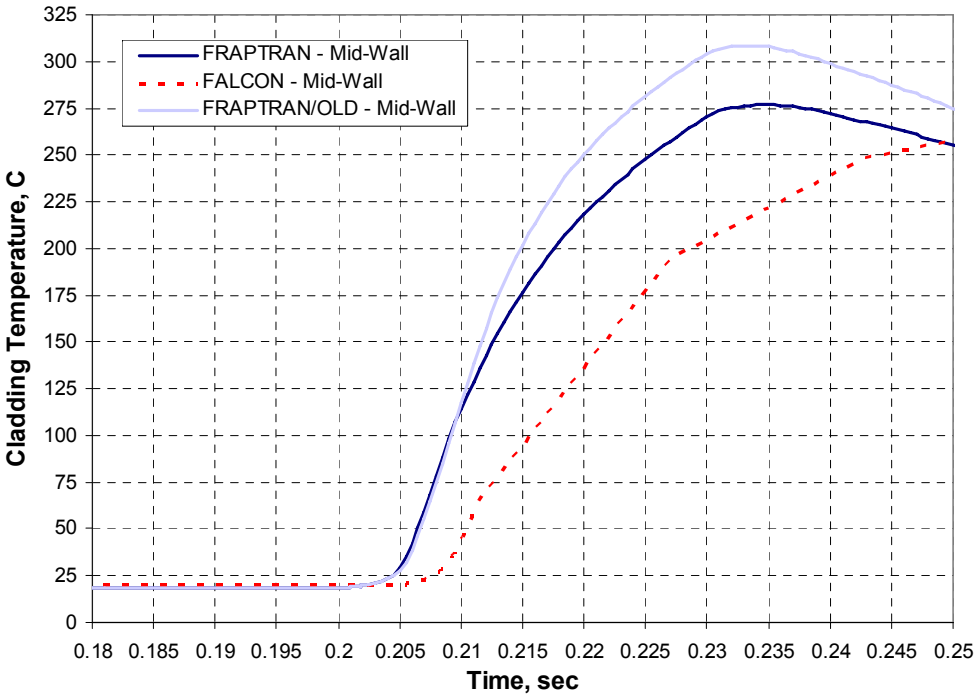
- Steady-State simpler model that produces fast cladding heating
  - Faster expansion
  - influences material properties
- Smears pulse width effect
  - No difference between fast or slow pulses
- Transient heat conduction allows for proper heat up of cladding
  - Sensitive to both fast and slow pulses

Effect of Pulse Width on Cladding Temperature



RepNa-3 9.5 ms Pulse

HBO-1 4ms Pulse



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