Computational Fluid Dynamics (CFD) Analysis of ANL Out-of-Cell LOCA Experiments

Presented by

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Outline

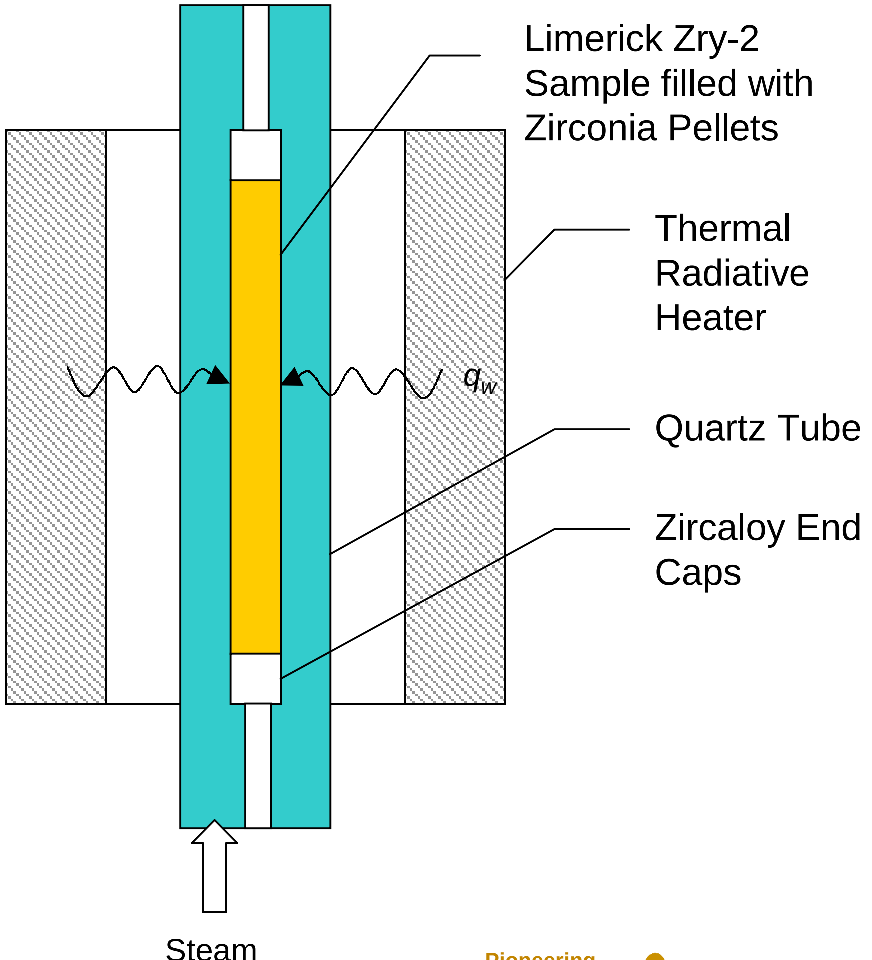
1. Introduction
2. Modeling
3. Results
4. Summary
5. Future Work

1. Introduction

- Background:
  - Independent evaluation of thermal hydraulic data from ANL out-of-cell LOCA experiments.
  - Small variations in circumferential and axial cladding surface temperatures at 1200°C can lead to significant variations in oxide layer thickness.
- Approach:
  - Utilize a detailed (CFD) approach to calculate cladding surface temperatures.
  - Perform parametric study by varying the steam flow rate, enclosure size (steam volume), and cladding profile (balloon and burst).

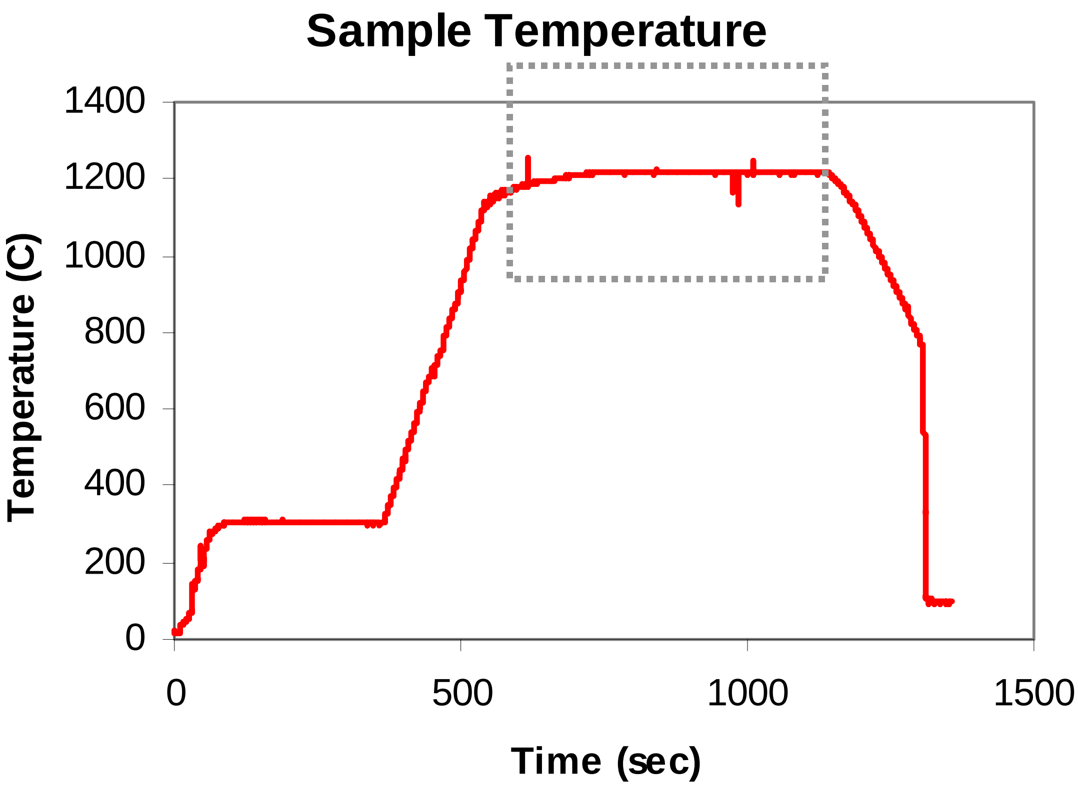
1. Introduction

- ANL LOCA Experiment
  - Limerick Zry-2 tubing (30.5 cm long, 11.2 mm OD and 0.715 mm wall) filled with zirconia pellets
  - Internal sample pressure: ~8.3 MPa gauge (He)
  - 100 °C steam flow: 0.286 m/s (Re ~ 186)
  - Radiative heater: 1.15 μm at 2500 K (short wave)
  - Total transient: ~20 min



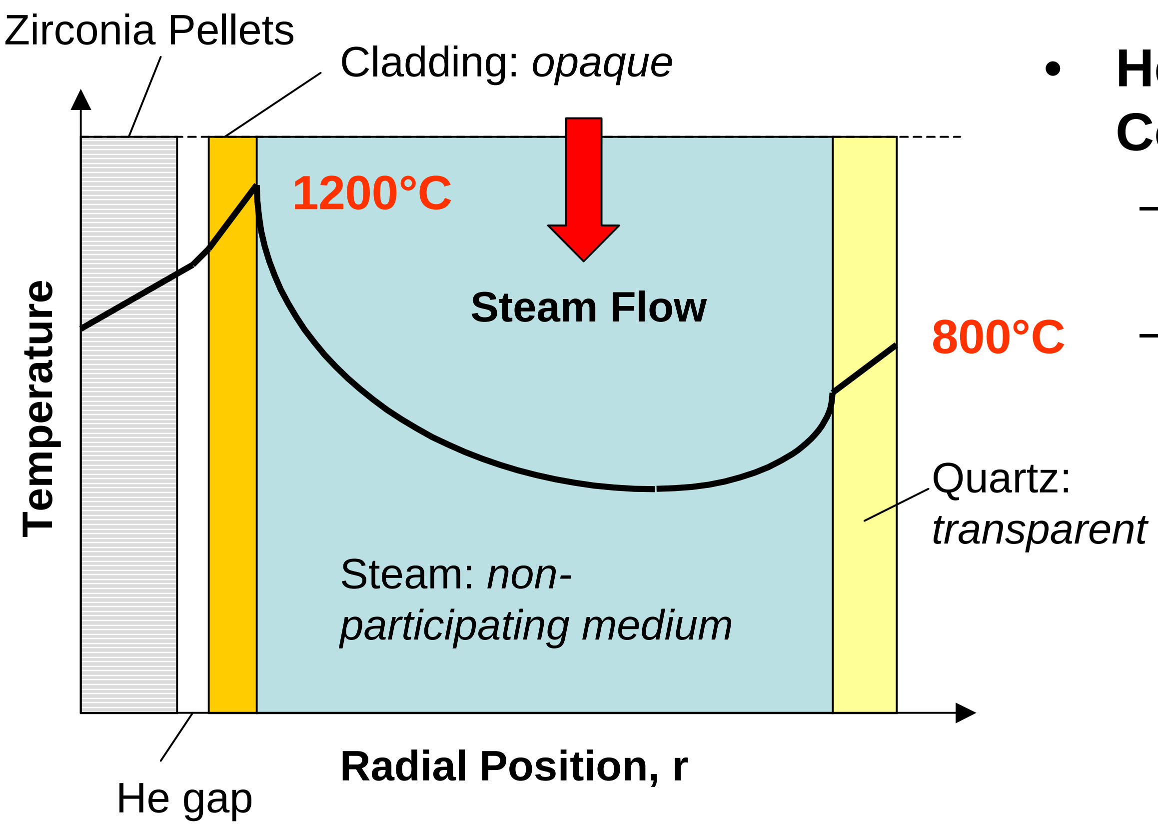
1. Introduction

- Typical Transient



2. Modeling

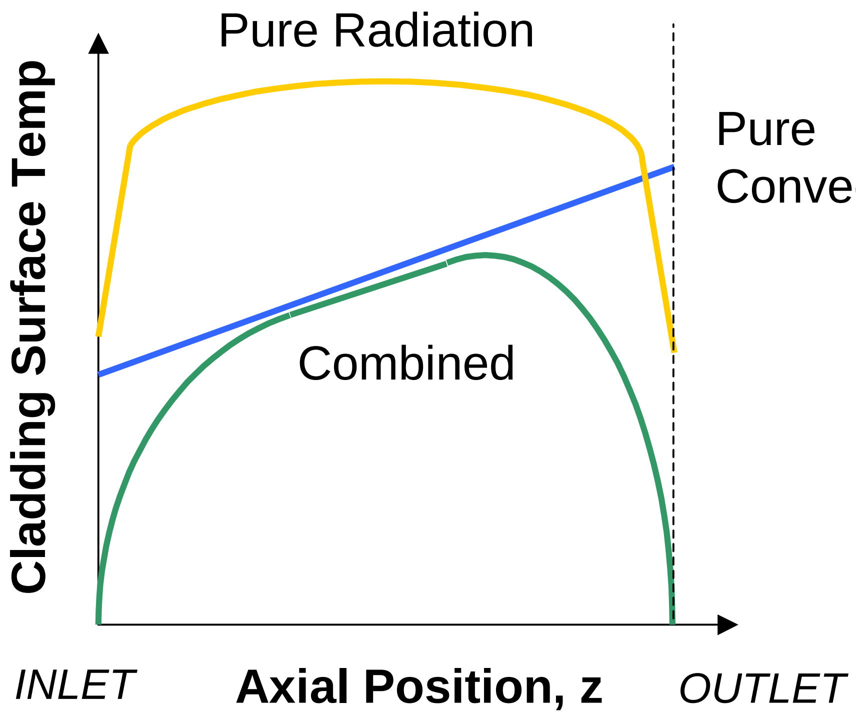
- Radial Temp Profile (Classical Solution)



- **Heat Transfer Considerations**
  - Heat sources: cladding and quartz tube.
  - Heat sinks: steam flow, air gap, zircaloy end caps, and zirconia pellets.

2. Modeling

- Axial Temp Profile (Classical Solution)



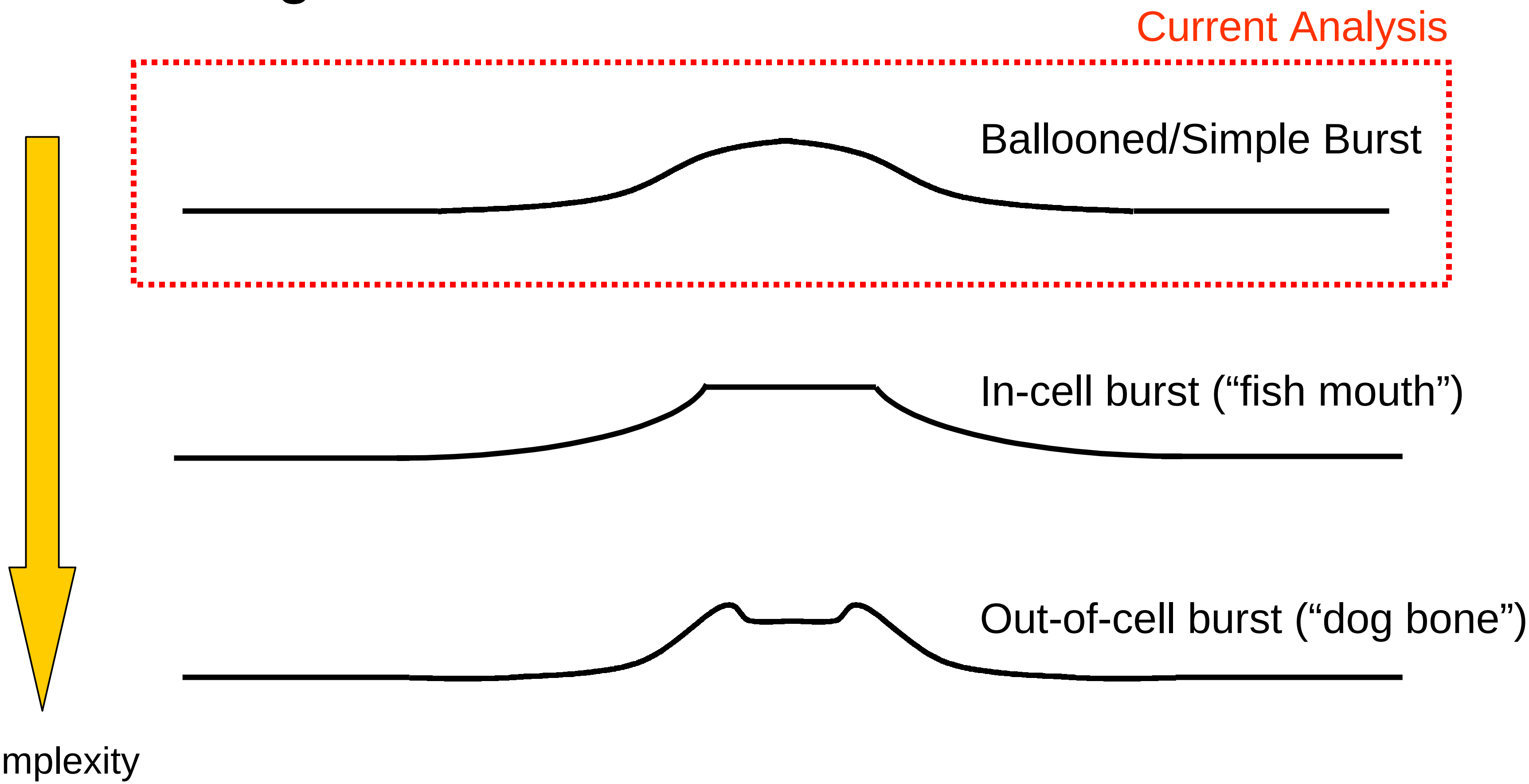
- **Heat Transfer Considerations**
  - Step 1: *solve* radiation problem to obtain axial cladding temp profile.
  - Step 2: *input* temp profile from radiation solution.
  - Step 3: *solve* convection/conduction problem.

2. Modeling

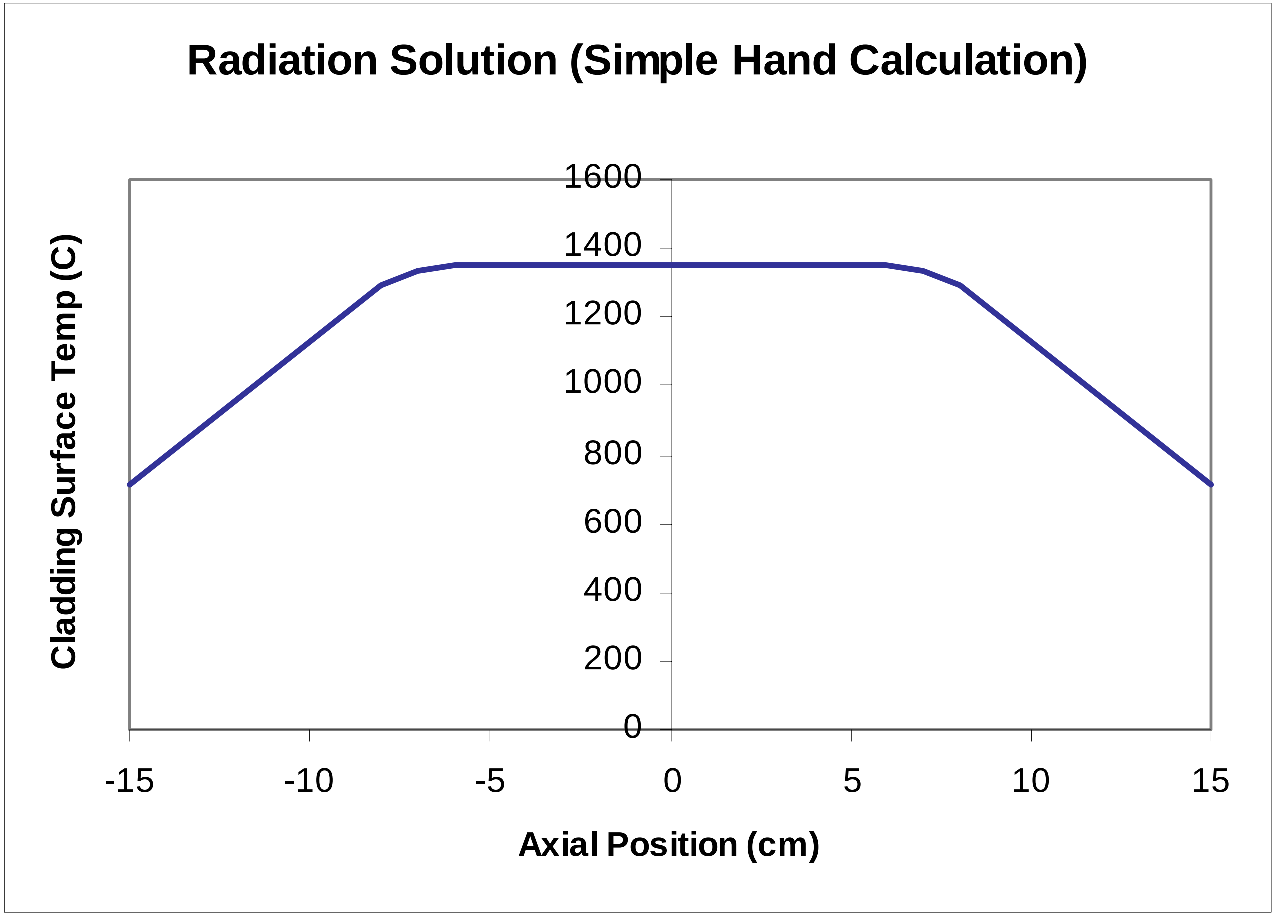
- Material Considerations
  - Zry-2 cladding: ε = 0.81 (weak dependence on oxide layer thickness in the 1200°C zone) *MATPRO*
  - Quartz tube: ε = 0.9, ρ = 0.1
  - Steam: non-participating medium (radiation)
  - Zirconia pellets: $Zr0_2$ material properties

2. Modeling

- Cladding Profiles



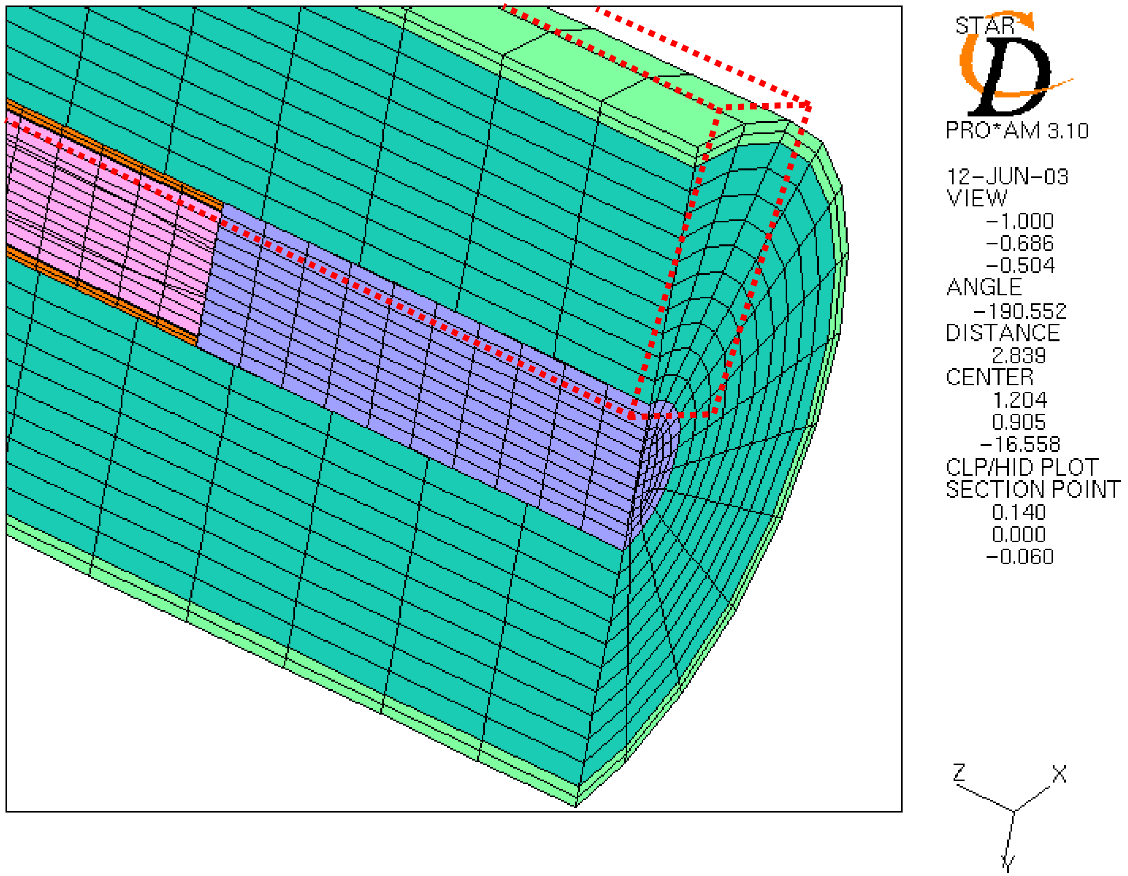
2. Modeling



Radiation Solution (Simple Hand Calculation)
1600
1400
1200
1000
800
600
400
200
0
-15
-10
-5
0
5
10
15
Axial Position (cm)
Cladding Surface Temp (C)

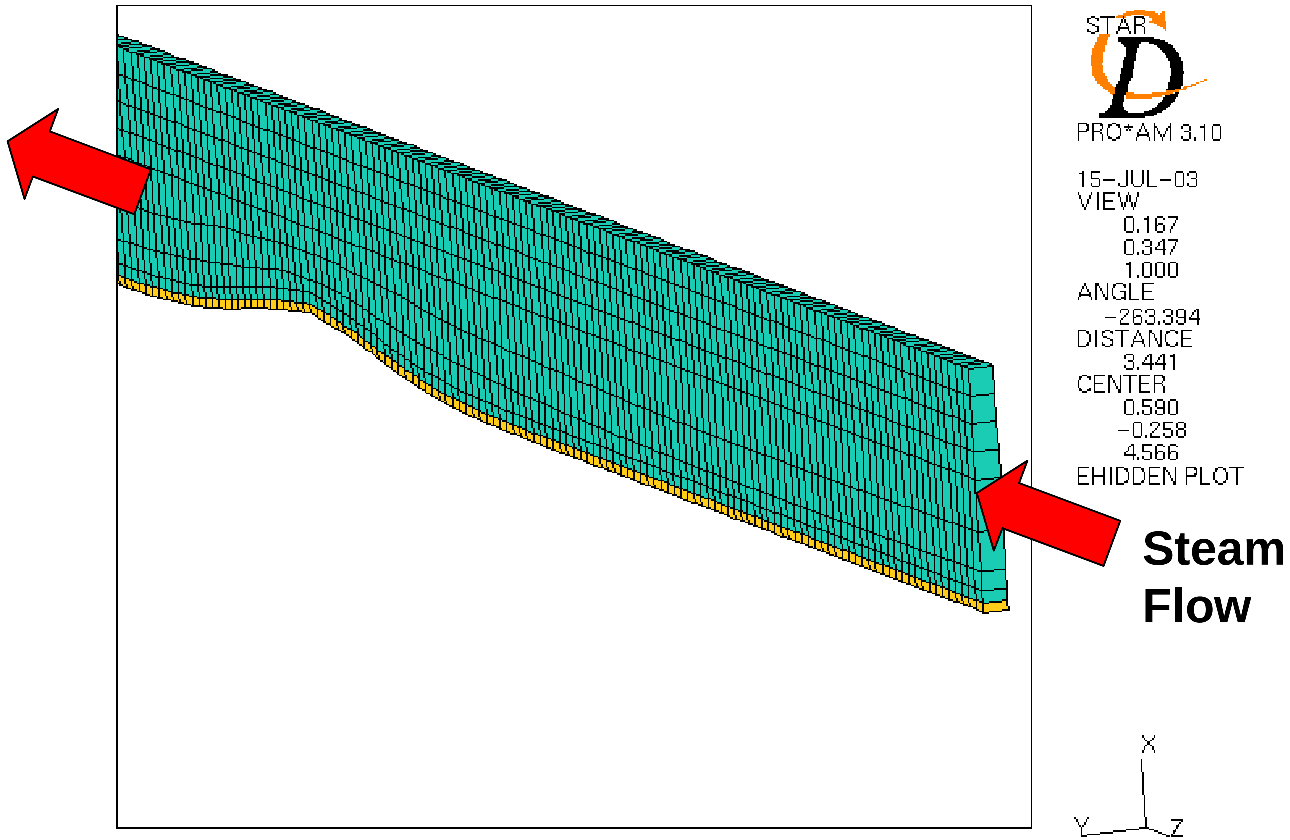
2. Modeling

- 3D Computational Mesh (Section View)

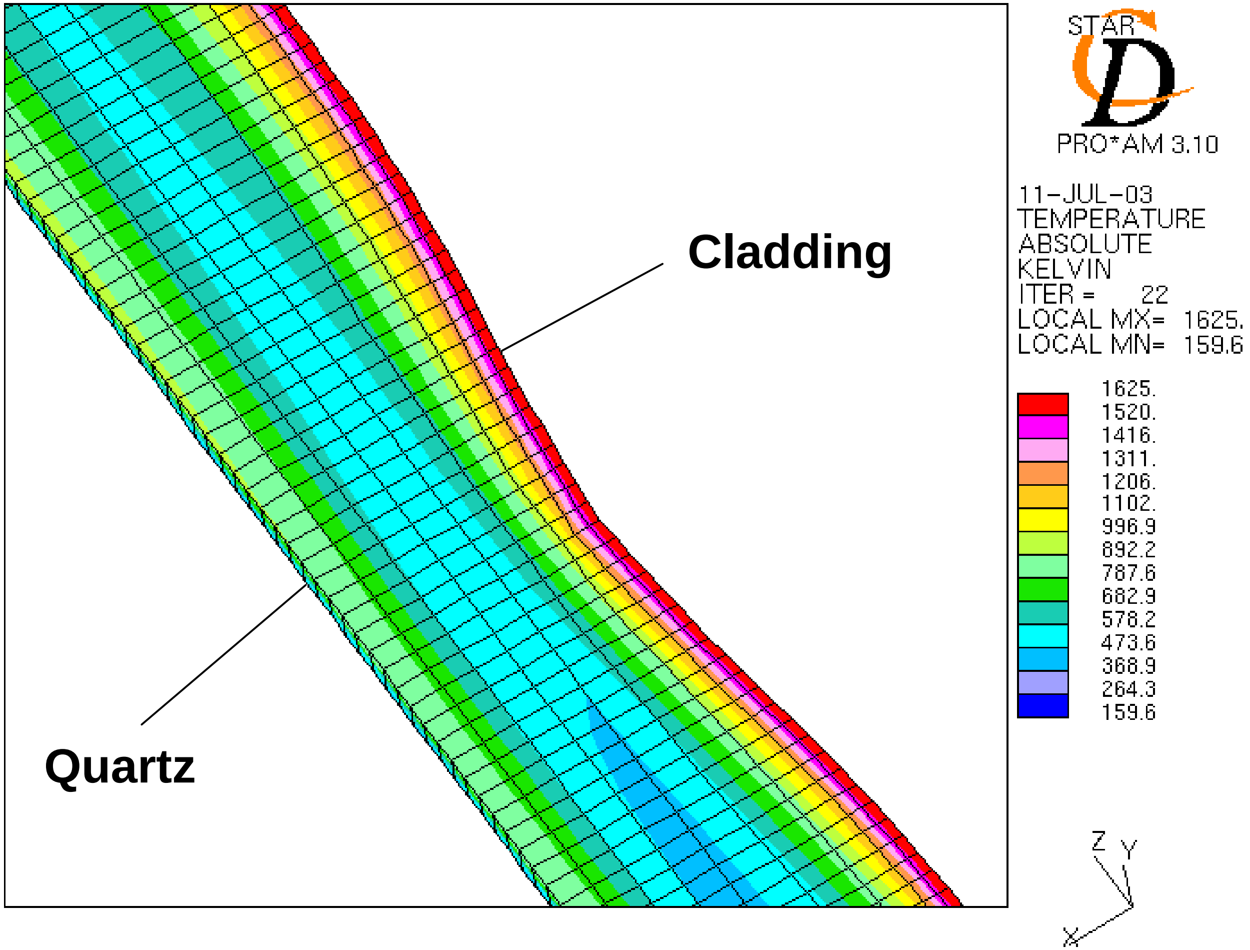


2. Modeling

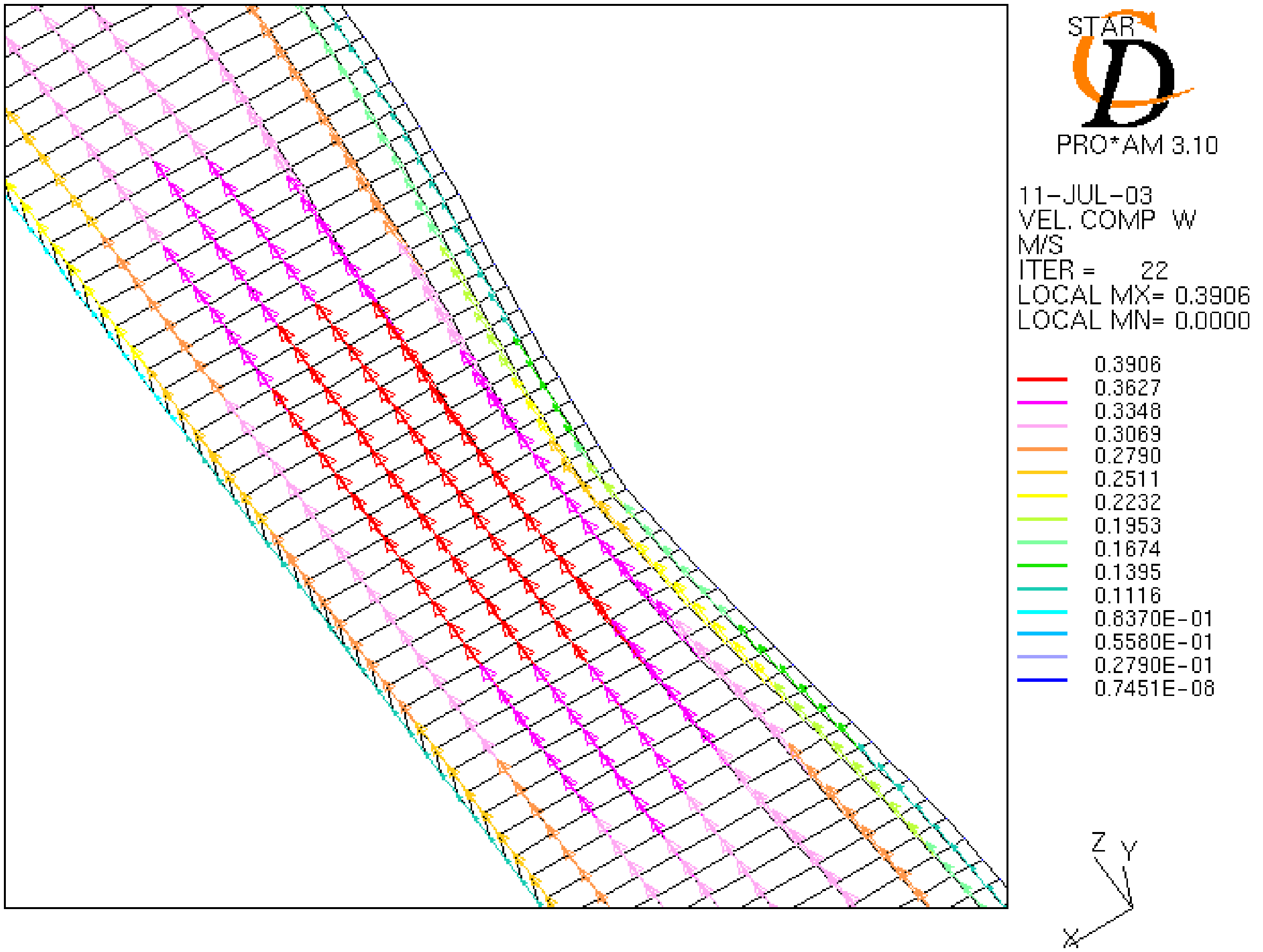
- 2D Section Slice



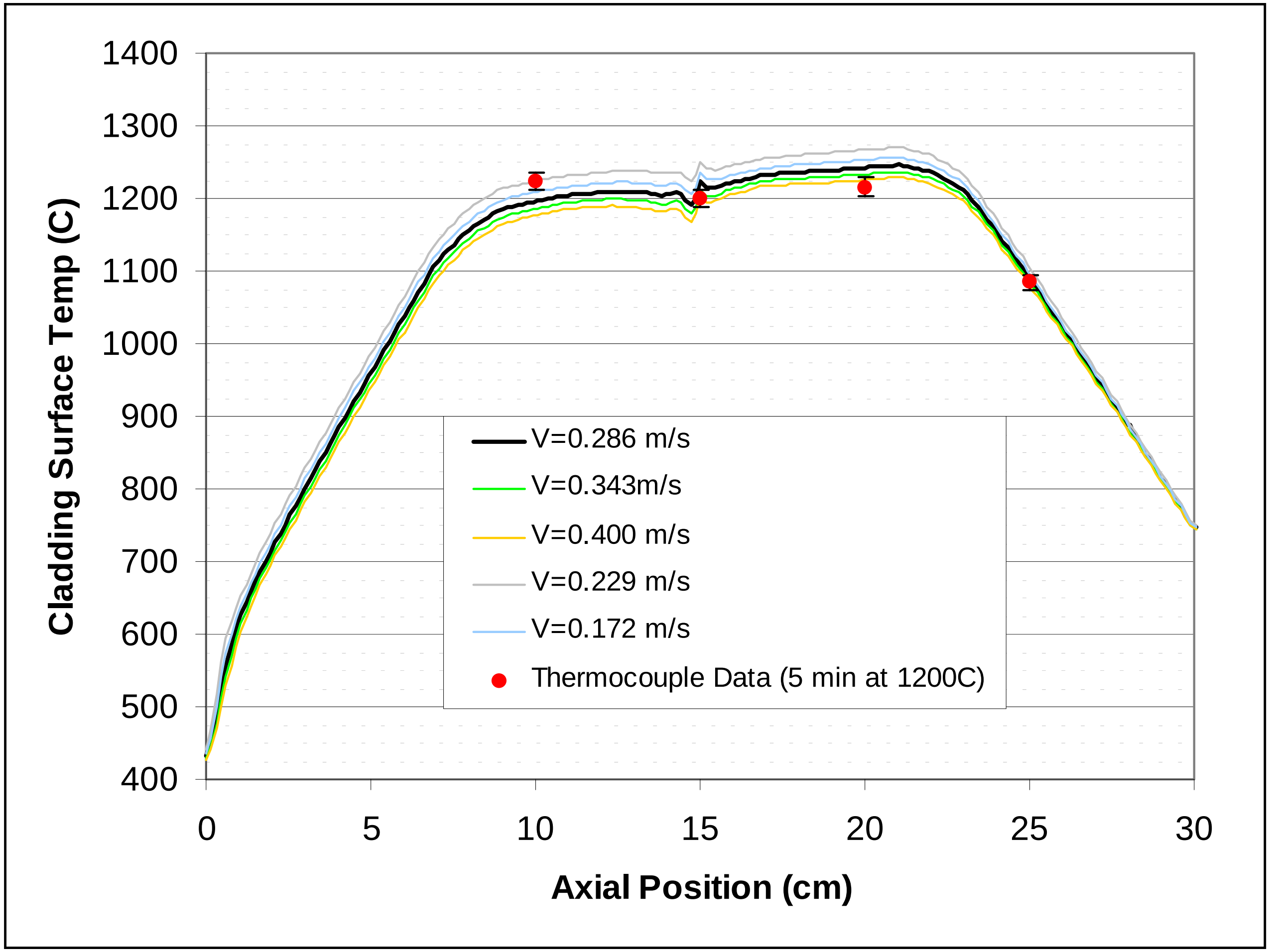
3. Results


Cladding
Quartz
STAR D
PRO*AM 3.10
11-JUL-03
TEMPERATURE
ABSOLUTE
KELVIN
ITER = 22
LOCAL MX= 1625.
LOCAL MN= 159.6
1625.
1520.
1416.
1311.
1206.
1102.
996.9
892.2
787.6
682.9
578.2
473.6
368.9
264.3
159.6
Z Y
X

3. Results


STAR
PRO*AM 3.10
11-JUL-03
VEL. COMP W
M/S
ITER = 22
LOCAL MX= 0.3906
LOCAL MN= 0.0000
0.3906
0.3627
0.3348
0.3069
0.2790
0.2511
0.2232
0.1953
0.1674
0.1395
0.1116
0.8370E-01
0.5580E-01
0.2790E-01
0.7451E-08
Z
Y
X

3. Results



Cladding Surface Temp (C)
1400
1300
1200
1100
1000
900
800
700
600
500
400
0
5
10
15
20
25
30
Axial Position (cm)
V=0.286 m/s
V=0.343m/s
V=0.400 m/s
V=0.229 m/s
V=0.172 m/s
Thermocouple Data (5 min at 1200C)

3. Results

- Axial Temperatures

Axial Position	T_{calc}	T_{data}	ΔT	% Diff.
- 5 cm	1197	1224	27	2.2
mid-plane	1201	1201	0*	0*
+ 5 cm	1242	1216	26	2.2
+ 10 cm	1084	1084	0**	0**

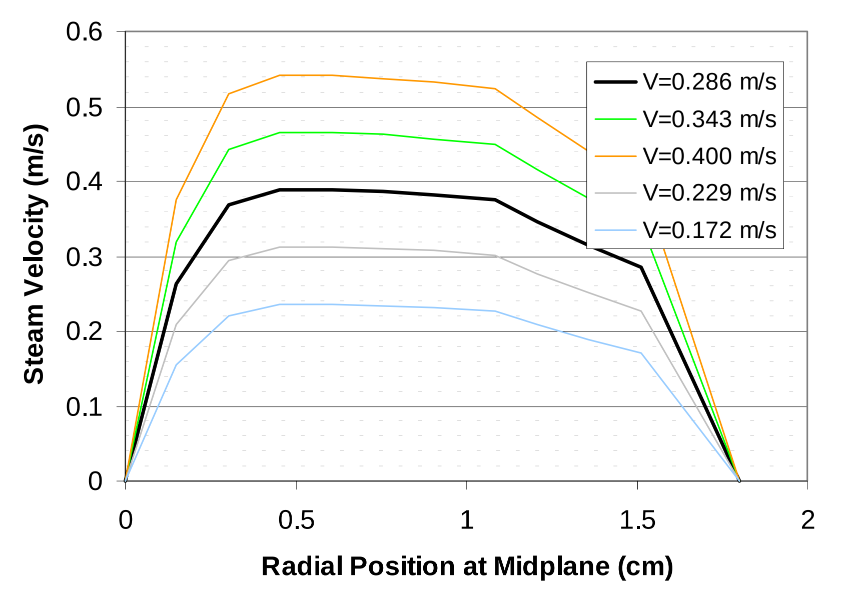
*Control thermocouple **Input temperature

	Calc	Data
ΔT (mid-plane to +5 cm), °C	4	23
ΔT (-5 cm to mid-plane), °C	41	15

3. Results

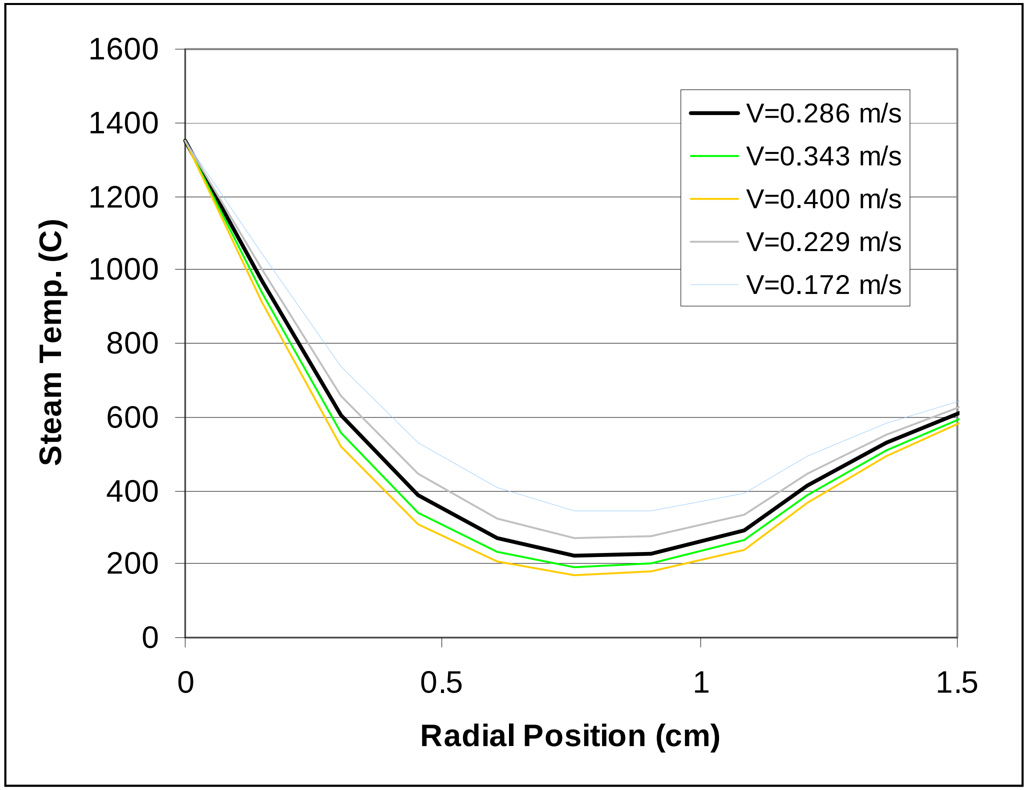
- Steam Velocity

ΔV_{inlet}%	$\Delta T_{midplane}$ (°C)	$\Delta T_{midplane}$ %
± 20	± 12	± 0.8
± 40	± 22	± 1.5



3. Results

- Steam Cross-flow Temperature



4. Summary

- Additional experiments were run at ANL to determine steam flow rate and quartz tube temp. as a function of control temp.
- Cladding surface emissivity is constant (ε = 0.81) for 5, 10 and 20 min. 1200°C oxidation (MATPRO, Rev. 2).
- 3D mesh created in STAR-CD for ballooned/simple burst test section.
- 2D simulations run at 1200°C with ballooned/simple burst profile.
- STAR-CD calculations predicted thermocouple data to within ± 2%.
- STAR-CD predicted a *relatively flat* axial temperature profile from -5 cm to +5 cm, consistent with thermocouple data.
- STAR-CD predicted a ± 12°C (0.8%) variation in cladding surface temperature when steam inlet velocity was varied by ± 20%.
- STAR-CD calculations may be improved by refining the radiation heat transfer solution.

5. Future Work

- Refine radiation solution to improve accuracy of STAR-CD calculations.
- Run STAR-CD simulations of “fish mouth” and “dog bone” burst profiles.
- Perform a parametric study of circumferential cladding temperatures using multiple (0°, 90° and 180°) 2D profile meshes.

5. Future Work (continued)

- 3D Burst Model (un-meshed/PRO-E)

Dog Bone Burst