Standard Problem Exercise No. 3

Phase Two

March 27, 2012

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Agenda

Tuesday, March 27, 2012		
Time	**Topic**	**Speaker**
8:30	Meet at Building Lobby for Badging and Security	
9:30	Opening Remarks / Welcome Address	NRC / AERB
9:45	Overview of Model 4 – Case 1 and 2	NRC / SNL / M&N
10:00	Model 4 Case 1 Presentations	All Participants
12:00	Group Photo	
12:15	Lunch – NRC Cafeteria	
1:00	Case 1 – Comparison of Results	NRC / SNL / M&N
1:30	Case 1 – Panel Discussion	All Participants
2:30	Break	All Participants
2:45	Model 4 Case 2 Presentations	All Participants
4:45	Adjourn	

Wednesday, March 28, 2012		
Time	**Topic**	**Speaker**
8:30	Meet at Building Lobby for Badging and Security	
9:00	Model 4 Case 2 Comparisons	NRC / SNL / M&N
9:30	Model 4 Case 2 Panel Discussion	All Participants
10:30	Break	
10:45	Leakage Rate Problem Definition	NRC / SNL / M&N / AERB
11:00	Leakage Rate Presentations By Participants	All Participants
12:00	Lunch – NRC Cafeteria	
1:00	Leakage Rate Presentations By Participants (continued)	All Participants
2:00	Leakage Rate Panel Discussion	All Participants
3:30	Discussion of Transition to Probabilistic Space	NRC / SNL / M&N
4:00	Probabilistic Space Presentations	All Participants
4:45	Adjourn	

Agenda

Thursday, March 29, 2012		
Time	**Topic**	**Speaker**
8:30	Meet at Building Lobby for Badging and Security	
9:00	Probabilistic Space Presentations (Continued)	All Participants
10:30	Probabilistic Space Panel Discussion	Participants
11:30	Discussion of In-Situ Vs Design (If Applicable)	Participants
12:00	Projects of Interest to Panel	NRC / SNL
12:15	Discussion of Future Work (Publications, Results sent in, Next Workshop)	All Participants
12:45	Adjourn	

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Phase One Overview

March 27, 2012

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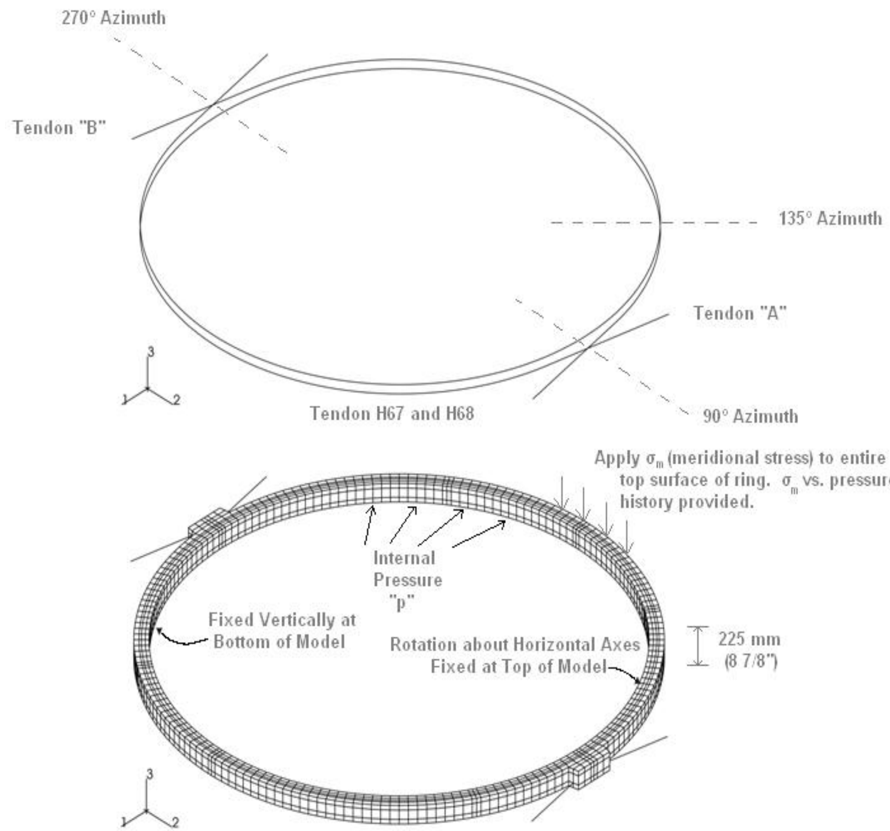
Model 1 Summary

- **Model 1: Tendon Behavior Model**
  - **Investigate Tendon Forces as a Function of Containment Dilation**
  - **Use Friction Models to Represent Slippage of Prestressing Cables**
  - **Pressure and Pressure/Temperature Analyses Completed**



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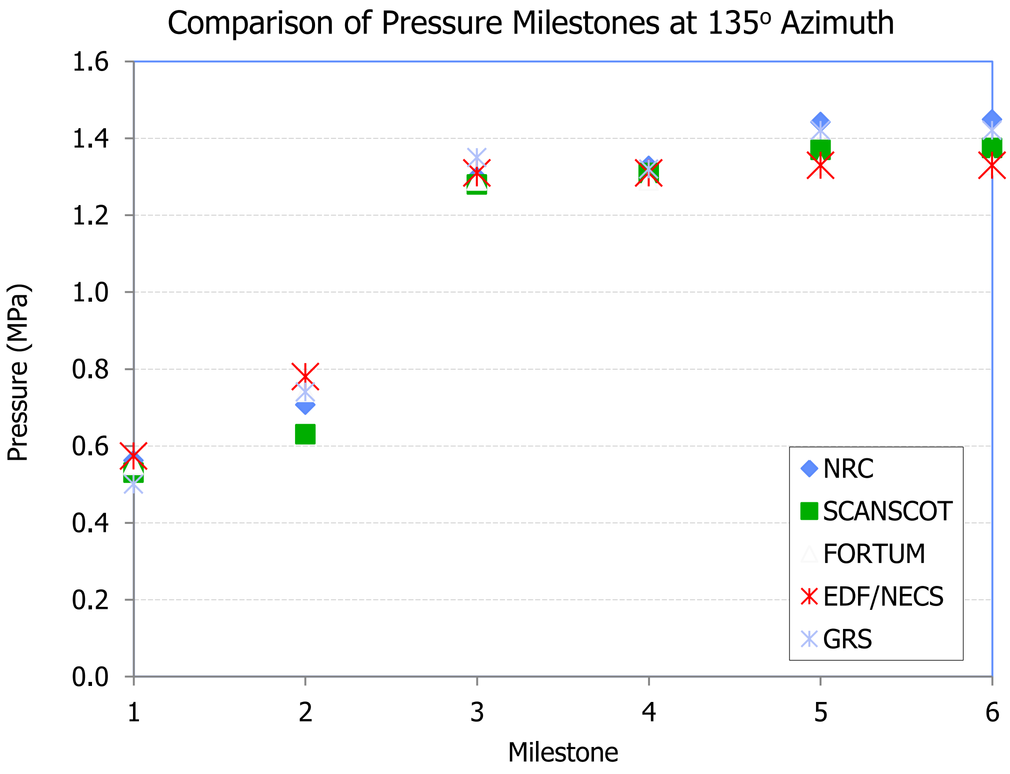
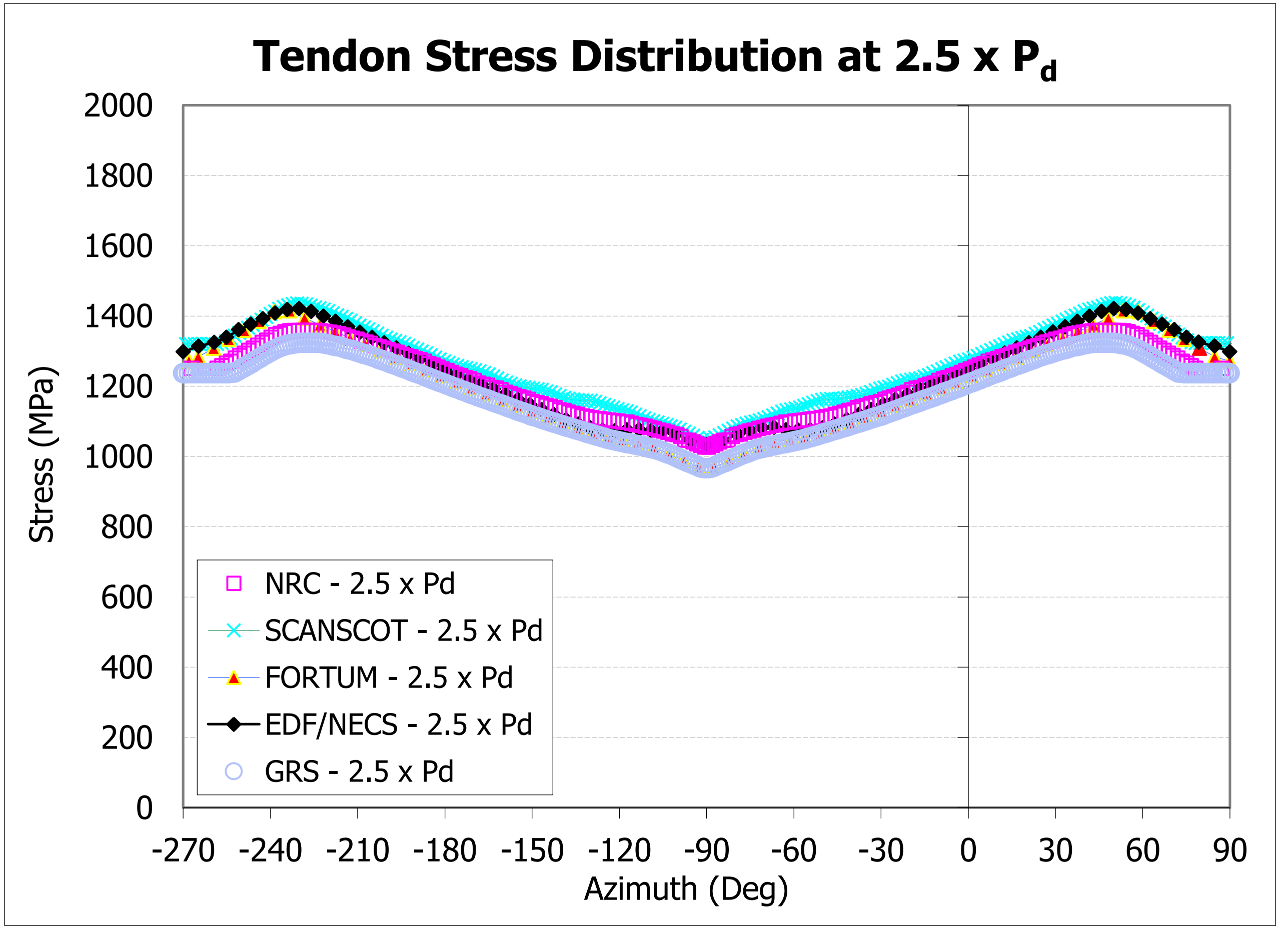
Model 1 Results

- **Milestones:**
  1. **Concrete Hoops Stress Equals 0**
  2. **Concrete Hoop Cracking Occurs**
  3. **Tendon A Reaches 1% Strain**
  4. **Tendon B Reaches 1% Strain**
  5. **Tendon A Reaches 2% Strain**
  6. **Tendon B Reaches 2% Strain**



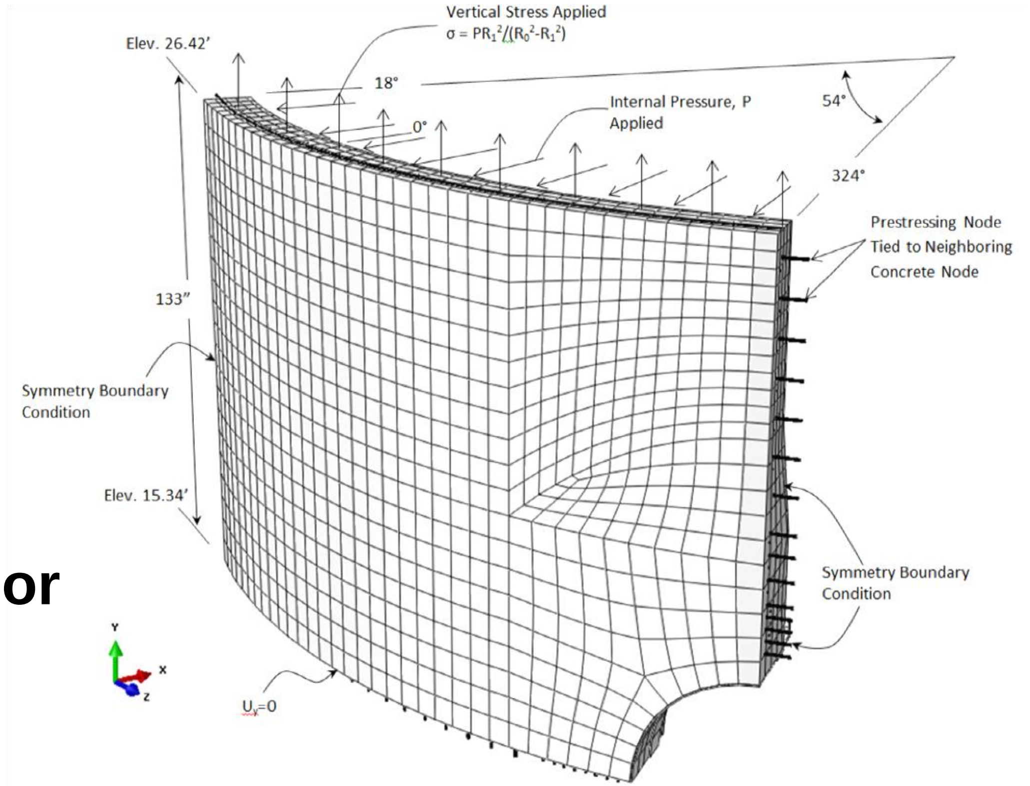
Model 1 Results

- **Example of Tendon Stress Distribution**



Model 2 Summary

- **Model 2: Equipment Hatch Model**
  - **Effects of Containment Dilation on Prestressing Force**
  - **Slippage of Prestressing Cables**
  - **Steel-Concrete Interface**
  - **Fracture Mechanics Behavior**
  - **Ovalization of Concrete vs Steel**
  - **Pressure Only Analysis**



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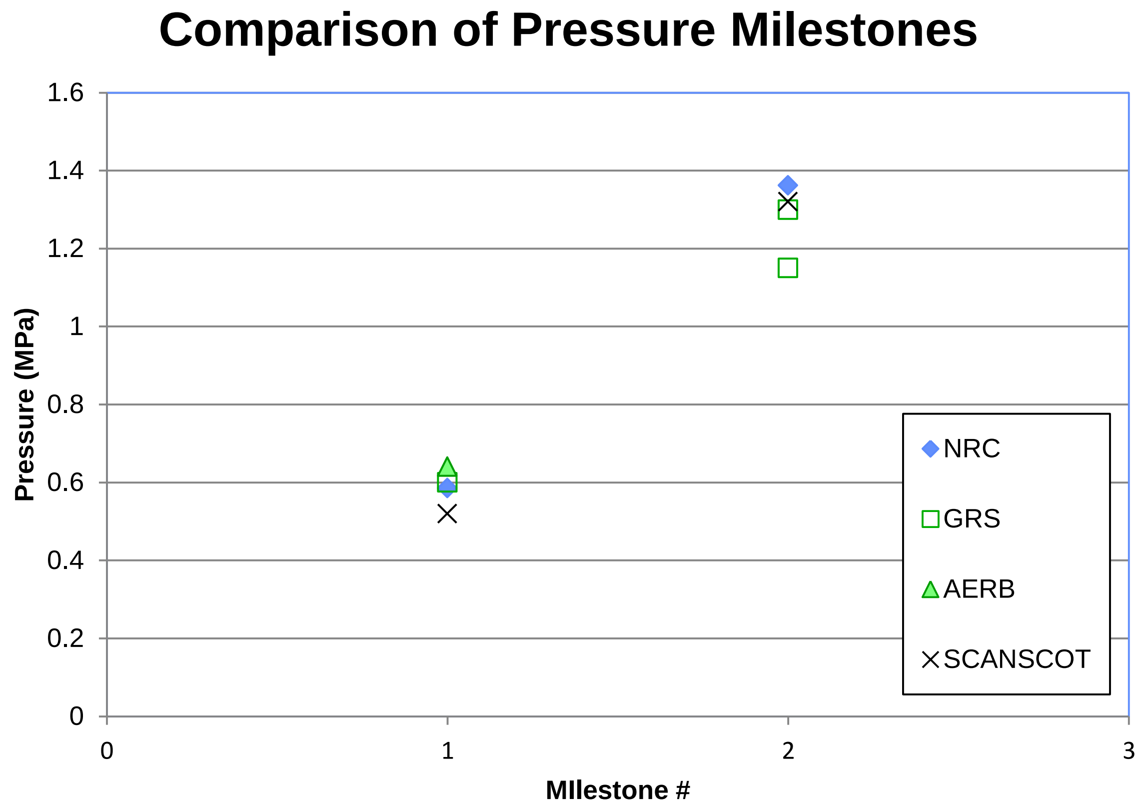
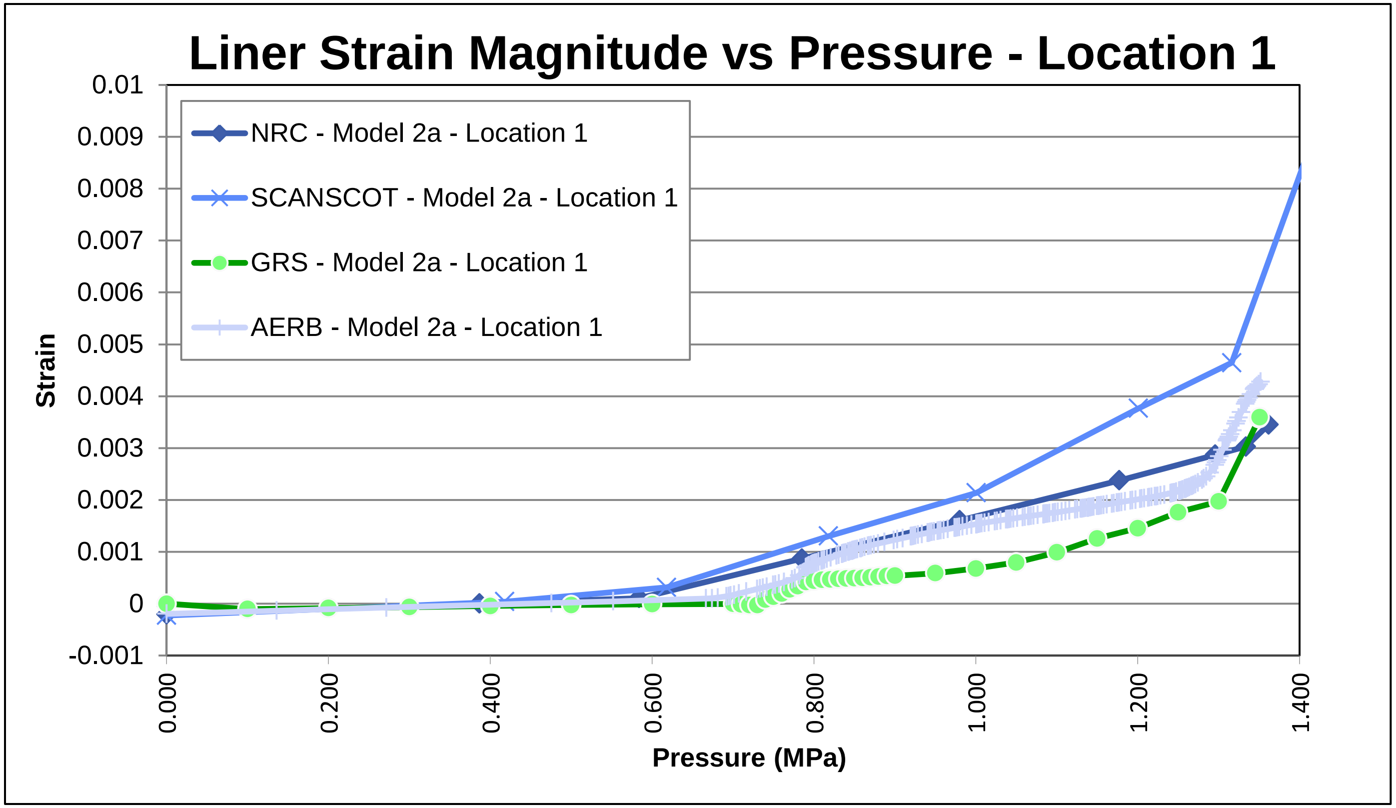
Model 2 Results

Pressure Milestones:

1. **Concrete Hoop Cracking Occurs**
2. **Tendon Reaches 1% Strain**

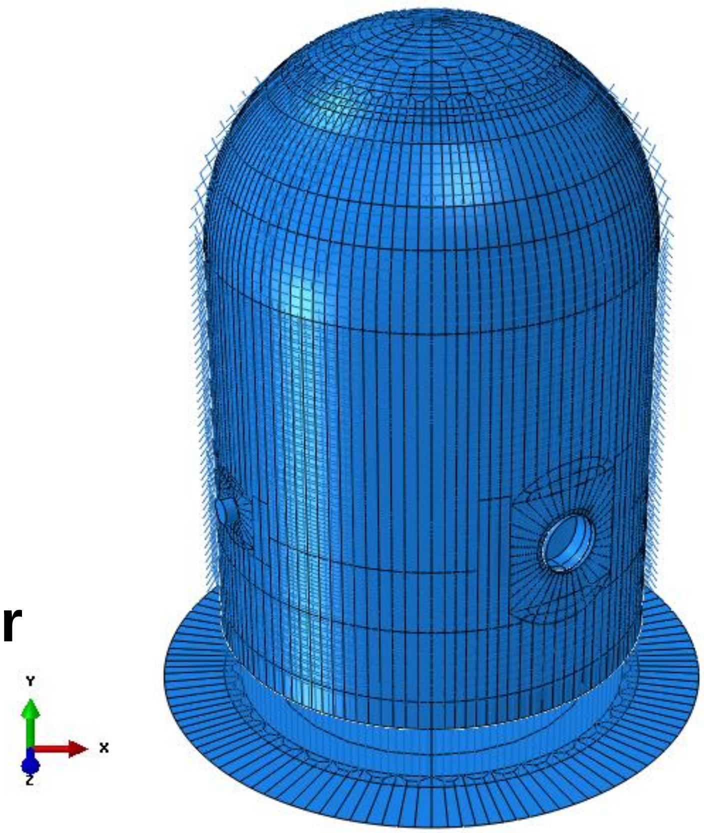


Model 2 Results

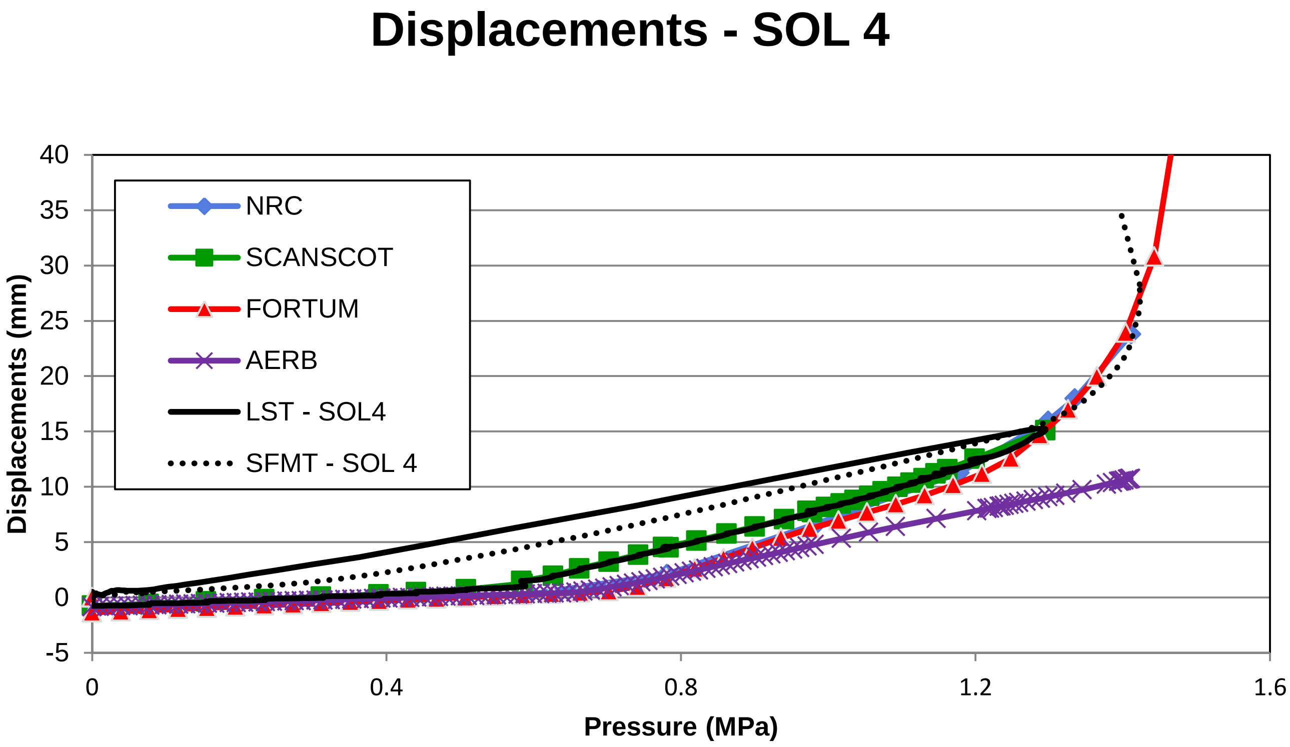


Model 3 Summary

- **Model 3: Detailed Global 3D Model**
  - **Effects of Containment Dilation on Prestressing Force**
  - **Slippage of Prestressing Cables**
  - **Steel-Concrete Interface**
  - **Fracture Mechanics Behavior**
  - **Ovalization of Concrete vs Steel**
  - **Pressure Only Anlaysis**



Model 3 Results



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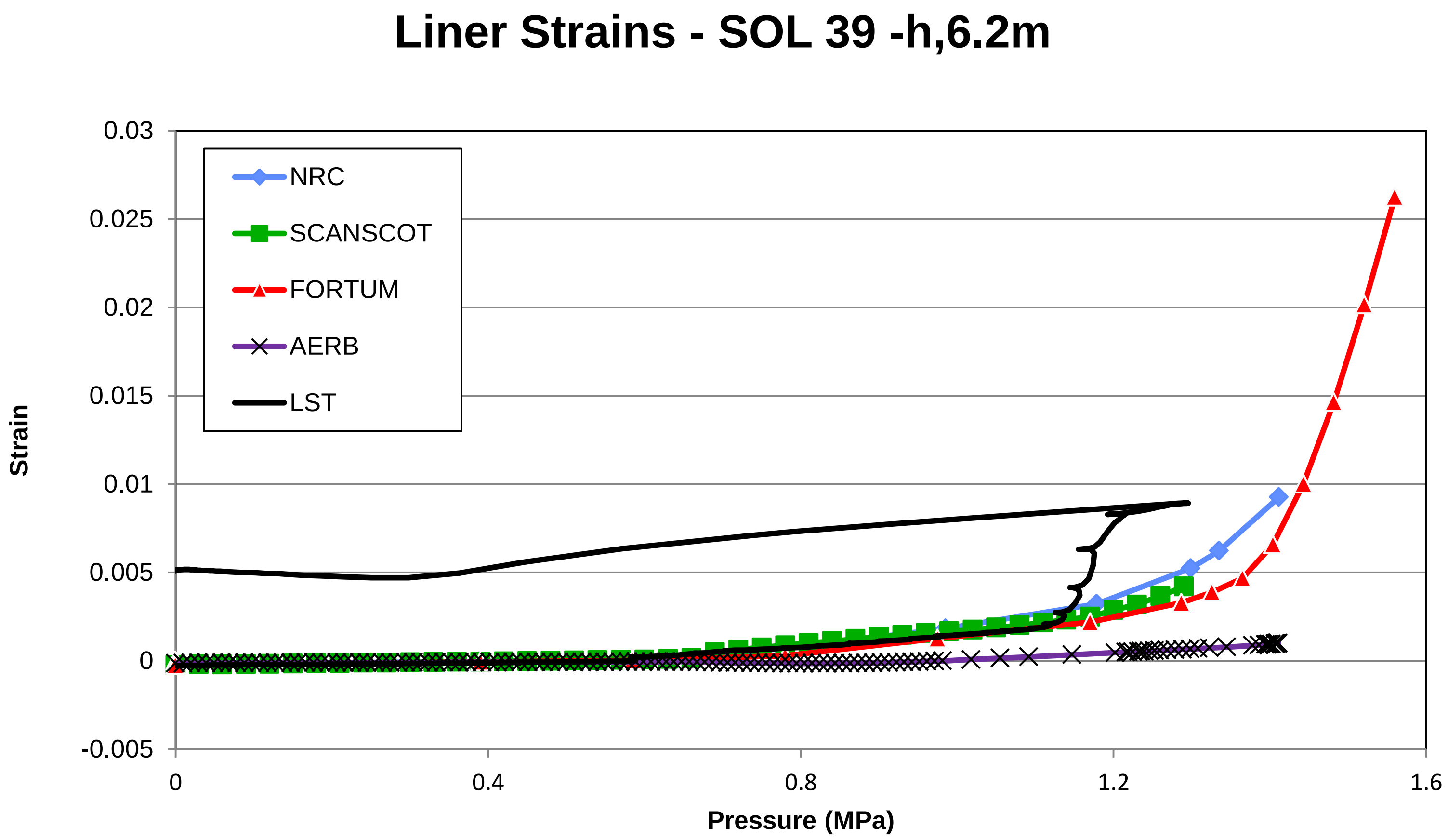
Model 3 Results



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Model 4 – Case 1 and 2

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Phase Two Overview

- Examine differences in behavior brought on by temperature
- Estimate Leak Rates as a Function of Pressure
- Estimate Leak Rates as a Function of Pressure and Temperature
- Transition to Probabilistic Space

Model 4 Overview

- **Use Model 3 as a Starting Point**
- **Modify Model 3 as Needed**
- **Apply Two New Load Cases To Model 4: Cases 1 and 2**

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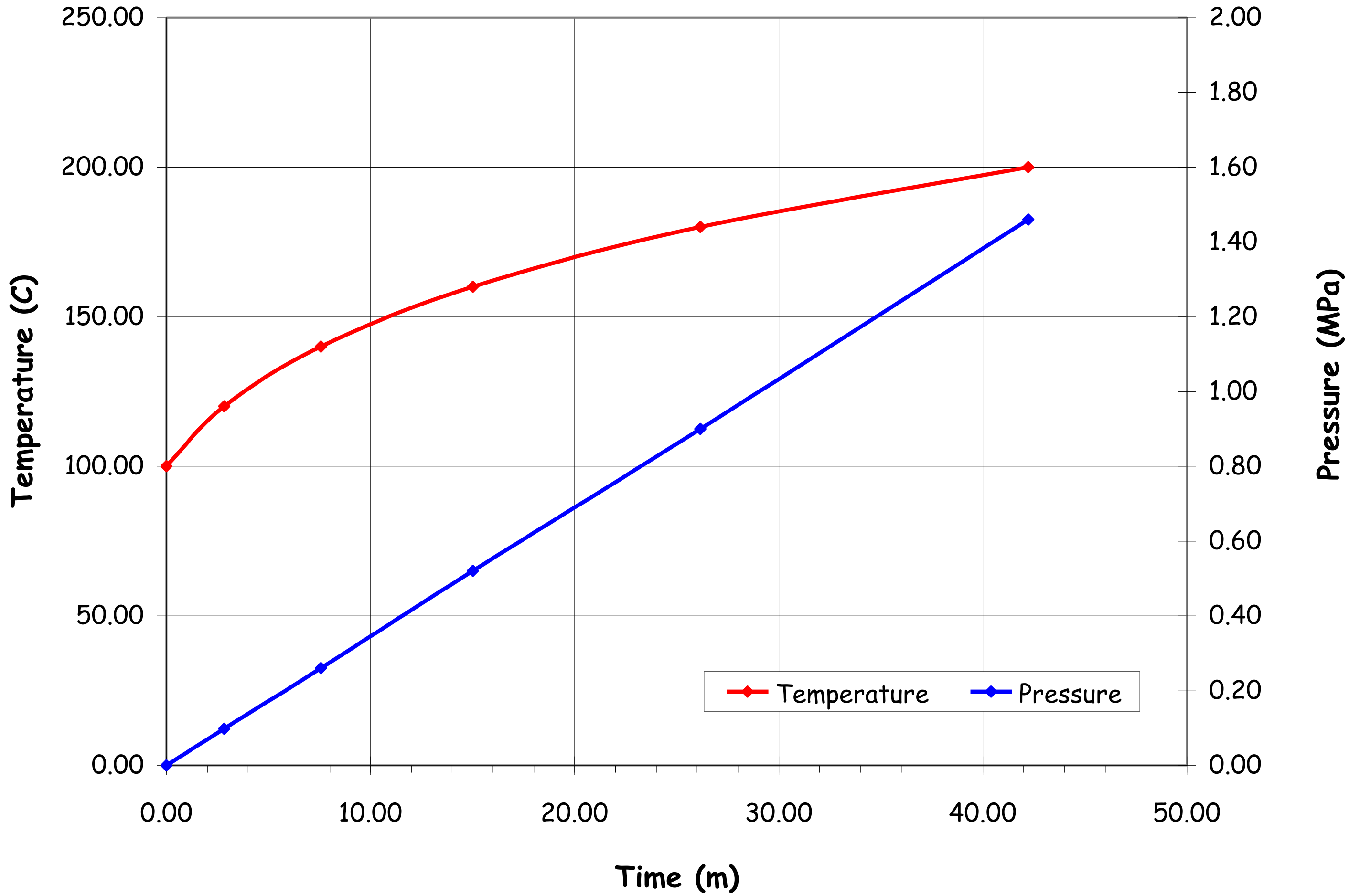
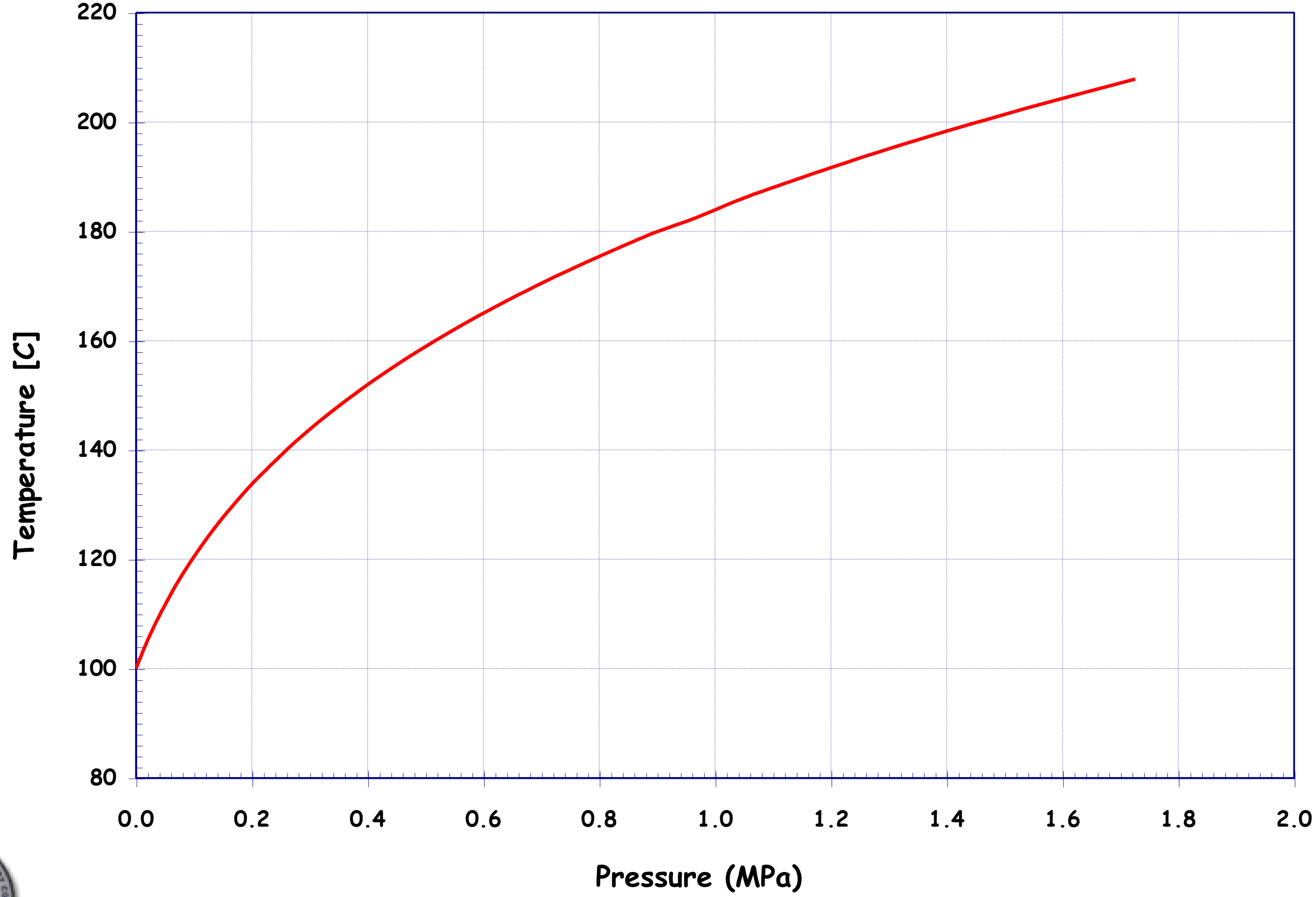
Case 1 – Saturated Steam



Case 1: Pressure-Temperature Relationship



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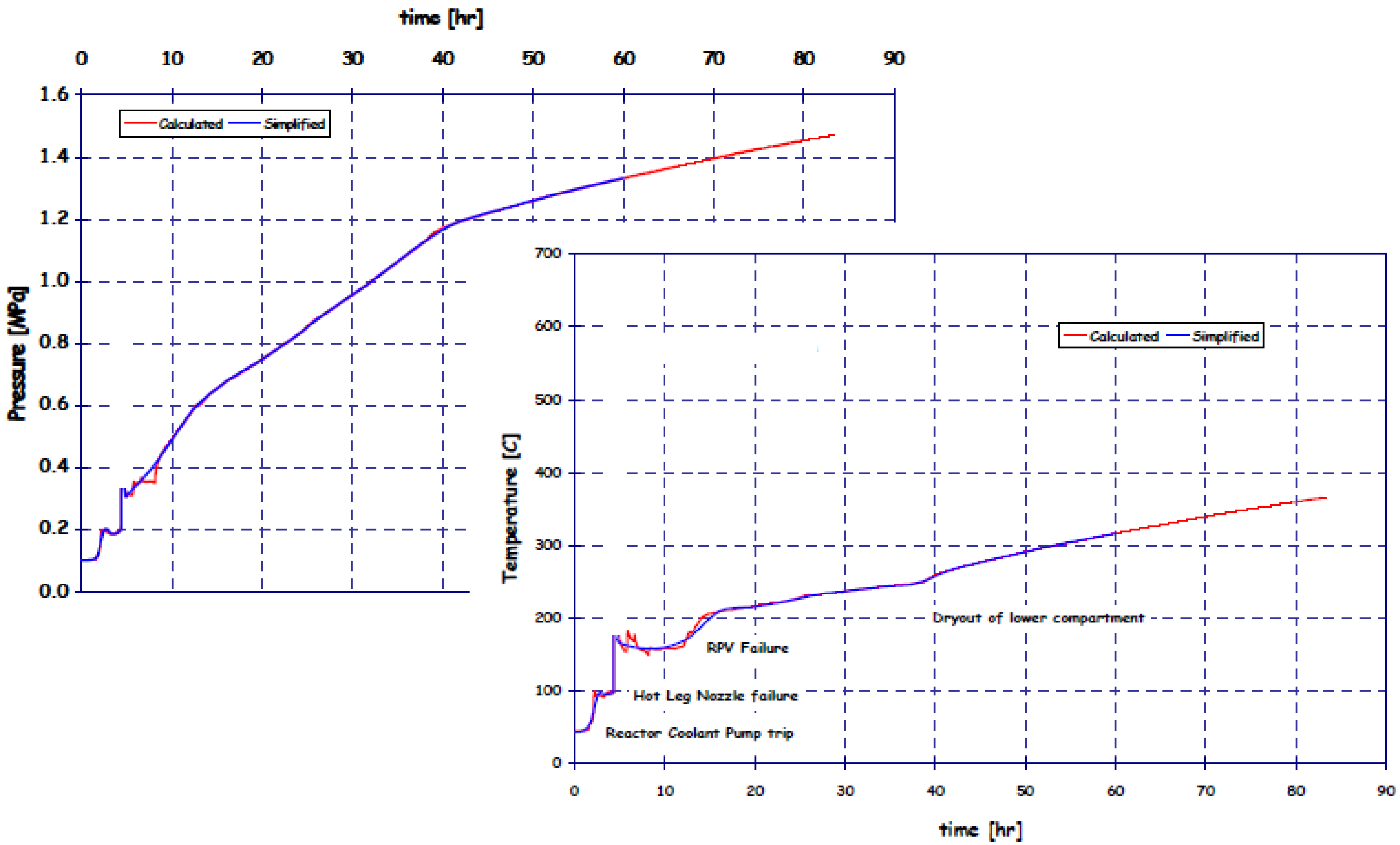
Case 2 – Station Blackout



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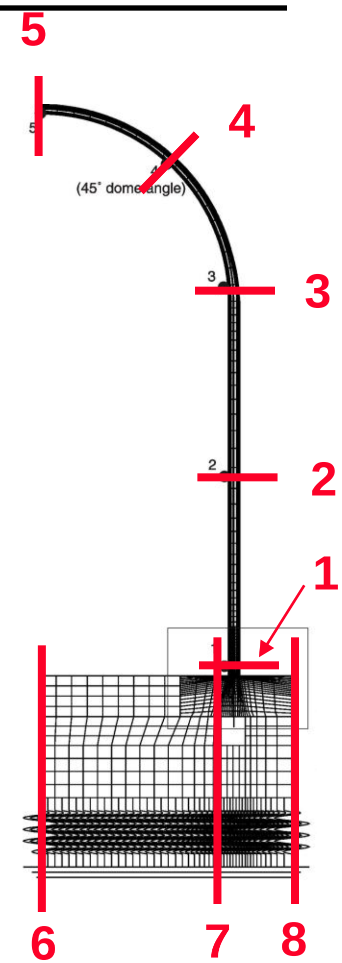
Thermal Analysis – Temp distr. From ISP48

- **Model: Full-scale Axisymmetric with additional nodes throughout cylinder and dome - 12 through-thickness**
- **Material Properties: based on typical data**
- **Thermal Gradient calculation locations:**
  - **See figure**
- **Boundary Conditions:**
  - **Liner: Uniformly applied temperature; quasi-static, but transient**
  - **Dome & Cylinder: convection to air**
  - **Basemat/soil: conduction**
- **Reference:**

Dameron, et. al., "Analysis of Axisymmetric Presstressed Concrete Containment Vessel (PCCV) Including Thermal Effects", May, 2004



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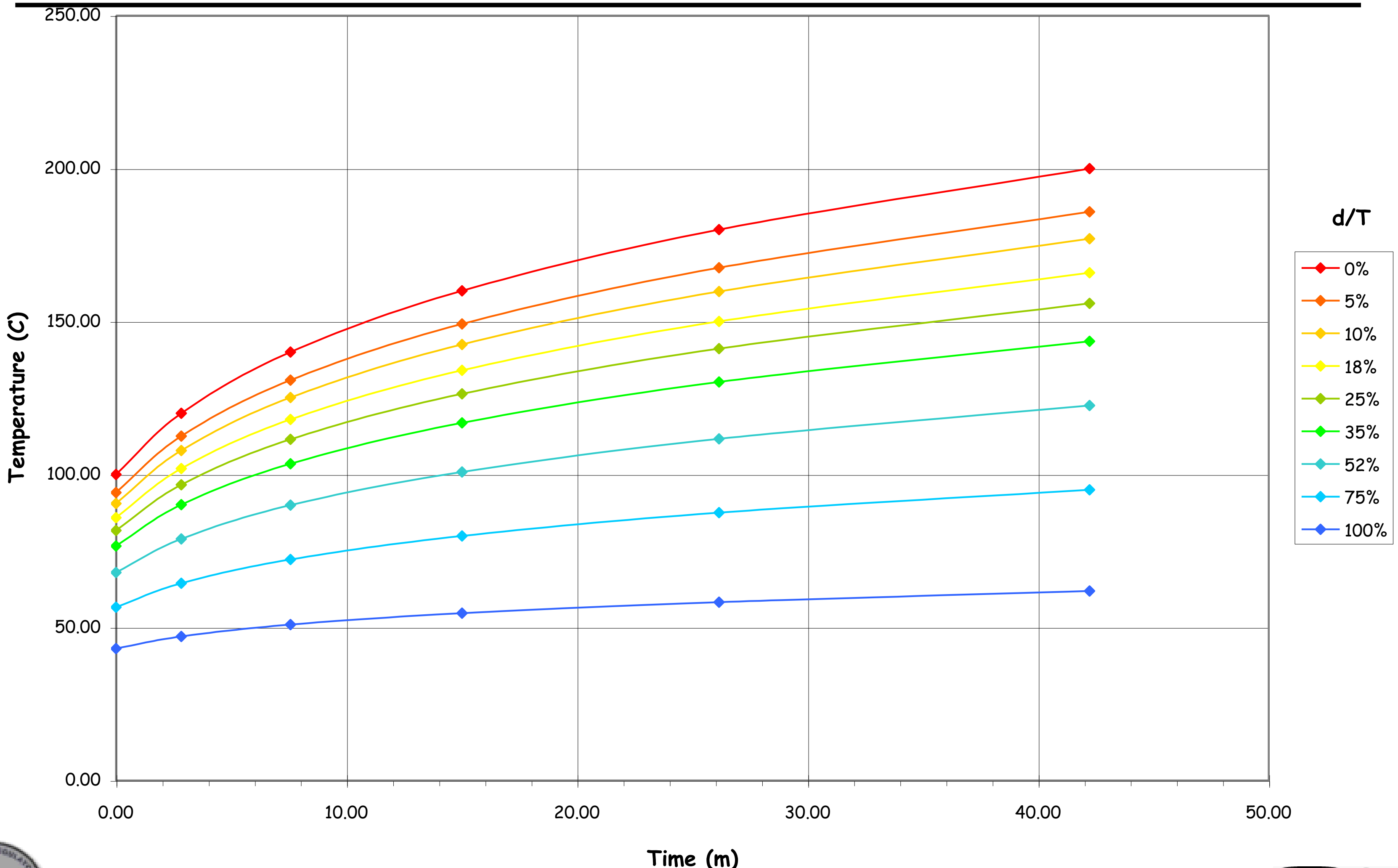
Case 1 Thermal Time Histories @ Section 2



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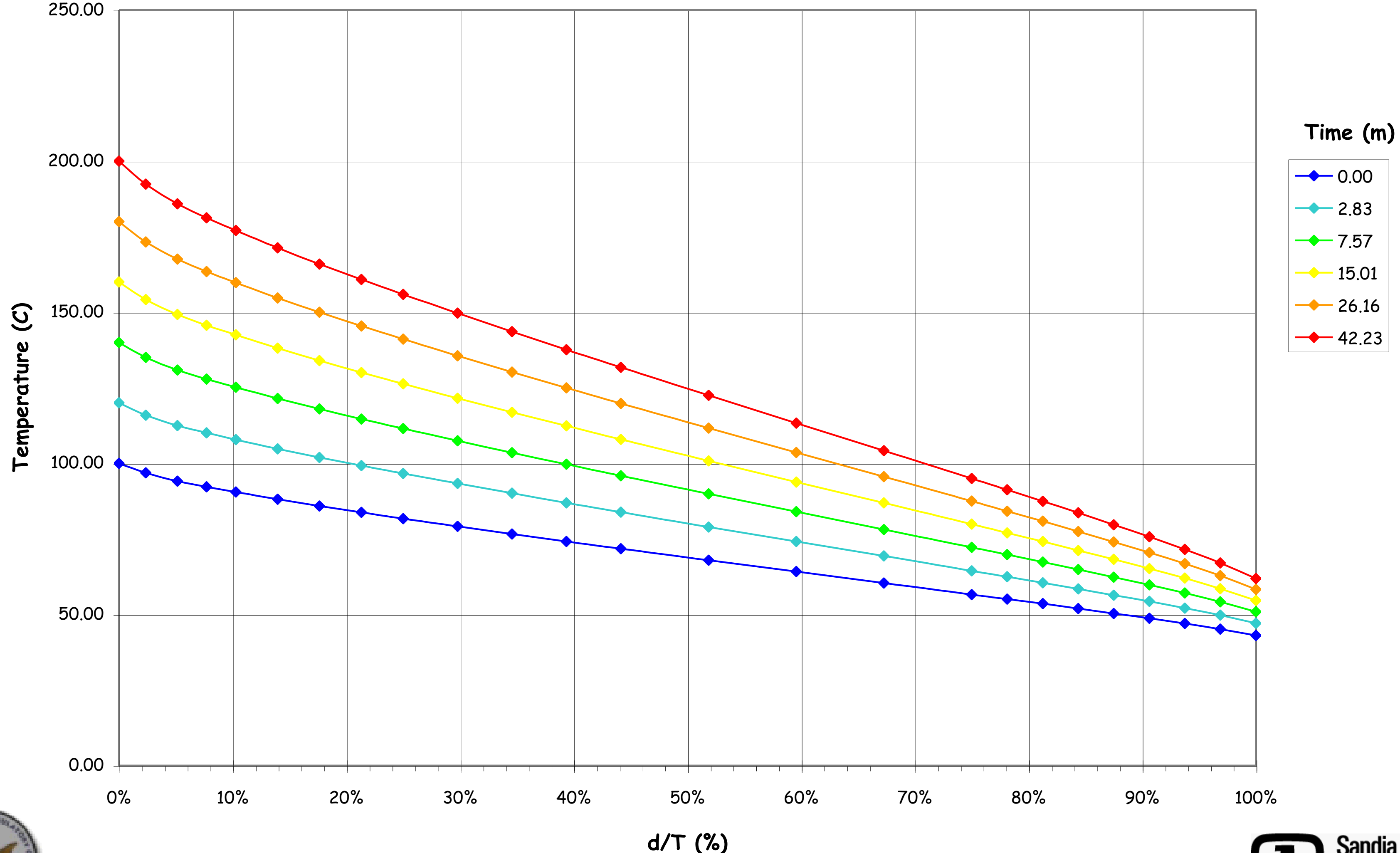
Case 1 Gradients @ Section 2



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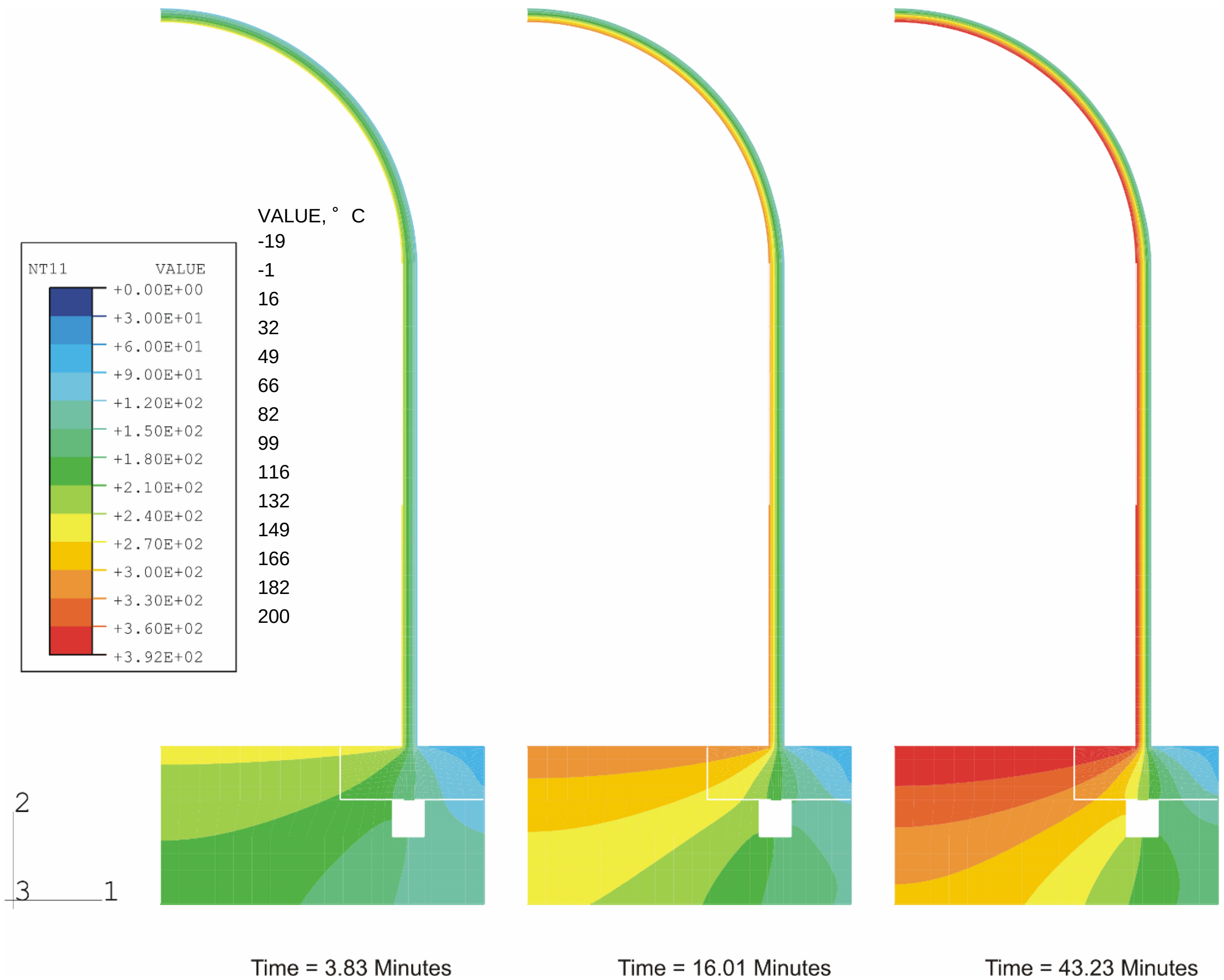
Case 1 Contours



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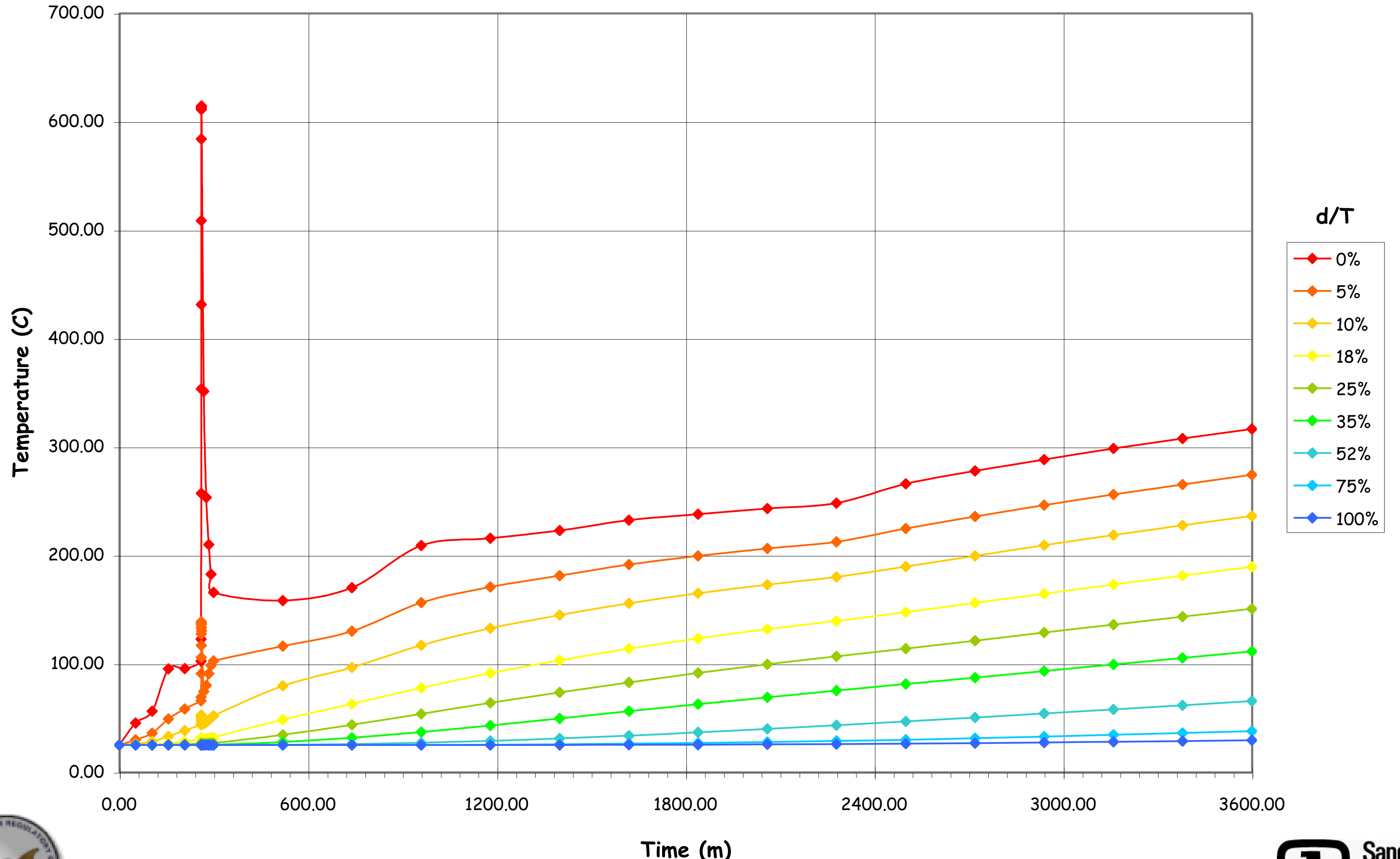
Case 2 Thermal Time Histories @ Section 2



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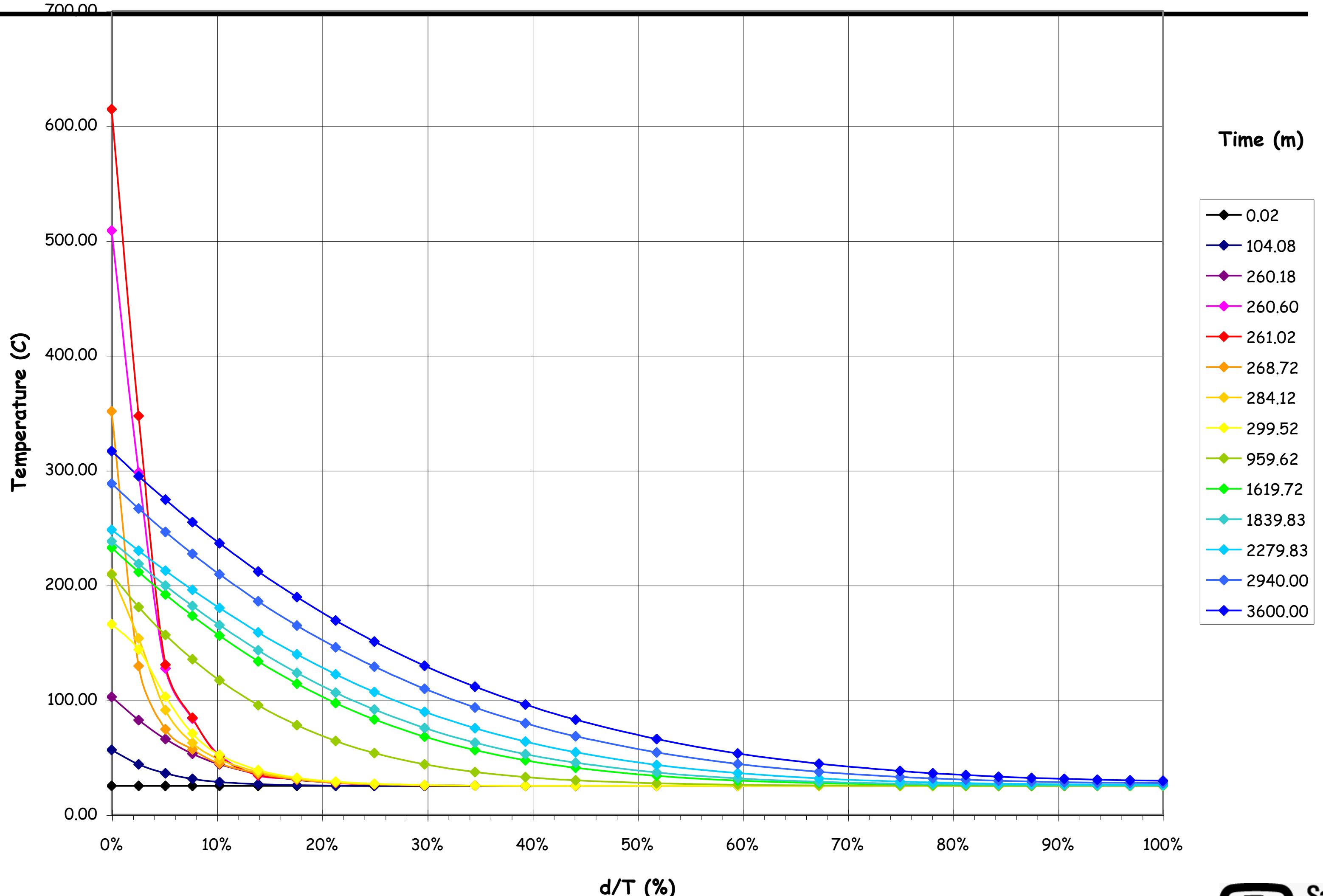
Case 2 Gradients @ Section 2



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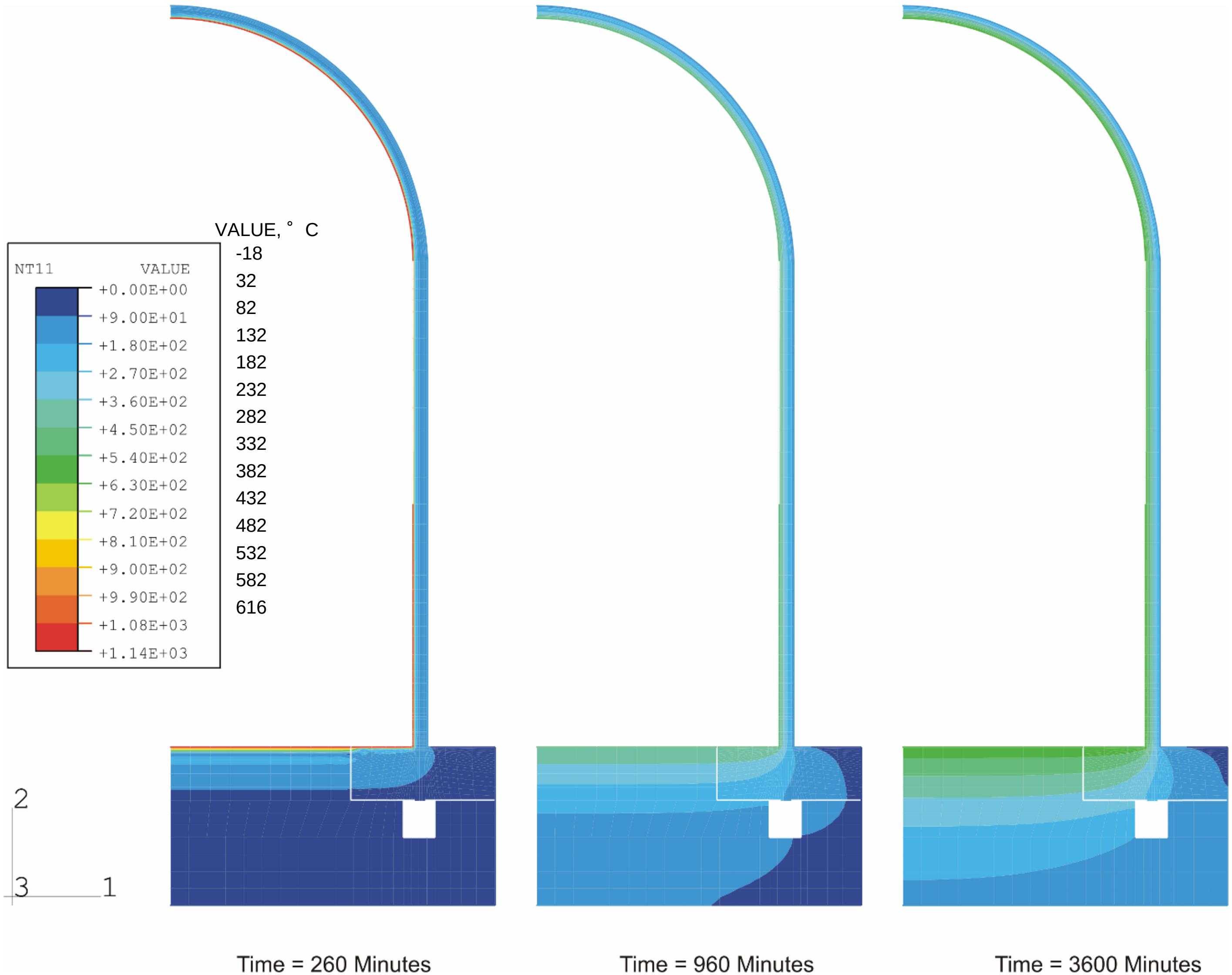
Case 2 Contours



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Concrete Degradation Properties at Elevated Temperatures per Eurocode

Concrete temp. θ	Siliceous aggregates			Calcareous aggregates		
	$f_{c,\theta} / f_{ck}$	$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$	$f_{c,\theta} / f_{ck}$	$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$
[°C]	[-]	[-]	[-]	[-]	[-]	[-]
1	2	3	4	5	6	7
20	1,00	0,0025	0,0200	1,00	0,0025	0,0200
100	1,00	0,0040	0,0225	1,00	0,0040	0,0225
200	0,95	0,0055	0,0250	0,97	0,0055	0,0250
300	0,85	0,0070	0,0275	0,91	0,0070	0,0275
400	0,75	0,0100	0,0300	0,85	0,0100	0,0300
500	0,60	0,0150	0,0325	0,74	0,0150	0,0325
600	0,45	0,0250	0,0350	0,60	0,0250	0,0350
700	0,30	0,0250	0,0375	0,43	0,0250	0,0375
800	0,15	0,0250	0,0400	0,27	0,0250	0,0400
900	0,08	0,0250	0,0425	0,15	0,0250	0,0425
1000	0,04	0,0250	0,0450	0,06	0,0250	0,0450
1100	0,01	0,0250	0,0475	0,02	0,0250	0,0475
1200	0,00	-	-	0,00	-	-

Steel Degradation Properties at Elevated Temperatures per Eurocode

Steel Temperature θ_a	Reduction factors at temperature θ_a relative to the value of f_y or E_a at 20°C		
	Reduction factor (relative to f_y) for effective yield strength $k_{y,\theta} = f_{y,\theta}/f_y$	Reduction factor (relative to f_y) for proportional limit $k_{p,\theta} = f_{p,\theta}/f_y$	Reduction factor (relative to E_a) for the slope of the linear elastic range $k_{E,\theta} = E_{a,\theta}/E_a$
20°C	1,000	1,000	1,000
100°C	1,000	1,000	1,000
200°C	1,000	0,807	0,900
300°C	1,000	0,613	0,800
400°C	1,000	0,420	0,700
500°C	0,780	0,360	0,600
600°C	0,470	0,180	0,310
700°C	0,230	0,075	0,130
800°C	0,110	0,050	0,090
900°C	0,060	0,0375	0,0675
1000°C	0,040	0,0250	0,0450
1100°C	0,020	0,0125	0,0225
1200°C	0,000	0,0000	0,0000

NOTE: For intermediate values of the steel temperature, linear interpolation may be used.

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Analysis Results

<u>Required Output/Results for Model 4:</u>

1. **Description of Failure Prediction Model or Criteria Selected**
2. **Assumptions Made In Geometric Modeling / Model Description**
3. **Subset of response information defined by “55 standard output locations” of 1:4 Scale PCCV round-robin;**
4. **Contour Plot of Peak Strains in Liner During LST at pressure milestones: P = 0 (prestress applied); 1 x P_d; 1.5 P_d; 2 P_d; 2.5 P_d; 3 P_d; 3.3 P_d; 3.4 P_d; Ultimate Pressure**

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For direct comparison amongst participants, also requested to plot (Using Excel)

- Liner Strain Magnitudes (Hoop Direction) at Locations Indicated in Figure 11 (of SPE problem statement), versus pressure
- Tendon stress distribution at P = 0 (prestress applied); 1 x P_d; 1.5 P_d; 2 P_d; 2.5 P_d; 3 P_d; 3.3 P_d; 3.4 P_d; Ultimate Pressure for
  - Hoop Tendons # H35, H53, H68
  - Vertical Tendon # V37 and V46
  - Plots of response versus pressure for Standard Output Locations:
- 1-15 (displacements)
- 22-29 (rebar strains)
- 36-42 (liner strains)
- 48-55 (tendon strains and stresses)

(see Table 4-1 in NUREG/CR-6809 for locations of SOL's)

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Leak Rate Problem Definition

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Failure Criteria for PCCV

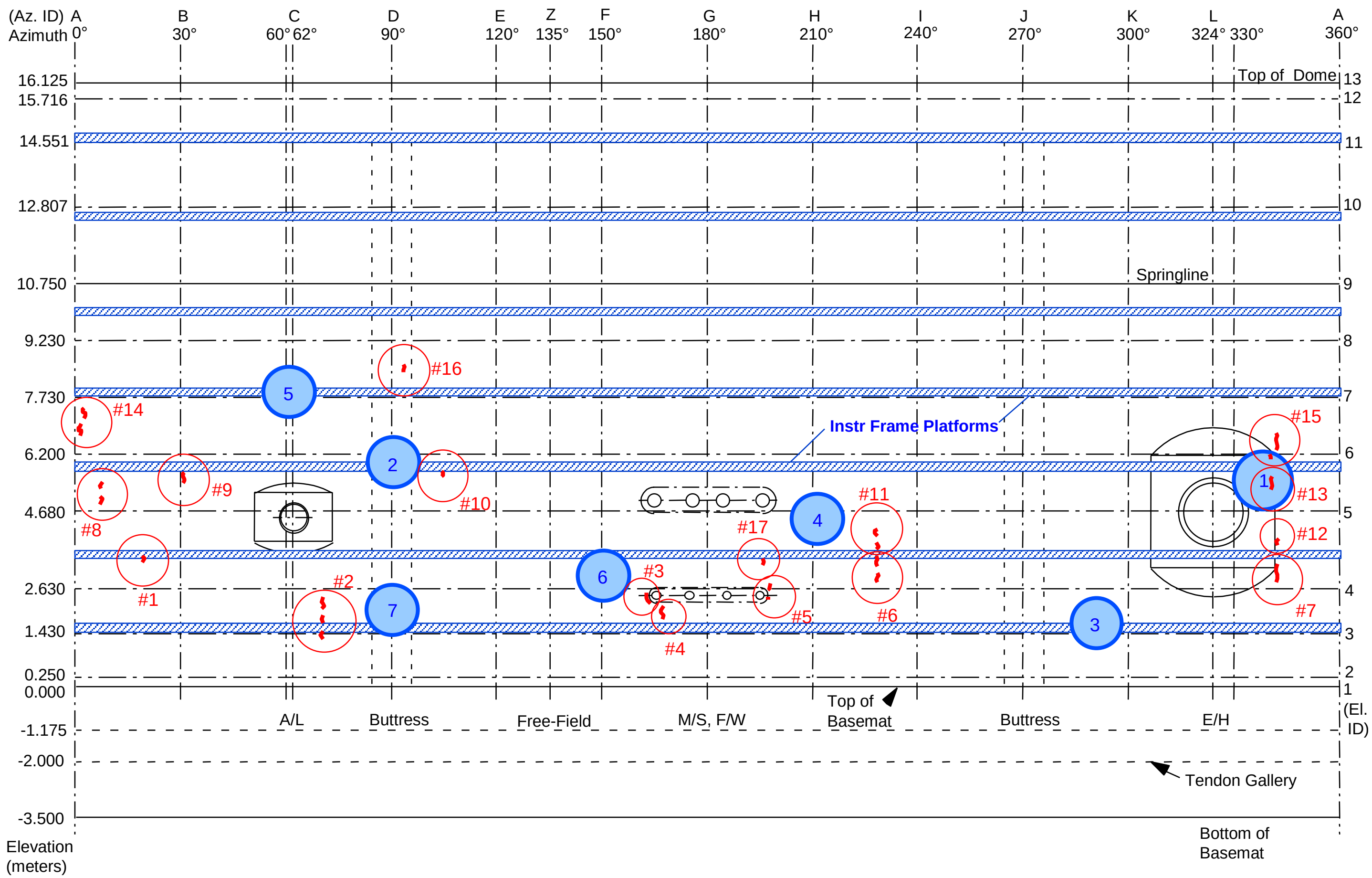
- From SPE Phase 1, the relevant failure criterion for Model 1 was Tendon failure. The rebar generally has higher ductility than the tendons, so it is not the controlling criteria. For Models 2, 3, and 4, Tendon Failure criteria remains at 3.8% strain as for Model 1. But for Models 3 and 4, liner tearing is the predominate failure mode
- For SPE Phase 2, a key objective of the work is to estimate crack size and leak area
- Based on the existing research of behavior of steel-lined concrete containments, liner-tearing with associated leakage is the failure mode for slow pressurization of the containment

Calculate Leak Rate

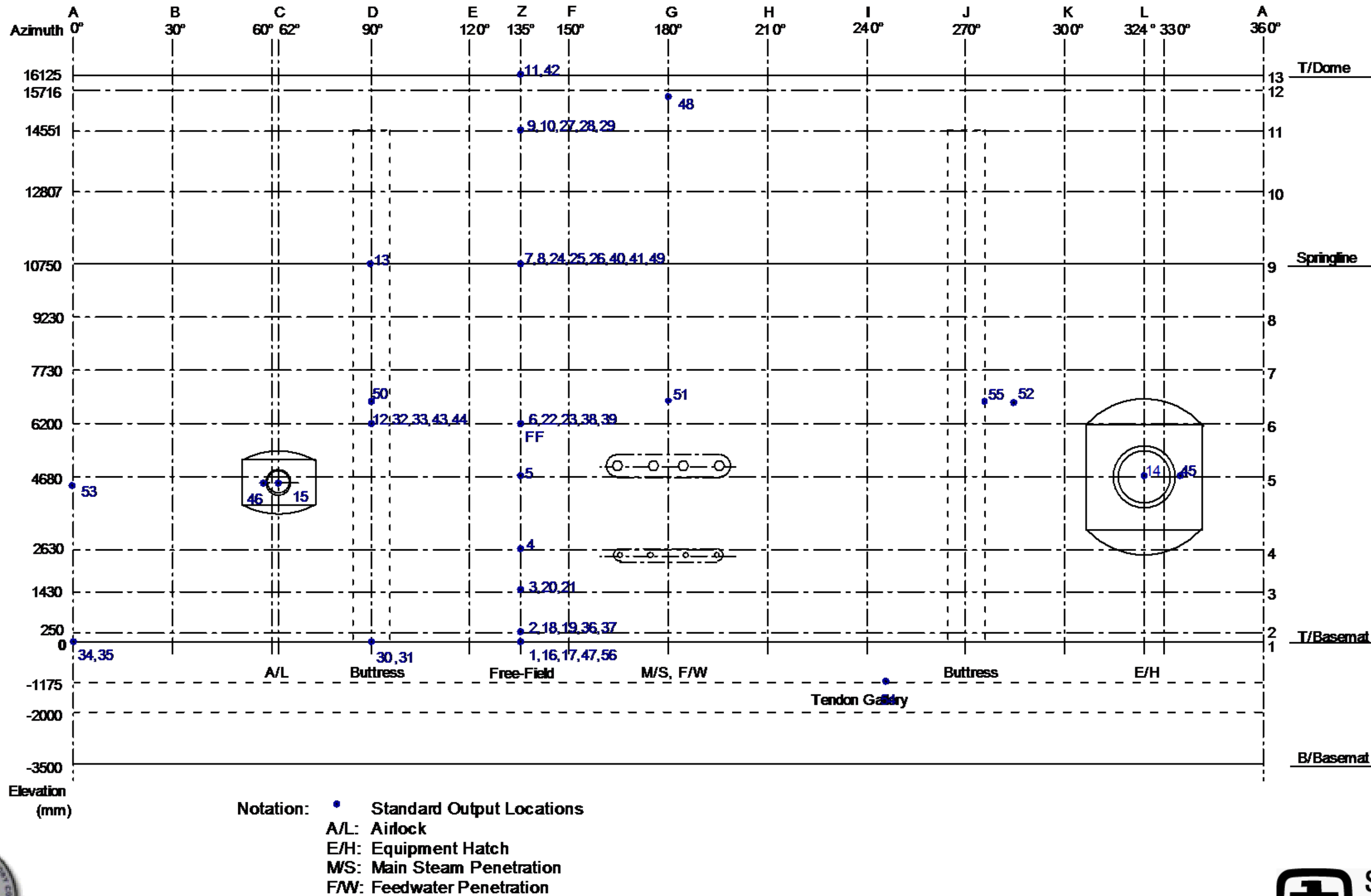
- **Participants are asked to develop a prediction of leak rate as a function of pressure.**
  - **Liner Strains**
  - **Crack Size**
  - **Leak Rate**
- **Participants shall use the functions provided by AERB to calculate leak rate based on crack area if they so desire**

Liner Tears and Acoustic Events

Acoustic Events:
1: 2.4 Pd
2: 2.6 Pd
3: 2.7Pd
4: 2.8 Pd
5: 2.8 Pd
6: 2.8 Pd
7: 3.0 Pd



Liner Strain Map (see results presentation)



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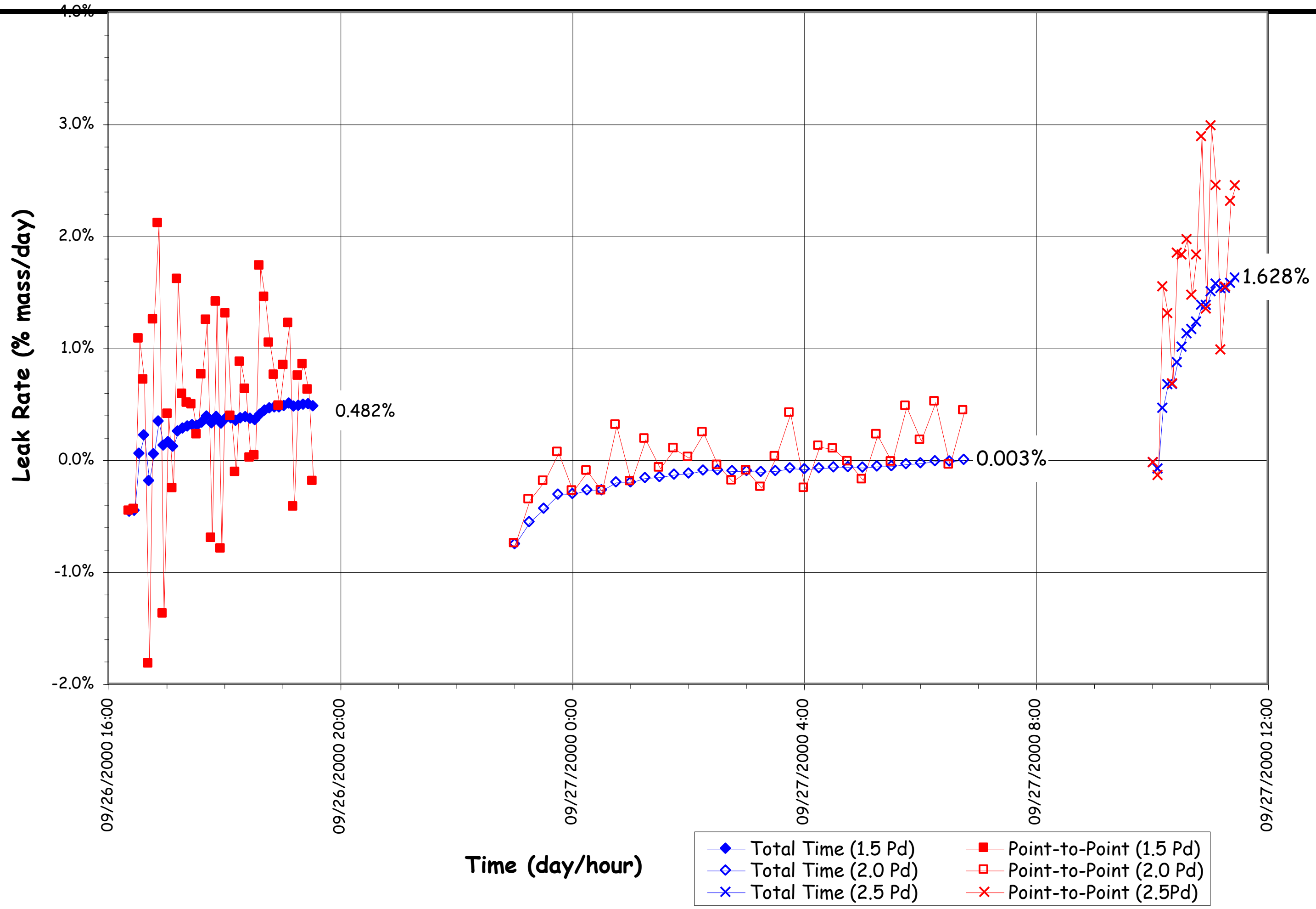
PCCV LST - Calculated Leak Rate



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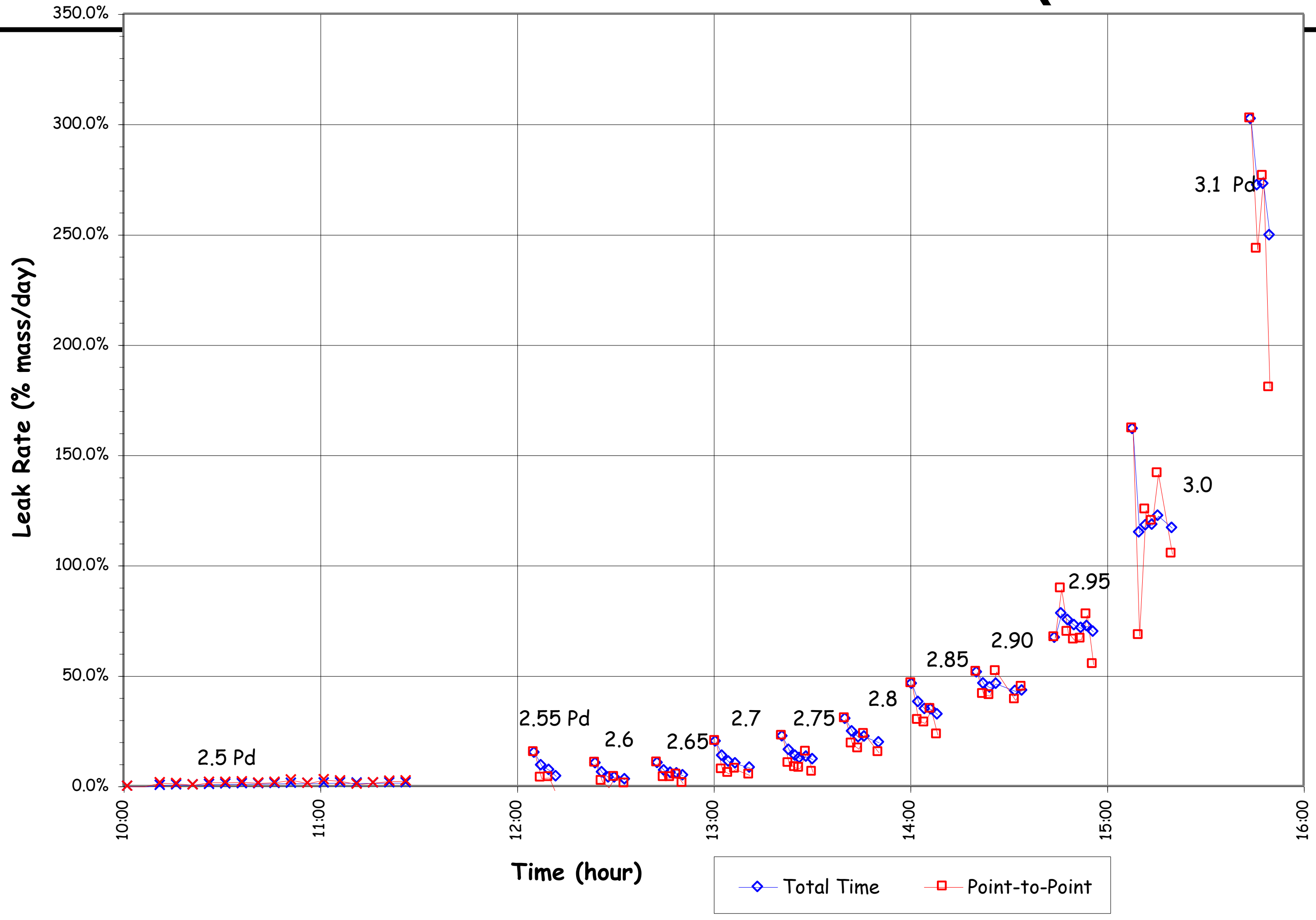
PCCV LST - Estimated Leak Rates (2.5-3.1 Pd)



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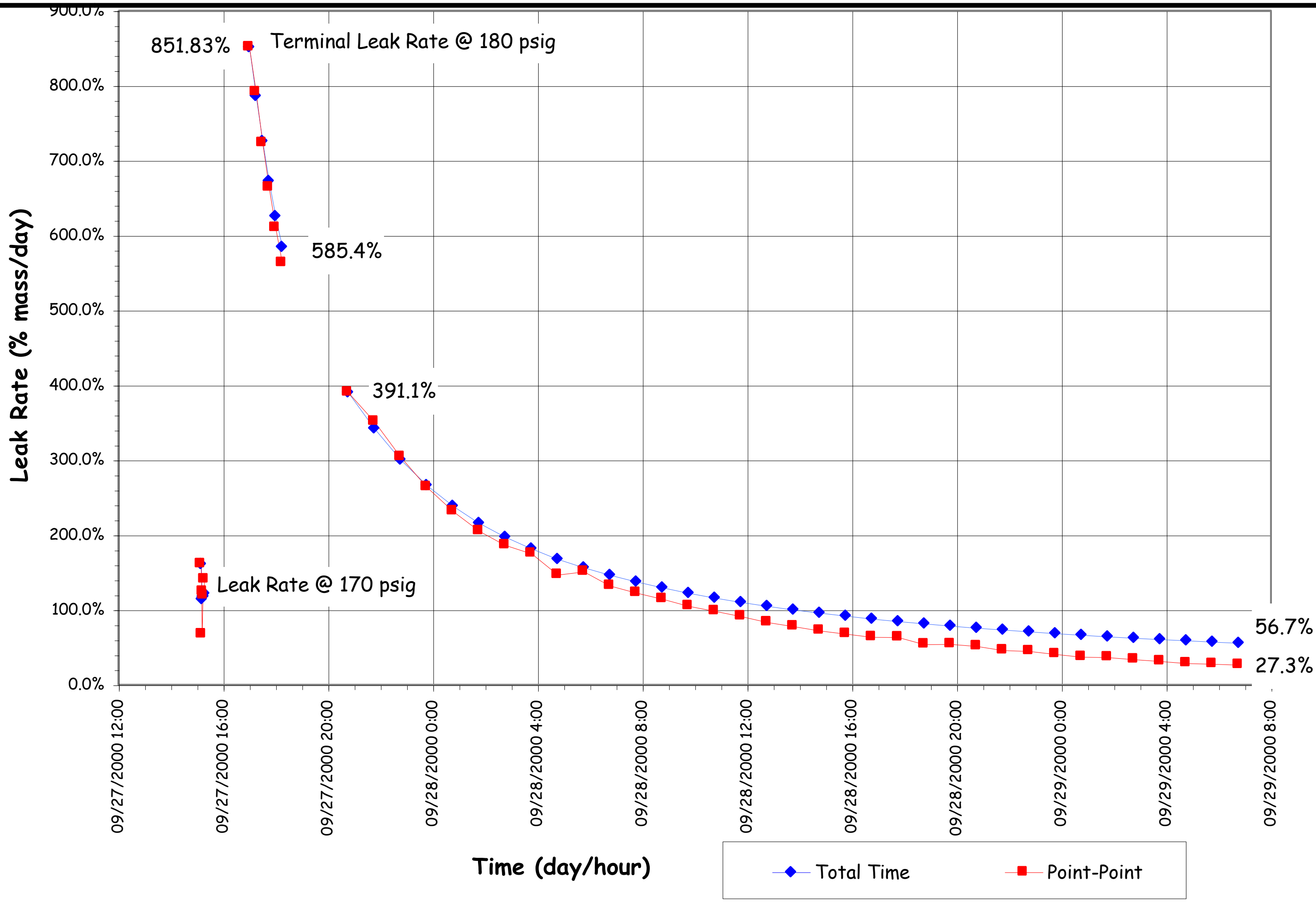
PCCV LST - Calculated Leak Rate



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Leak Rate as a Function of Crack Size

- See Presentation by AERB

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Transition to Probabilistic Space
Problem Definition

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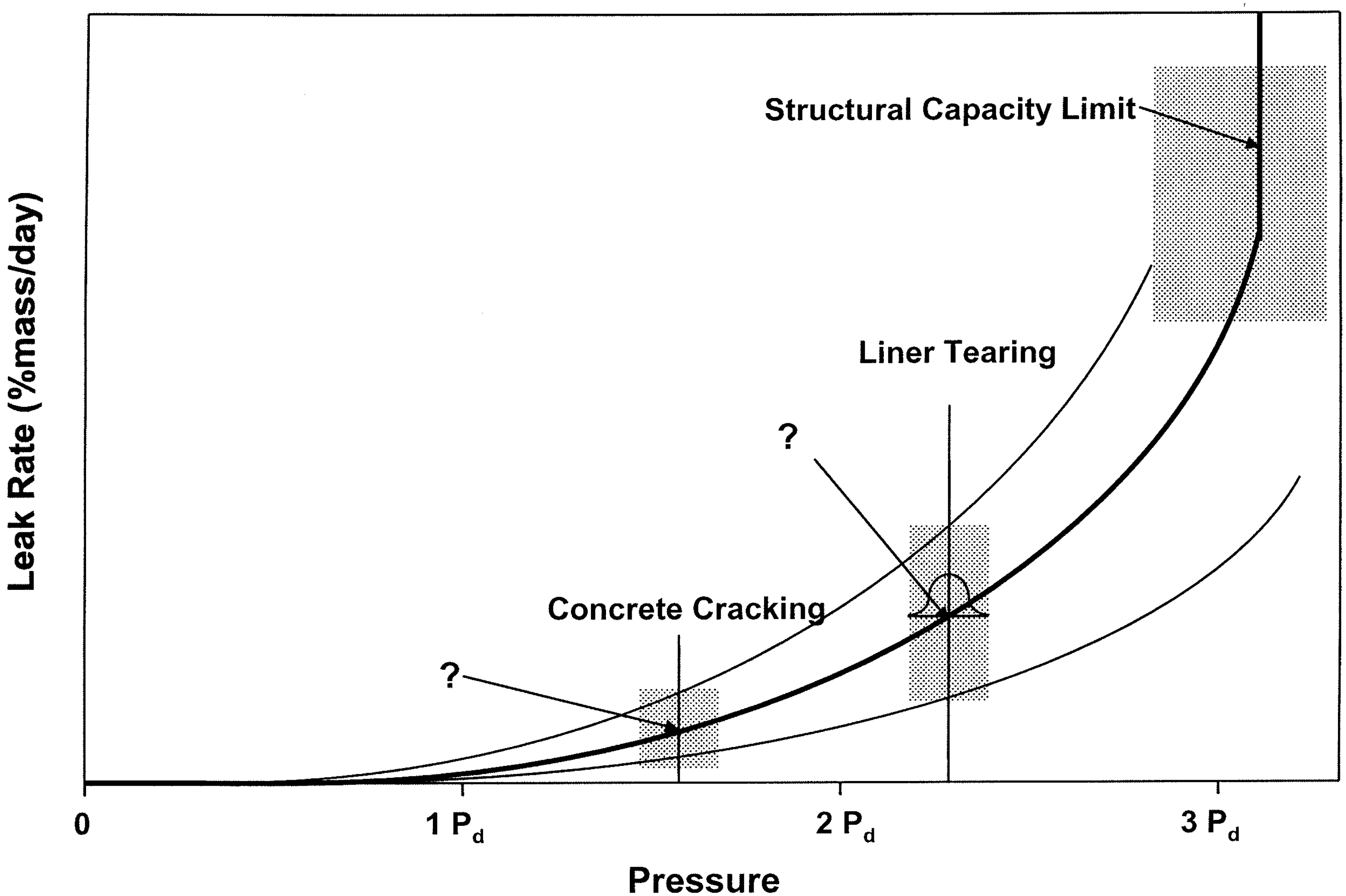
Probabilistic Space



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Projects of Interest

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Projects of Interest

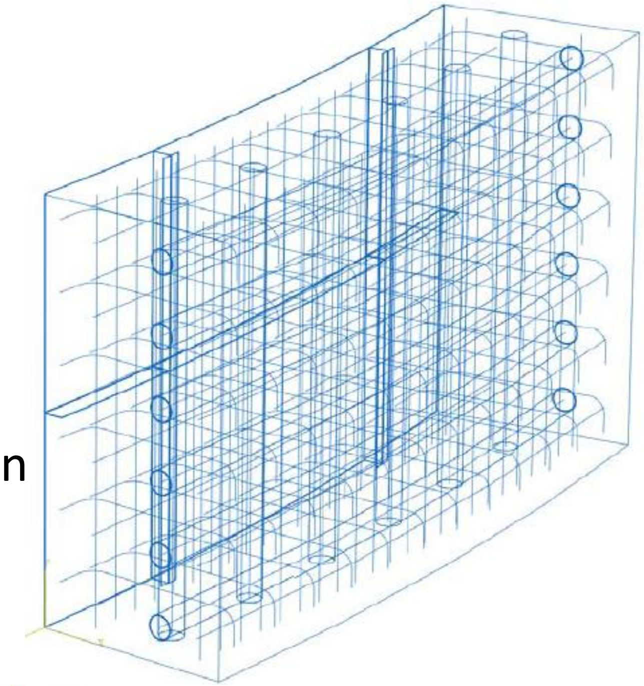
NRC / SNL Projects:

Degraded containment research

- Detailed submodeling
  - Global boundary conditions
  - Refined mesh
  - Additional detail
  - XFEM
- Plant specific investigation
  - Forensic analysis
  - Computational reconstruction

Grouted Tendon Study

- Behavior
- Monitoring
- Corrosion



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Projects of Interest

- **Insert Slides from NRC here**

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Future Work

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Future Work

- NUREG Publication of Phase One and Phase Two Reports
- Follow Up Workshop?
- Additional Publications?

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