Introduction of Possible Topics for the SPE #3

Herman Graves – U.S. Nuclear Regulator Commission
Robert Dameron – David Evans & Associates
Lili Akin – Sandia National Laboratory

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Objective

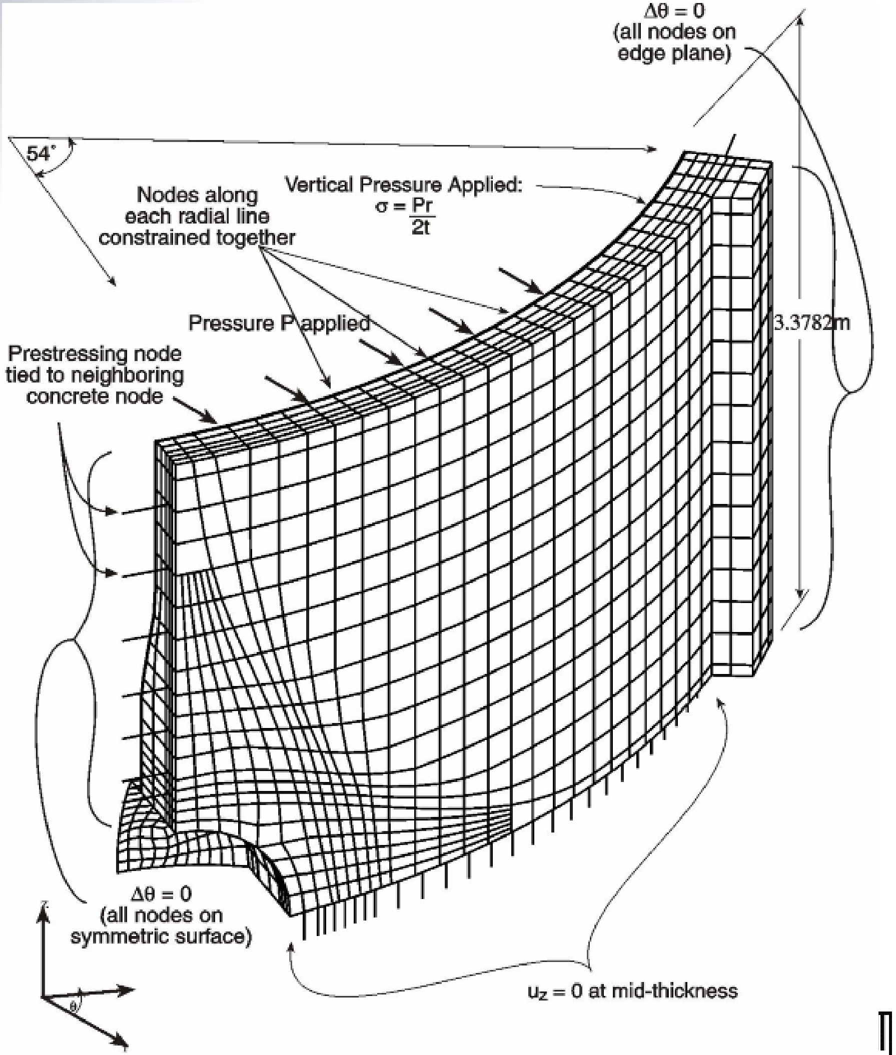
- **Primary Objective of Workshops:**
  - **Enhance Knowledge in the Characterization of Prestressed Concrete Containment Vessels (PCCVs)**
  - **Assess the Current Practices and State of the Art with Respect to the Calculation of Response to Severe Accident Conditions**
  - **Improve Knowledge In:**
    - **Local Containment Behavior Under Beyond Design Basis Pressures**
    - **Characterization of Leakage Behavior as a Function of Pressure and Temperature**
    - **Probabilistic Aspects of Containment Response**

SPE and Related Analysis Work

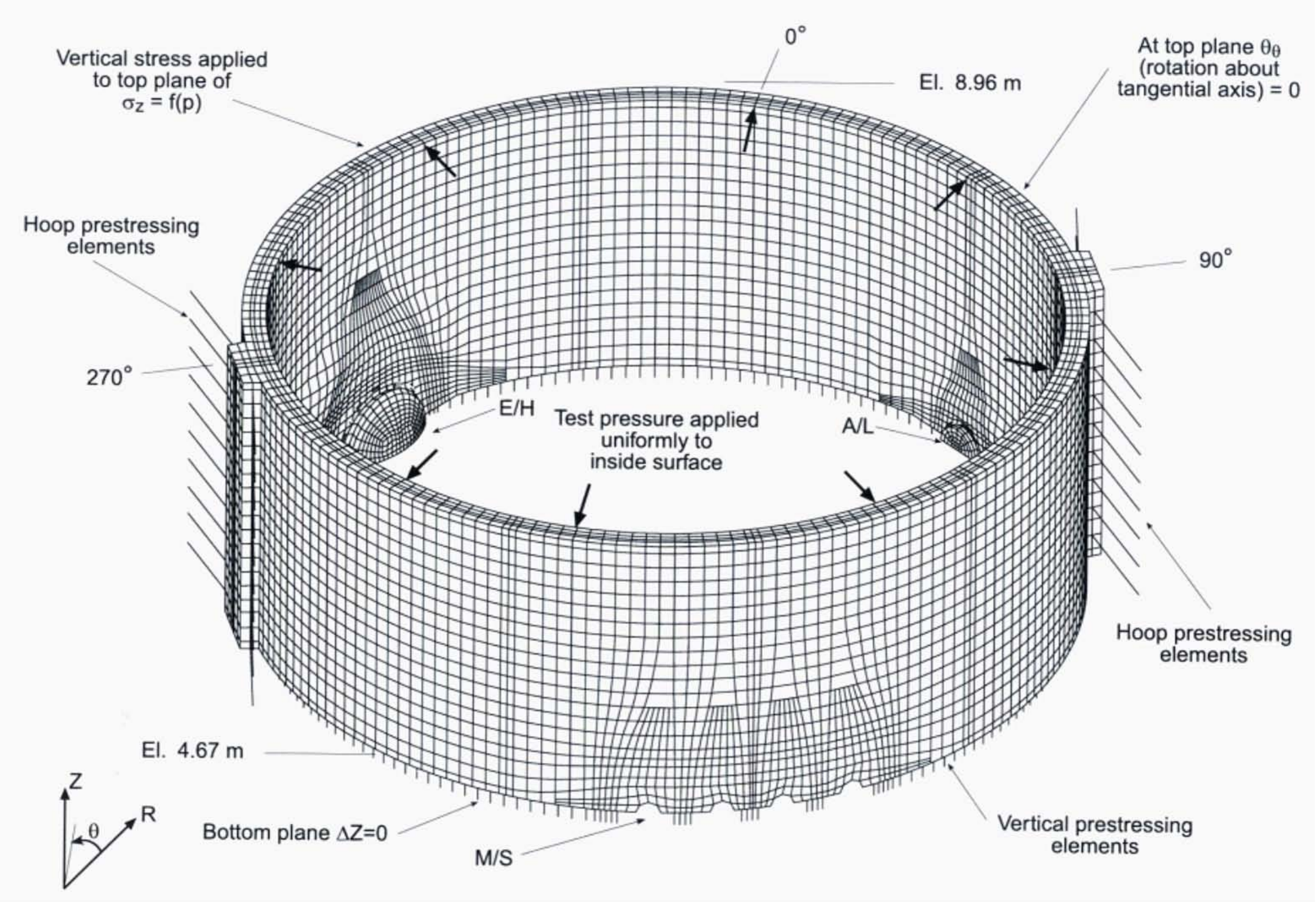
- **An additional goal of this work can be to improve industry consensus on**
  - **means and methods for analyses**
  - **selection of FE model types, and modeling extent**
  - **applicable loads and problem definitions**

- **For example,**
  - **Some scopes and details of FE models….**
  - **Definitions of pressure plus thermal histories….**

Choice of Models / Examples



Choice of models / Examples



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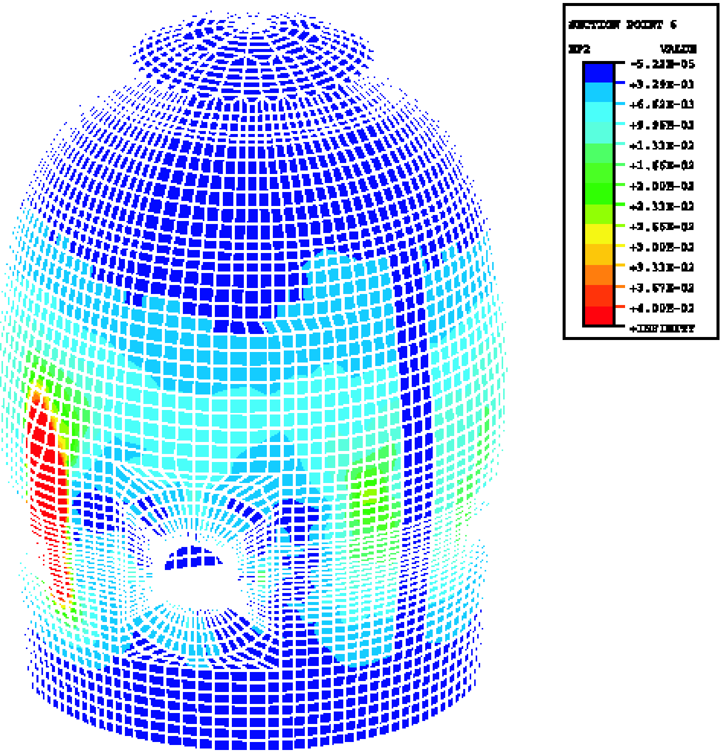
SPE #3 Outline

- Stage 1 of Round Robin Analysis
  - Behavior of Tendon Forces as a Function of Containment Dilation
  - Friction Models Used to Represent Slippage of Prestressing Cables
  - Steel-Concrete Interaction Surrounding Penetrations
  - Failure Mechanisms in the Liner
  - Use of Nominal Design Parameters Versus In-Situ Material Properties and Boundary Conditions
- Stage 2 of Round Robin Analysis
  - Characterization of Leakage Behavior of Containment Vessels as a Function of Pressure and Temperature

Phase 1 – Uses 1:4 Scale PCCF Structural Failure Mode Test as Starting Point

F.E. Model: Strain at 3.5 x Design Pressure

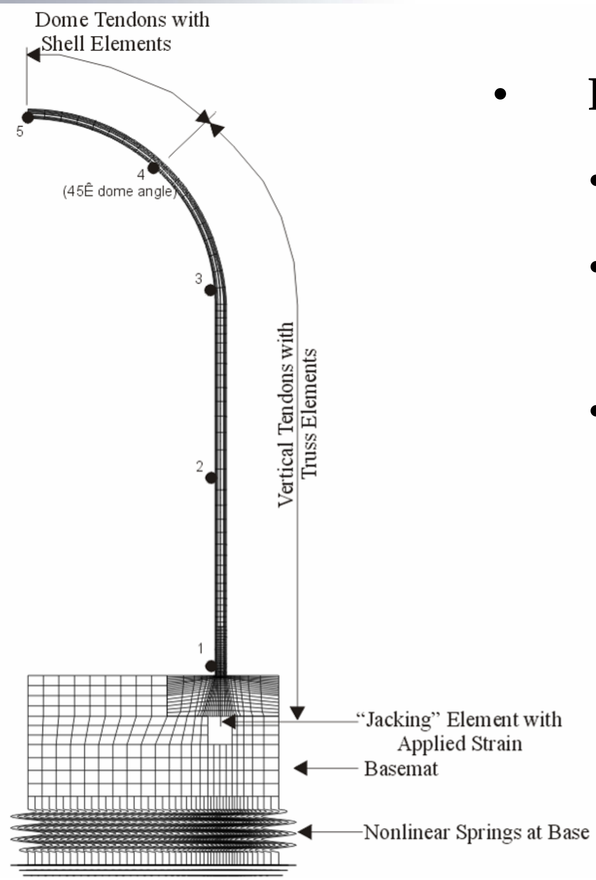


Tendon Rupture (Strain ~4%)

Phase 1.1 Tendon Forces

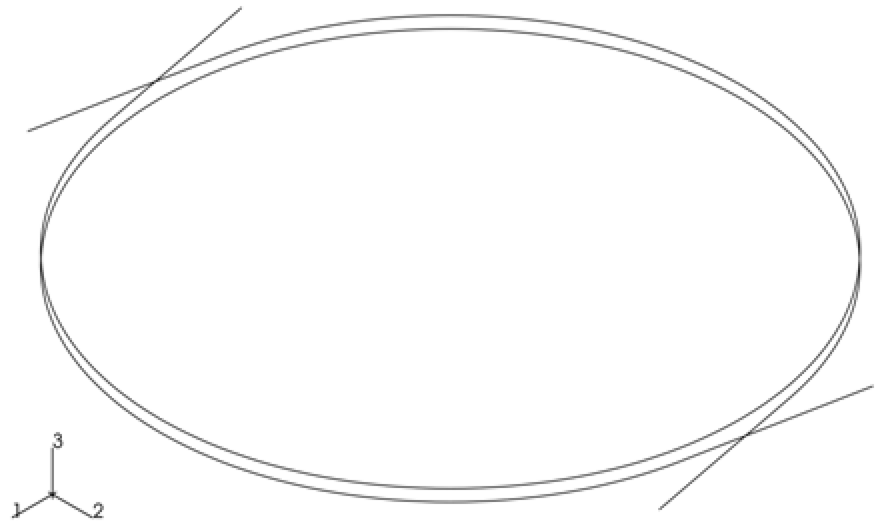
- **Observations from Previous Analyses Related to Hoop Tendon Measurements as a Function of Increasing Pressure:**
  - Changes in Tendon Stress Distribution Under Loading
  - Interior Tendon Forces Exceeded Force at Anchor
  - Poor Agreement in Hoop Tendon Stress Distribution Despite Good Agreement With Radial Displacements
  - Overprediction of Dome and Overall Vertical Displacements and Anchor Forces
  - Underprediction of Interior Gage Stresses
- **Participants Will Be Asked to Analytically Explore Tendon Forces as a Function of Containment Dilation**

Phase 1.1 Tendon Forces (continued)

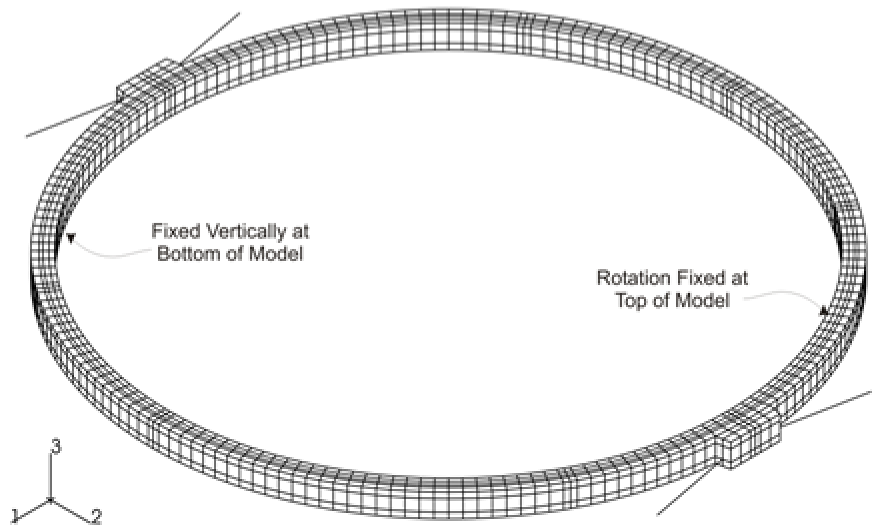


- **Participants Shall Output:**
  - **Displacements (Positions 1-11)**
  - **Rebar Strains at Cylinder Midheight (Output Locations 22 and 23)**
  - **Liner Strains at Cylinder Midheight (Output Locations 38 and 39)**

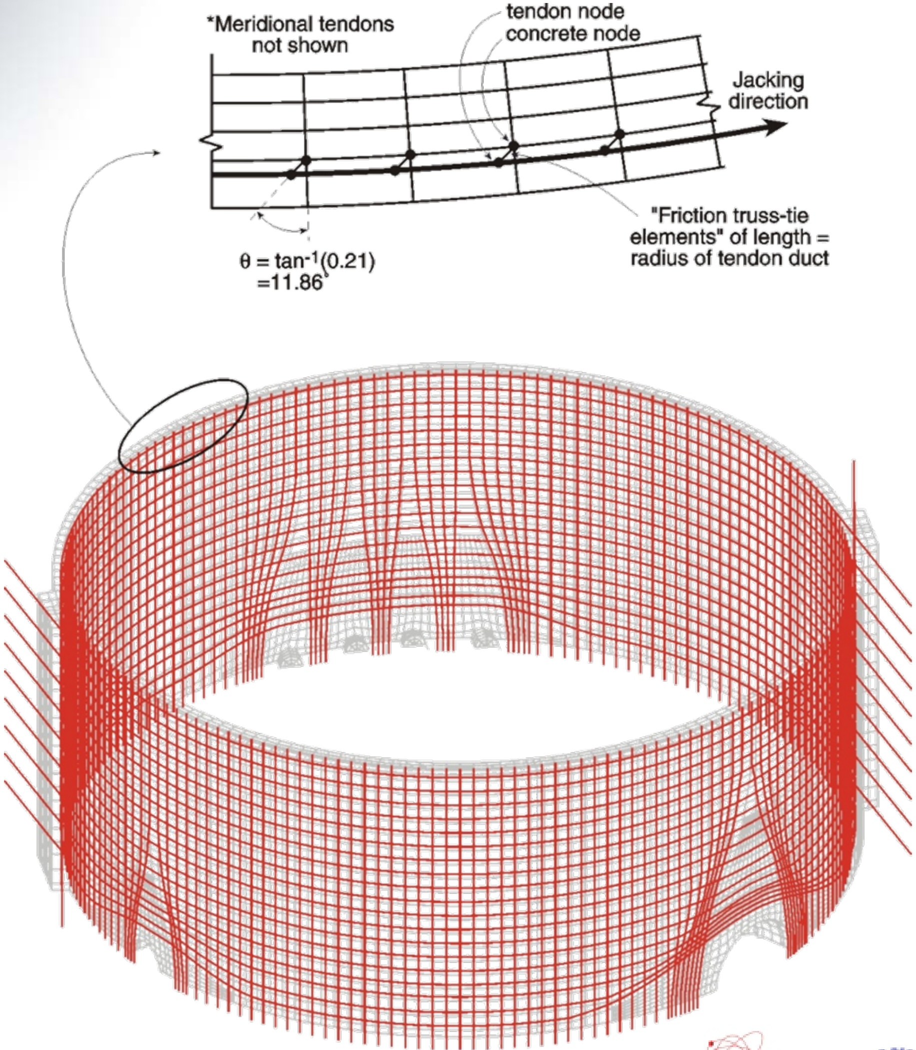
Phase 1.1 Tendon Forces (continued)



Tendon Groups H67 and H68



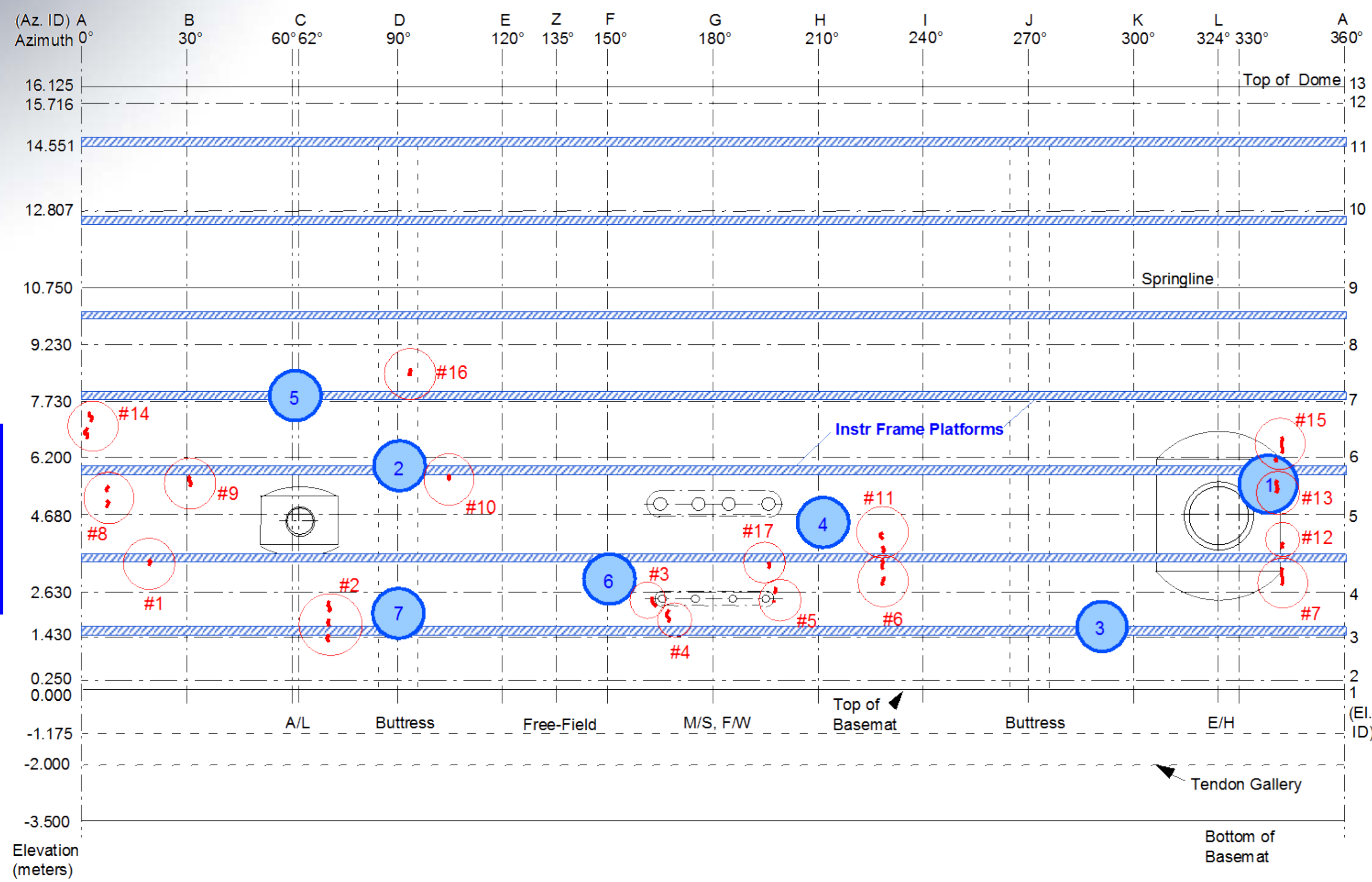
Phase 1.2 Slippage of Prestressing Cables



Phase 1.3 Steel-Concrete Interface

- **Participants Shall Investigate the Separation Between the Concrete and Sleeves, the Stress Concentrations that Lead to Liner Tearing, and the Development of Potential Leak Paths Using Strain Information**
  - **Separations Were Observed Surrounding Containment Penetrations During Testing of the PCCV Structure**
  - **Many of the Highest Strains Recorded During the Limit State Test Were Near the Mainsteam and Feedwater Penetrations**
  - **Wide Variation in Peak Strain Data at Locations with Identical Geometry Due to Slight Variations in Liner Thickness (Caused by Manufacturing and Weld Repair Grinding), Gage Position Relative to the Collar/Weld, Material Properties, etc.**
- **Participants Shall Quantify the Risk Associated with the Formation of a Gap as a Function of a Potential Leak Path**

Phase 1.3 Steel-Concrete Interface (continued)



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

NUPEC/NRC 1:4 Scale PCCV Model Liner

Linier Tears and Acoustic Events After LST

Phase 1.3 Steel-Concrete Interface (continued)

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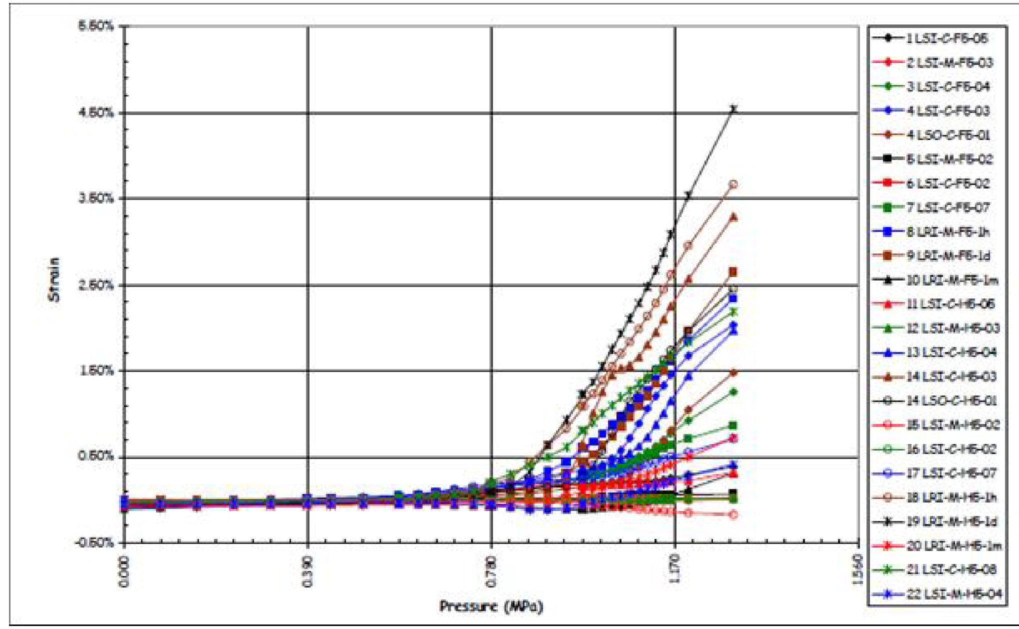
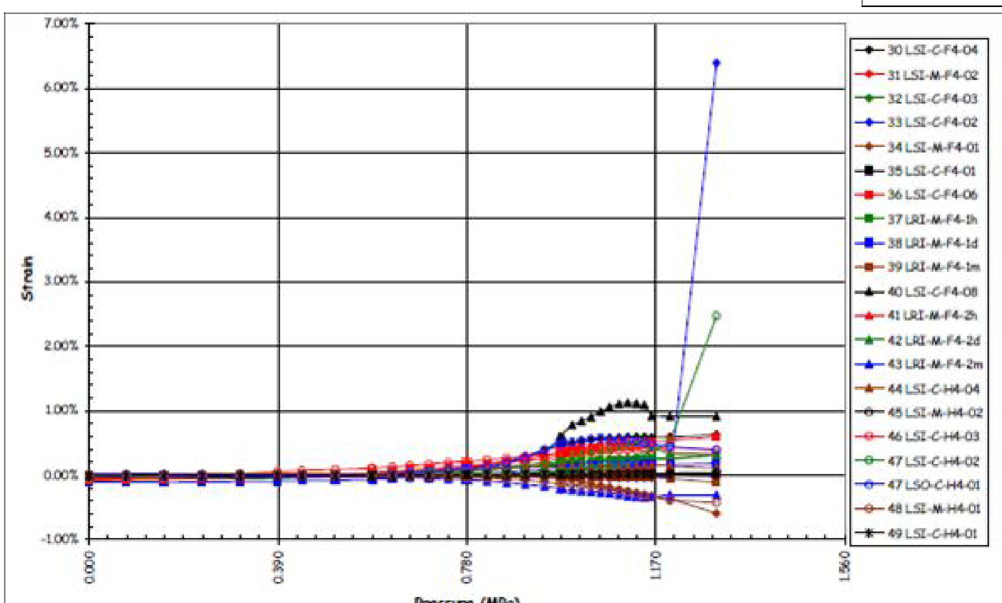
Phase 1.3 Steel-Concrete Interface

Liner Strains (DOR) at F/W
(Ref D-SN-P-220)





Liner Strains (DOR) at M/S
(Ref D-SN-P-220)

Phase 1.4 Failure Mechanisms

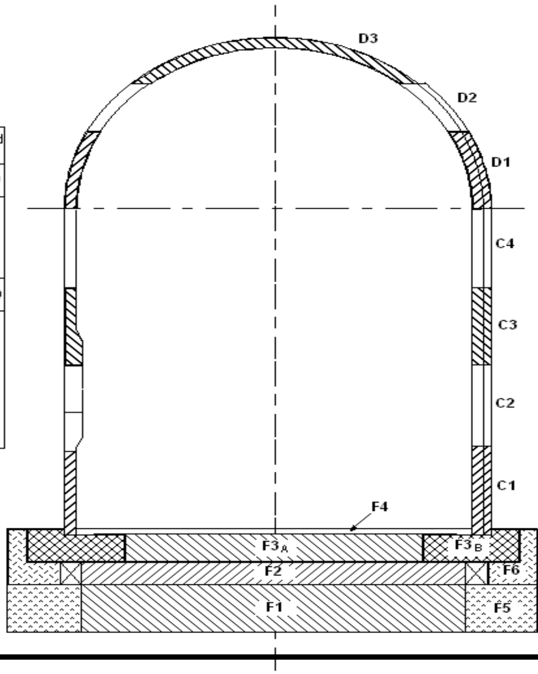
- **Participants Shall Characterize the Liner Tearing Mechanism**
  - **Applicability of Fracture Mechanics Approach Versus Ductile Failure Approach in PCCV Model**
  - **Predict Tears in the Liner From Finite Element Model Strains**
  - **Compare with Map of Liner Tears**

Phase 1.5 Nominal Design vs. In-Situ Construction

- **Participants Shall Evaluate Differences Between Model Design and In-Situ Construction**
- **Examples of Variation:**
  - **Concrete Material Properties (f'_c, density, E, etc.)**
  - **Rebar Material Properties**
  - **Prestressing**
  - **Geometry**
  - **Temperatures Causing Localized High Strains**
  - **Etc.**

Phase 1.5 Nominal Design vs. In-Situ Construction (continued)

	Concrete Pour Completion Date	Specified Strength F_c' (MPa)
F1	2-12-97	29.42
F2	2-28-97	29.42
$F3_A$	5-8-97	29.42
$F3_B$	5-8-97	44.13
F4	7-2-97	44.13
	Planned Date	F_c' (MPa)
C1	(11-98)	44.13
C2	(12-98)	44.13
C3	(1-99)	44.13
C4	(1-99)	44.13
D1	(2-99)	44.13
D2	(4-99)	44.13
D3	(5-99)	44.13
F5	(5-00)	29.42
F6	(5-00)	44.13



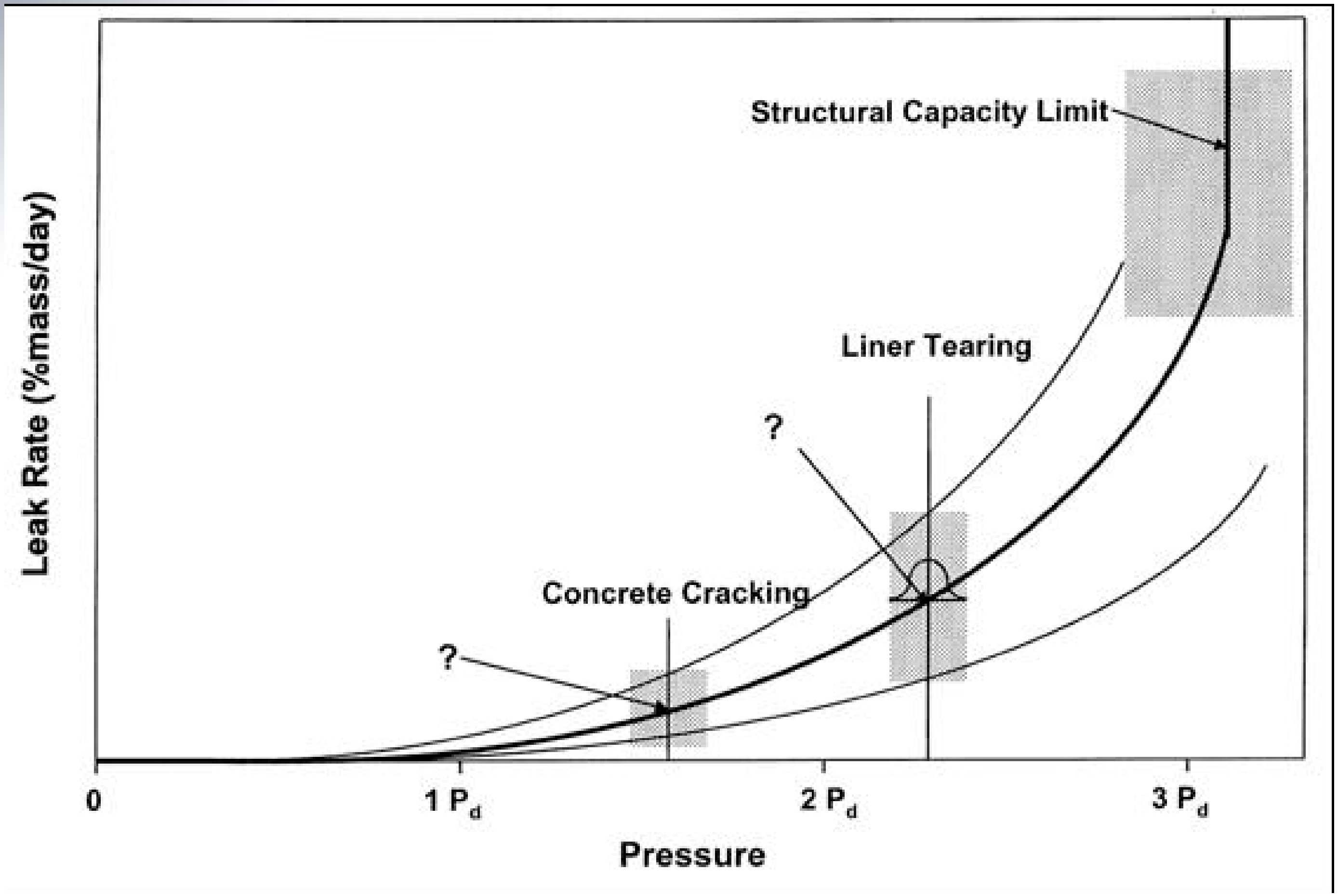
Days	fc′ = 29.42 MPa (4300 psi) Standard Curing MPa (psi)	fc′ = 29.42 MPa (4300 psi) Field Curing MPa (psi)	fc′ = 44.13 MPa (6400 psi) Standard Curing MPa (psi)	fc′ = 44.13 MPa (6400 psi) Field Curing MPa (psi)
7	32.06 (4650)	-	39.64 (5750)	-
14	35.37 (5130)	-	42.89 (6220)	-
28	38.96 (5650)	37.02 (5370)	48.61 (7050)	42.40 (6150)
91	-	39.16 (5680)	-	47.30 (6860)
104	47.85 (6940)	-	56.12 (8140)	-

Test Items		fc′ = 29.42 MPa Standard Curing	fc′ = 29.42 MPa Field Curing	fc′ = 44.13 MPa Standard Curing	fc′ = 44.13 MPa Field Curing
Compressive Strength (MPa)	(1 week)	33.64	29.42	39.13	40.99
Compressive Strength (MPa)	(4 weeks)	40.31	33.44	49.72	48.25
Compressive Strength (MPa)	(13 weeks)	51.39	41.68	60.21	48.84
Tensile Strength (MPa)	(13 weeks)	3.93	3.37	4.21	3.45
Flexural Strength (MPa)	(13 weeks)	5.37	4.00	5.58	5.51
Young’s Modulus ($\times 10^3$) (MPa)	(13 weeks)	29.03	27.95	31.97	26.97
Poisson’s Ratio	(13 weeks)	0.20	0.18	0.20	0.18
Density (ton/m^3)	(13 weeks)	2.25	2.21	2.26	2.19

Phase Two – Leakage as a Function of Pressure and Temperature

- **Second Stage Focus: Characterization of Leakage Behavior as a Function of Pressure and Temperature**
  - **Leak Rate as a Function of Pressure**
  - **Leak Rate as a Function of Temperature and Pressure for Two Representative Cases**
  - **Prediction of Leak Rate as a Probabilistic Function of Pressure and Temperature in an Effort to Determine the Significance and Applicability of Standard Assumptions Used When Assessing Containment Structures**
  - **Recast Containment Analysis Conclusions Into a Containment Performance Framework**

Phase Two – Leakage as a Function of Pressure

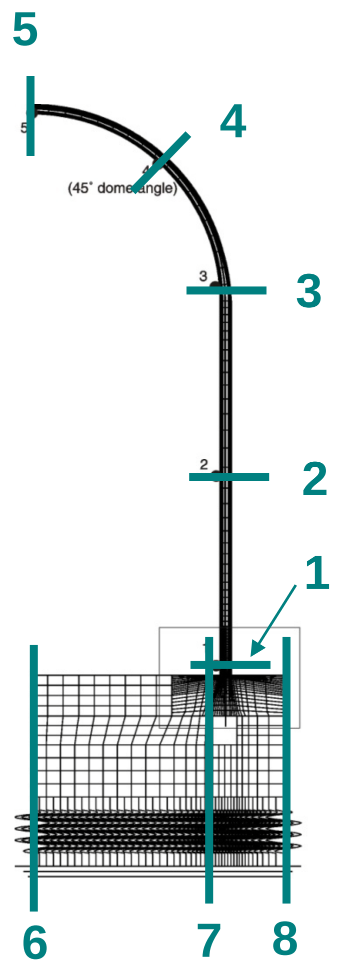


Consider Leak-Rate Versus Pressure Probabilistically

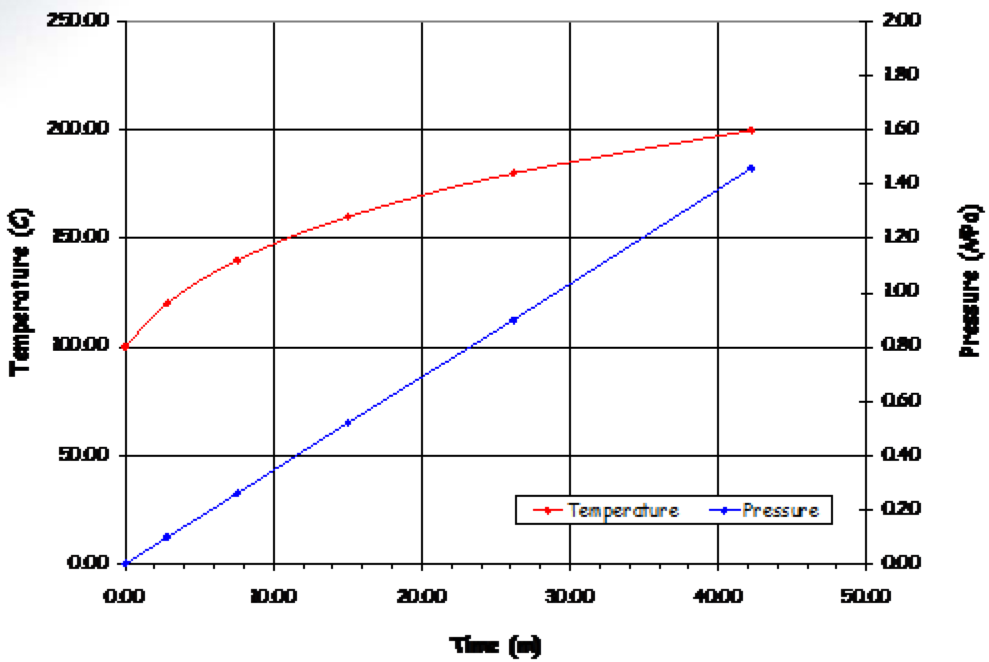
Phase Two - Thermal Analysis

- **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

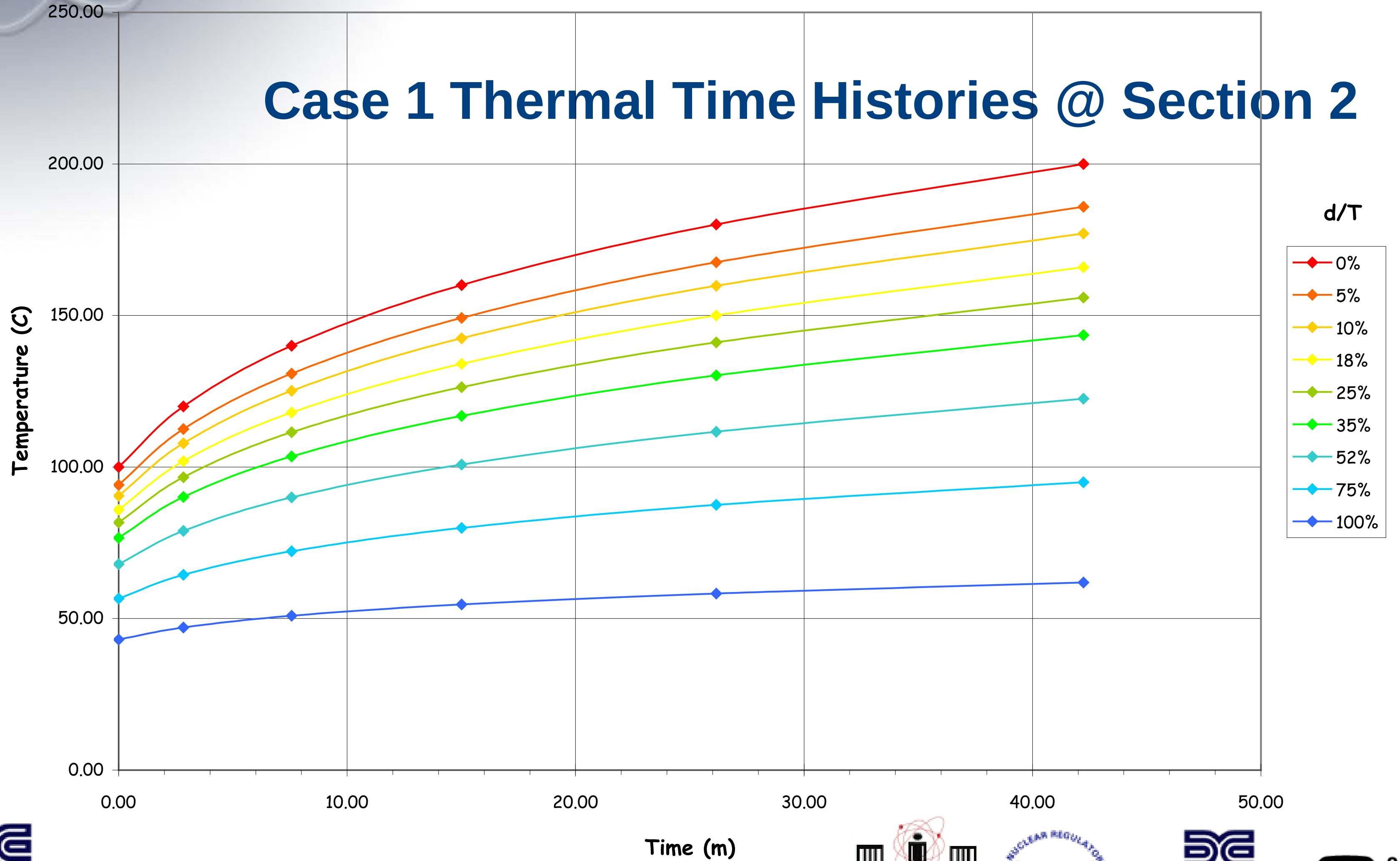


Phase Two – Leakage as a Function of Pressure and Temperature

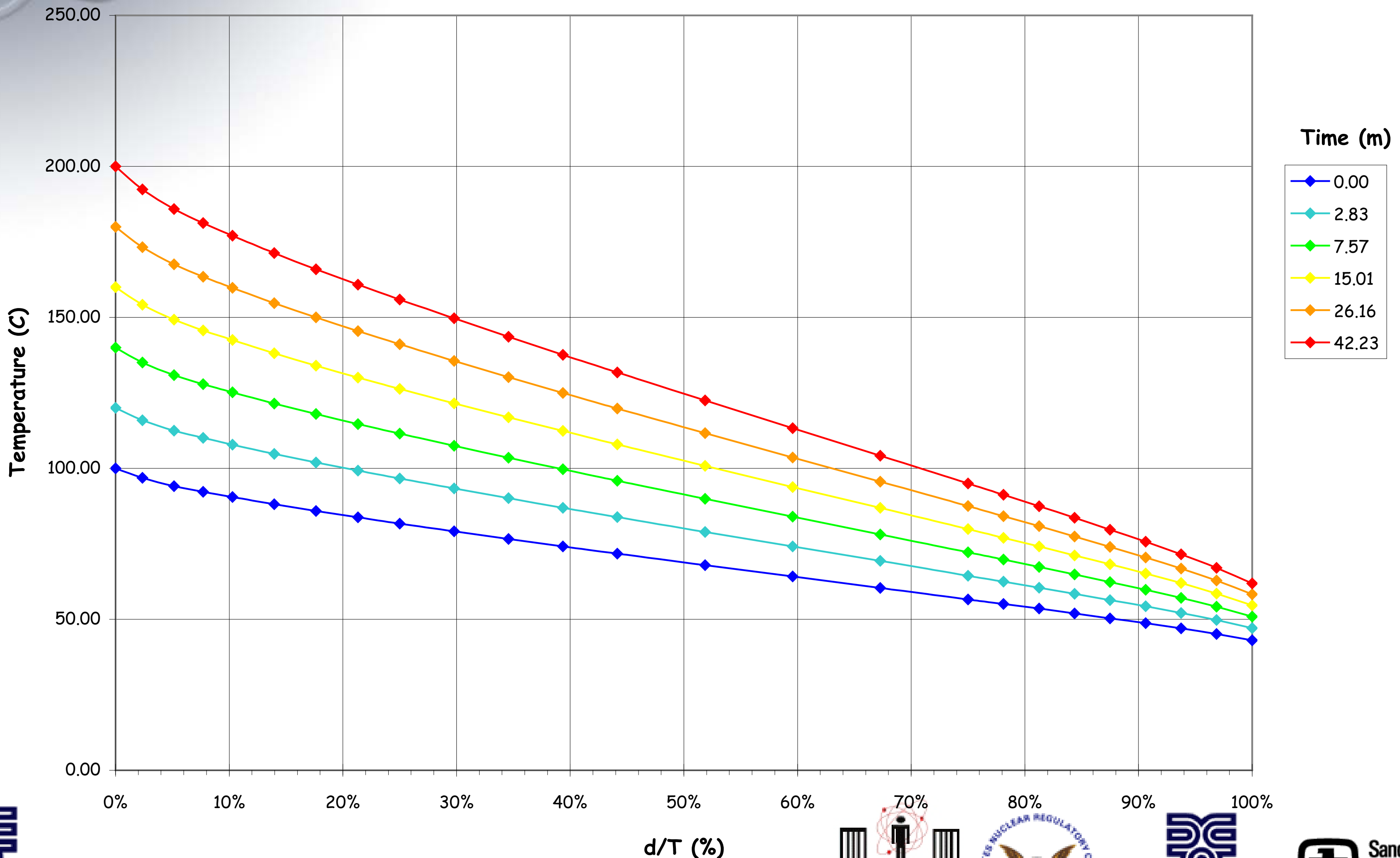


Case 1: A Saturated Steam Condition (Adding Temperature to Each Pressure Step from the Original PCCV Pressure Analysis)

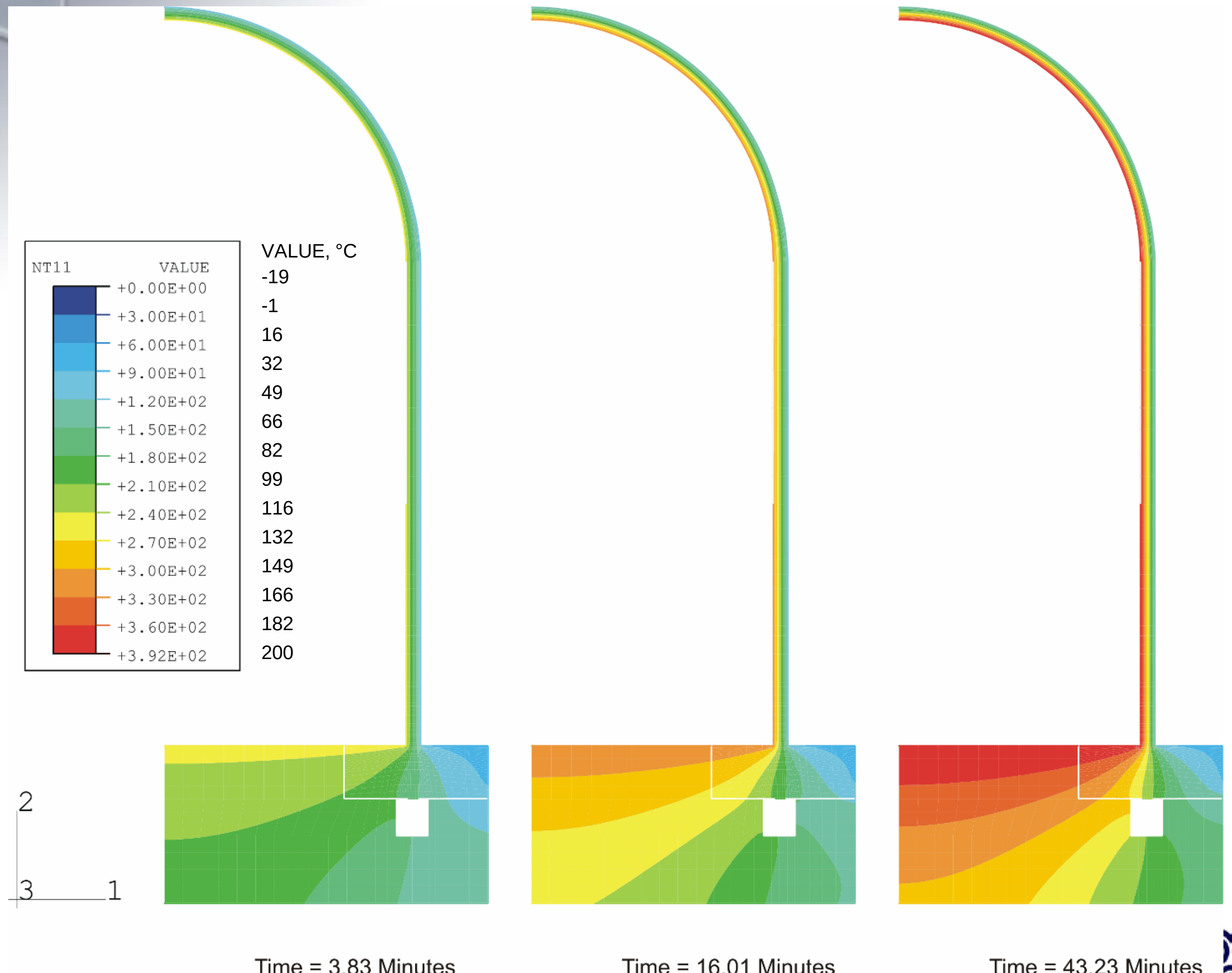
Phase Two – Case 1 Thermal Time Histories @ Section 2



Phase Two - Case 1 Gradients @ Section 2



Phase Two - Case 1 Contours



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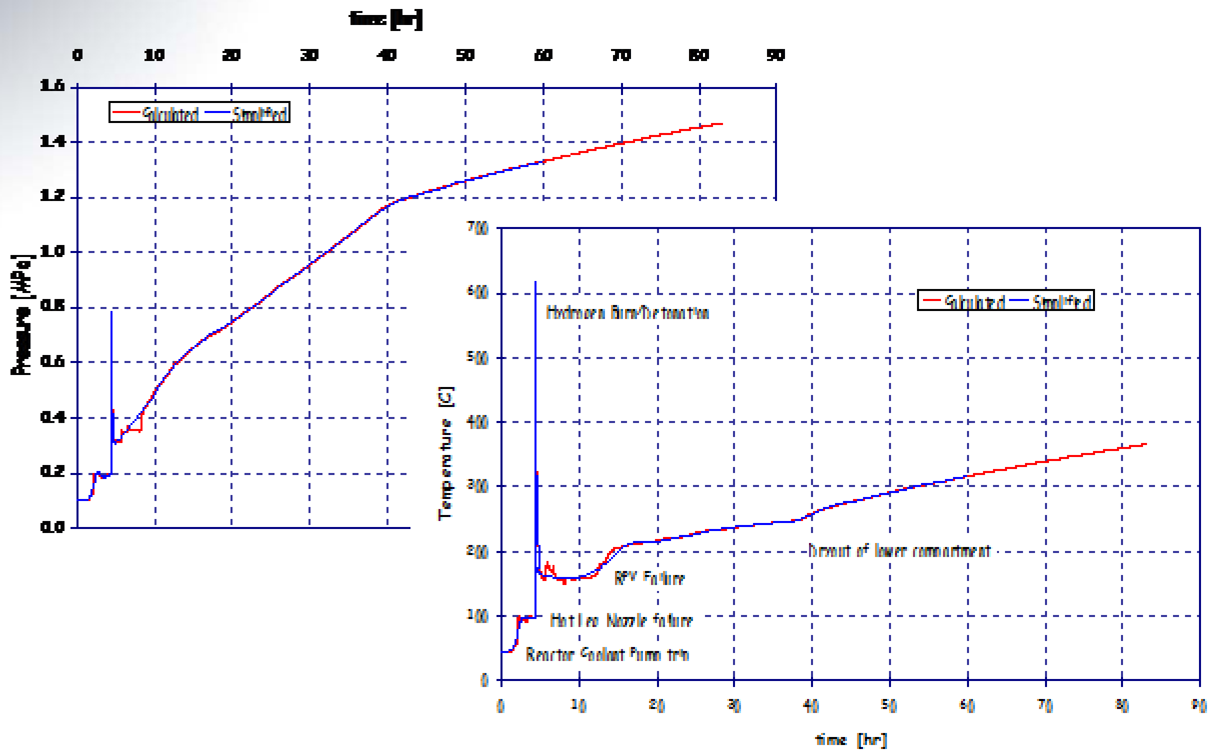
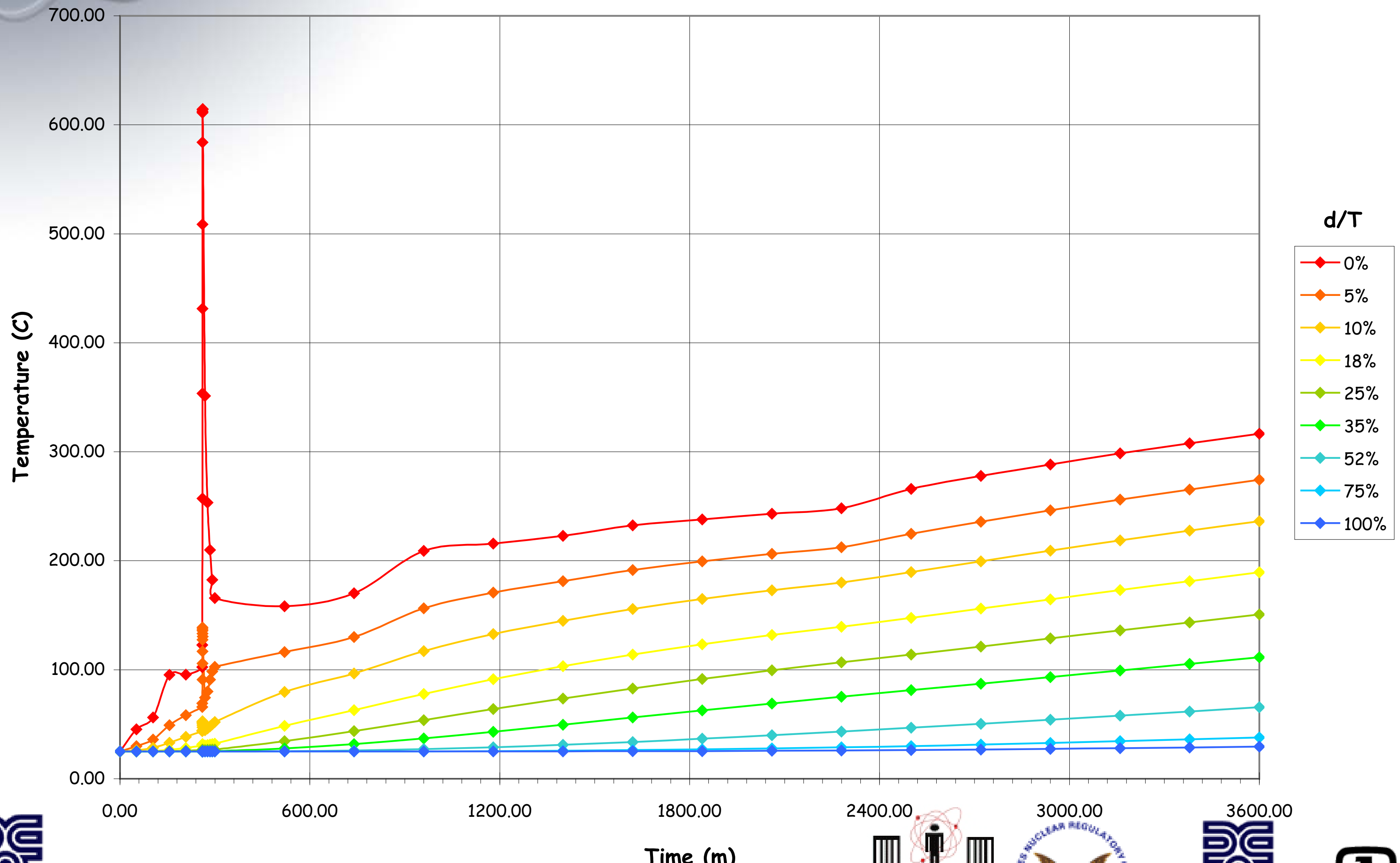
Phase Two – Leakage as a Function of Pressure and Temperature

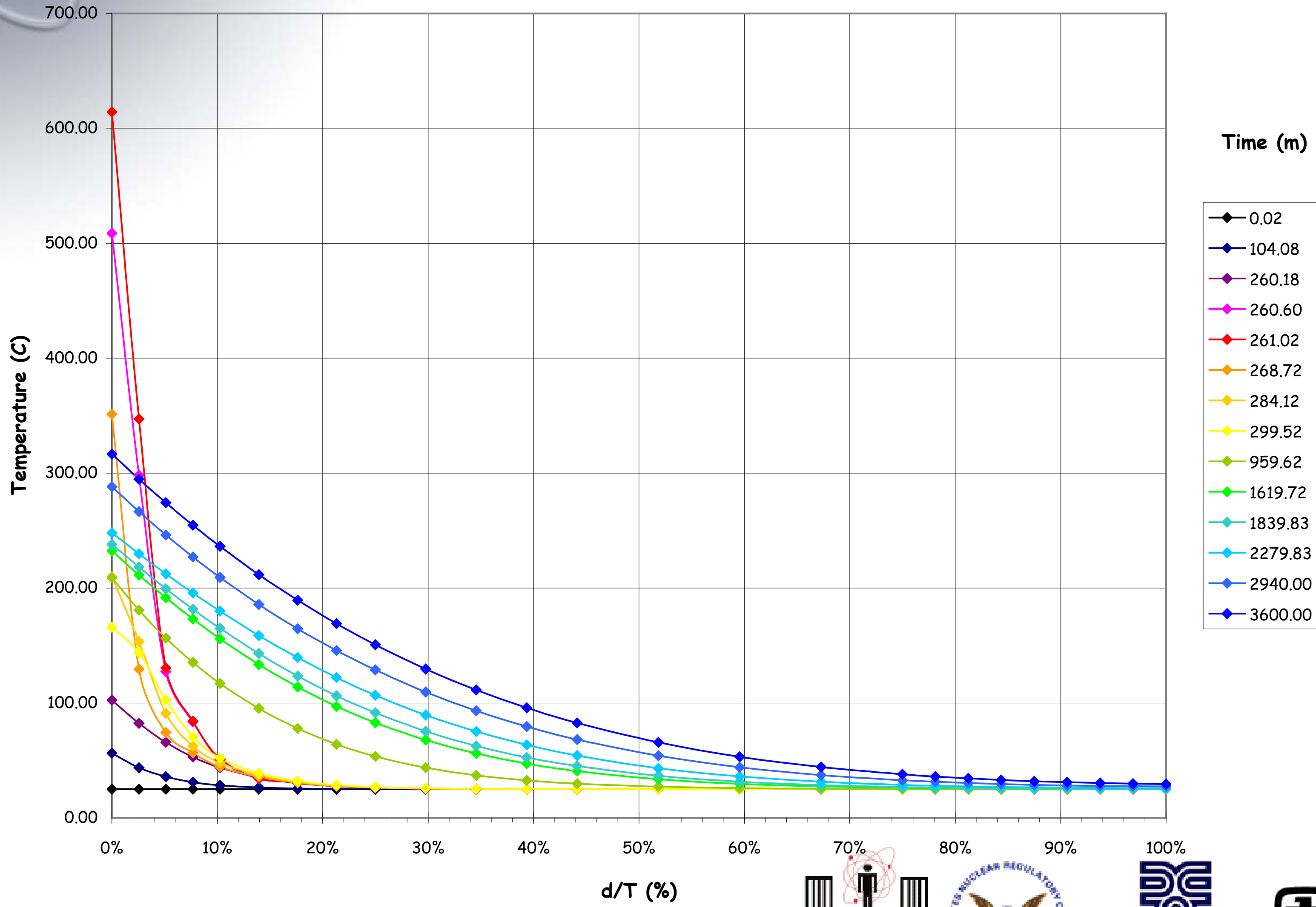


Case 2: An Accident Safety Case (Essentially a Station Blackout Scenario with a Hydrogen Burn at About 4 ½ Hours Into the Event)

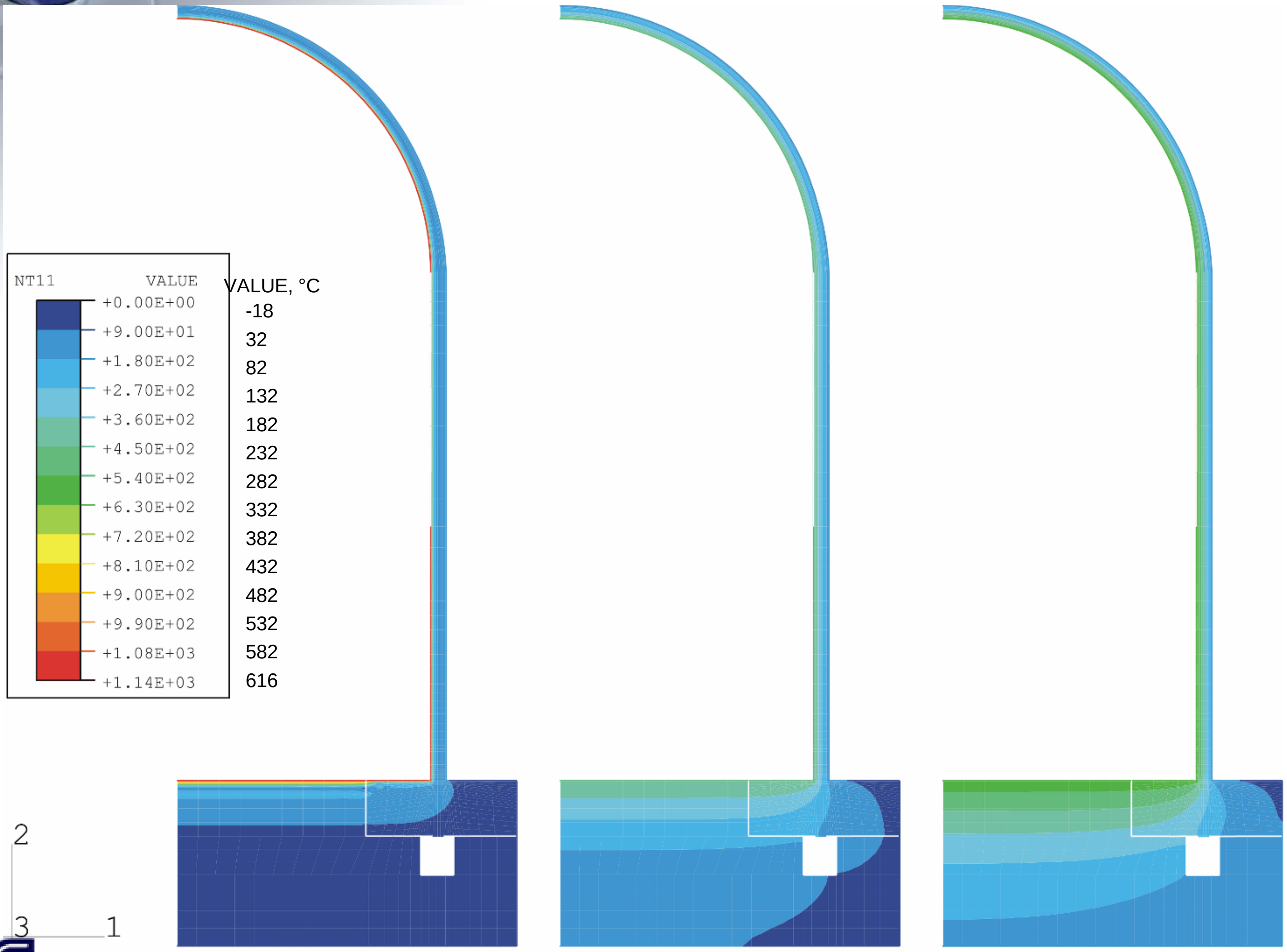
Phase Two - Case 2 Thermal Time Histories @ Section 2



Phase Two - Case 2 Gradients @ Section 2



Phase Two - Case 2 Contours



Time = 260 Minutes

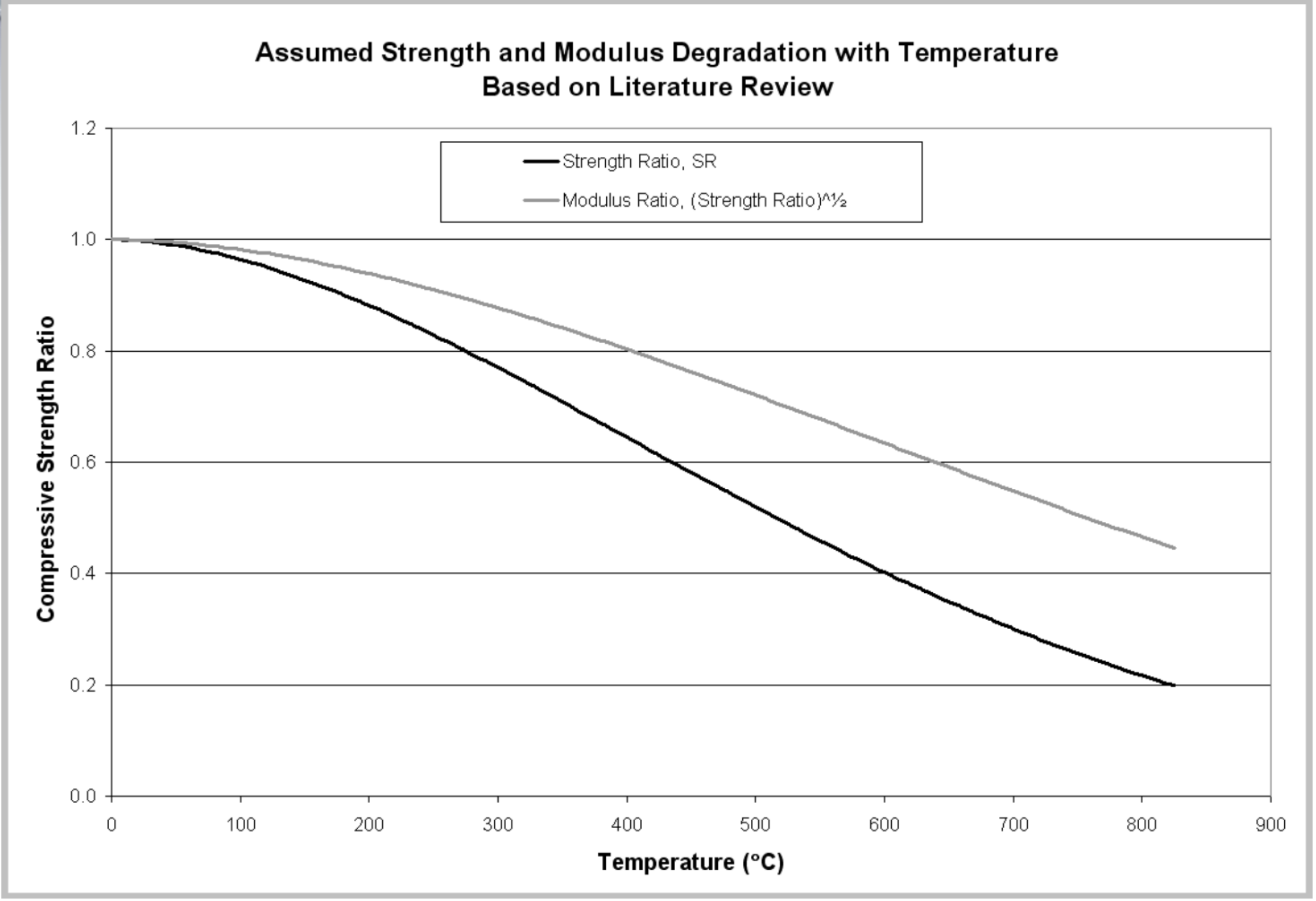
Time = 960 Minutes

Time = 3600 Minutes

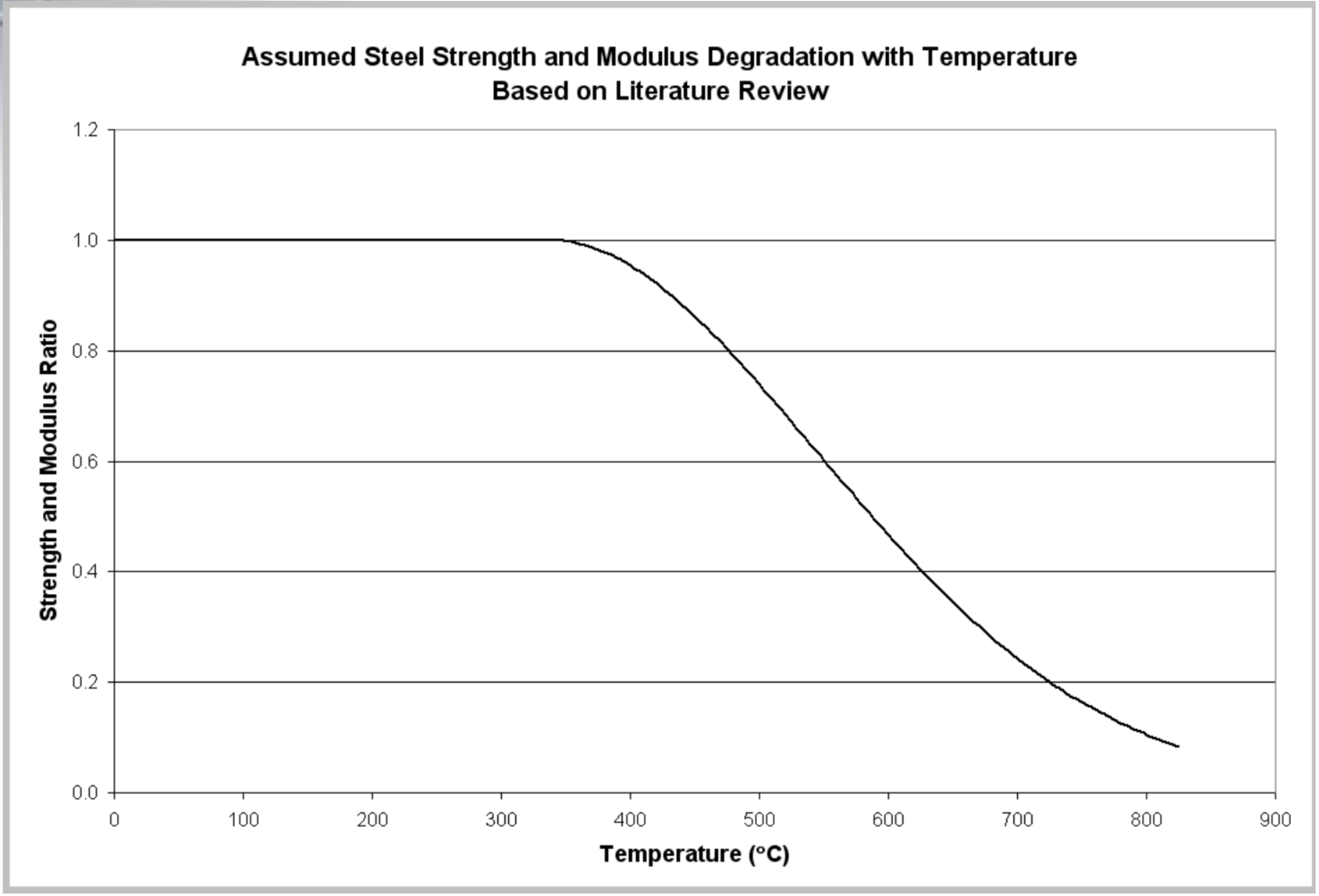
Phase Two – Additional Goal

- **Another goal is to reach consensus on influence of temperatures on containment material behaviors**

Phase Two - Concrete Degradation due to Temperature



Phase Two - Steel Degradation due to Temperature



Proposed Schedule

- **Initial Workshop – June 30-July 2, 2010**
- **Phase One Calculations and Documentation Due – October 22, 2010**
- **Phase Two Calculations and Documentation Due – July 29, 2011**
- **Final Workshop (Location TBD) – November 2011**
- **Final Report Sent to Participants – February 2012**