Crystal River Unit #3
Containment Investigation and Repair

June 30, 2010

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Agenda

- CR3 Containment Design Features Overview
- SGR Opening Sequence & Identification of Delamination
- Root Cause Analysis Results
- Repair Approach
- Repair Activities to Date
- Design Basis Analysis & 50.59 Approach
- Remaining Repair & Validation Activities
  - Post-Modification Testing
- Other Topics
- Summary and Questions

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Crystal River Unit 3
Design Features Overview

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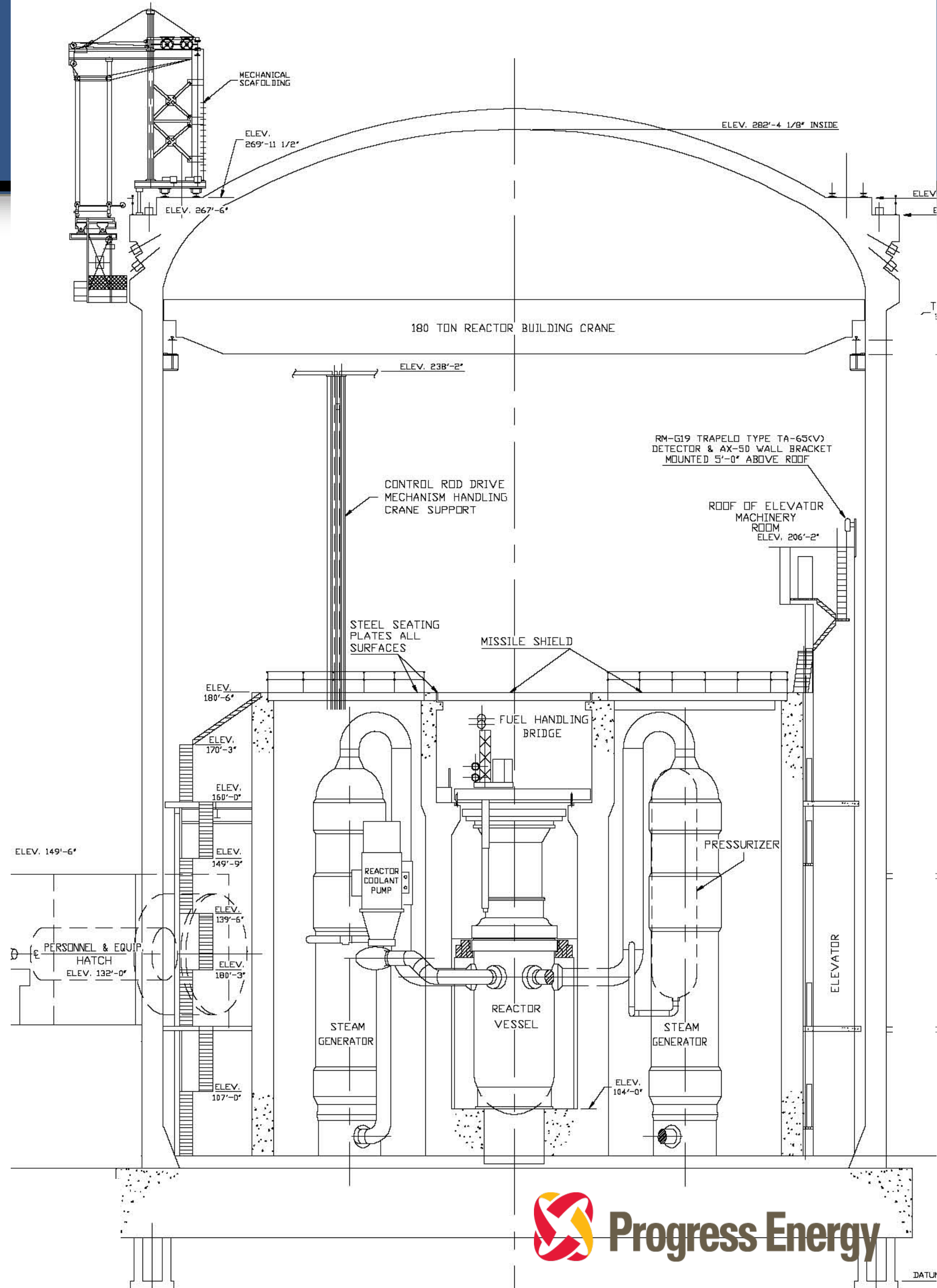
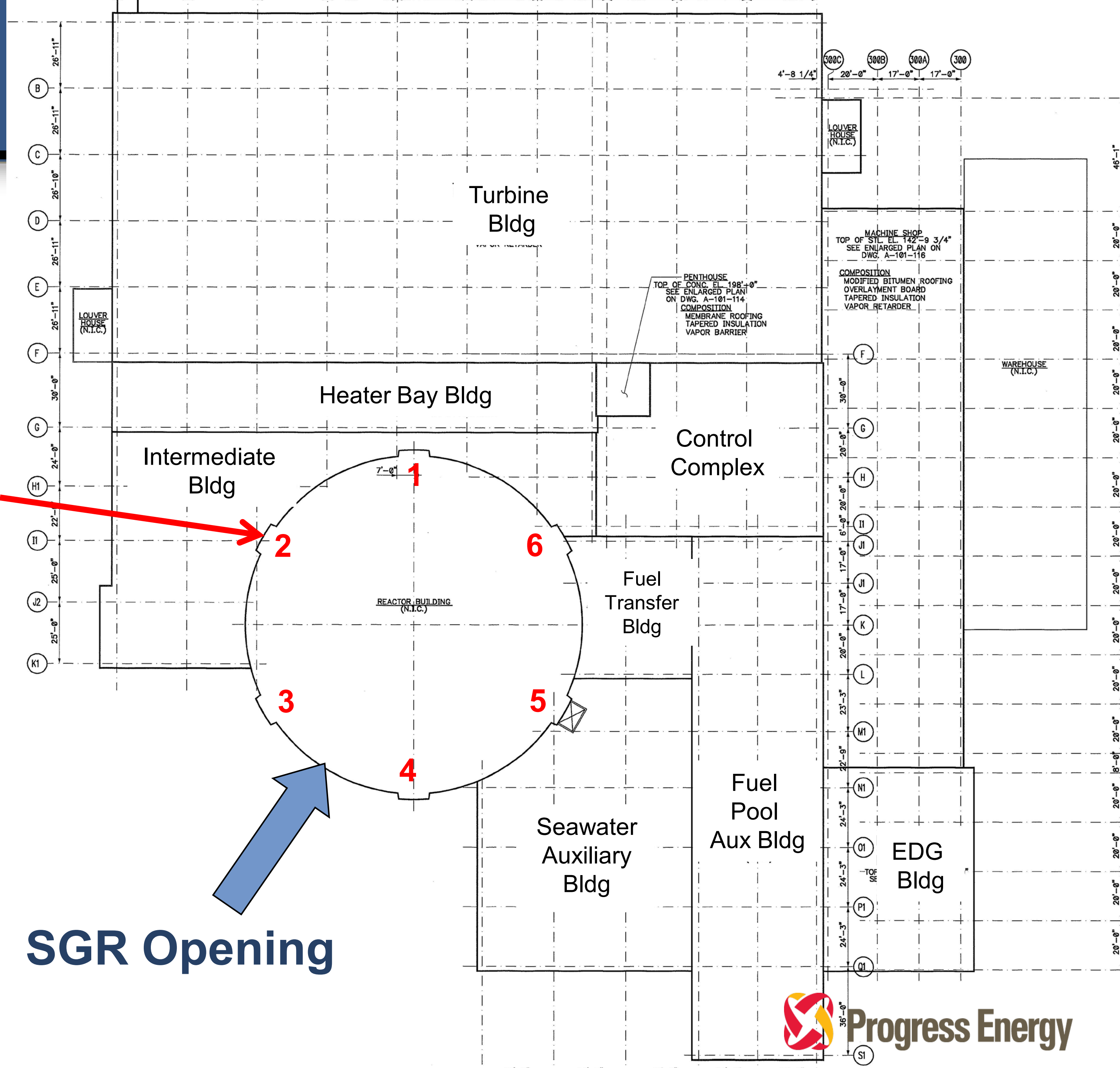
CR3 Containment Dimensions

Dimension	Value
Containment Outside Dimension (OD)	137 ft 0.75 in
Dome Thickness	36 in
Basemat Thickness	12 ft 6 in
Liner Thickness	0.375 in
Wall Thickness	42 in
Buttress Wall Thickness	70 in
Vertical & Hoop Conduit OD	5.25 in
# of Vertical Tendons	144
# of Tendon Hoops	94
# of Tendons per Hoop	3
# of Prestressed Dome Tendons	123



Plan View



Buttress #
(typical)
SGR Opening
1
2
3
4
5
6
Turbine Bldg
Heater Bay Bldg
Intermediate Bldg
Control Complex
Fuel Transfer Bldg
Fuel Pool Aux Bldg
Seawater Auxiliary Bldg
EDG Bldg
REACTOR BUILDING (N.I.C.)
LOUVER HOUSE (N.I.C.)
WAREHOUSE (N.I.C.)
PENTHOUSE
TOP OF CONC. EL. 198'+0"
SEE ENLARGED PLAN ON DWG. A-101-114
COMPOSITION
MEMBRANE ROOFING
TAPERED INSULATION
VAPOR BARRIER
MACHINE SHOP
TOP OF STL. EL. 142'-9 3/4"
SEE ENLARGED PLAN ON DWG. A-101-116
COMPOSITION
MODIFIED BITUMEN ROOFING
OVERLAYMENT BOARD
TAPERED INSULATION
VAPOR RETARDER
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SGR OPENING SEQUENCE & IDENTIFICATION OF DELAMINATION

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Steam Generator Replacement (SGR) Opening
(between Buttresses 3 and 4)

SGR Opening Dimensions

@ Liner
23’ 6” x 24’ 9”

@ Concrete Opening
25’ 0” x 27” 0”

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Steam Generator Replacement (SGR) Opening

Hydro-Excavation

Concrete & Liner Removal
Sequence

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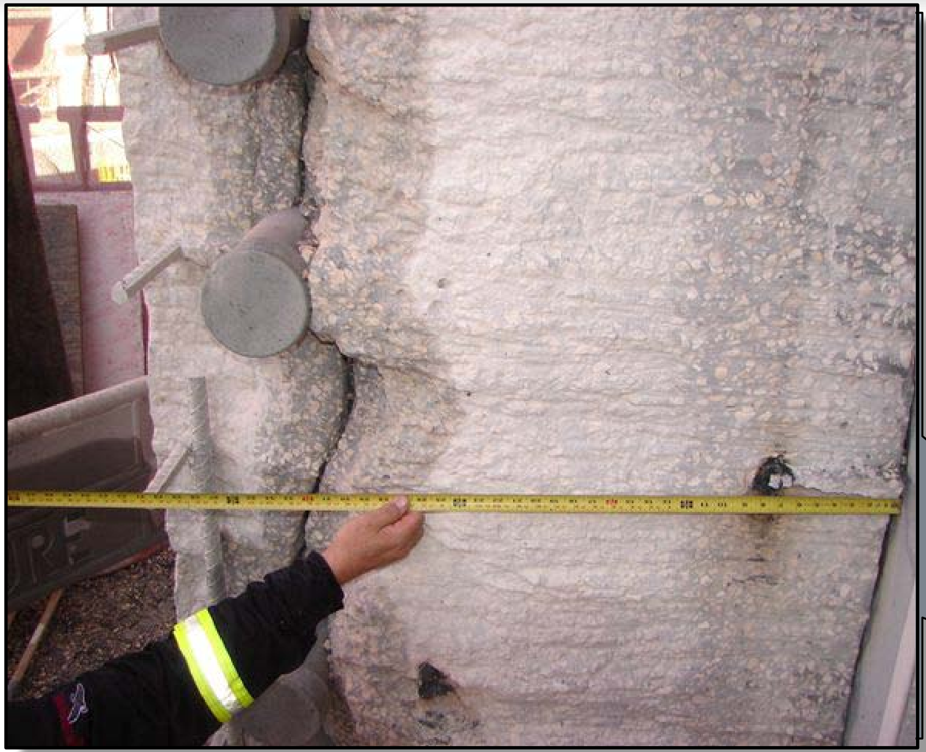
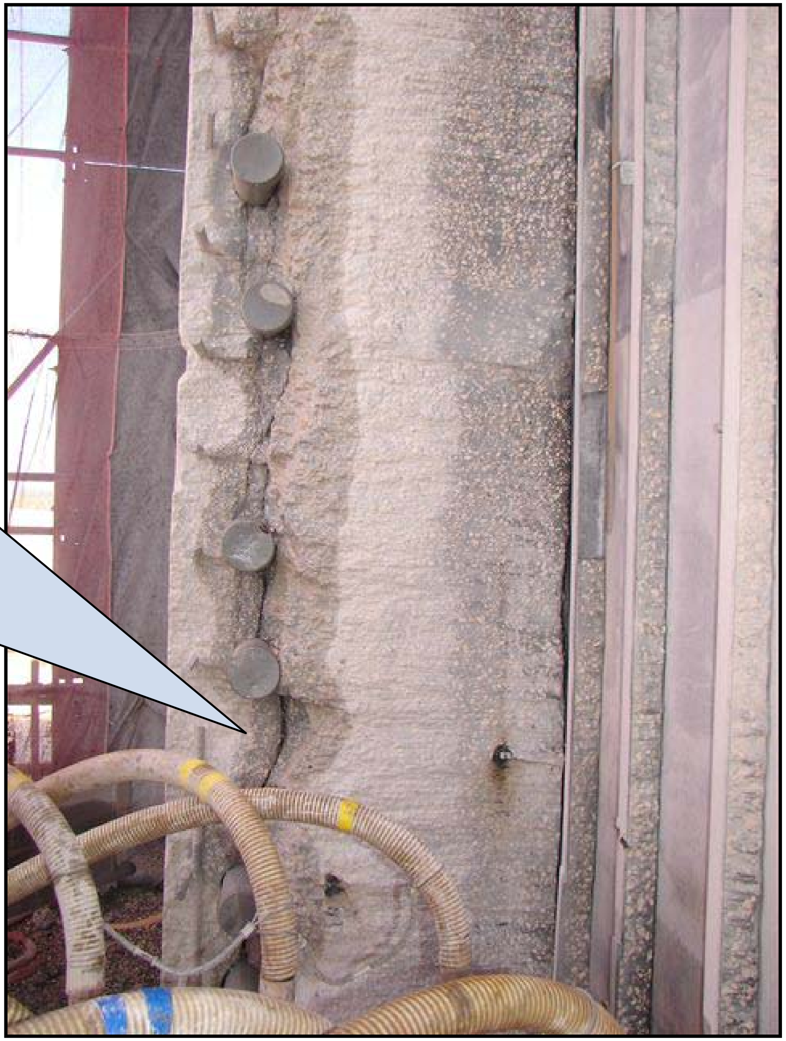
Concrete & Liner Removal

Sequence (continued)

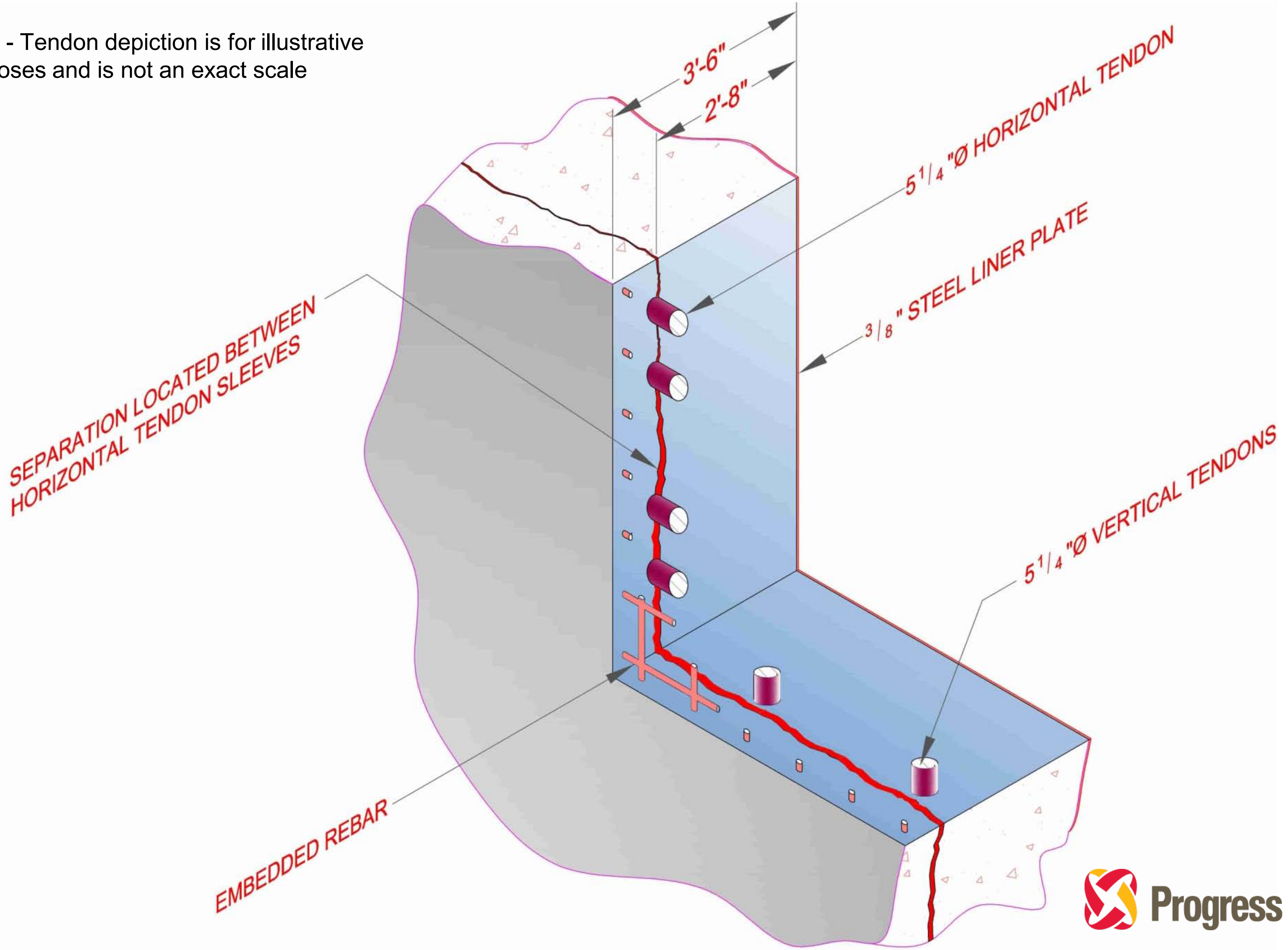
Delamination Close-up





Location of the Delamination

Note - Tendon depiction is for illustrative purposes and is not an exact scale



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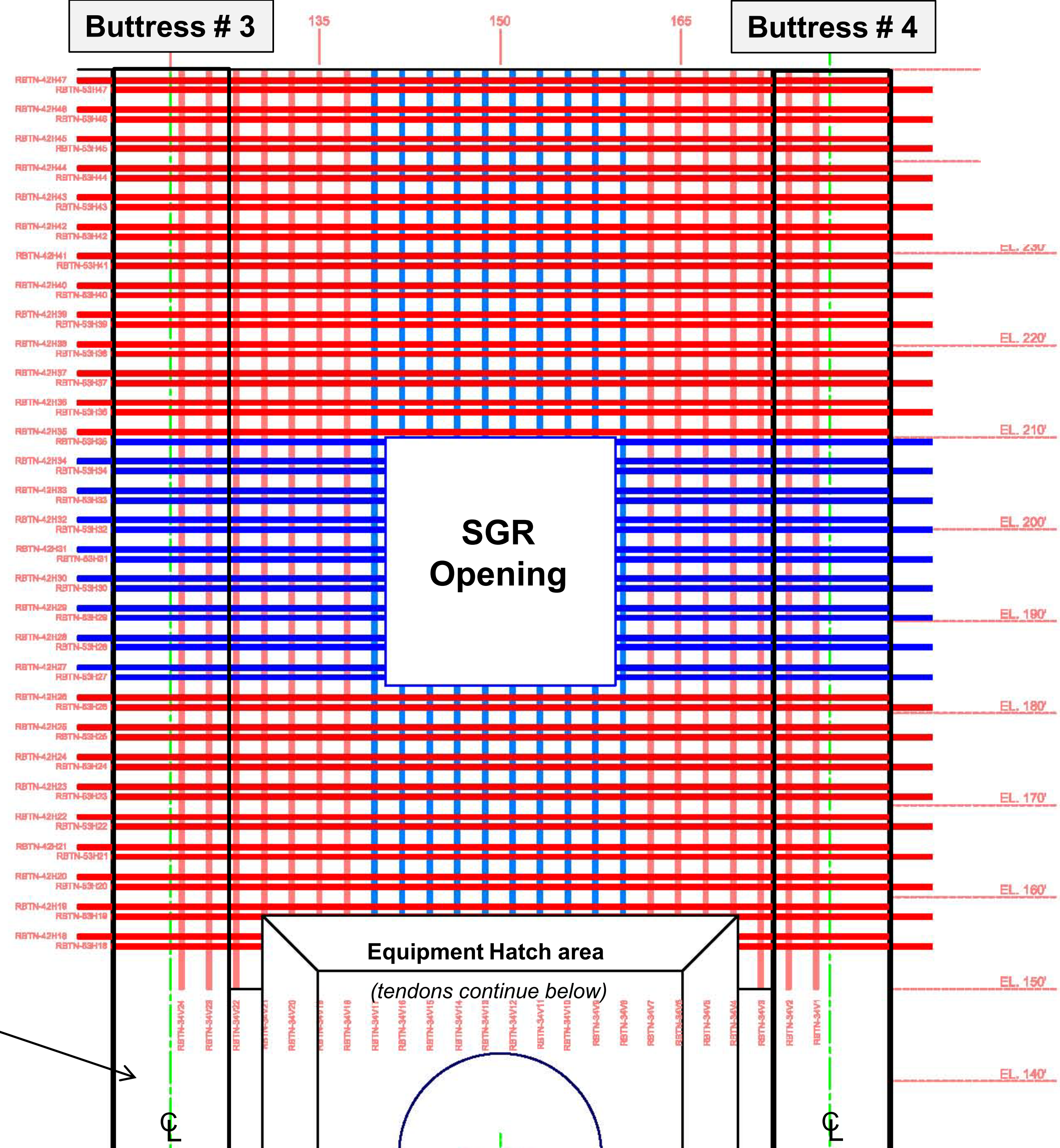
Tendon Pattern

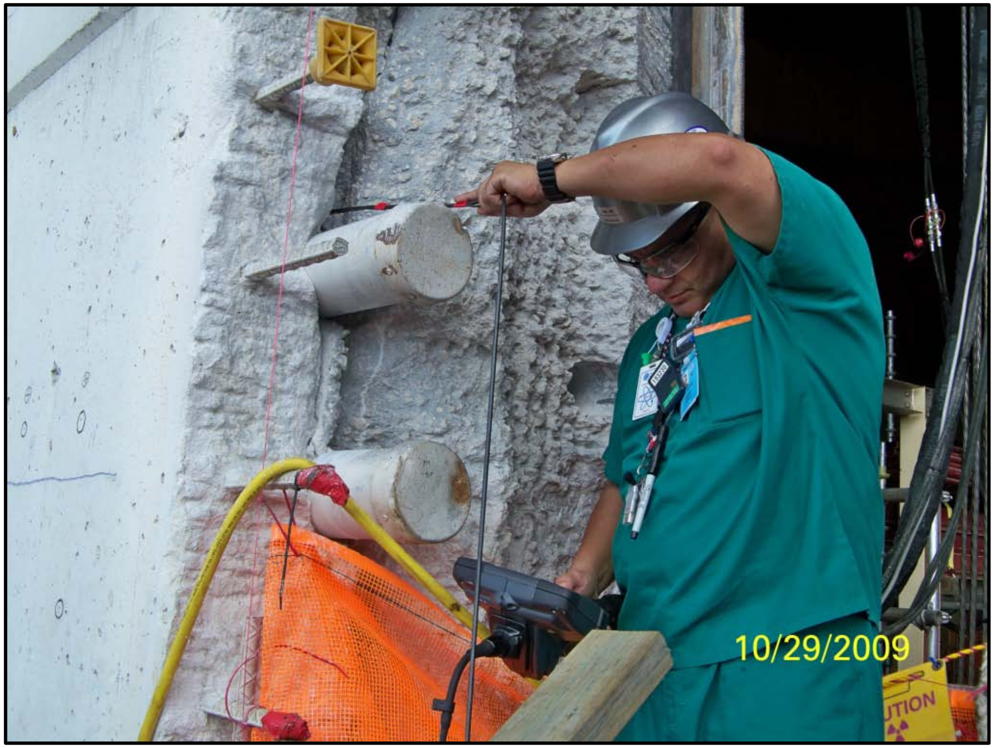
Tendon Pattern at Time of Cutting SGR Opening

- Energized Tendon
- Removed Tendon



Buttress (typical)

ROOT CAUSE ANALYSIS RESULTS



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Root Cause Analysis (RCA)
Investigation & Design Basis Team

- Comprehensive Team Commissioned
  - Progress Energy personnel - expertise across fleet
  - Industry peers (Exelon, Southern Company, SCE&G)
  - External expertise:
    - *Performance Improvement International (PII)*
    - *MPR Associates*
    - *AREVA*
    - *Worley Parsons*
    - *Wiss, Janney, Elstner Associates (WJE)*
    - *Construction Technology Laboratories (CTL)*

- Numerous PhD's (11) with expertise in root cause investigation techniques, nuclear engineering, nuclear operations & maintenance, material science & testing, concrete standards & construction, concrete testing, concrete creep, concrete fracture, human performance, process analysis, containment analysis, reliability and computer modeling

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Root Cause Analysis
Condition Assessment

- Condition Assessment & Laboratory Testing
  - NDT - *Construction Technology Laboratories (CTL)*
  - Labs - *MacTec, Soil & Materials Engineers (S&ME)*
  - Other Field Data - *Sensing Systems, Inc; Core Visual Inspection Services (Core VIS), Nuclear Inspection & Consulting, Inc; Precision Surveillance; Gulf West Surveying Inc; AREVA*

- Non-Destructive Testing (NDT) of Containment Wall Surfaces
  - Use of Impulse Response (IR) Method and Ground Penetrating Radar (GPR)
    - Over 8,000 IR data points taken
  - Comprehensive on all accessible areas

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Root Cause Analysis
Condition Assessment (continued)

- Visual Inspections
  - Delamination cracks at SGR opening
  - Fragments from concrete removal process
  - Containment external surfaces

- Concrete Core Bores
  - Over 150 core bores performed
  - Ranged from 1” to 8” diameter, 6” to 32” long
  - Validated IR data, along with boroscopic inspections
  - Laboratory testing

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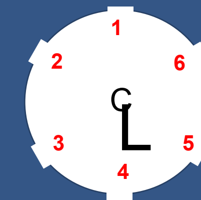
Root Cause Analysis
Condition Assessment (continued)

- Concrete Core Laboratory Analyses
  - Petrographic Examination
  - Modulus of Elasticity and Poisson's Ratio
  - Density, Absorption, and Voids
  - Compressive Strength, Splitting Tensile Strength, and Direct Tensile Strength
  - Fracture Energy
  - Accelerated Creep Test
  - Accelerated Alkali Silica Reaction (ASR) Test
  - Chemistry and Contamination Test
  - Scanning Electron Microscope (SEM) Examination of Micro-Cracking

Containment “Unfolded” – Buttress 2 to 5

Mosaic IR Overlay scale is approximate



IR scans completed with no delamination

Blue = no delamination

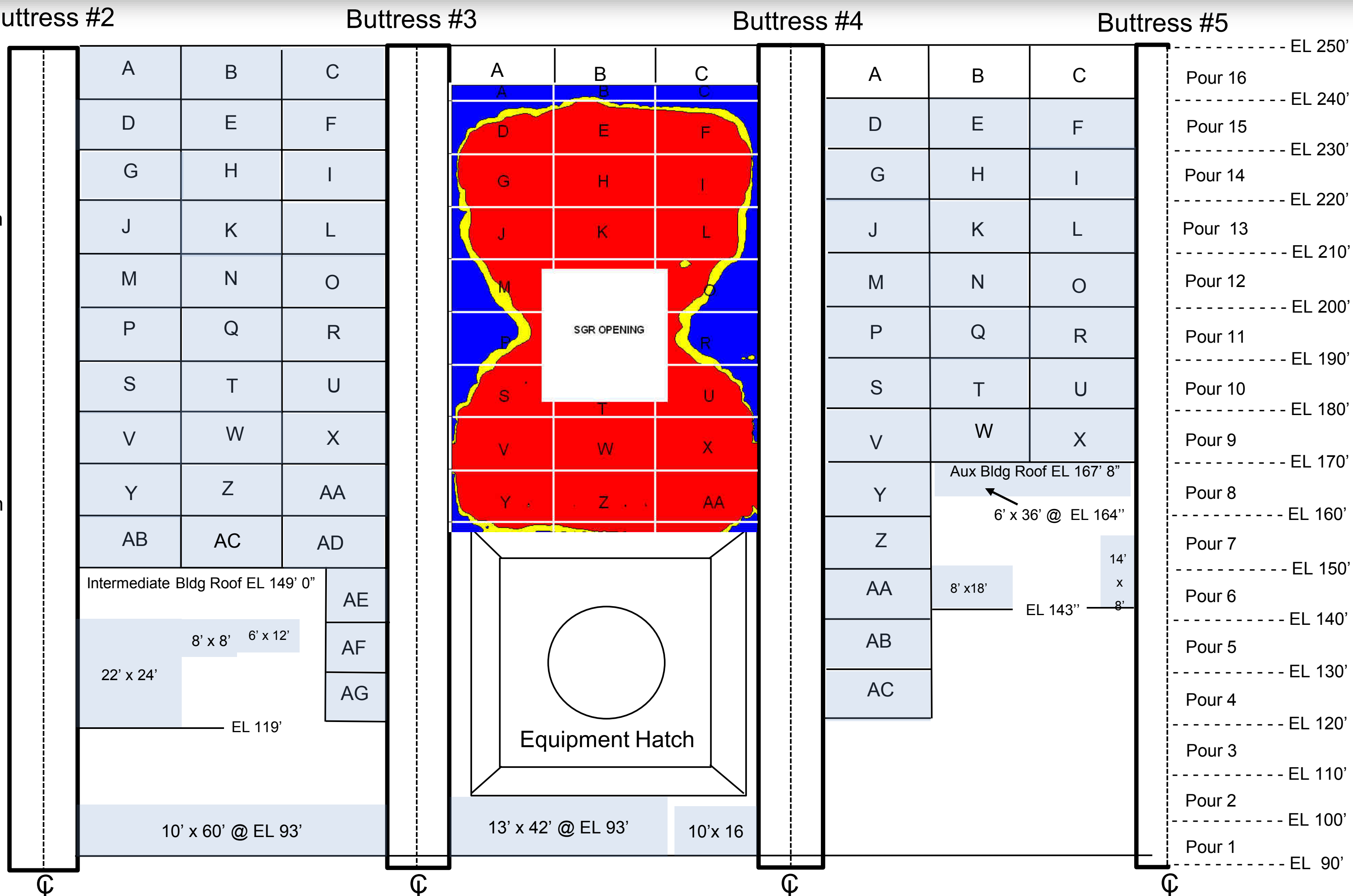
Actual IR scan output data:

Blue = no delamination

Yellow= transition

Red = delaminated

Drawing scale is not exact



Conclusion – IR scans with confirmation core bores identified delamination only in the Buttress 3-4 span above the Equipment Hatch, as shown in red above

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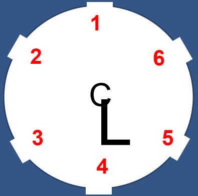
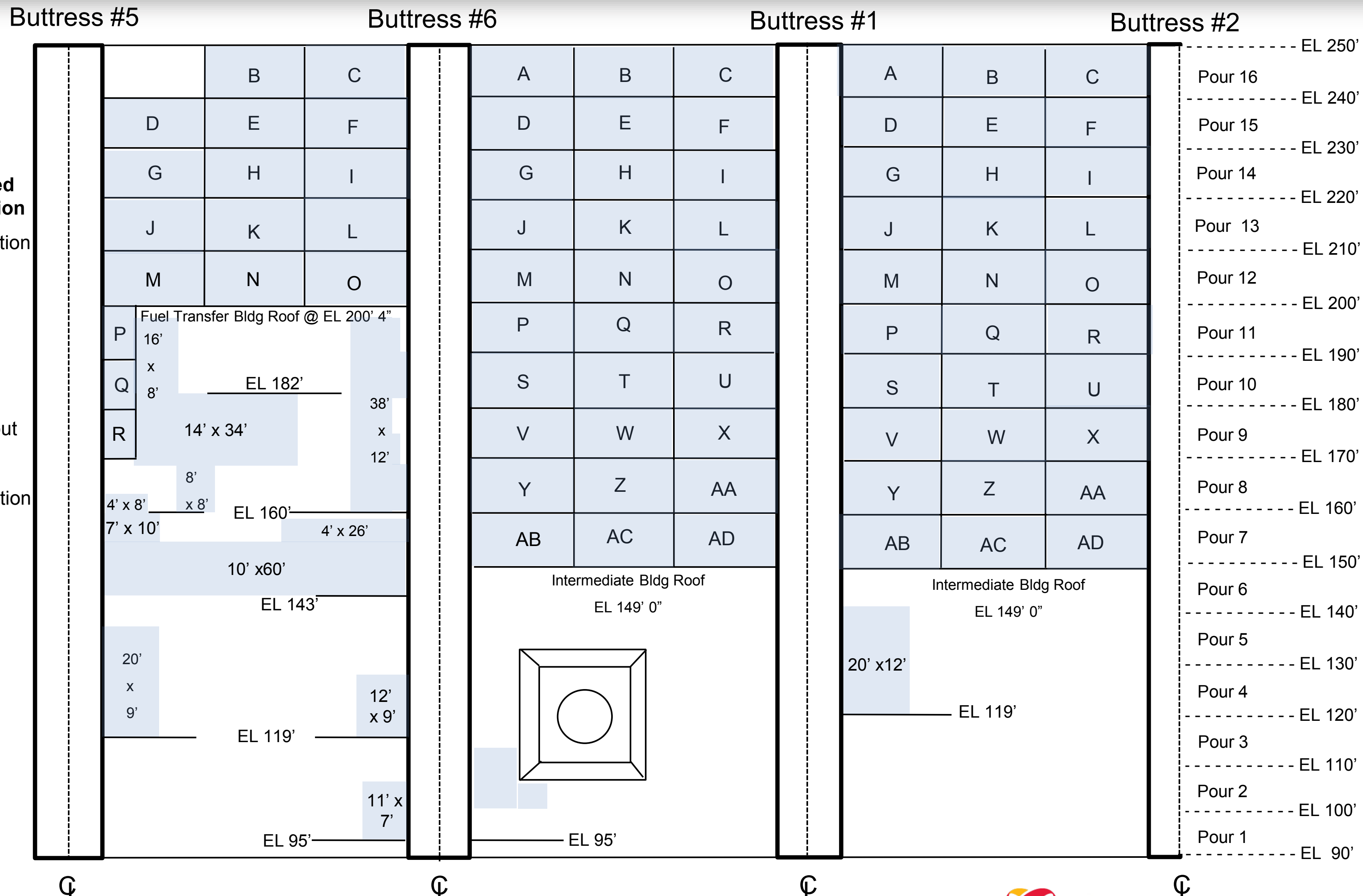
Containment “Unfolded” – Buttress 5 to 2





IR scans completed with no delamination

Blue = no delamination

Actual IR scan output data:

Blue = no delamination

Yellow= transition

Red = delaminated

Drawing scale is not exact

Conclusion – No delamination identified in these Buttress spans

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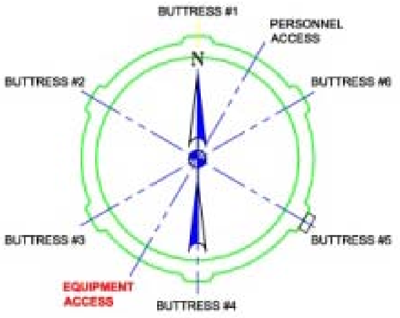
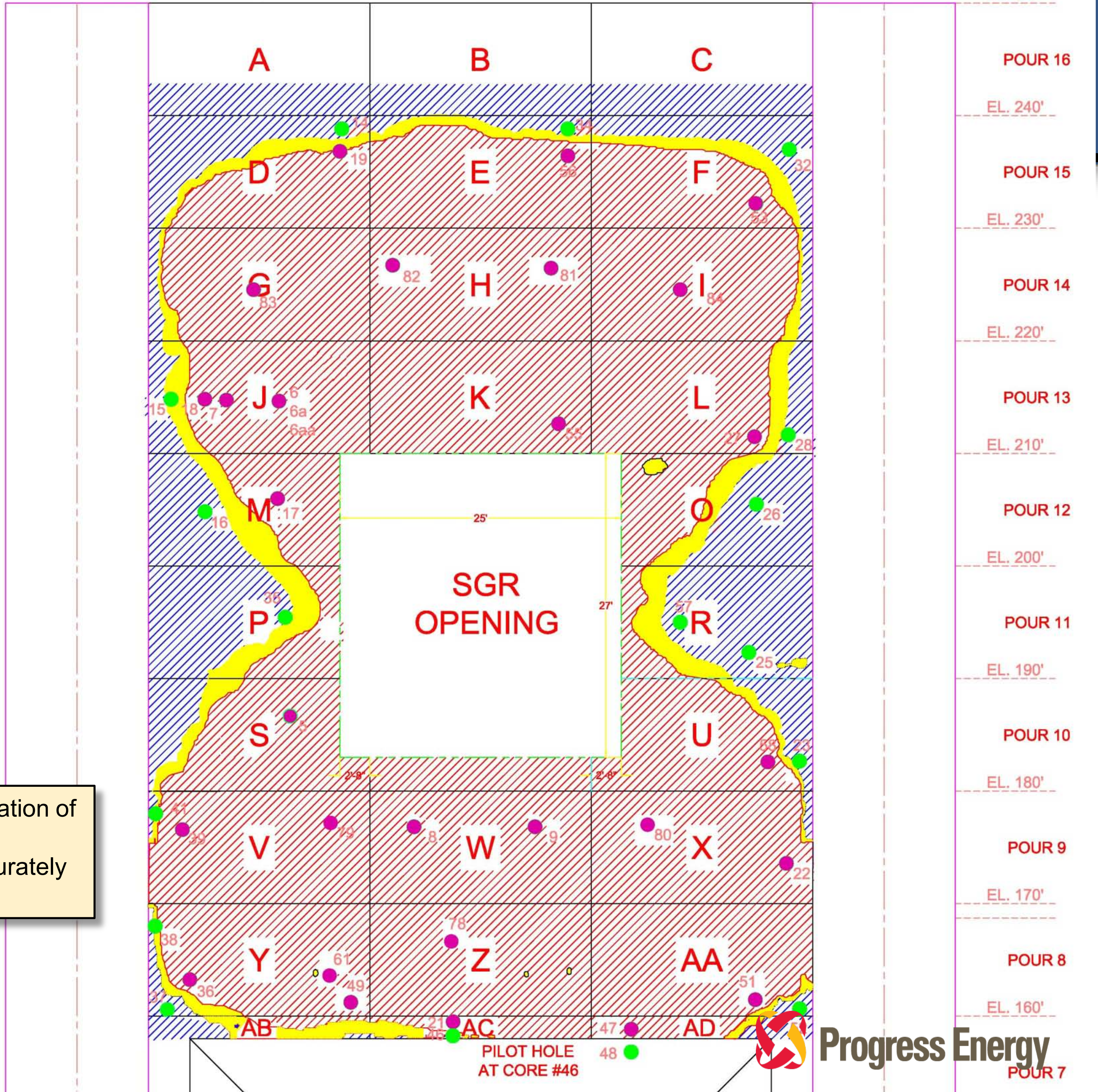
Core Borings



CORE BORE WITH DELAMINATION

CORE BORE NOT DELAMINATED



Conclusion – Physical observation of core boring has validated the delamination boundary, as accurately predicted by IR.

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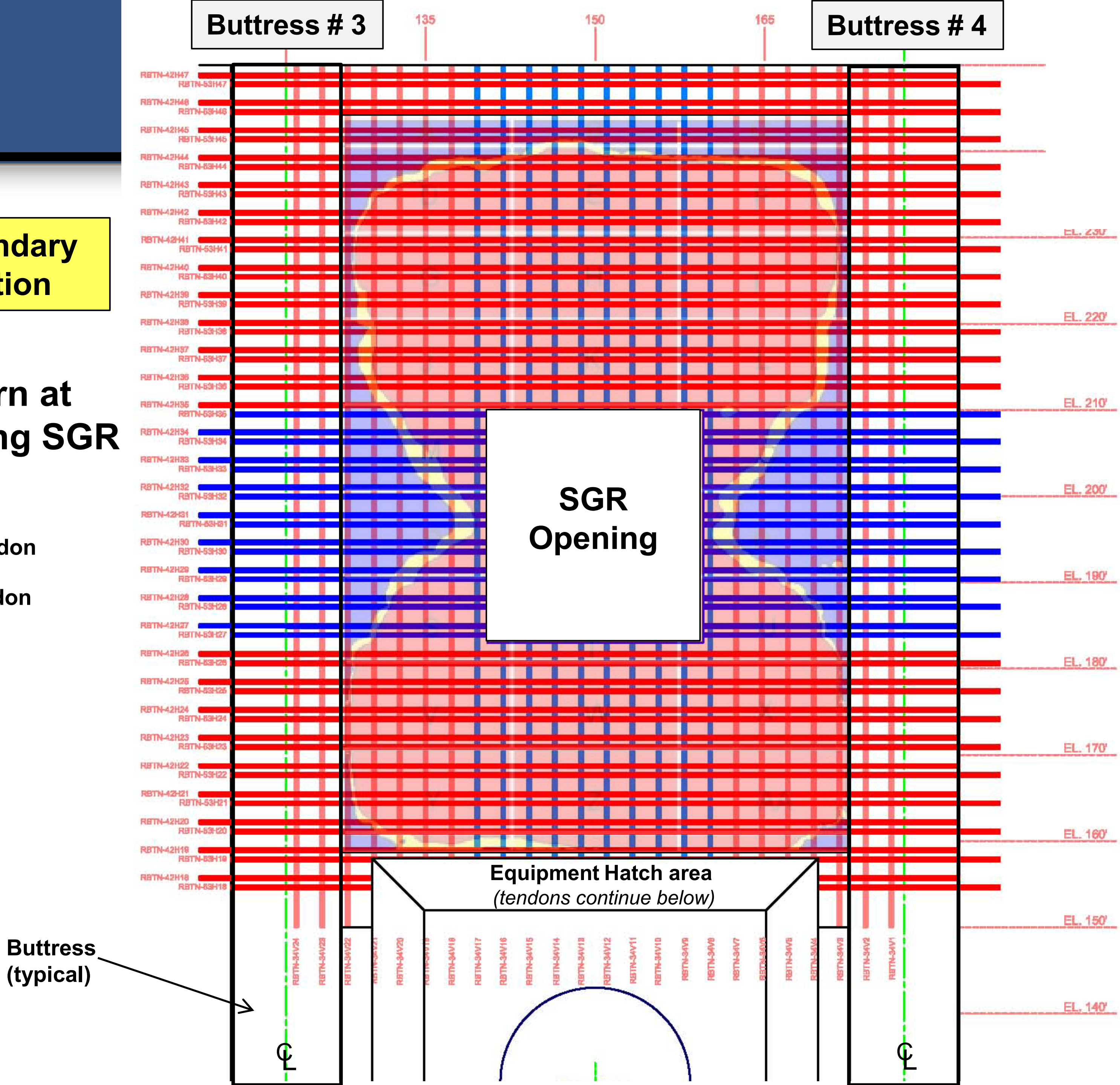
Tendon Pattern

Showing boundary of delamination

Tendon Pattern at Time of Cutting SGR Opening

- Energized Tendon (red)
- Removed Tendon (blue)



SGR Opening
Showing Delamination Boundary

SGR Opening Dimensions

@ Liner
23’ 6” x 24’ 9”

@ Concrete Opening
25’ 0” x 27” 0”

Root Cause Analysis
Failure Modes

- 75 potential Failure Modes considered
- Grouped into 9 categories:
  - Containment Design & Analysis
  - Concrete Construction
  - Use of Concrete Materials
  - Shrinkage, Creep and Settlement
  - Chemically or Environmentally Induced Distress
  - Concrete – Tendon – Liner Interactions
  - SGR Containment Cutting
  - Operational Events
  - External Events

Root Cause Analysis
Failure Modes (continued)

- 67 Failure Modes were refuted by PII
  - Remaining 8 Failure Modes were combined for Root Cause Analysis (with 3D Fracture Analysis and Various Special Tests) to determine their significance

- Failure Mode categories refuted in whole:
  - Concrete Shrinkage, Creep, & Settlement
  - Chemical or Environmentally Induced Distress
  - Concrete - Tendon - Liner Interactions
  - Operational Events
  - External Events

Root Cause Analysis
Finite Element Analysis (FEA) Modeling Tools

- Existing industry analysis techniques predicted acceptable margin to delamination at CR3
- Investigation required new tools of progressively increasing complexity
  - NASTRAN
    - Linear-elastic model
    - Determined local conditions for input to Abaqus 3D
  - Abaqus 3D (180° model)
    - Evaluated local conditions and determined if damage resulted

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Root Cause Analysis
Finite Element Analysis Modeling Tools (continued)

- Final FEA model uses Abaqus Global Model
  - 360° Supermodel
  - Visco-elastic / non-linear model
  - Model includes individual tendons, rebar, liner, etc
  - Sub-models provide higher resolution of localized behavior

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Root Cause Analysis

Group 1 Failure Modes (FMs): Containment Design

CR3 Containment design features are acceptable for normal and emergency operations.

The following failure modes apply to the specific evolution of creating an SGR Opening at CR3.

- Failure Mode 1.1 – **Vertical and Hoop Stress**
- Failure Mode 1.2 – **Radial Tensile Stresses / Radial Reinforcement**
- Failure Mode 1.15 – **Design Analysis Methods for Local Stress Concentration Factors**

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Root Cause Analysis

Groups 2 & 3 FMs: Concrete Construction / Use of Concrete Materials

CR3 Containment concrete construction and materials meet design requirements, and are acceptable for normal and emergency operations.

The following failure modes apply to the specific evolution of creating an SGR Opening at CR3.

- Failure Mode 2.12 – **Strength Properties**
- Failure Mode 3.4 – **Aggregates**

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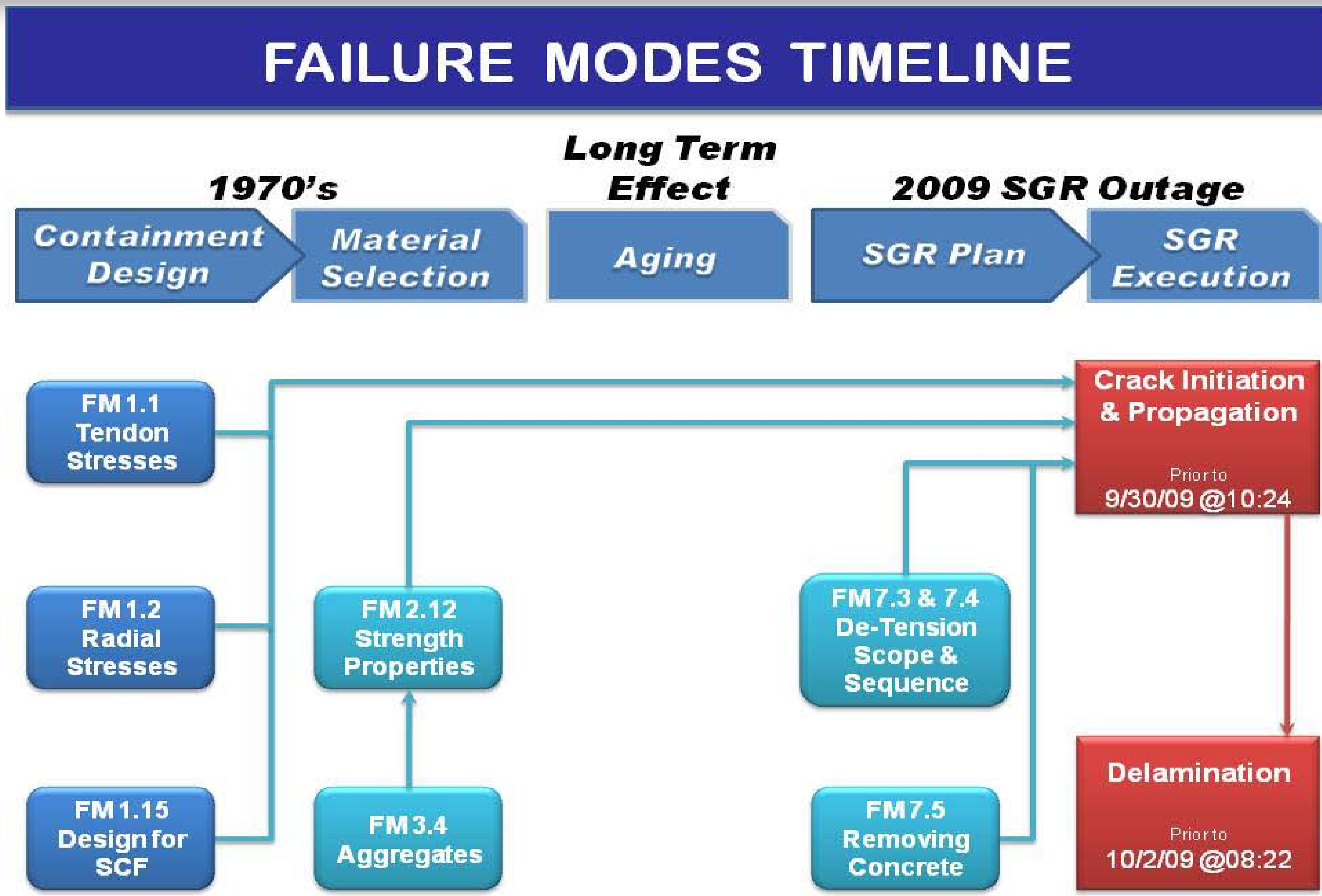
Root Cause Analysis

Group 7 FMs: SGR Containment Cutting Activities

The following failure modes apply to the specific evolution of creating an SGR Opening at CR3.

- Failure Modes 7.3 & 7.4 – **De-tensioning Scope and Sequence** *(Root Cause)*
  - The number and order of de-tensioned tendons resulted in redistribution of stresses in the containment wall that exceeded tensile capacity, initiating the delamination
- Failure Mode 7.5 – **Added Stress Due to Removing Concrete at the Opening**
  - Removal of concrete increased the stress in the remaining concrete, contributing to the final extent of delamination

Root Cause Analysis
Failure Mode Timeline



Root Cause Analysis

Summary

- **Root cause:** De-tensioning scope and sequence resulted in redistribution of stresses that exceeded tensile capacity
  - Could not have been predicted based on existing information and models at that time
- **Conclusion:** Delamination occurred as a result of outage activities to create an opening for steam generator replacement

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REPAIR APPROACH

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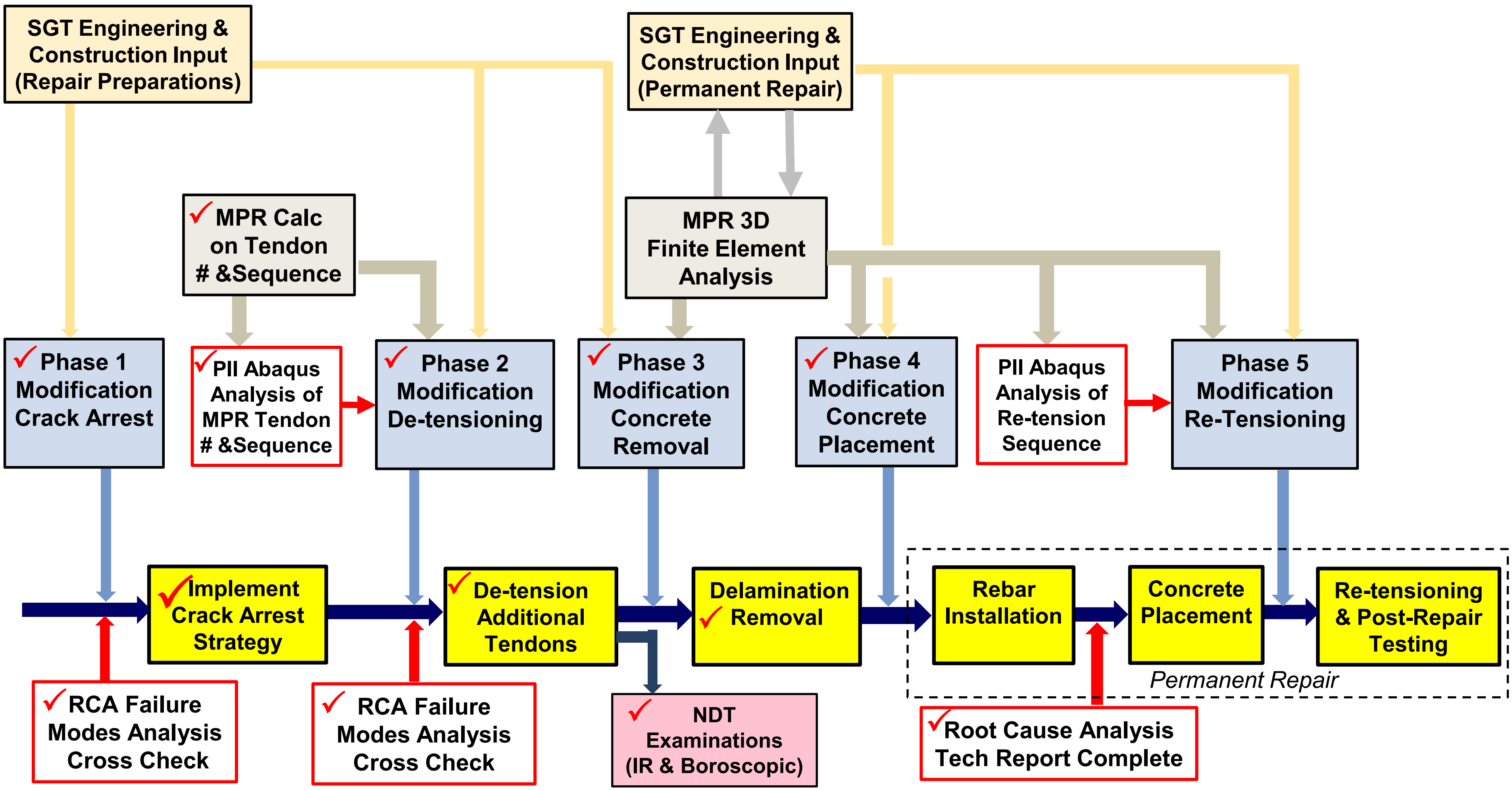
Repair Approach
Alternatives Considered

- **Use-as-Is** - *Rejected*
- **Anchorage Only** - *Rejected*
- **Cementitious Grout** - *Rejected*
- **Epoxy Resin** - *Rejected*
- **Delamination Removal and Concrete Replacement** - *Selected*

Repair Approach
Engineering & Field Work Flow



✓ Indicates Completed Task

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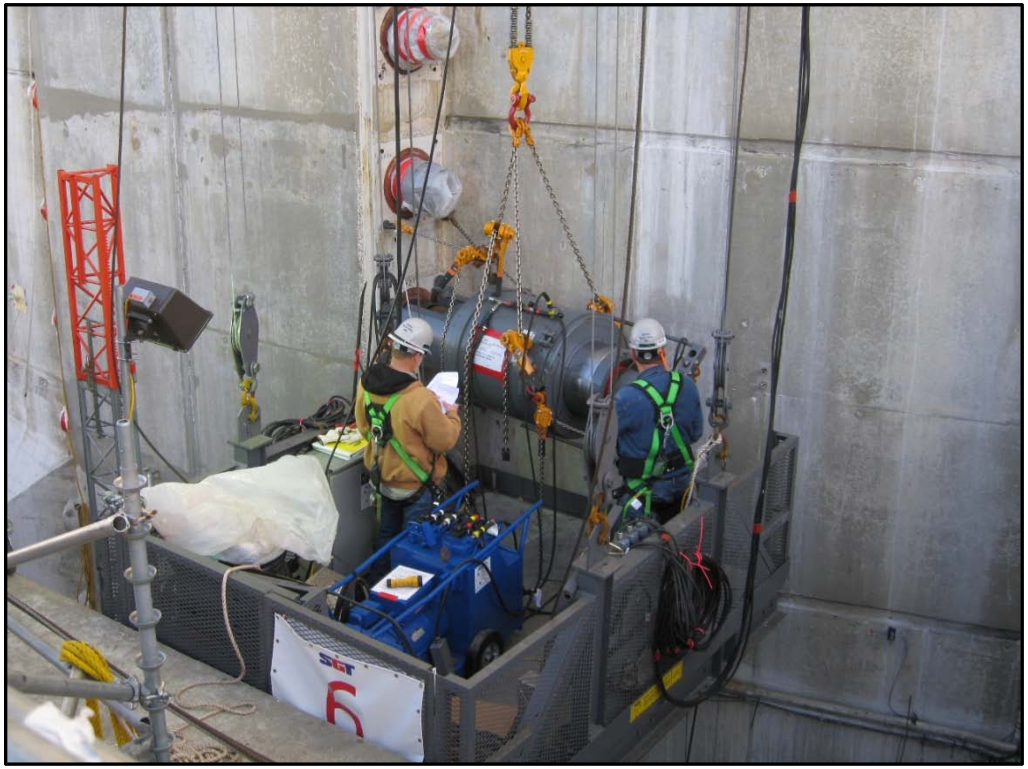
Repair Activities to Date
De-tensioning Scope & Sequence



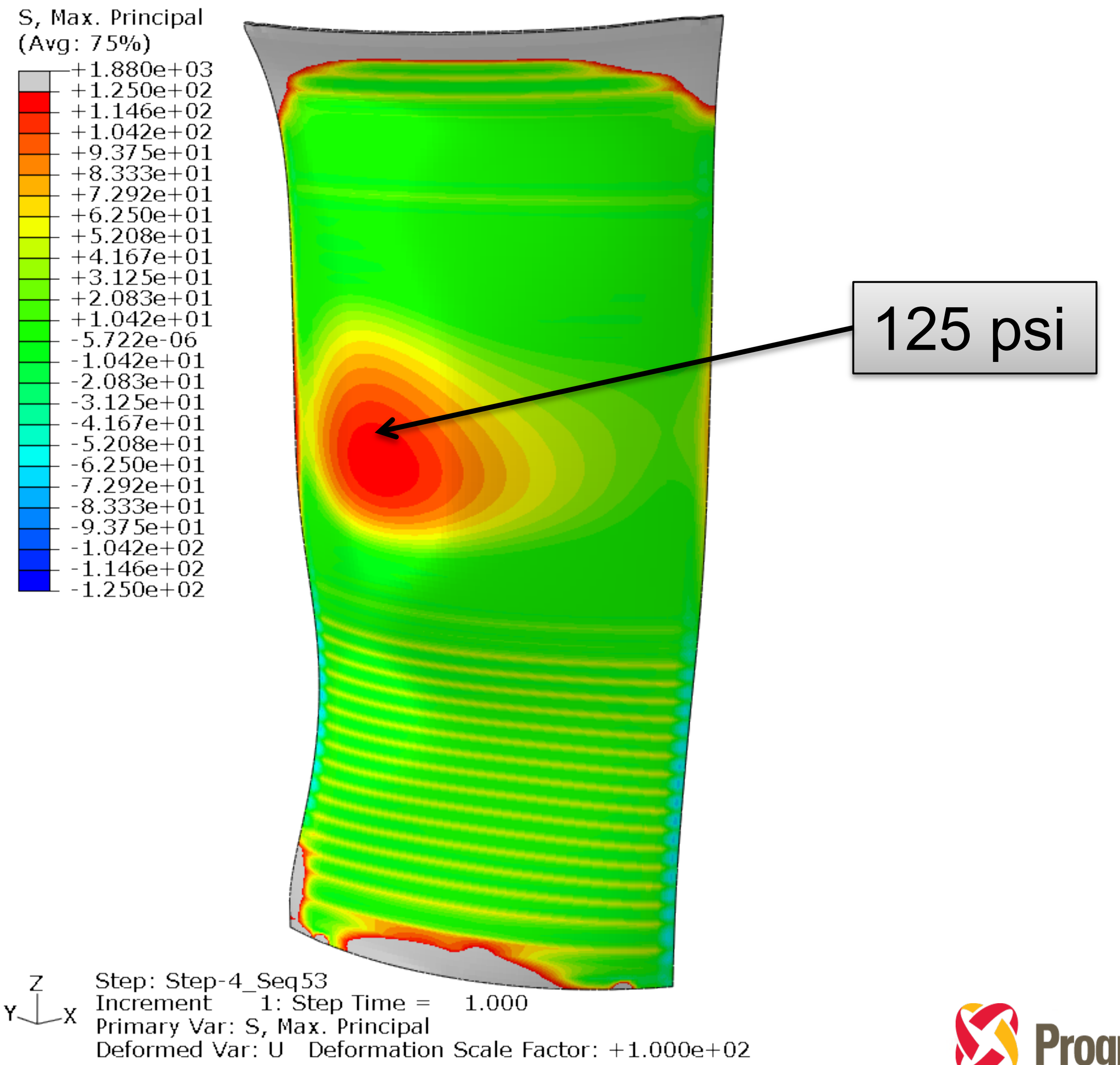
Repair Tendon De-tensioning

Sequence & Scope Refinement

- MPR analysis of de-tensioning scope and sequence
  - Analysis completed to ensure that restored concrete can be prestressed to meet design requirements
  - Stress analysis for the construction evolution
- PII cross reviews using RCA insights/models
  - Abaqus model to ensure no delamination in other areas during expanded de-tensioning scope
- Final Scope / Sequence (Option 10F)
  - 155 Horizontals (17 already de-tensioned as part of SGR)
  - 64 Verticals (10 already de-tensioned as part of SGR)

Repair Tendon De-tensioning

Option 10 F Results - Limiting Stress Check at Panel 2 – 3



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Repair Tendon De-tensioning

Final Scope & Sequence – Option 10 F

- Total of 11 De-tensioning Passes (3 vertical and 8 horizontal)
  - 1V (5 Sequences, 10 tendons)
  - 1H (7 Sequences, 20 tendons)
  - 2V (6 Sequences, 24 tendons)
  - 2H (8 Sequences, 18 tendons)
  - 3H (14 Sequences, 32 tendons)
  - 4H (14 Sequences, 35 tendons)
  - 5H (3 Sequences, 7 tendons)
  - 6H (4 Sequences, 10 tendons)
  - 3V (5 Sequences, 20 tendons)
  - 7H (4 Sequences, 10 tendons)
  - 8H (3 Sequences, 6 tendons)

Repair Activities to date
Delamination Removal

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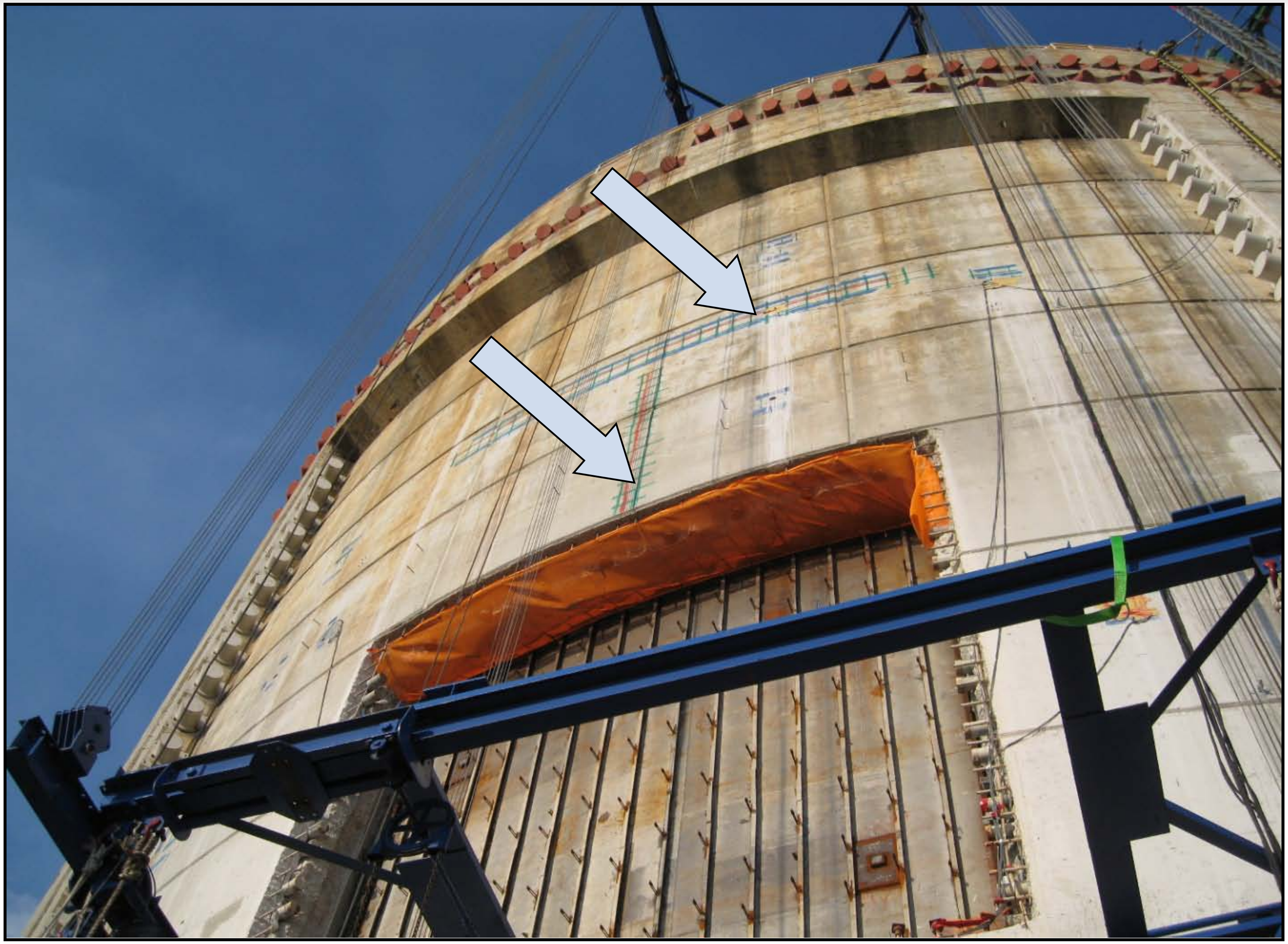
Delamination Removal

Stress Relief Cut



Delamination Removal
Hydro-Excavation in Progress

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Delamination Removal
Hydro-Excavation Completed

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Delamination Removal
Hydro-Excavation Completed

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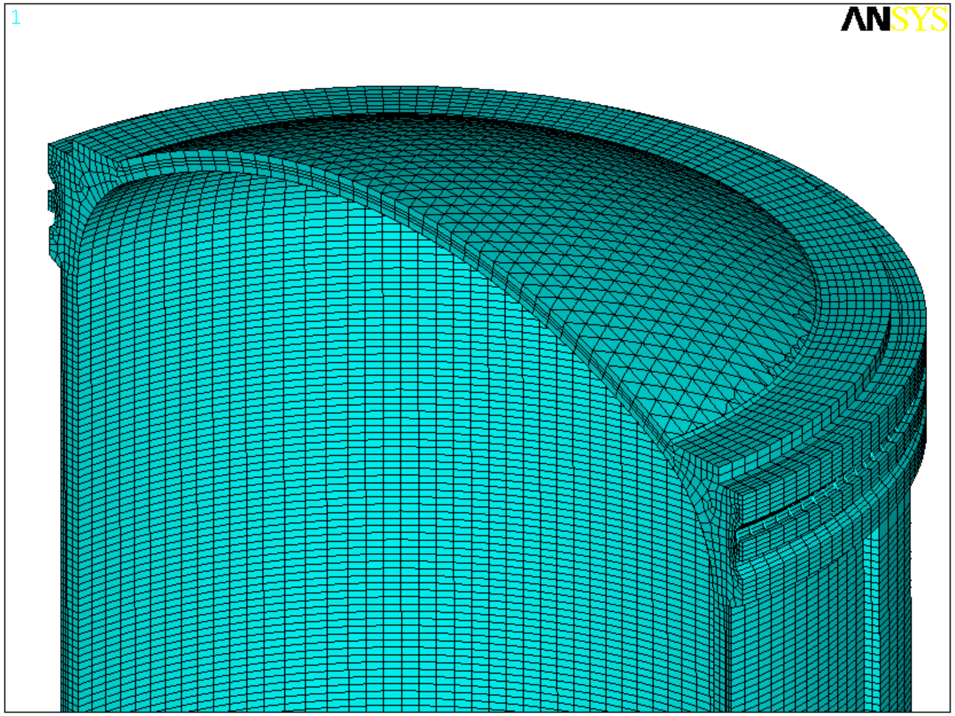
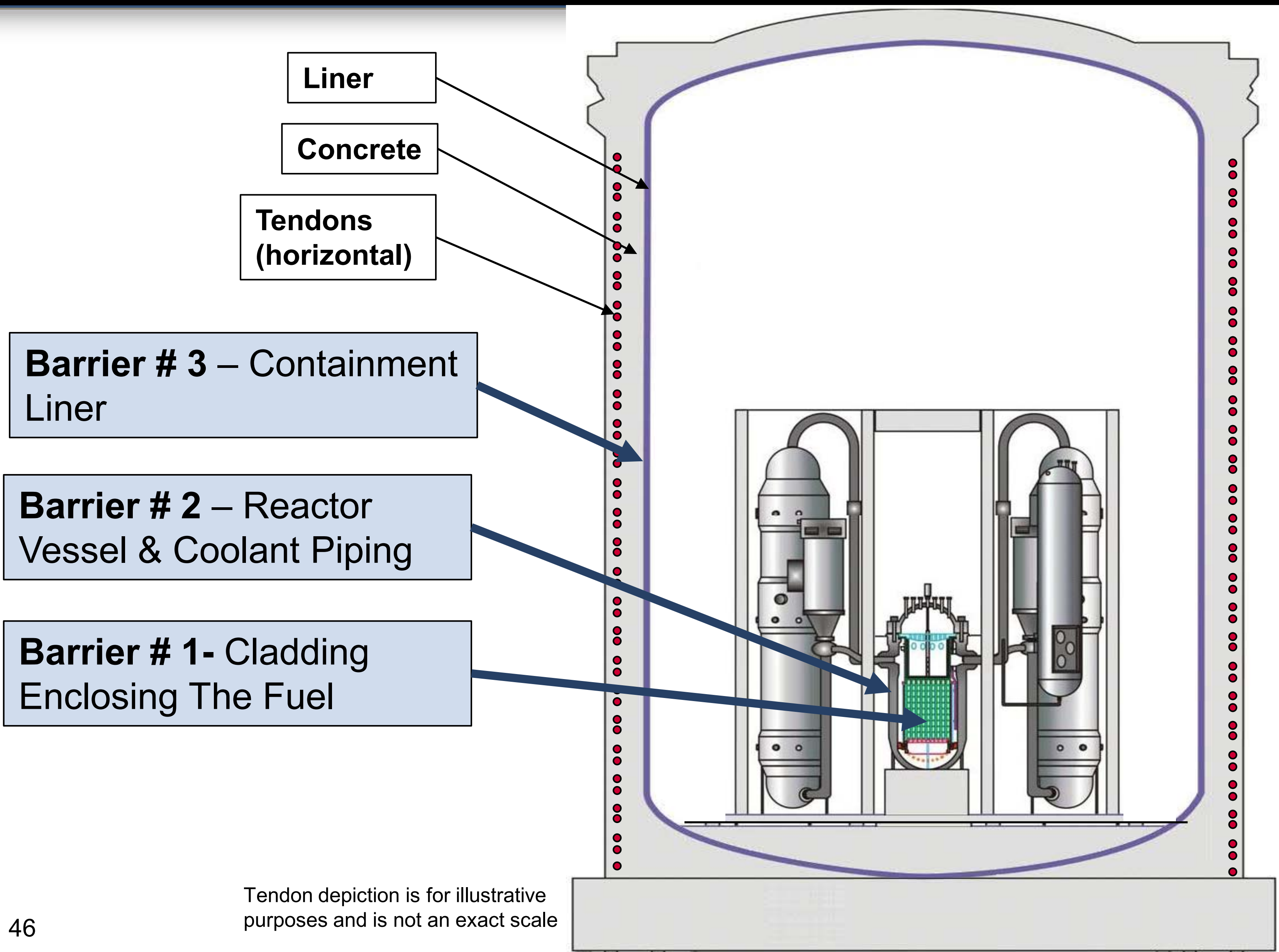
DESIGN BASIS ANALYSIS & 50.59 APPROACH



Fission Product Barriers

Simplified Schematic



Tendon depiction is for illustrative purposes and is not an exact scale

Design Basis
FSAR Design Loads

- **All Containment Design Loads Analyzed**
  - Live, Prestress, Dead Loads
  - Wind (110 mph@ 30' increasing to 179 mph @ 166'10")
  - Tornado Wind (300 mph)
  - Tornado Pressure (external pressure drop of 3 psig)
  - Tornado Missiles
  - Seismic (OBE – 0.05 and SSE – 0.10)
  - Temperature Loads
  - Accident Pressure (LOCA) (55 psig)
  - Accident Containment Spray Actuation Pressure (-2.5 psig)/ and (-6.0 psig effect on liner)

Design Basis
FSAR Structural Design Parameters

- **Containment Design Features Remain Unchanged**
  - Prestressed concrete cylindrical wall (shell), shallow dome roof
  - Carbon steel liner serves as fission product barrier
  - Liner anchored to concrete

- **Containment Design Basis Maintained**
  - Leak-tight structure to contain Design Basis LOCA
  - Elastic response to design basis loading to protect liner
  - Design loads and combinations based on operating, accident and applicable code requirements
  - Load factors applied to provide safety margin

Design Basis

FSAR Design Criteria / Codes

- **Restoration Area Design Requirements Satisfied**
  - Designed to ACI 318-63 for all load combinations
  - Load capacity of structure defined by strength and deformation limits
    - Strength - Upper limit of elastic behavior of effective load carrying materials
    - Deformation Limits – Liner strain limit of 0.005 and min yield
  - Reinforcement provided for resulting loads on structure
  - Utilized concrete compressive strength of 5800 psi based on 90 day strength tests in accordance with ACI 301-66 and ACI 318-63

- **Restoration Area Containment Codes (ACI) Satisfied**
  - ACI 318-63; Building Code Requirements for Reinforced Concrete
  - ACI 301-66; Specifications for Structural Concrete Buildings
  - ACI 505-54; Specification for the Design and Construction of Reinforced Concrete Chimneys

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Design Basis

FSAR Allowable Stress

- **Restored Containment Allowable Stress Satisfied**
  - Concrete shell prestressed to eliminate tensile stress due to membrane forces under design loads
  - Credit not taken for concrete tensile capacity in the hoop or vertical direction
  - Reinforcement added based on cracked section design per ACI 318-63, Part IV-B and ACI 505-54 where required
  - Reinforcement added to concrete sections with secondary bending tensile stress to limit crack width, spacing, and depth per ACI 505-54
  - Service load combination used working stress design per ACI 318-63, Part IV-A
  - **Liner strains and stress within limits for all design basis load cases**

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Design Basis
Tendon Forces

- Analysis uses higher Minimum Required Prestress force
  - Horizontal tendon minimum force raised from 1252 kips to 1435 kips
  - Vertical tendon minimum force raised from 1149 kips to 1500 kips
- Reset de-tensioned tendons to the original tendon force
- Predicted end of life values remain above new minimum values
  - Time dependent losses calculated account for: shrinkage and creep in concrete, and tendon wire relaxation

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Design Basis
Tendon Forces (continued)

- Higher Minimum Required Prestress force acceptable under 50.59 per NEI 96-07 (endorsed by Regulatory Guide 1.187) guidance as an input to the evaluation methodology
  - Minimum Required Prestress force previously removed from Tech Specs, by amendment, and placed under control of 50.59
  - No increase in probability of malfunction since ISI Code requirements verify actual force and maintain them above predicted (and minimum) values
  - Not a design basis limit for a fission product barrier; the values are not in the FSAR

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Design Basis

Method of Evaluation for the Repair

- **Method of Evaluation has not changed**
  - Finite element analysis (FEA) used in both original design analysis and restoration analysis
- Original Design Analysis
  - “Method of evaluation” is comprised of a combination of analysis techniques
  - Kalnins finite differences analysis for uniform shell of revolution
  - Finite element analysis used for effect of discontinuities on the shell
- Restoration Analysis
  - ANSYS finite element analysis model representing the integrated containment structure used for the effect of the restored area (new discontinuity) on the structure
  - Consistent with treatment of SGR construction openings throughout the industry under 50.59

Design Basis

Method of Analysis 50.59 Approach

- 50.59 Evaluation Approach
  - Widely used finite element analysis tool applied under 10 CFR 50 Appendix B
  - Benchmarked against original analysis predicted deformations for Structural Integrity Test with excellent agreement
  - Accepted per guidance in NEI 96-07 as ‘conservative or essentially the same’

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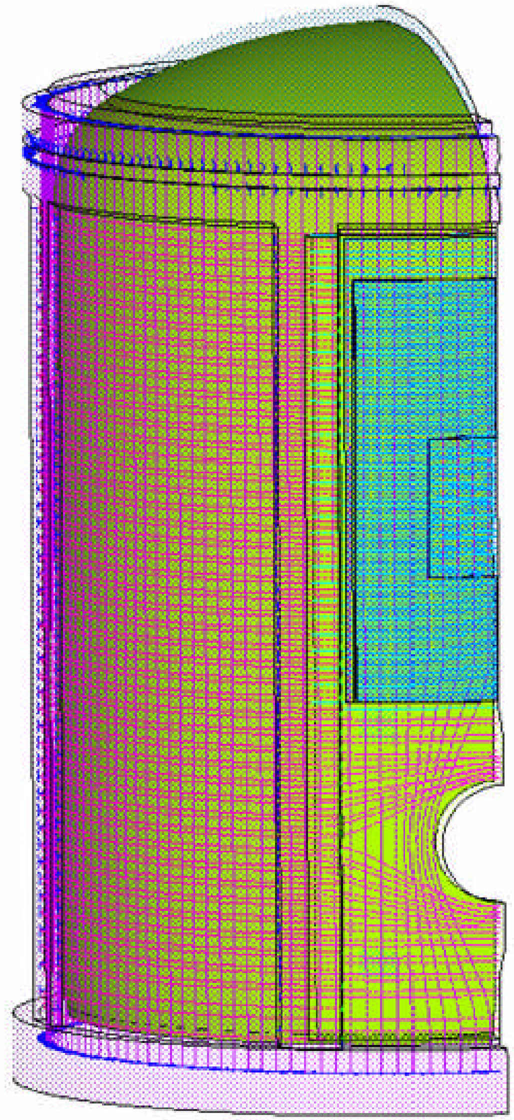
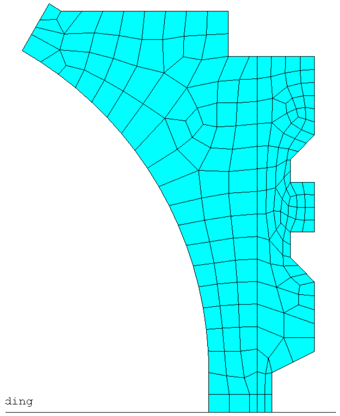
MPR Design Basis Analysis

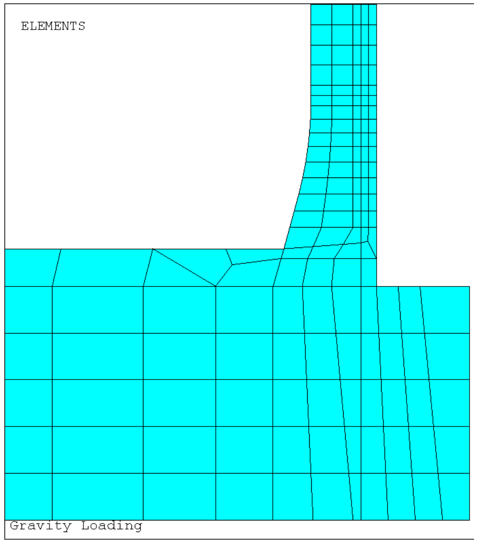
Finite Element Analysis (FEA) Model Details



Composite FEA Model



Mesh at Ring Girder connection



Mesh at Foundation connection

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Design Basis

Restoration Area (Bay 3 – 4) – Addressing Hairline Cracks

- **Hairline cracks identified after delamination removal will be repaired or will meet design and code requirements**
  - Repaired - In areas above and below the SGR opening, additional concrete was removed to liner
  - Repaired - In areas adjacent to SGR opening, localized concrete removal and replacement with concrete is planned
  - Other remaining reinforced areas (in Bay 3-4) will meet design and code requirements
    - Analysis verifies observed cracks (< 0.005”) close and stress redistribution is acceptable

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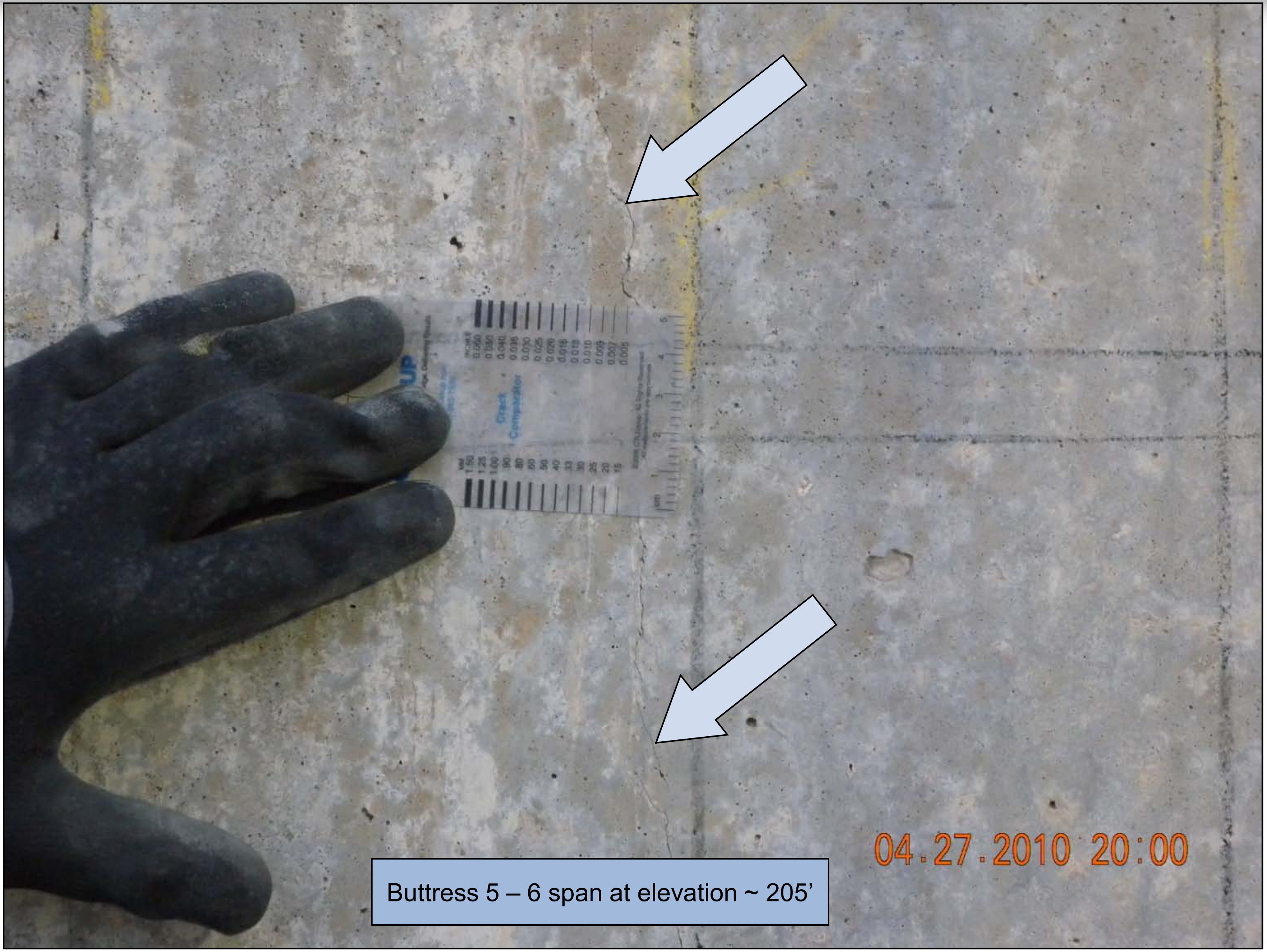
Design Basis

Hairline Cracking Outside of Restoration Area

- Vertical hairline cracking was identified in de-tensioned areas of the containment cylinder outside Bay 3 - 4
  - Observed after expanded de-tensioning
  - Located near some vertical tendon locations
  - Width < 0.010” (as measured at surface and within concrete core holes)

- In all areas of the containment cylinder still tensioned - no observations of vertical hairline cracking during detailed inspections

Design Basis
Hairline Cracking Outside of Restoration Area



Buttress 5 – 6 span at elevation ~ 205’

Design Basis Analysis

Hairline Cracking Outside Restoration Area – Design/50.59 Approach

- **Even without hoop tensile capacity in these areas, design basis satisfied**
  - Concrete behaves as an un-cracked section
  - For design loads
    - Concrete remains in compression
  - For factored load case - $1.5P + T_a$
    - Concrete has tensile stresses due to liner expansion
    - For areas with concrete tensile stresses, prestressed steel and reinforcing steel to be evaluated consistent with ACI 318-63 and ACI 505-54 requirements
  - **Liner strain and stress acceptance criteria is met for all load cases**
- **Expected to be acceptable under current licensing basis**

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Design Basis

Hairline Cracking Outside Restoration Area – Other Considerations

- ASME Section III Division 2, Article CC-6000, 'Structural Integrity Test (SIT) of Concrete Containments' fully anticipates that cracks will exist in containments prior to the SIT

- For the performance of a Structural Integrity Test
  - Article CC-6225 only requires crack measuring devices to be capable of measuring a minimum width of 0.005"
  - Article CC-6350 only requires mapping of cracks that exceed 0.010"
  - Article CC-6530 requires that a summary and discussion of crack measurement be included in the Test Report

Design Basis
Hairline Cracking Outside Restoration Area - Cause

- Stress Reversal - Initial Tensioning to De-tensioning
  - After initial tensioning - the steel liner, reinforcement and tendon conduits increased in compressive elastic strain due to concrete creep
  - After de-tensioning - the steel liner, reinforcement and tendon conduit elastic strains reversed, but the concrete did not due to creep
  - Result was tensile stress in the concrete at the vertical tendons that exceeded tensile capacity

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Design Basis

Hairline Cracking Outside Restoration Area – Cause (continued)

- Updated PII model (Abaqus) analysis supports hairline cracking development
  - Model executed both with and without the liner, reinforcement and tendon conduits for the de-tensioning sequence
  - Vertical hairline cracks do not develop when these steel components taken out of model
- Contributor
  - Portion of volume change in concrete due to concrete shrinkage

Summary of 50.59 Approach

- **Final repair condition expected to be acceptable under 10 CFR 50.59**
  - FSAR design basis loading conditions will be satisfied
  - FSAR design code requirements will be met
  - Changes to analysis inputs accepted by 50.59 evaluation
  - Analysis consistent with the existing FSAR described Method of Evaluation

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REMAINING REPAIR & VALIDATION ACTIVITIES

Remaining Repair & Validation Activities

Mock-up Testing – Reinforcement Installation

Remaining Repair & Validation Activities

Mock-up Testing - Soaking

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Remaining Repair & Validation Activities

Instrumentation Installation

Strain Gauge installed in the Mock-up

Remaining Repair & Validation Activities
Instrumentation Installation (continued)

Strain Gauge (see arrows) & Temperature Monitors installed on the Containment wall

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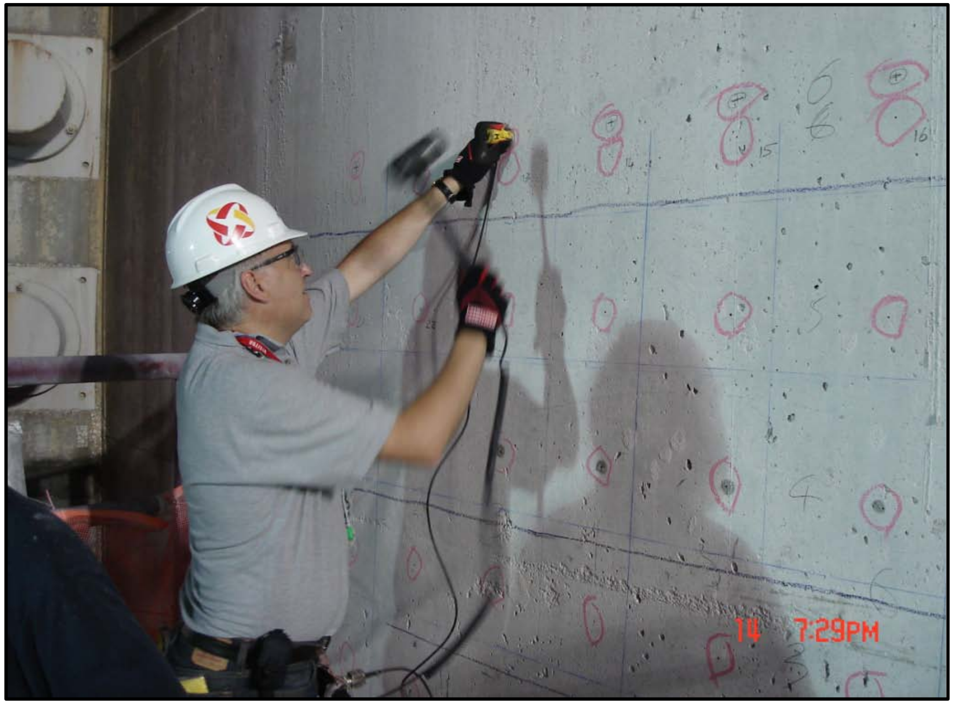
Remaining Repair & Validation Activities

Concrete Batch Plant

POST-MODIFICATION TESTING



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Post Modification Testing

Pressure Test

- Integrated Leak Rate Test (ILRT) required per ASME XI code
  - For removing / replacing liner in SGR opening
- Plan to perform a Structural Integrity Test (SIT)
  - SIT is normally a one-time initial construction structural test
  - Test intent: measures structural integrity and deformation at 1.15 Peak Design Pressure (63.3 psig)
  - SIT will be followed by ILRT

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Post Modification Testing
Monitoring Plans

- Re-tensioning Monitoring Plans
  - Strain gauges during re-tensioning
  - Additional visual examinations will be performed after re-tensioning
  - Non-destructive testing (Impulse response) will be performed after re-tensioning
- Pressure Test Monitoring Plans
  - Strain gauge measurements
  - Deformation measurements
  - Visual examinations will be performed in conjunction with system pressure test in accordance with ASME XI, Subsection IWL

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Other Topics

Other Topics
Dome

- Containment Dome Condition Assessment
  - Comprehensive IR scans complete
  - Core bores performed specifically to verify IR scanning results
  - Final assessment of all data being performed by Architect Engineer (AE)
  - Outcome will verify design basis continues to be met or will be restored

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Other Topics
Liner Bulges

- Containment Liner Bulges
  - Liner bulges between vertical stiffeners (18” apart)
  - Extent of condition bounded by laser scanning and visual inspections
  - UT measurements have confirmed no generalized corrosion or liner wall thinning
  - Analysis is expected to verify no impact, and continued conformance to liner design requirements

Summary

- Containment original design and construction are acceptable for normal and emergency operations
- Planned repair approach meets design basis requirements and code requirements
- The final repair condition is expected to be acceptable under 10 CFR 50.59
- Containment will be fully capable of meeting its design safety function upon completion of repairs and testing

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Questions