Shield Building Crack Investigation and Root Cause Presentation

FENOC

FirstEnergy Nuclear Operating Company

Davis-Besse Nuclear Power Station

August 9, 2012

Agenda

- **Introduction**
  - **Barry Allen**, Site Vice President – Davis-Besse
- **Shield Building Condition Evaluation**
  - **Ken Byrd**, Director – Site Engineering
- **Shield Building Root Cause Investigation**
  - **Jon Hook**, Design Engineering Manager
- **Shield Building Corrective Actions**
  - **Ken Byrd**, Director – Site Engineering
- **Closing Comments**
  - **Barry Allen**, Site Vice President – Davis-Besse

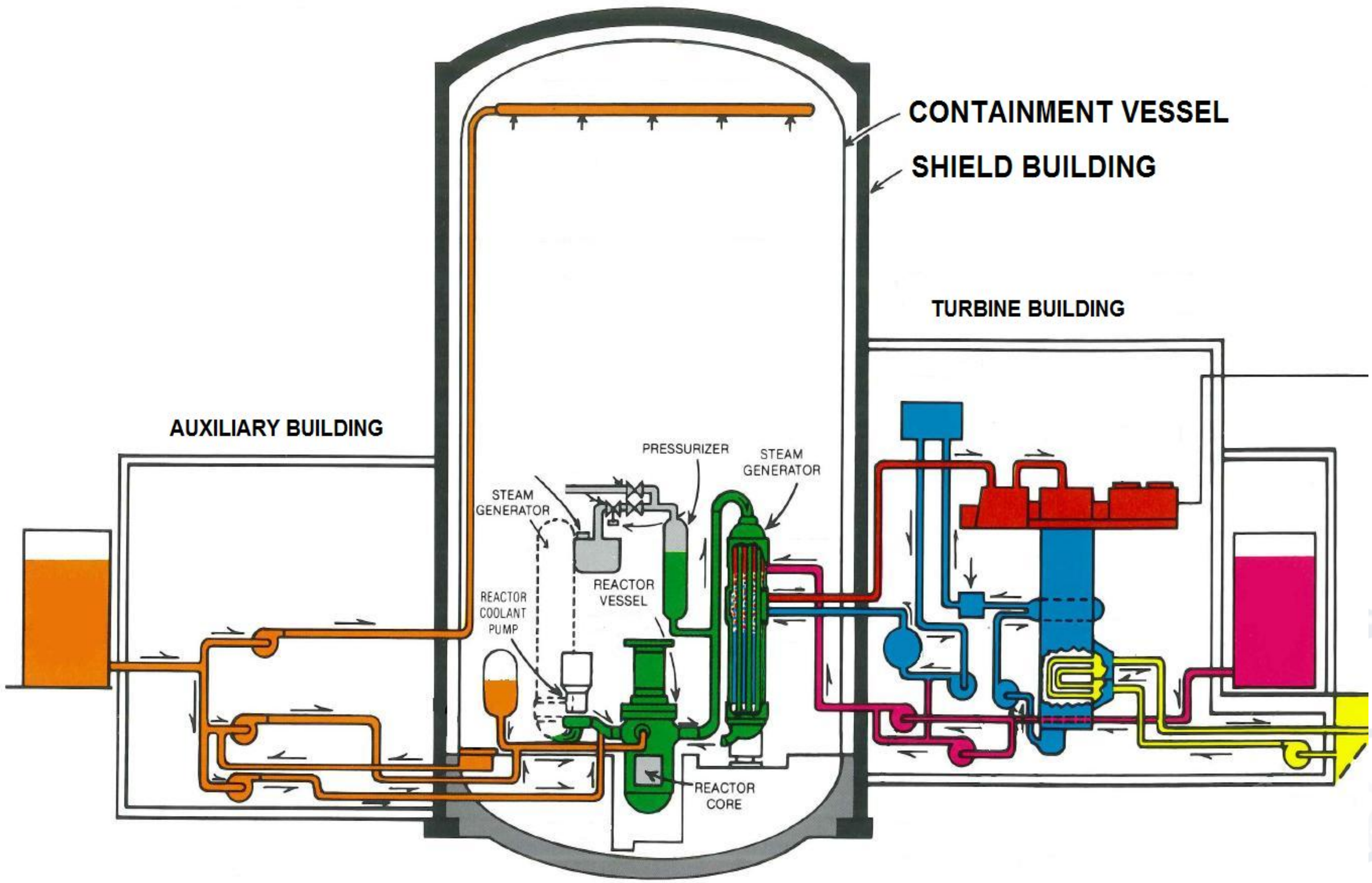
Shield Building Condition Evaluation

Ken Byrd,
Director - Site Engineering

Background

- Mid-cycle outage to replace Reactor Pressure Vessel Head
- Access opening required in concrete Shield Building
- Opening dimensions
  26.5’ wide X 35.5’ high
- Hydro-demolition method employed
- Previous opening in 2002 used similar method
- Size and orientation different than in 2002

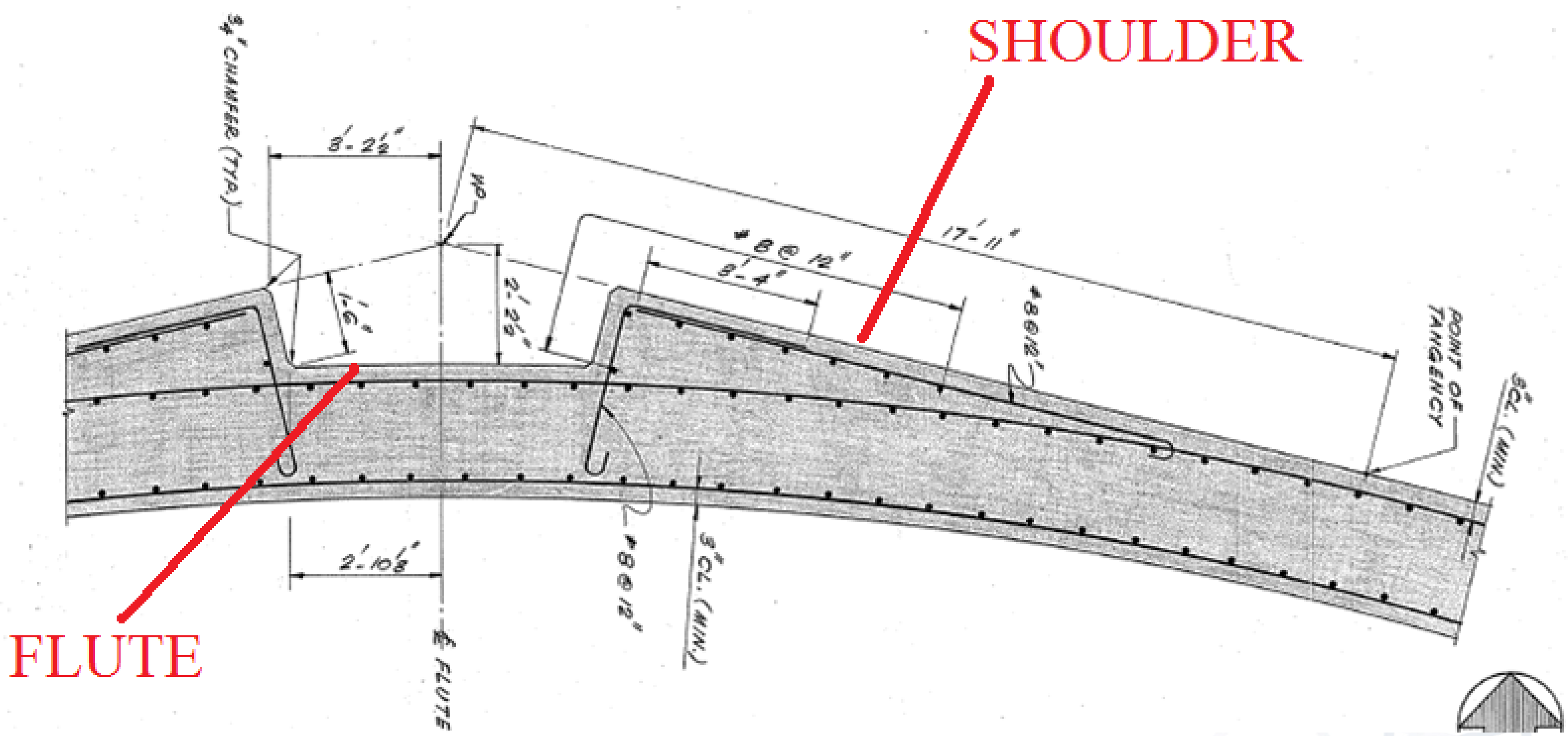
Shield Building



Shield Building

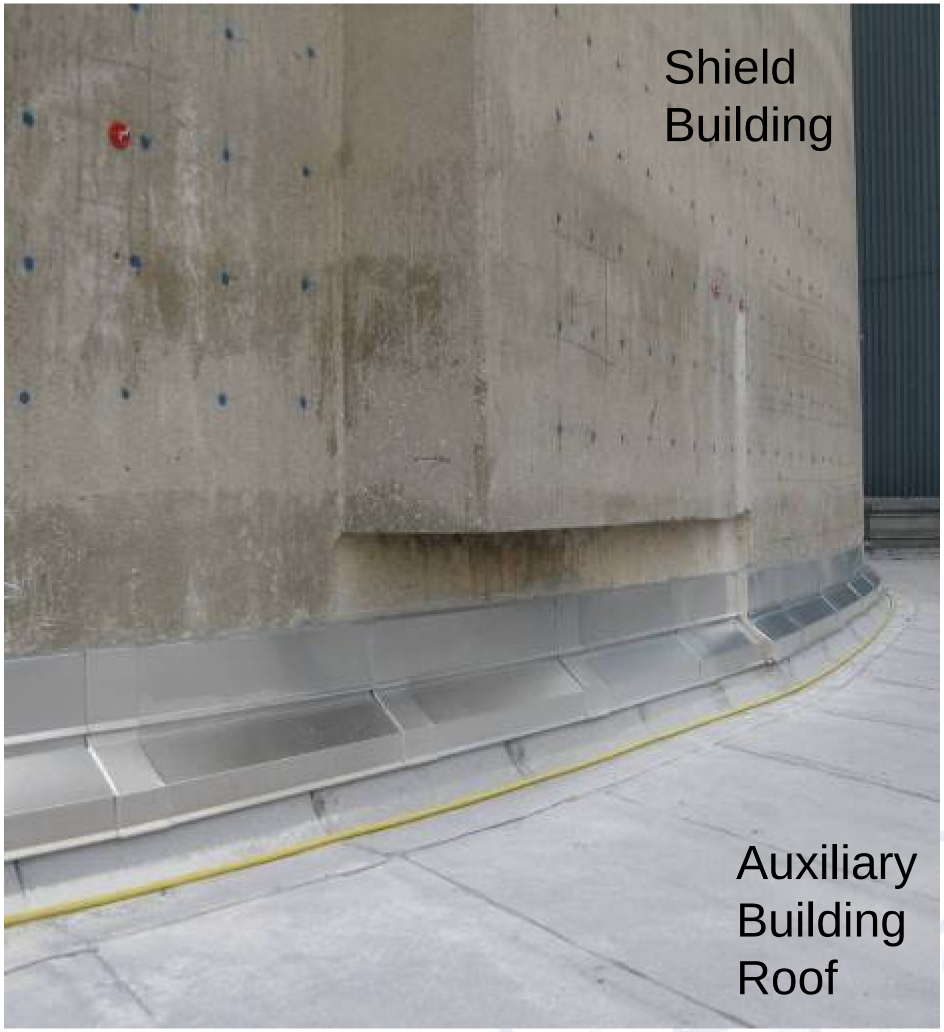
- **Purpose of Shield Building**
  - Biological shielding
  - Environmental protection for Containment Vessel
  - Controlled release of Annulus atmosphere under accident conditions

Shield Building Flutes/Shoulders



Shield Building Flute Shoulders

- **Architectual Feature**
  - The flute shoulders are a part of the Shield Building; concrete for shoulders and building shell was placed concurrently
  - Evaluation of structural capacity of Shield Building does not credit flute shoulders
  - Evaluated as a dead load in structural analysis



Discovery

- Cracking found on October 10, 2011, during hydro-demolition
- NRC resident notified
- Condition Report written
- Restraint on restart established
- Team of experts to investigate issue mobilized

Investigation

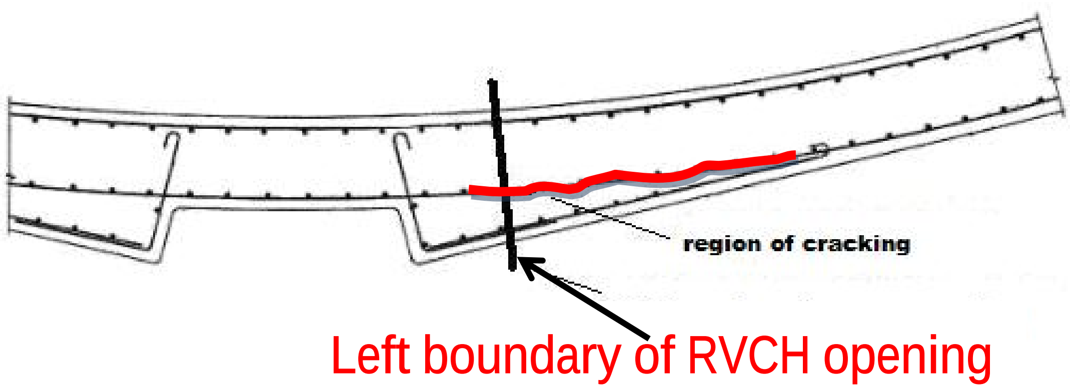
- **Impulse Response (IR) testing methodology used to investigate extent of crack**

Investigation, *continued*

- **Core bores taken to validate IR testing results, to determine crack depth and to determine crack width**
- **Investigation results were documented in the corrective action process, and the NRC was promptly notified of findings**

Summary of Shield Building Condition

- **Cracking is generic to flute shoulder regions and can be assumed to be present at any elevation in the flutes shoulders; cracking was observed to be more prevalent on the south side of the building**
- **Cracks are located near the outer reinforcing mat; no cracking observed in interior reinforcing mat**



Summary of Shield Building Condition, *continued*

- **Cracking exists at the top 20 feet of the Shield Building wall outside the flute shoulder region**
- **Two small regions adjacent to the Main Steam Line penetration have similar cracks**
  - The extent of these regions is localized and unique to these particular penetrations
- **Cracks are very tight**

Structural Evaluation

- **Original Shield Building design**
  - Building designed and constructed with significant reinforcement
  - Significant margin under design basis loads
  - Design Basis
    - Earthquake 6–6.5 on Richter magnitude scale
    - Tornado winds of 300 miles per hour
    - Tornado depressurization and missiles
- **Impact of laminar cracks on original design**
  - Potentially reduce the bond strength between concrete and reinforcing steel
  - Cracks of little impact unless reinforcing bars are spliced in the cracked region
  - Shield Building remains adequate for safety function

Bounding Building Analysis

- **Bond strength of reinforcement lap splices with adjacent cracks could not be quantified and were conservatively treated as non-existent in analysis**
- **Calculations performed to provide a bounding evaluation of the effect of cracking**
  - Vertical and horizontal reinforcement assumed ineffective for strength in flute shoulders, two steam line penetration areas and in regions at top of shield building.
- **Any bond between reinforcement and concrete in crack regions provides additional margin**

Summary of Calculation Results

- **Shield Building meets strength requirements**
- **Any bond between the concrete and reinforcement in cracked regions would be an additional margin of safety**
- **Shield Building is capable of performing all safety functions with margin**

Shield Building Root Cause Investigation

Jon Hook,
Manager - Design Engineering

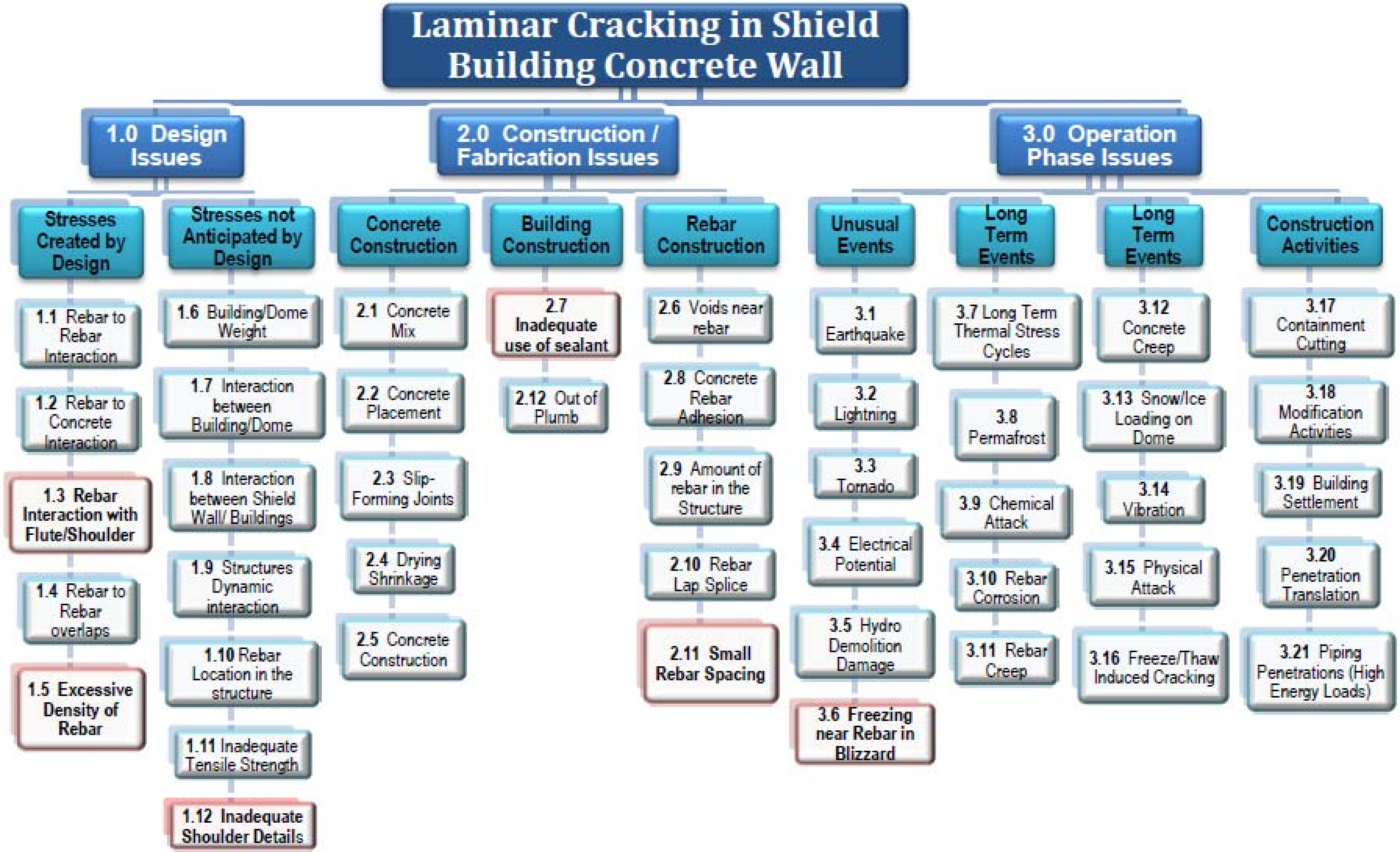
Root Cause Overview

- Established independent team of experts
- Established a comprehensive Failure Modes Analysis
- Investigated the design, materials, construction methods, and present day operational conditions
- Performed concrete tests
- Performed analyses
- Identified root cause

Root Cause Overview, *continued*

- **Performance Improvement International (PII)**
  - The PII team are experts in root cause investigation
  - Team consist of Professional Engineers, PhDs, and university professors
  - Performed more than 500 root causes
- **Industry experts as well as assistance from FENOC Engineering**
- **Followed our established and proven root cause process**

Shield Building Root Cause Fault Tree



Shield Building Concrete

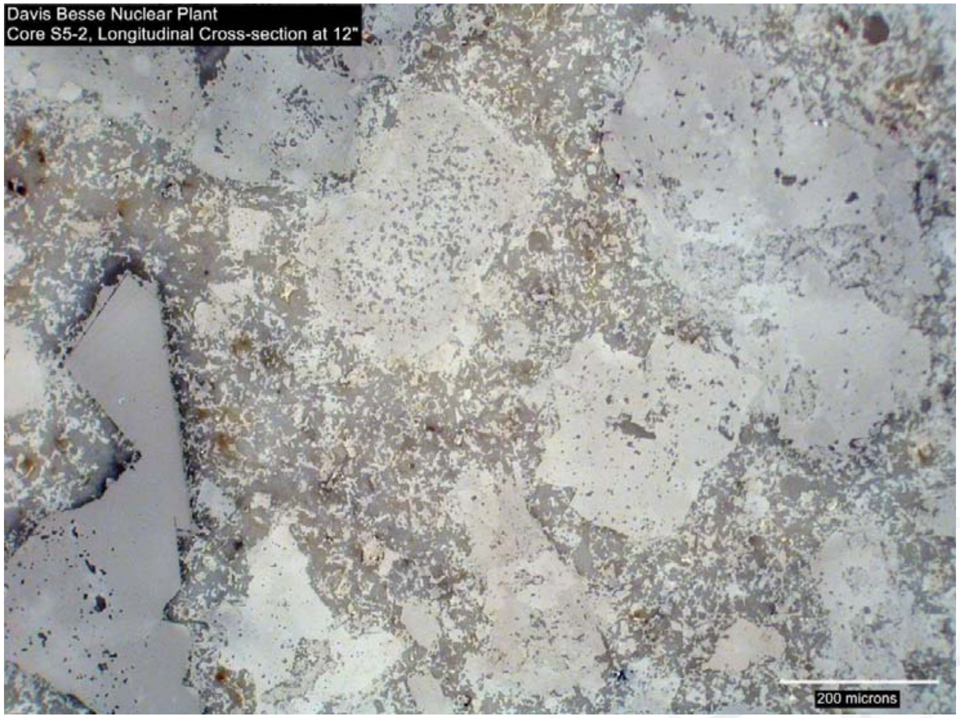
- **Concrete was subjected to a series of tests**
- **36 concrete cores from the Shield Building tested**
- **Concrete properties were determined**
- **Test results confirmed the concrete is sound and can be ruled out**

Shield Building Concrete, *continued*

- **Typical concrete sample showing the laminar crack sheared the coarse aggregate**
- **Therefore, laminar crack occurred after the concrete achieved it strength**

Shield Building Concrete, *continued*

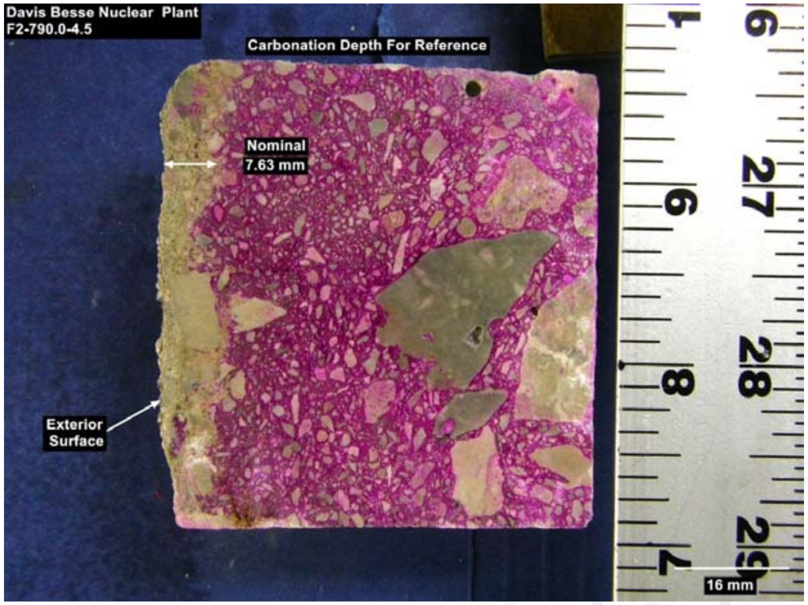
- **No evidence of micro cracks**
- **No signs of cyclic load mechanism**
- **No cyclic freeze-thaw mechanism**
- **No indication of fatigue or age related events**



Magnification at 100 Times

Shield Building Concrete Tests, *continued*

- **16 samples were tested for carbonation**
  - Average depth of carbonation is 8.57 mm (0.337 inches)
  - Maximum average 11.7 mm (0.46 inches)
  - Typical for concrete 40 years old



Shield Building Concrete - Conclusion

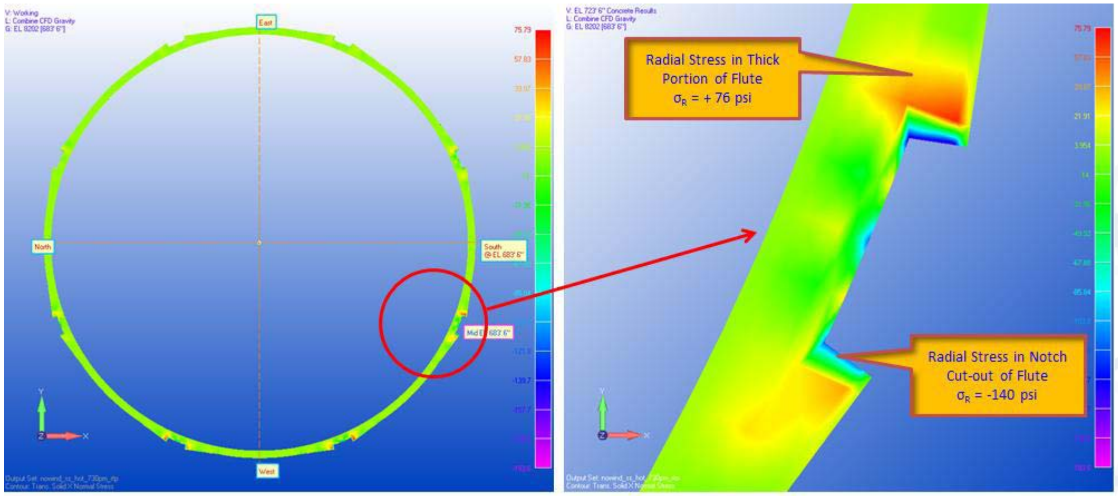
- **Crack passed through the course aggregate**
  - Strong bond between the cement paste and the coarse aggregate; therefore, initial placement concerns can be ruled out
  - Large tensile force is required to initiate the crack
- **No micro cracks identified that would indicate freeze-thaw or cyclic events**
- **Chemical properties, carbonation, corrosion, etc, were all acceptable**
- **Based on the above, concrete can be ruled out as an initiating or contributing cause**

Shield Building Configuration

- **Cracking is predominantly located in the shoulder areas, the top 20 feet of the Shield Building, and near the Main Steam Line penetration block-outs; cracking concentrated on southern exposures**
- **Shoulder areas are regions of discontinuity**
- **Limited radial reinforcing steel in the shoulder areas**
- **High rebar density (6” spacing) located at the top of the Shield Building and around the Main Steam Line penetration construction block-outs**
- **Conclusion**
  - There is a correlation between the crack locations and the physical layout of the reinforcing steel that needed to be investigated

Shield Building Analytical Analyses

- **Numerous computer analyses were performed for normal design conditions**
  - Self weight, wind loads
  - Thermal analyses (summer hot and winter cold conditions)
  - Fujita Category 2 tornado
- **Stresses were significantly below the normal tensile capacity of the concrete**



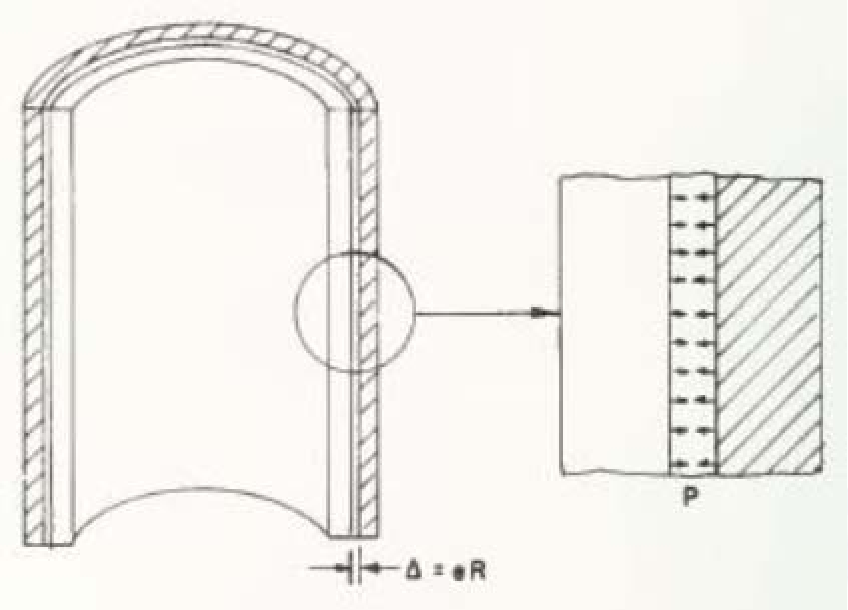
Overall View @ EL 683' 6"   Close-Up View @ EL 683' 6"

Shield Building Analytical Analyses, *continued*

- **Analysis showed:**
  - Design stresses can not initiate the laminar crack
  - Significant stresses beyond what is normally analyzed would be required to crack the concrete
- **Investigate industry experience for similar conditions**

Industry Experience with Laminar Cracks

- **Ontario Ministry of the Environment study on 50 above ground water tanks in Ontario**
- **Water migrated into the concrete from the inside**
  - Inner layer of the wall freezes and expands
  - Outer layer of wall contracts
  - Creates high radial stress
  - Results in laminar cracking



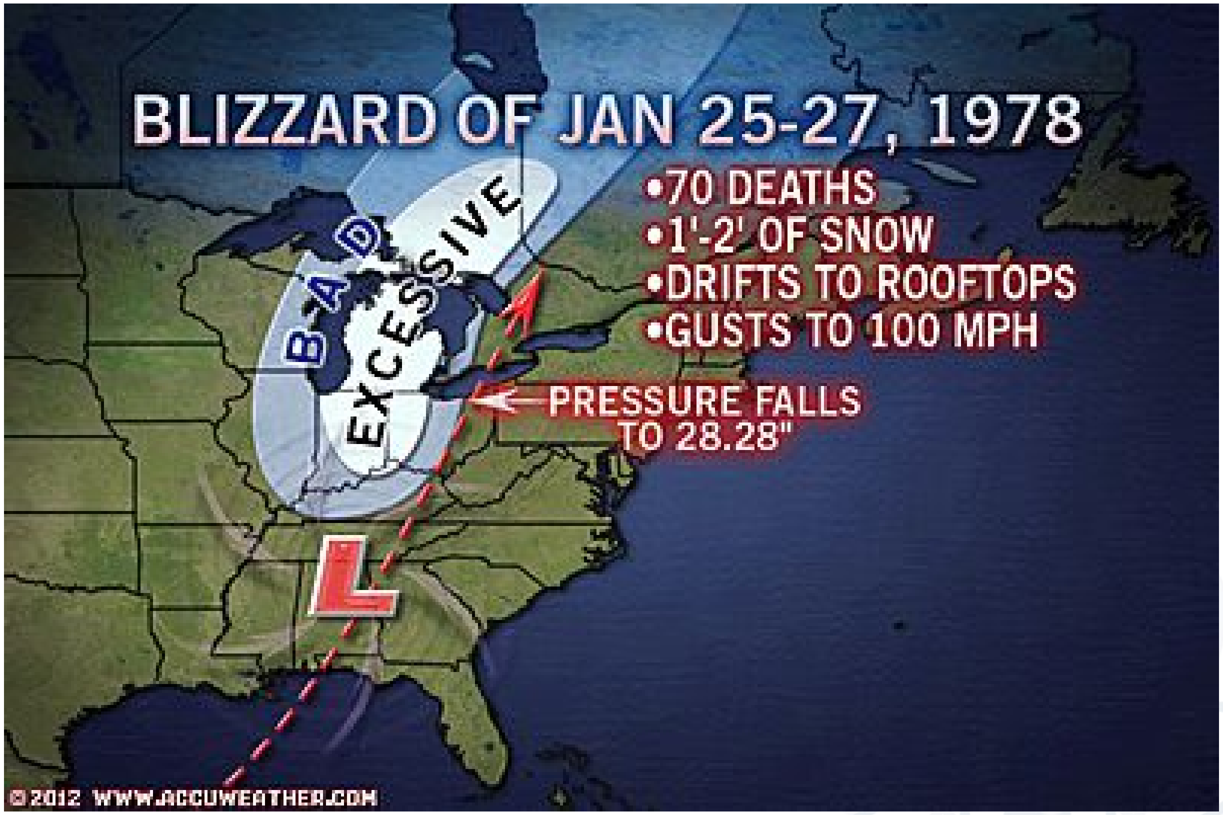
- **Conclusion: Laminar cracking as a result of water freezing is a real potential**

Shield Building Investigation into Water Intrusion/Freezing

- The effects of moisture intrusion and sub freezing temperatures was investigated as a possible cause
- The review of severe environmental conditions that the plant was exposed to was performed
- The most significant event recorded at the site and also in Ohio history was the storm of January 25-27, 1978

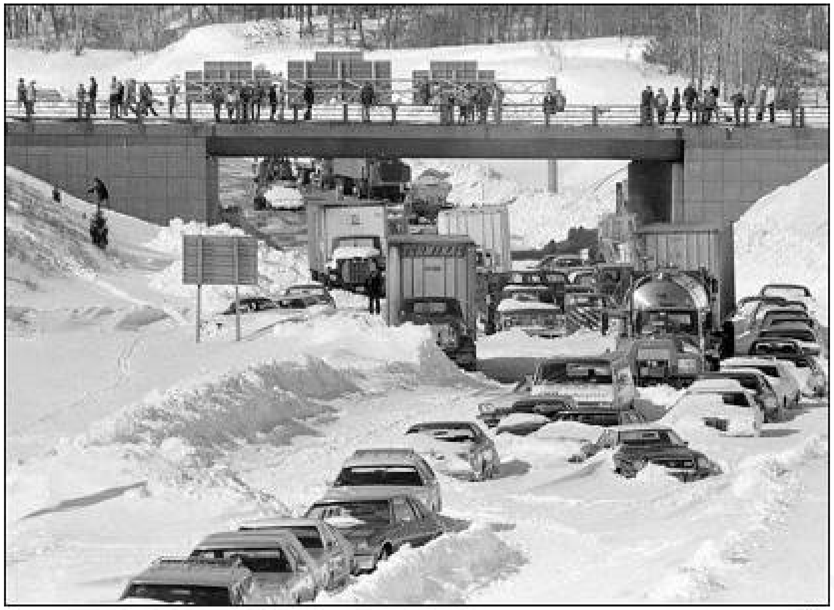
Moisture Intrusion and Low Temperatures

- **January 25-27, 1978, was the worst in terms of:**
  - Moisture
  - Winds
  - Temperature
  - Duration
  - Pressure



Moisture Intrusion and Low Temperatures, *continued*

- **Scenario:**
  - Temperature near zero
  - Sustained strong winds
  - Moisture penetrated the Shield Building
  - Moisture trapped in the outer layer of concrete crystallized
  - Concrete expansion exceeded the tensile capacity of the concrete and propagated the crack



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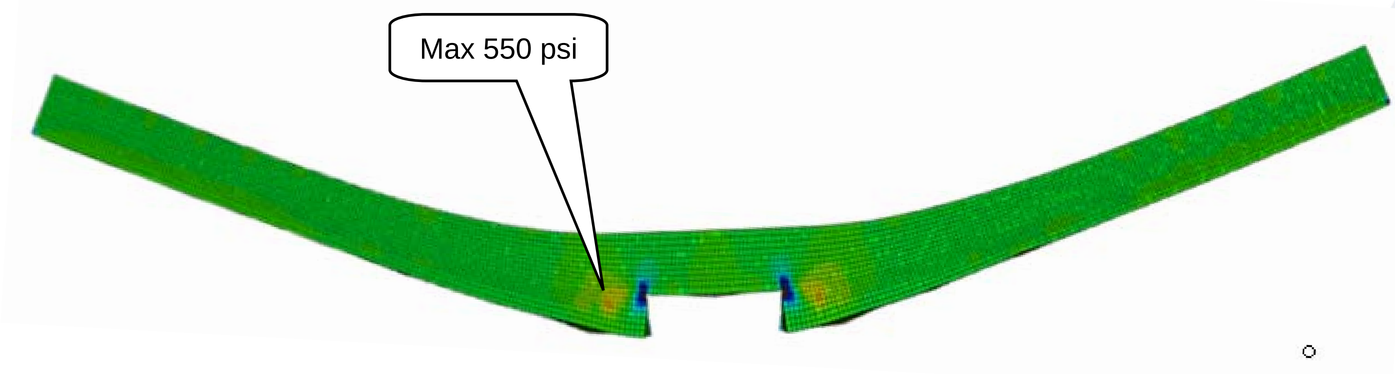
Moisture Intrusion and Low Temperatures, *continued*

- **A complex computer model of the Shield Building was developed**
- **Concrete properties from the concrete core tests were used**
- **Laboratory tests showed moisture infiltration up to four inches**
- **Maximum radial stress in the shoulder area were approximately the tensile capacity of the concrete**
- **High stresses were located in areas of observed cracking**



Sensitivity Analysis – High Density of Rebar

- **A complex computer model evaluated the affects of rebar spacing to determine the potential for developing cracks**
- **Evaluation showed laminar cracks could:**
  - Form in regions of closely spaced rebar and
  - Less likely in areas were the rebar is spaced at 12 inches
- **This analysis establishes that rebar spacing is a probable contributing factor**

Summary of Analyses

- **Normal design conditions result in low stresses which could not cause cracking**
- **Moisture and freezing could cause high stresses in the shoulder areas that results in cracking**
- **Analysis shows closely spaced reinforcing steel can be a contributor to laminar cracking**
- **Observed cracking coincides with the locations of high stress in the shoulder areas and in the areas of high density of rebar; cracking concentrated on southern exposures**

Shield Building Root Cause

- **Root Cause:**
  - Lack of water sealant on the concrete exterior
- **Contributing Causes:**
  - Shoulder reinforcing details (discontinuity and no radial rebar)
  - High density of rebar spacing
  - High moisture, severe wind, and low temperature conditions

Shield Building Additional Actions

Ken Byrd,
Director - Site Engineering

Shield Building – Preventative Action

- **Root Cause**
  - Lack of concrete sealant
- **Preventative Action to Prevent Recurrence**
  - The exposed exterior surfaces of the Shield Building will be sealed
  - Contractor has started and is expected to be completed by the end of September of this year

Shield Building – Additional Actions

- **The Root Cause has established several additional Corrective Actions**
  - Complete Impulse Response (IR) examinations on the Shield Building wall
  - Perform IR mapping on another structure (Auxiliary Building) to confirm assumptions of our analyses
  - Develop and implement a test program to establish capacity in an area of laminar cracks
  - Develop a Long-Term Monitoring program

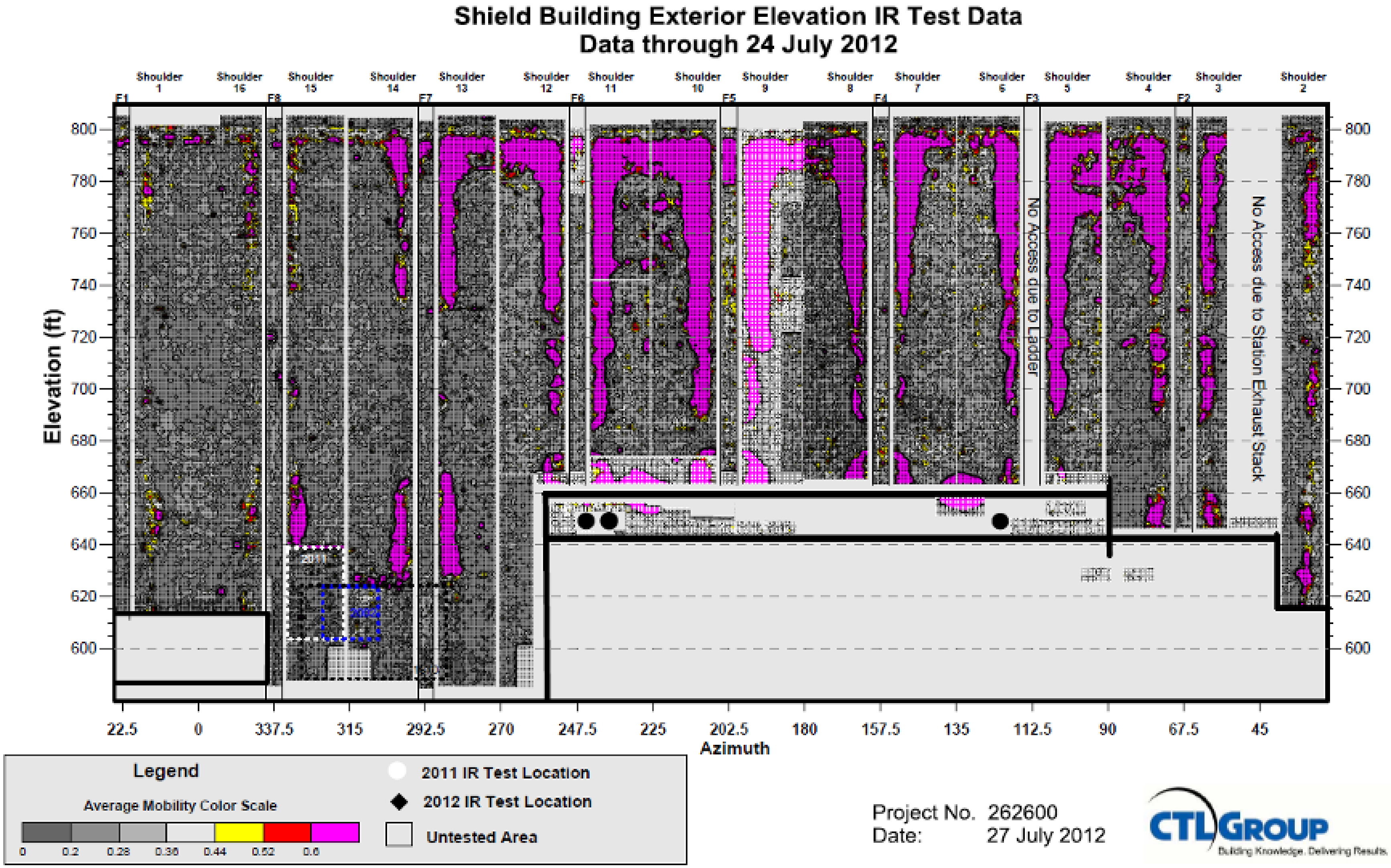
Additional Actions - IR Mapping

- **Complete IR examinations on the Shield Building wall and an independent structure**
  - All accessible areas of the Shield Building wall were mapped
  - Over 60,000 individual readings were obtained to fully characterize the condition of the building

Additional Actions - IR Mapping, *continued*

- **The IR validated our original assessment that the laminar cracks are generally confined to:**
  - The shoulder areas
  - Top of the Shield Building
  - Near one corner of the Main Steam Line penetration
- **Impulse Response reading on an independent structure validated that laminar cracks are not present**

Additional Actions - IR Mapping, *continued*



Additional Actions – Testing

- **Tests were developed and conducted at two nationally recognized universities**
- **Professors are industry experts and are American Concrete Institute (ACI) Committee members**

Additional Actions – Testing, *continued*

- **Two different methods were used to create laminar cracks in the samples to be tested**
- **Results were independently verified**

Additional Actions – Testing, *continued*

- **Testing results**
  - Full capability of reinforcement is maintained in regions with longer splice lengths (upper portion of Shield Building)
  - Results showed near to full capability of reinforcement in regions with shorter splice lengths
- **Testing conclusions**
  - The tests provide high confidence of the capability of the rebar located in regions of laminar cracking
  - Testing confirms the assumptions made in structural calculation prior to restart were very conservative

Additional Actions – Long Term Monitoring

- **Establish a Long-Term Monitoring Program**
  - FENOC has established a long-term monitoring plan that includes:
    - Monitoring existing core bores for crack propagation
    - Inspection of the integrity of the Shield Building coatings
    - Inspection of the integrity of other safety related building coatings

Summary

- **The corrective actions established will:**
  - Prevent moisture from entering the Shield Building and freezing
  - Provide comprehensive characterization of the laminar crack
  - Establish the capacity of the rebar in the area of laminar crack
  - Provide long term monitoring of the shield building

Closing Comments

Barry Allen,
Site Vice President