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DATE OF MEETING
7/25/03

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Docket Number(s): 50-265

Plant/Facility Name: QUAD CITIES UNIT 2

TAC Number(s) (if available): MB9539

Reference Meeting Notice: 2003-0546

Purpose of Meeting (copy from meeting notice): Discuss the Root Cause and Corrective Actions for Steam Dryer Damage at Quad Cities Unit 2

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
C.F. LYON	Project Manager

OFFICE: NRR

DIVISION: DLPM

BRANCH: PD3

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Quad Cities Nuclear Power Station
Unit 2
Steam Dryer Performance
Exelon/GENE

July 25, 2003

Non-Proprietary Version

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Meeting Agenda/Purpose

Tim Tulon

Site Vice President

Quad Cities Nuclear Power Station

Agenda

Exelon Nuclear

• Meeting Agenda/Purpose	Tim Tulon
• Background	Tom Wojcik
• Root Cause Determination	Keith Moser
• Dryer Repair Evaluation	Keith Moser
• QCNPS Unit 2 Extent of Condition	Roman Gesior
• Independent Review Team	Jim Meister
• Startup and Power Ascension Monitoring	Bud Swenson
• Planned Actions	Jim Meister
• Status of Regulatory Commitments	Pat Simpson
• Conclusion	Tim Tulon

Purpose

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- Present the results of our root cause determination
- Summarize actions we have taken to address the steam dryer structural integrity issues
- Discuss the relationship of the degradation to extended power uprate (EPU) operations
  - Extent of condition on other reactor pressure vessel internal components and main steam line piping
- Describe the program implemented to monitor and detect dryer structural integrity issues
- Provide the basis and schedule for returning Quad Cities Nuclear Power Station (QCNPS) Unit 2 to full EPU power
- Describe plans for QCNPS Unit 1 and Dresden Units 2/3

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Background

Tom Wojcik
Engineering Programs Manager
Quad Cities Nuclear Power Station

Background
Dryer Configuration

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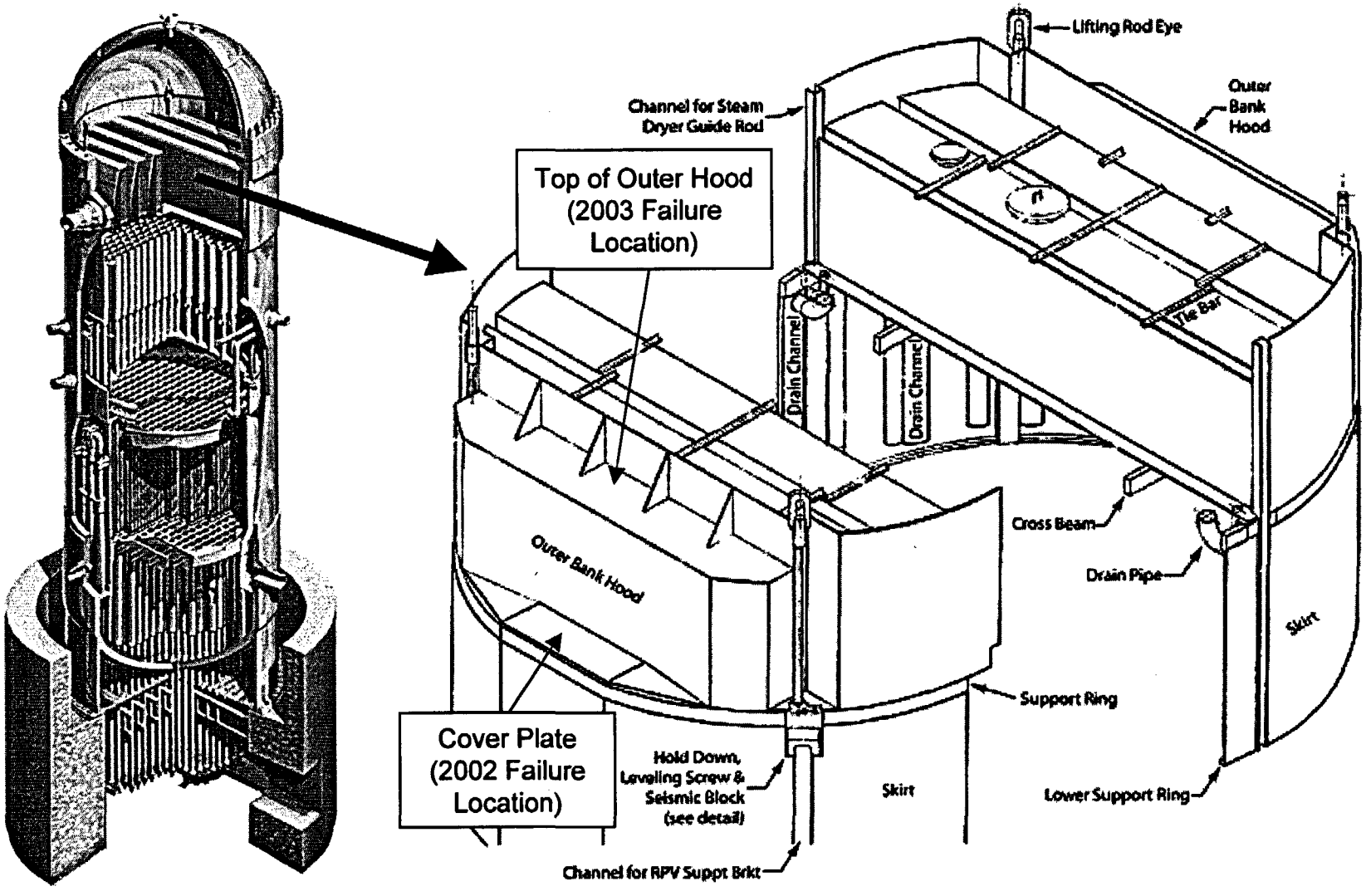

Background
Dryer Nomenclature

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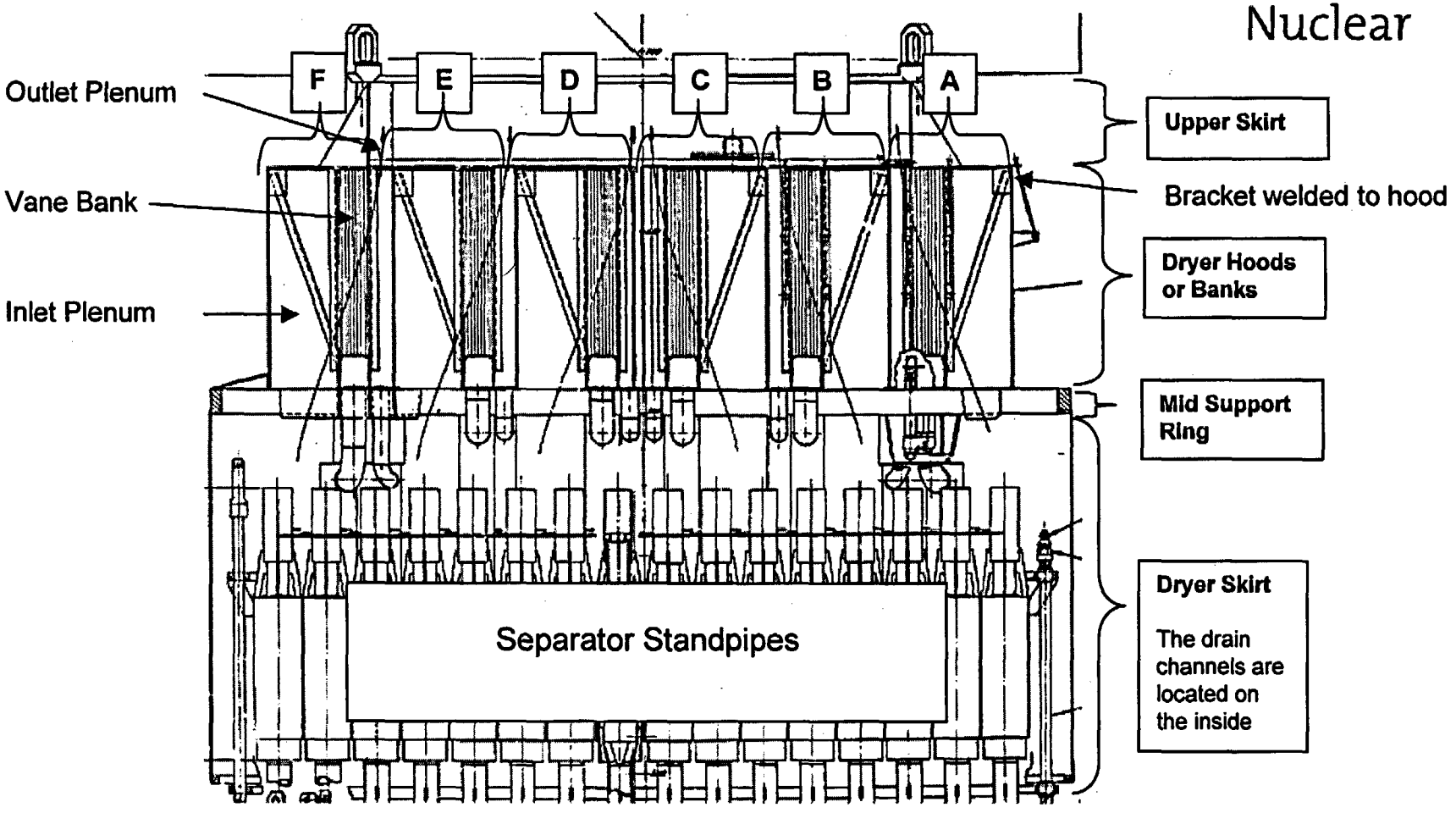

Section View

Background
Dryer/Main Steam Line Layout

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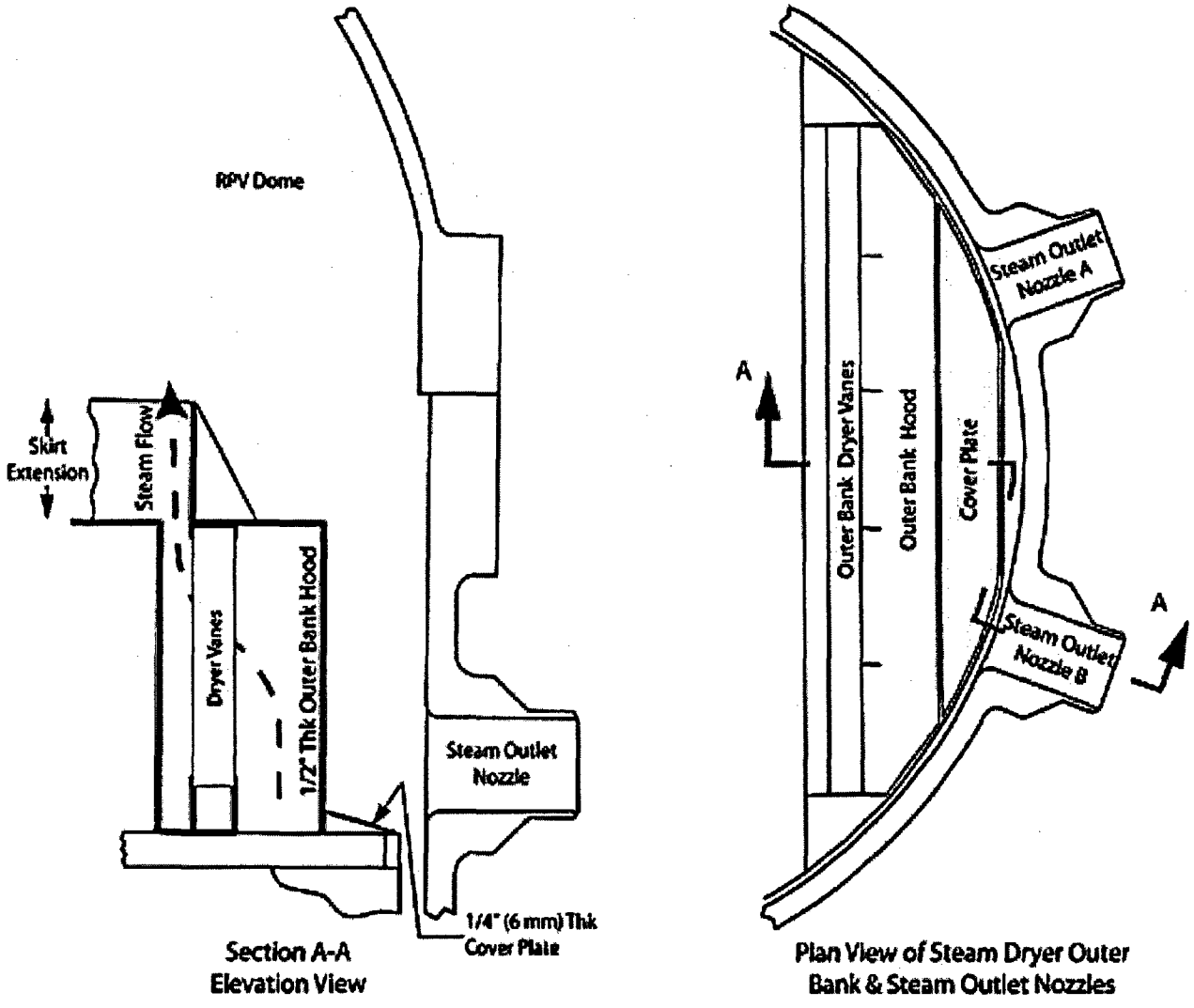

Background
Main Steam Line Piping

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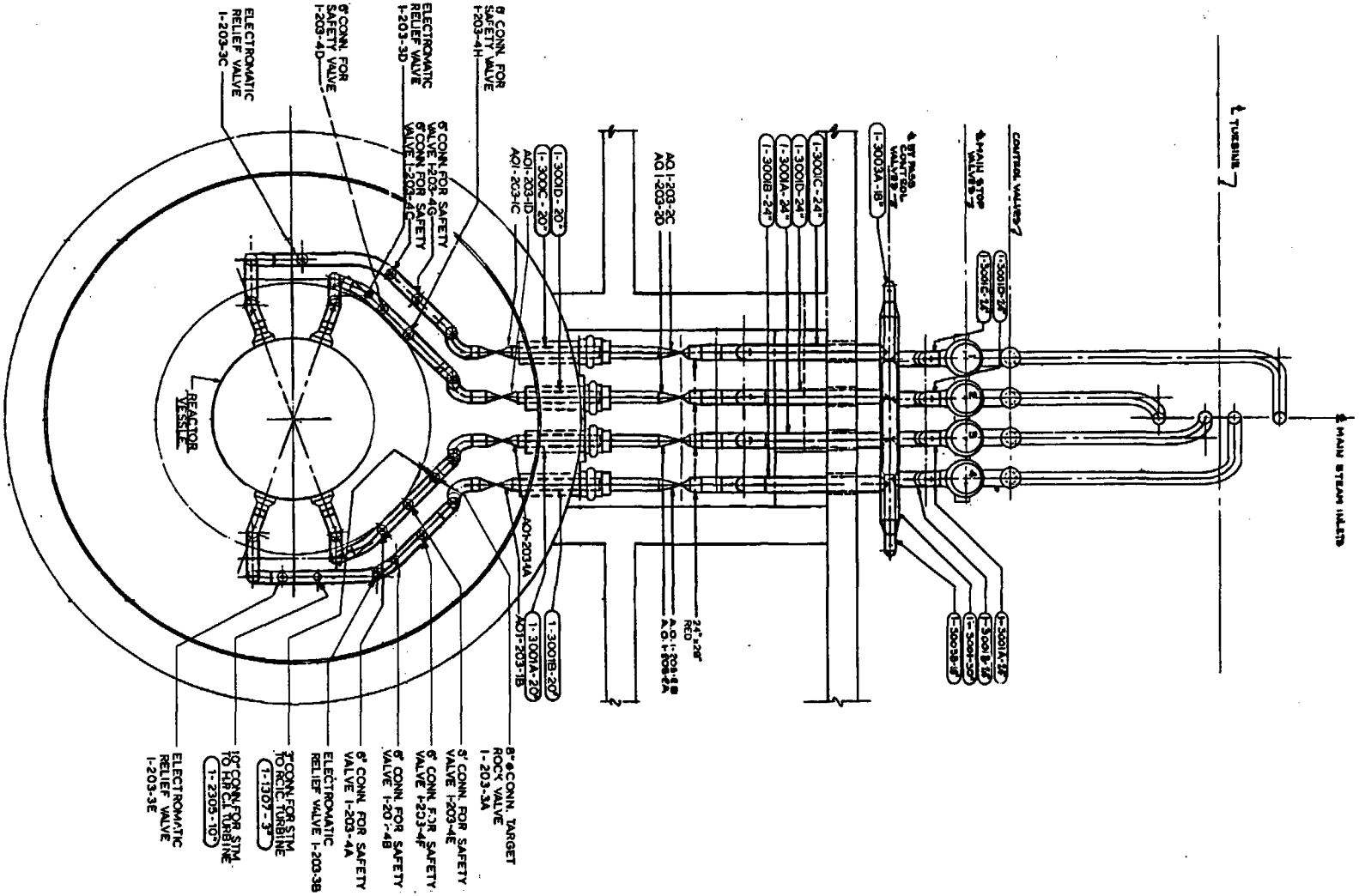

Background
Main Steam Line Piping

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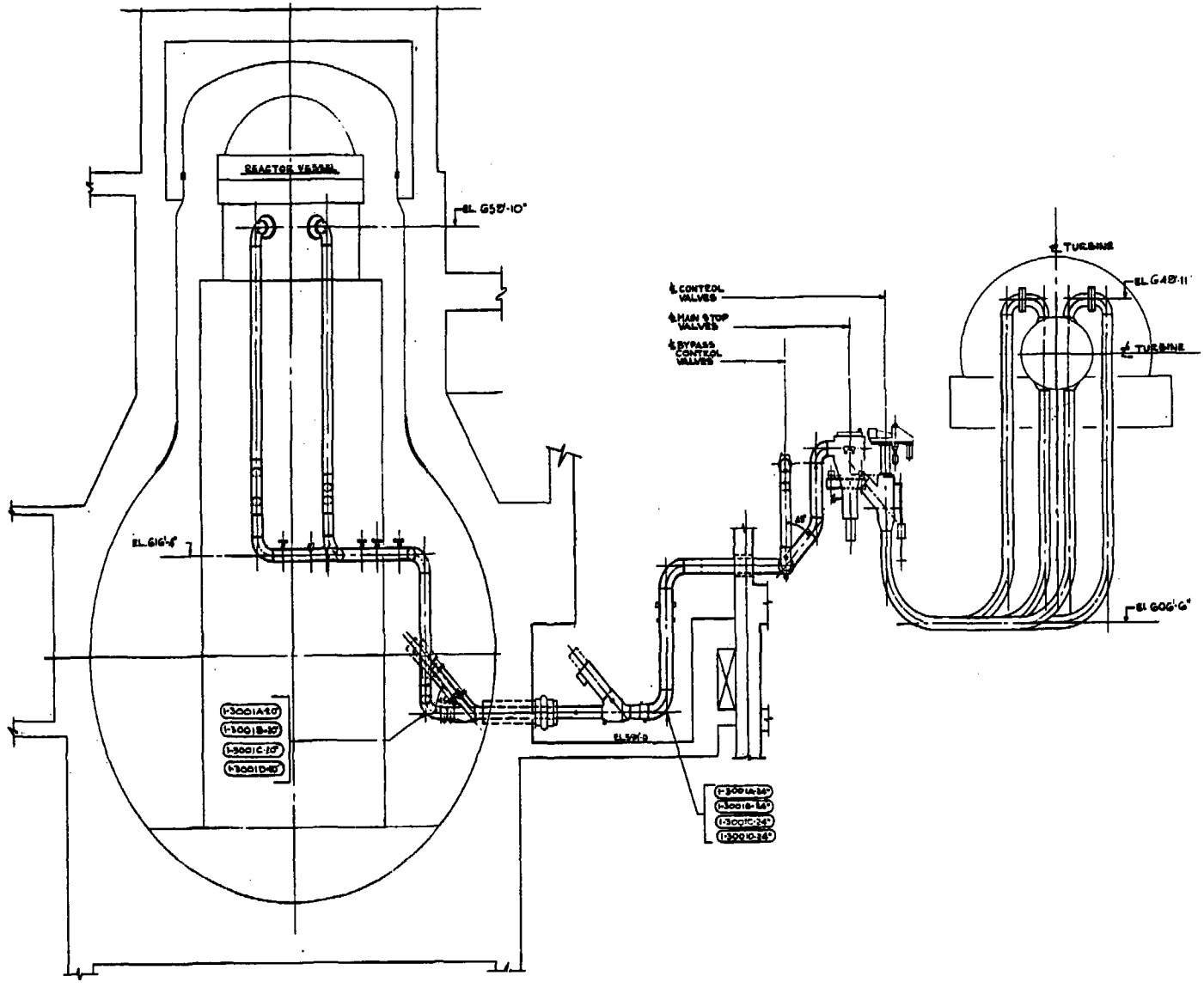

Background
Function and Safety Considerations

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- The function of the steam dryer is to remove moisture from steam exiting the reactor by vanes and perforated plates
- The steam dryer does not perform a safety function
  - The steam dryer is not required to prevent or mitigate the consequences of accidents
- Failure Modes and Effects Analysis (FMEA) evaluated the likelihood and consequences for bounding loose parts
- For a degraded dryer, structural integrity is adequate if the safety consequences of any loose part that may be generated are analyzed to be acceptable
  - FMEA demonstrates that loose parts will not interfere with the ability to shutdown the reactor, provide adequate core cooling, or isolate the main steam lines
- Safe reactor operation is not compromised by a degraded steam dryer

Background
Moisture Carryover Trend

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- Normal moisture carryover (post-EPU) is less than 0.1%
- April 16: Inadvertent opening of 3B PORV
- May 6: Moisture carryover increased to 0.2%
- May 28: Moisture carryover increased to >0.35%
  - Power reduced to pre-EPU level
  - Moisture carryover decreased and remained steady at 0.2%
  - No significant/actionable changes in key reactor parameters
- June 10: Unit 2 shutdown
  - Detailed statistical analysis showed small changes in B main steam line flow and reactor water level fluctuations
  - Performed thorough inspection and damage assessment

Steam Dryer Visual Inspections

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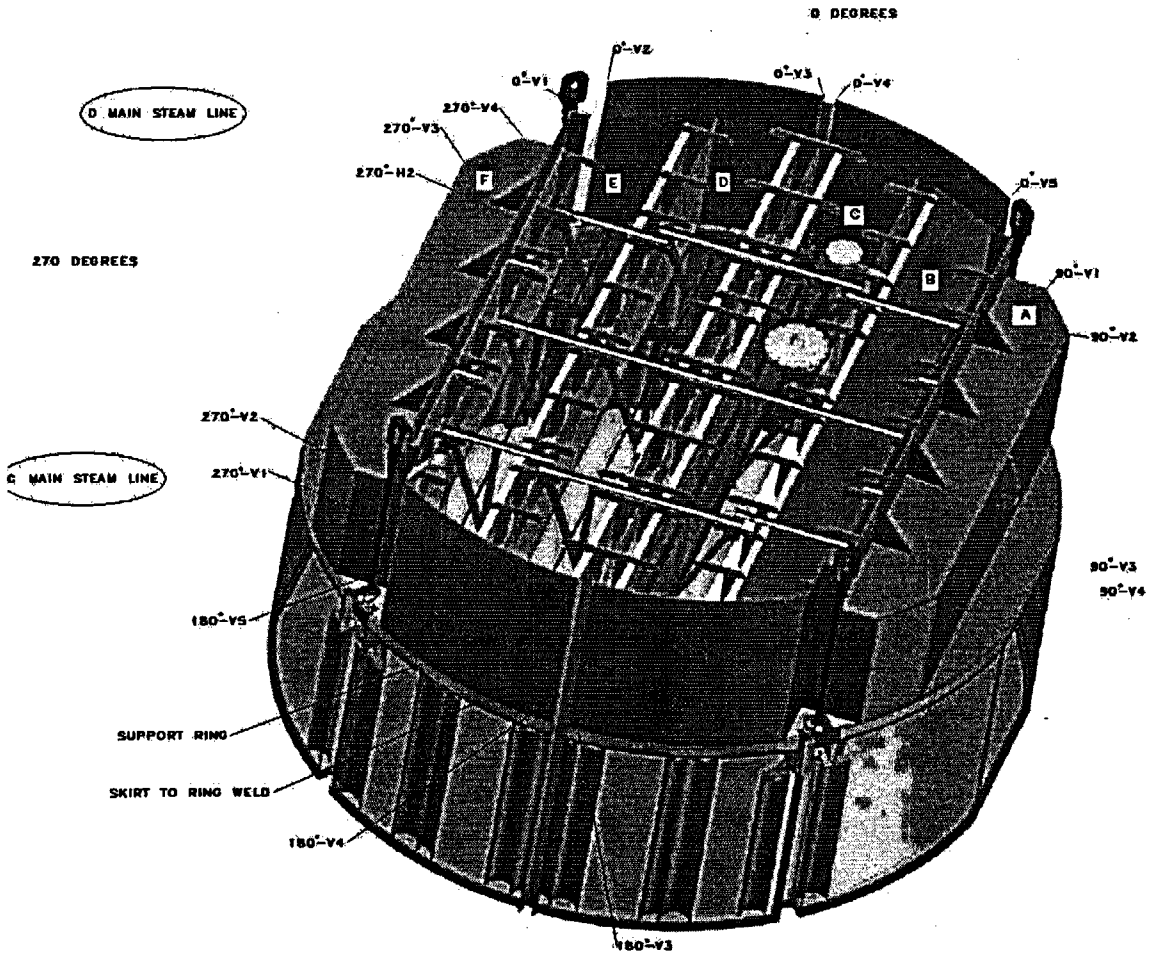

Visual Exam Scope

- 100% Bank Vertical Welds
  - At 90° & 270° (V-1, V-2, V-3, V-4, and V-5)
  - At 0° & 180° (V-1, V-2, V-3, V-4, V-5, and V-6)
- 100% Bank and Hood Welds
  - H-1, H-2, and H-3
  - Hood Tie Bars
- Hood Interior
- Interior Braces to Hood
- Bank to Ring Weld
- Skirt to Ring Weld

Summary of Inspection Results

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- Damage assessment
  - Top of outer hood cover plates
    - Through-wall crack (90° side)
    - Incipient cracking (270° side)
  - Internal bracing
    - Three braces detached in outer 90° hood
    - One severed vertical brace in outer 270° hood
  - Three tie bars connecting dryer banks cracked
    - Industry experience shows tie bar failures at both EPU and pre-EPU conditions
- Inspected for collateral damage
  - None identified
- All loose parts retained within the dryer envelope
  - All parts retrieved

Damage Assessment
90° Top of Bank A

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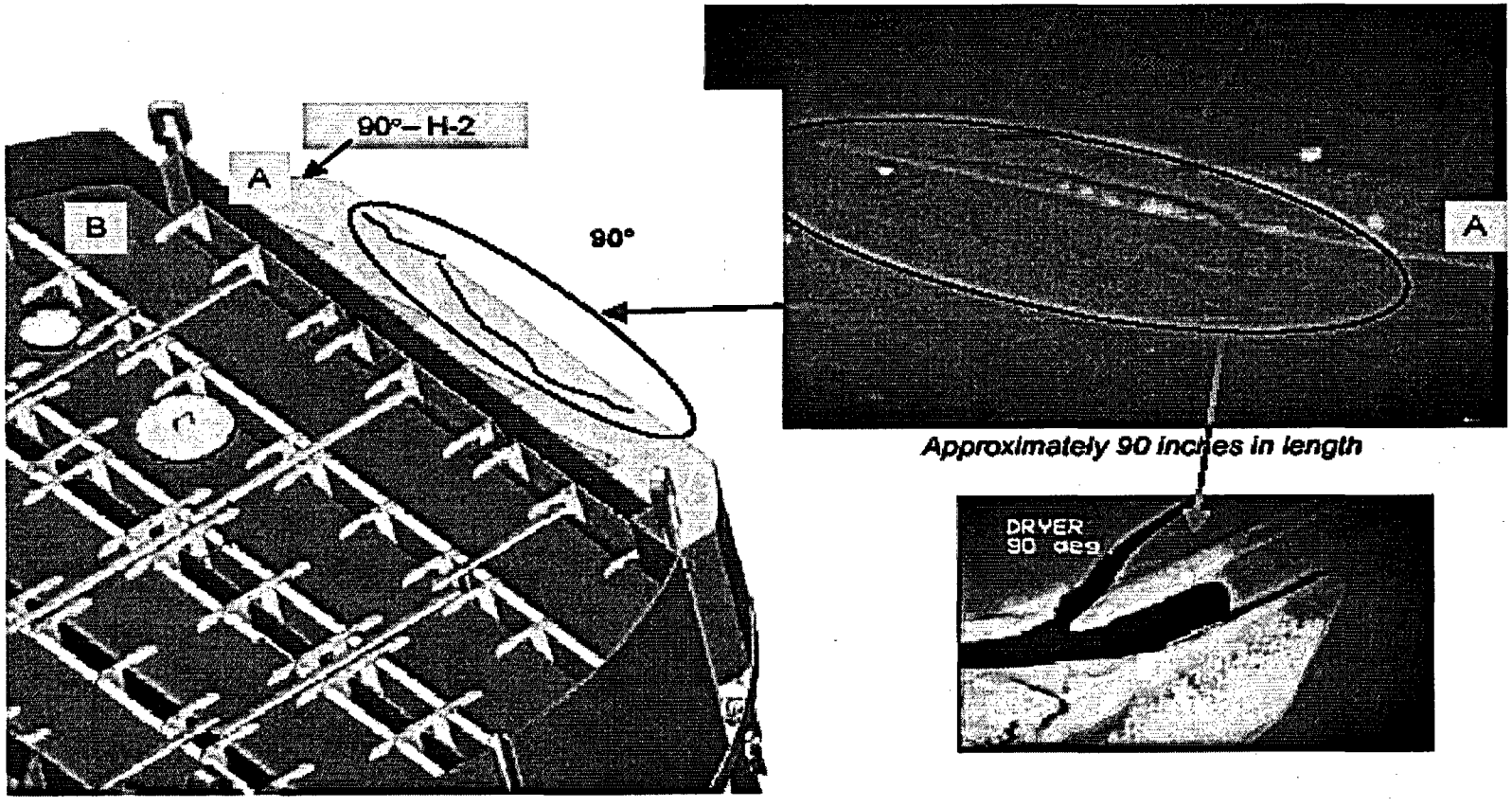

Damage Assessment
90° Bank A Interior Surfaces

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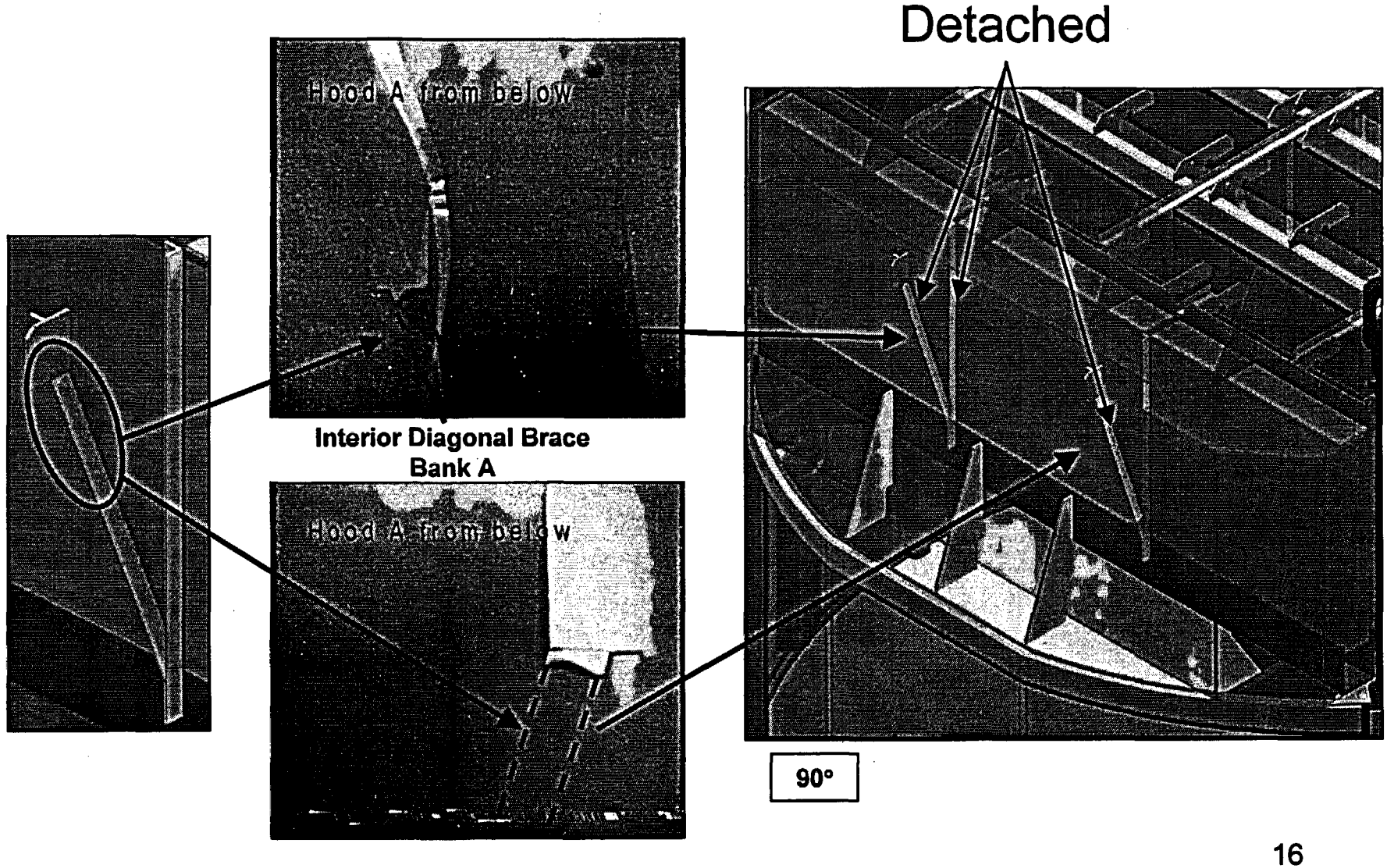

Damage Assessment
270° Bank F Interior Surfaces

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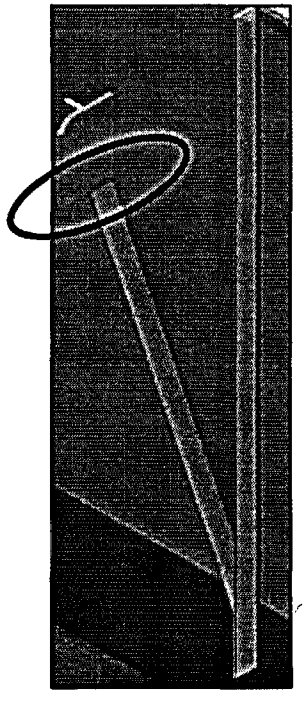
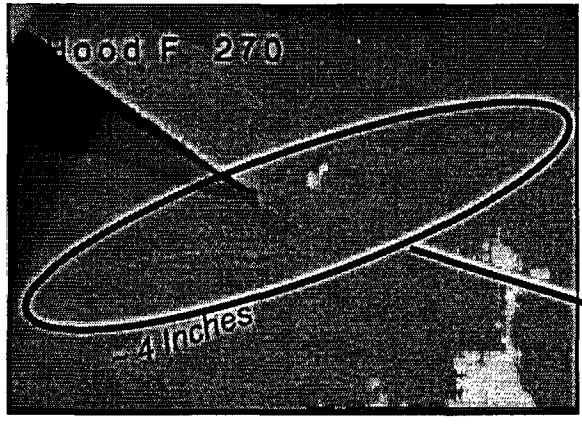
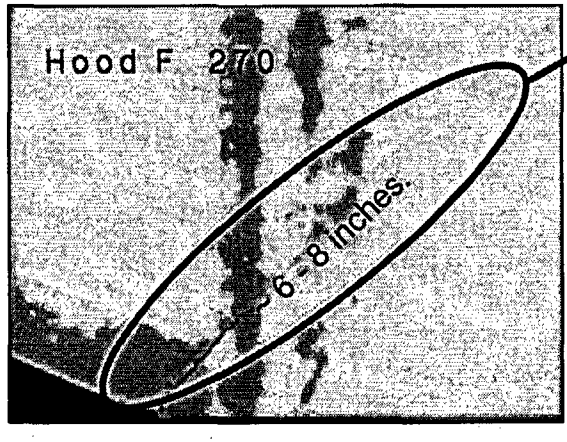
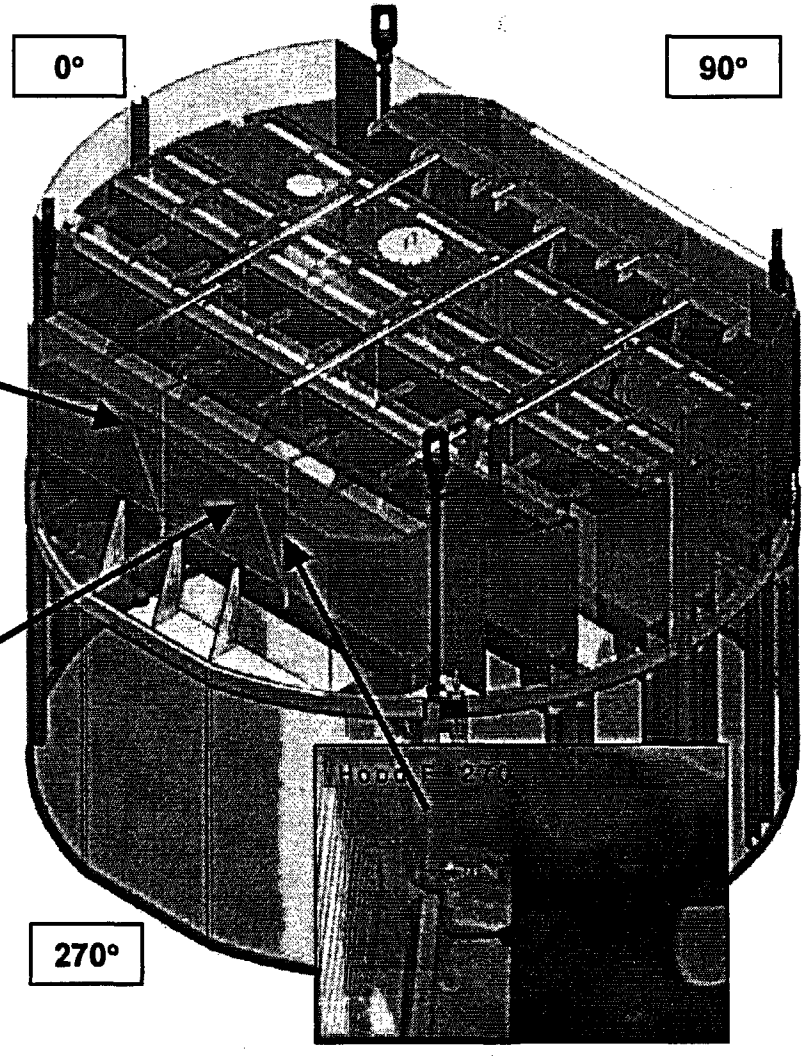




Interior Diagonal Brace to Hood Weld Bank F





Background

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- Three teams formed in response to dryer failure
  - Root cause team
  - Repair team
  - Independent review team
- Performed comprehensive analyses to understand failure mechanism and extent of condition
- Dryer repairs and modifications were installed
- Developed and implemented a power ascension monitoring plan
- Unit 2 was returned to service on June 29, 2003

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Root Cause Determination

Keith Moser
Asset Management Engineering

2002 Dryer Damage
Root Cause Overview

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- QCNPS Unit 2 was shutdown on July 11, 2002, due to suspected steam dryer degradation
- Visually inspected outer surface of dryer
  - Dryer cover plate (at hood-skirt transition) damage
    - Cover plate natural frequency approximately 180 Hertz
  - No additional damage observed
- Root cause was high cycle fatigue due to high frequency acoustic resonance (130 to 230 Hertz)

2002 Dryer Damage
Root Cause Overview

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- Extent of condition review was focused on components susceptible to high frequency (130 to 230 Hertz) flow induced vibration (FIV)
- Dryer repairs were completed
  - Both cover plates were replaced with thicker plates using larger welds
- Continued to evaluate failure to improve understanding of dryer loading
  - Computational Fluid Dynamic (CFD) analysis
  - Scale model testing
  - Full 3-D finite element model

2003 Dryer Damage
Root Cause Overview

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- Utilized diverse analytical techniques
  - CFD analysis
  - Scale model testing
  - Full 3-D finite element model
  - Acoustic circuit evaluation
  - Metallurgical evaluation
- Expanded evaluation methodology applied
- Expanded extent of condition review
  - 0 to 230 Hertz frequency ranges considered
  - Reactor internals for EPU conditions
  - Steam path components for EPU conditions
- The root cause of the dryer failure is high cycle fatigue resulting from low frequency pressure oscillations

Root Cause Evaluation Methodology

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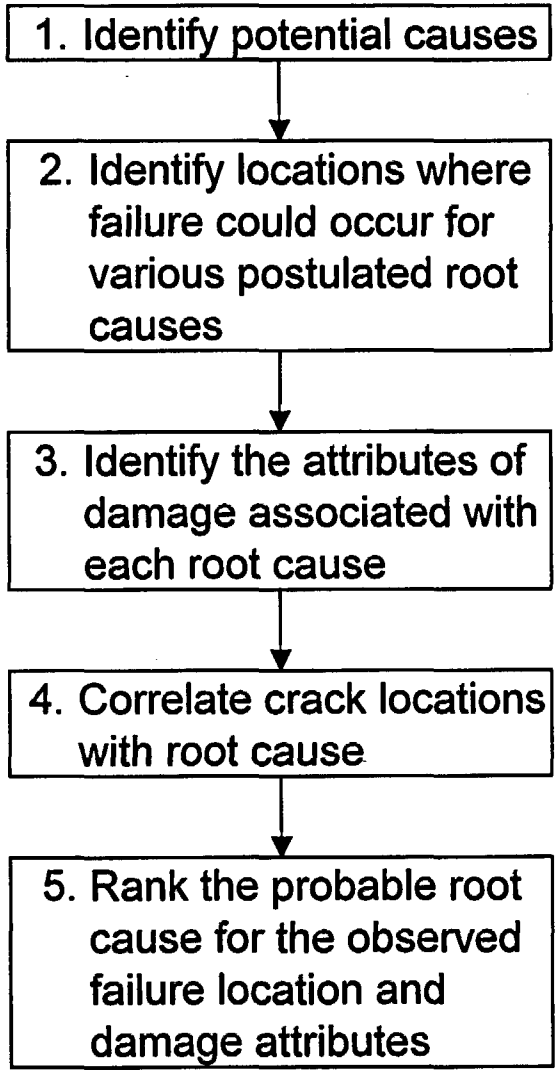

Dryer Potential Root Causes

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- Evaluated credible potential root causes
  - Material/fabrication issues
    - Weld defects
    - Poor quality plate material
  - Thermal fatigue
  - Fatigue due to pre-EPU operation
  - Intergranular Stress Corrosion Cracking (IGSCC)
  - Dryer support ring deflection
  - Bi-stable flow
  - **Increased stress from 2002 cover plate failure**
  - **Transient loading due to power operated relief valve (PORV) operation**
  - **EPU increased steam flow effects on original dryer design**
    - FIV high frequency (130 to 230 Hertz)
    - FIV medium frequency (50 to 130 Hertz)
    - **FIV low frequency (0 to 50 Hertz)**
      - **Sources from main steam lines**
      - Sources inside reactor pressure vessel

Analysis Technique

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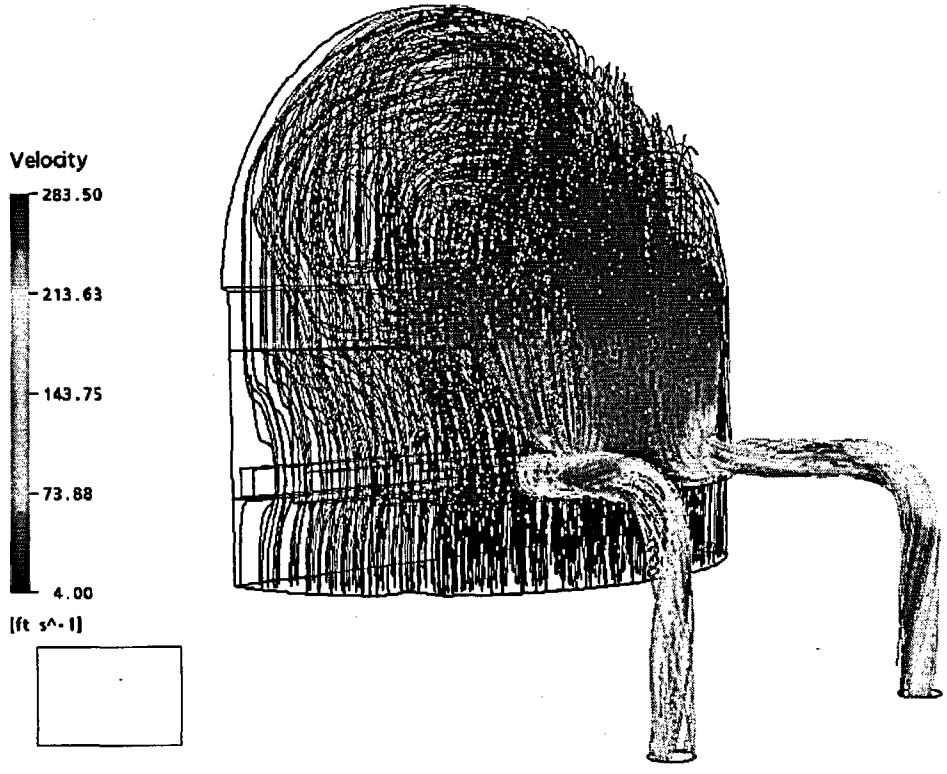
- CFD Model
  - Steam dryer, steam dome, portion of main steam lines in model
  - Velocity and pressure fields in/around dryer computed at steady state EPU conditions
  - Outputs incorporated into finite element structural evaluations



CFD Model Results
EPU Steam Dryer Flow Patterns

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Analysis Technique and Results

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Analysis Technique

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Finite Element Model Results

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Finite Element Model
Forcing Functions

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Analysis Technique

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- Acoustic Circuit Analysis
  - Purpose is to locate potential sources of low frequency pressure waves
  - Model identifies potential acoustic drivers in system
  - Predicts system nominal acoustic frequencies

Acoustic Circuit Analysis Results

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Analysis Technique

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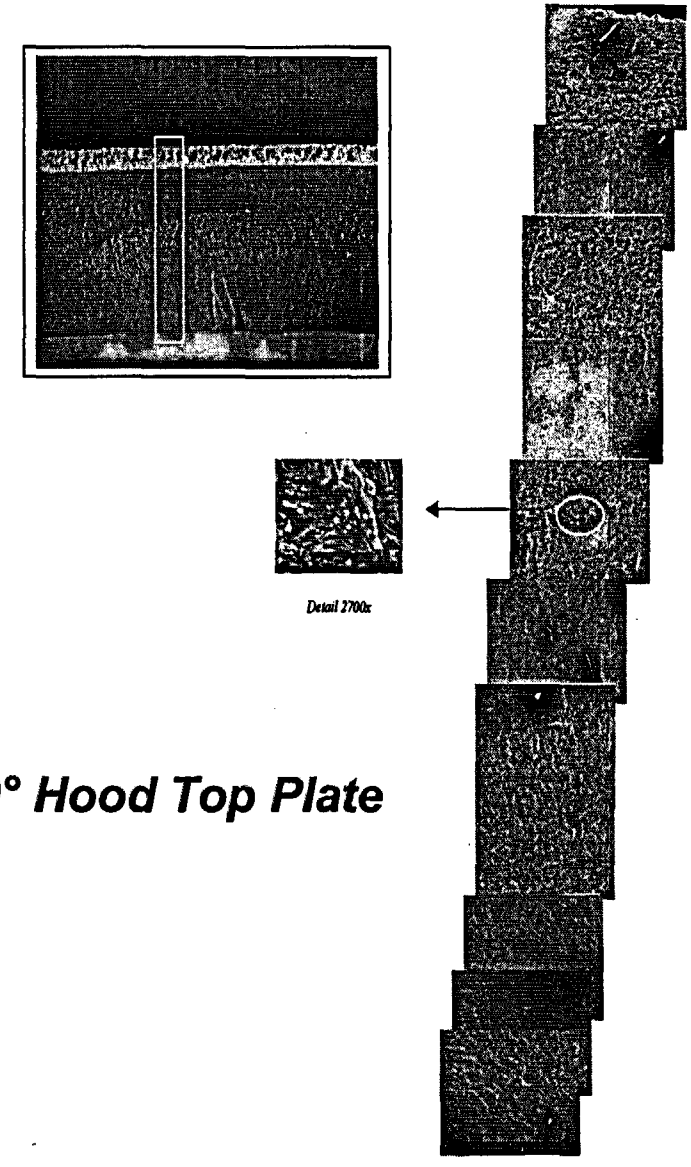
- Metallurgical Evaluation
  - Base/weld material
    - Chemical properties
    - Mechanical properties
  - Scanning electron microscopy (SEM)
  - Metallographic examinations



270° Hood Top Plate

Metallurgical Evaluation

SEM of Hood Horizontal Plate Fracture Surface

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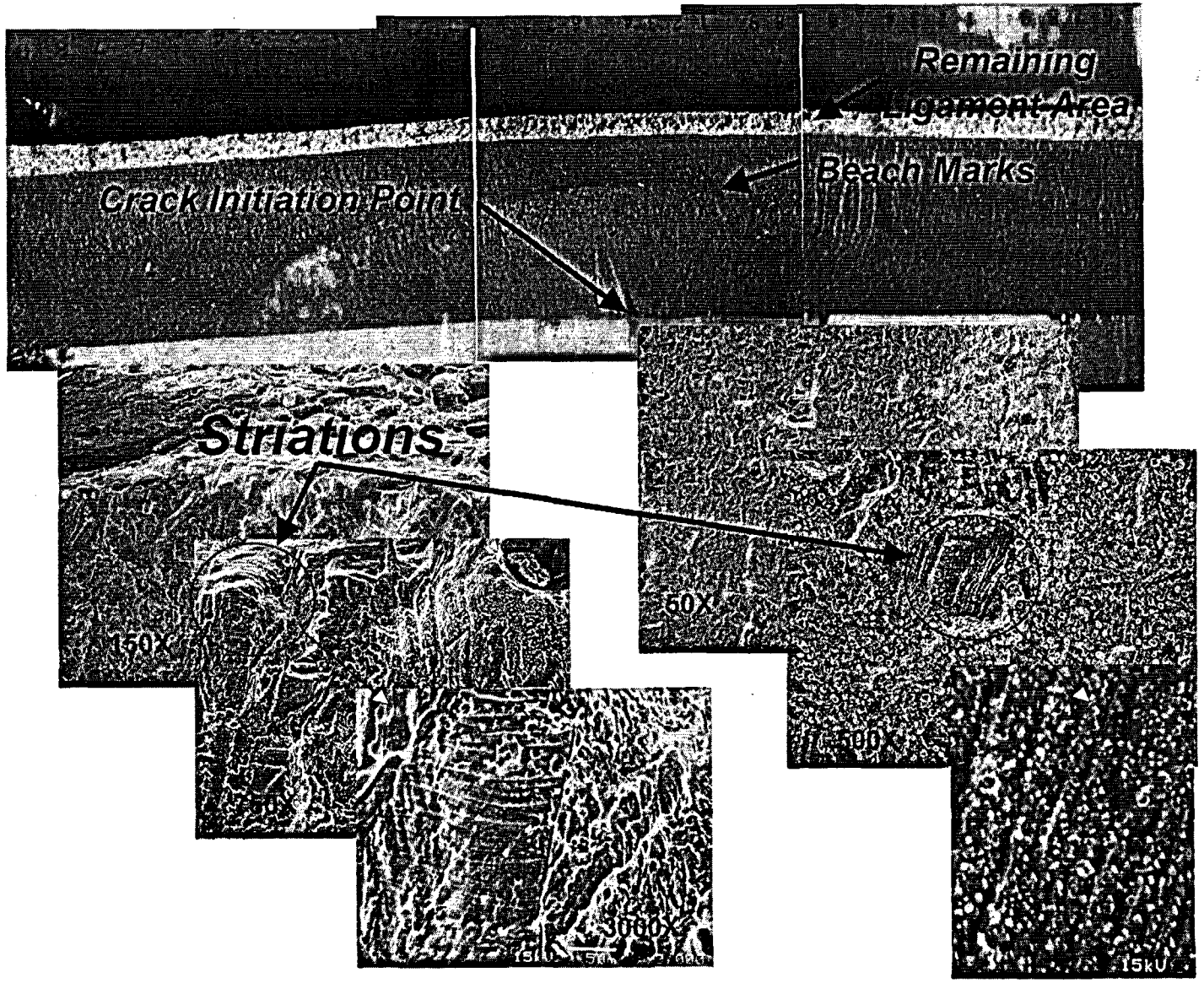

Metallurgical Evaluation Results

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- The cause of the steam dryer hood cracking was high cycle fatigue; final fracture resulted from decompression wave (PORV actuation)
- The fractures initiated at the stress concentrations at the bracket joint to the interior surface of the hood
  - No weld flaws were identified
  - Crack propagated lengthwise at a higher rate
    - Remaining ligament on 90° side is 0.03 inch through-wall
    - Remaining ligament on 270° side is 0.1 inch through-wall
- No chemistry, material, welding, or manufacturing deficiencies were identified
- No evidence of IGSCC was observed

Assessment of Load Frequencies Causing Damage

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Root Cause Summary

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- The root cause of the dryer failure is high cycle fatigue resulting from low frequency pressure oscillations
  - The cracks in the hoods and braces started during normal EPU power operation at the high stress location of the bracket plate on the outer hood
  - The length of the cracks continued to increase until the transient pressure loading from the inadvertent 3B PORV opening and subsequent valve openings caused the crack to open through-wall (remaining ligament 0.03 inch), leading to the observed increased moisture carryover
  - Most likely source of loading is main steam line D-ring acoustic frequency

Contributing Factors

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- Operation with failed cover plate in 2002 resulted in increased fatigue damage in the 90° hood area
- PORV opening caused a decompression wave
  - 2 to 3 times steady state loading on degraded hood
  - Small remaining ligament (approximately 0.03 inch through-wall) on the 90° hood failed
    - This provided an opening which resulted in an increase in moisture carryover

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Dryer Repair Evaluation

Loadings in Dryer Evaluation

Low Frequency FIV Peak Loading Magnitude

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- Performed dryer evaluation to determine loads for repair design
  - Calculated loads based on observed cracks
  - Scale model testing
  - Evaluation based on turbulent fluid flow theory resulted in lower values
  - Benchmarked against observed vendor in-vessel measured data
  - Spatial distribution determined by CFD modeling
- Determined bounding low frequency pressure load

Dryer Structural Evaluation

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- Load conditions
  - Bounding low frequency pressure load
  - Dead weight load and dryer support ring fluctuations
  - Pressure load corresponding to PORV event (all main steam lines simultaneously)
- Repairs performed to address high-stress locations and evaluated with bounding loads

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Dryer Analysis With Repairs
Finite Element Analysis Model

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Repair Evaluation

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- Optimization analyses
  - Selected designs to move plate frequency to a region of low excitation
  - Decreased stress levels below the previous stress levels by a factor of two or more
- Diagonal and vertical braces
  - Diagonal bracket attachment led to higher stress concentrations at the hood – now removed
  - Finite element model showed little change with brackets and braces removed
- Dryer repairs ensure structural integrity for QCNPS Unit 2 at EPU conditions

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QCNPS Unit 2
Extent of Condition

Roman Gesior
Director, Asset Management

QCNPS Unit 2 Extent of Condition

Scope of Impact on Non-Dryer Components

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- Evaluated EPU changes to identify potentially impacted components
- Components included in review
  - Reactor internals
    - Components instrumented during startup testing
    - Components in steam path
  - External steam path
    - Main steam line piping
    - Steam path components

QCNPS Unit 2 Extent of Condition
Evaluation Methodology

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- EPU effects
  - Constant pressure and temperature – uprate changes:
    - Core power: +18%
    - Core flow: no change
    - Feedwater/steam flow: +20%
    - Feedwater temperature: +16°F
    - Reactor internal pressure differences (RIPD): up to 2.2 psid
    - Slight increase in recirculation pump speed and carryunder
  - Component evaluation
    - Focused on EPU parameter changes
    - Root cause insights from QCNPS Unit 2 dryer failure factored into additional evaluations

QCNPS Unit 2 Extent of Condition
Evaluation Methodology

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- Evaluation methods
  - Startup testing scaled to EPU conditions
  - Development testing
  - Frequency evaluations
  - Finite element analysis
  - Plant monitoring data
- Screening criteria
  - Component natural frequency
  - Susceptibility to low frequency loading
  - Susceptibility to high frequency loading
  - Failure history
  - Loose part assessment
  - Safety consequence

QCNPS Unit 2 Extent of Condition
Screening Matrix

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QCNPS Unit 2 Extent of Condition
Results Matrix

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QCNPS Unit 2 Extent of Condition
Summary

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- Reactor internal components and components in the steam flow path were evaluated in light of the dryer failure
- Detailed evaluations were performed for these components to determine their susceptibility to FIV at EPU conditions
- Evaluations validate the results of previous EPU component analyses
- QCNPS Unit 2 can operate at EPU conditions without exciting internal or main steam line components above established vibration limits

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Independent Review Team

Jim Meister
Vice President, Engineering

Independent Review Team

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- External independent review team was comprised of members from Structural Integrity Associates (SIA)
- Assessed repairs (prior to QCNPS Unit 2 restart) and root cause evaluation
- Provided additional areas to include for main steam path extent of condition evaluation
- Conclusions
  - The dryer failure was due to high cycle fatigue, other potential failure mechanisms have been eliminated
  - The load definition is reasonable, especially considering repair margins are on the order of 2 to 3
  - An adequate structural evaluation has been performed to:
    - Understand failure locations
    - Ensure adequacy of repair
    - Evaluate the acceptability of not replacing the diagonal braces
  - Dryer repair will lead to an improvement in structural performance

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Startup and Power Ascension Monitoring Plan

Bud Swenson
Plant Manager
Quad Cities Nuclear Power Station

QCNPS Unit 2 Dryer Performance
Results to Date

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- High frequency acoustic monitor
  - No vibration alarms during or after power ascension to full pre-EPU power (2511 MWt)
- Moisture carryover
  - Current value is 0.01% at 2511 MWt
- Main steam line vibration monitoring results
  - Readings taken at approximately 53%, 76%, and 85% rated thermal power
  - Evaluation concluded vibration readings were not indicative of a challenge to main steam line performance or a change in dryer performance
- Key parameter review (monitored and recorded reactor pressure, reactor water level, main steam line flows, and steam-feed flow mismatch on an hourly basis)
  - No adverse trends identified
- No indications of steam dryer structural integrity issues

Overview of Power Ascension Plan
2511 MWt to 2957 MWt

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- Steam dryer monitoring plan will be implemented from the current power level of 2511 MWt to full EPU power
- Evaluation points will be established at 92% thermal power (approximately mid-way) and at full EPU power; each evaluation point will include:
  - Documented review and assessment of plant data
    - Moisture carryover
    - High frequency acoustic monitor
    - Main steam line vibration levels
    - Key reactor parameters
  - Plant Operations Review Committee will be convened to perform an assessment of continued power ascension/operation
- On a weekly basis until the next refuel outage, an engineering review and documented assessment of dryer performance will be performed considering trends in reactor power, reactor water level, main steam line flow, and steam-feed flow mismatch

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Planned Actions

Jim Meister
Vice President, Engineering

Planned Actions

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- Monitoring plan
  - Comprehensive plan to provide early detection of dryer structural integrity issues
  - Implemented daily monitoring of moisture carryover and other key reactor and plant parameters while operating at full power
- Detailed dryer visual inspections of susceptible areas will be performed during the next refueling outage on each unit
  - VT-3 methodology will be used
- Based upon inspections and further evaluations, the Dresden and QCNPS Unit 1 dryers will be modified as necessary
  - Insights from QCNPS Unit 2 finite element modeling will be applied

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Status of Regulatory Commitments

Pat Simpson
Manager, Licensing

Status of Regulatory Commitments

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Commitment	Status
Repair dryer and perform assessment to determine acceptability to operate at full pre-EPU power level	Complete
Implement daily monitoring of moisture carryover and other key reactor parameters	Complete
If dryer structural integrity concerns are identified, power levels will be reduced to pre-EPU levels on the affected unit	No change in status
Re-evaluate monitoring parameters and frequency following root cause evaluation	Complete – no changes recommended
Evaluate the effects of EPU conditions on reactor internal components and main steam line piping	Complete
If required, supplement previous EPU licensing correspondence	August 15, 2003

Status of Regulatory Commitments

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Commitment	Status
Complete root cause evaluation including metallurgical analysis	Complete
Perform detailed finite element analysis and inspect susceptible areas	No change in status – next refueling outages at Dresden and QCNPS
Evaluate the insights gained for QCNPS Unit 2 dryer failure for impact on similar designs, share generic issues with BWROG	No change in status – September 5, 2003
Evaluate and disposition extent of condition on reactor vessel internal components and main steam line piping	Complete
Submit voluntary LER	No change in status – August 22, 2003

Conclusion

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- Root cause of the dryer failure is high cycle fatigue resulting from low frequency pressure oscillations
- The repaired dryer is qualified for bounding loads at EPU flow conditions
- Extent of condition evaluation of reactor internals and main steam path components identified no concerns
- A comprehensive program for monitoring and detecting dryer structural integrity issues has been established
- QCNPS Unit 2 is acceptable for operation at full EPU power level