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Quad Cities Unit 2 (QC2) Dryer Update

April 10, 2006

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Introduction

Patrick Simpson
Licensing Manager

Agenda

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- Background — Tim Hanley
- Dryer Inspection Results — Tim Hanley
- Preliminary Cause — Roman Gesior
- Repair Strategy — Tim Hanley
- Conclusions/Outage Status — Randy Gideon

Background

Tim Hanley

Director Midwest Operations Projects

Background

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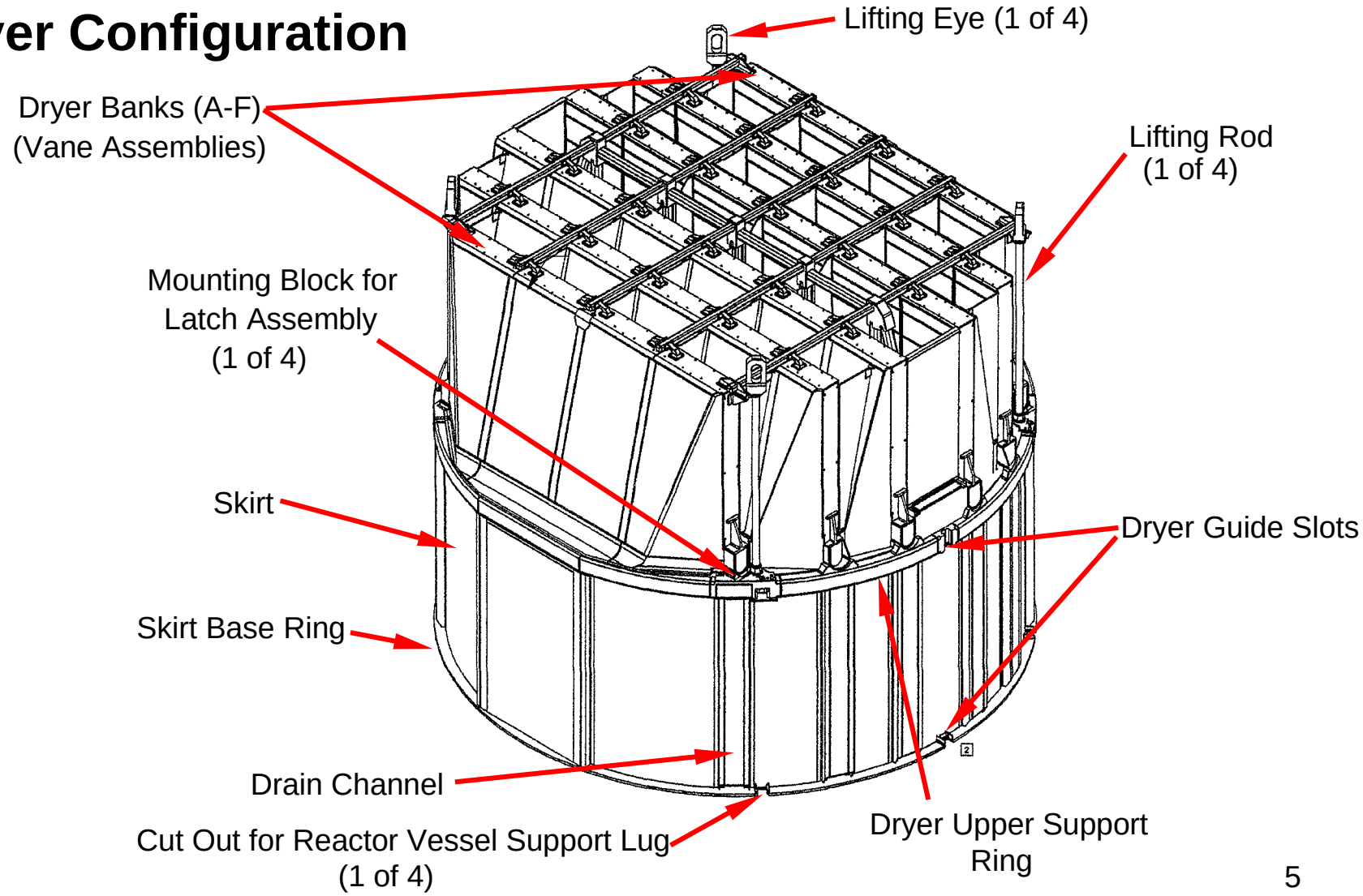
Dryer Configuration

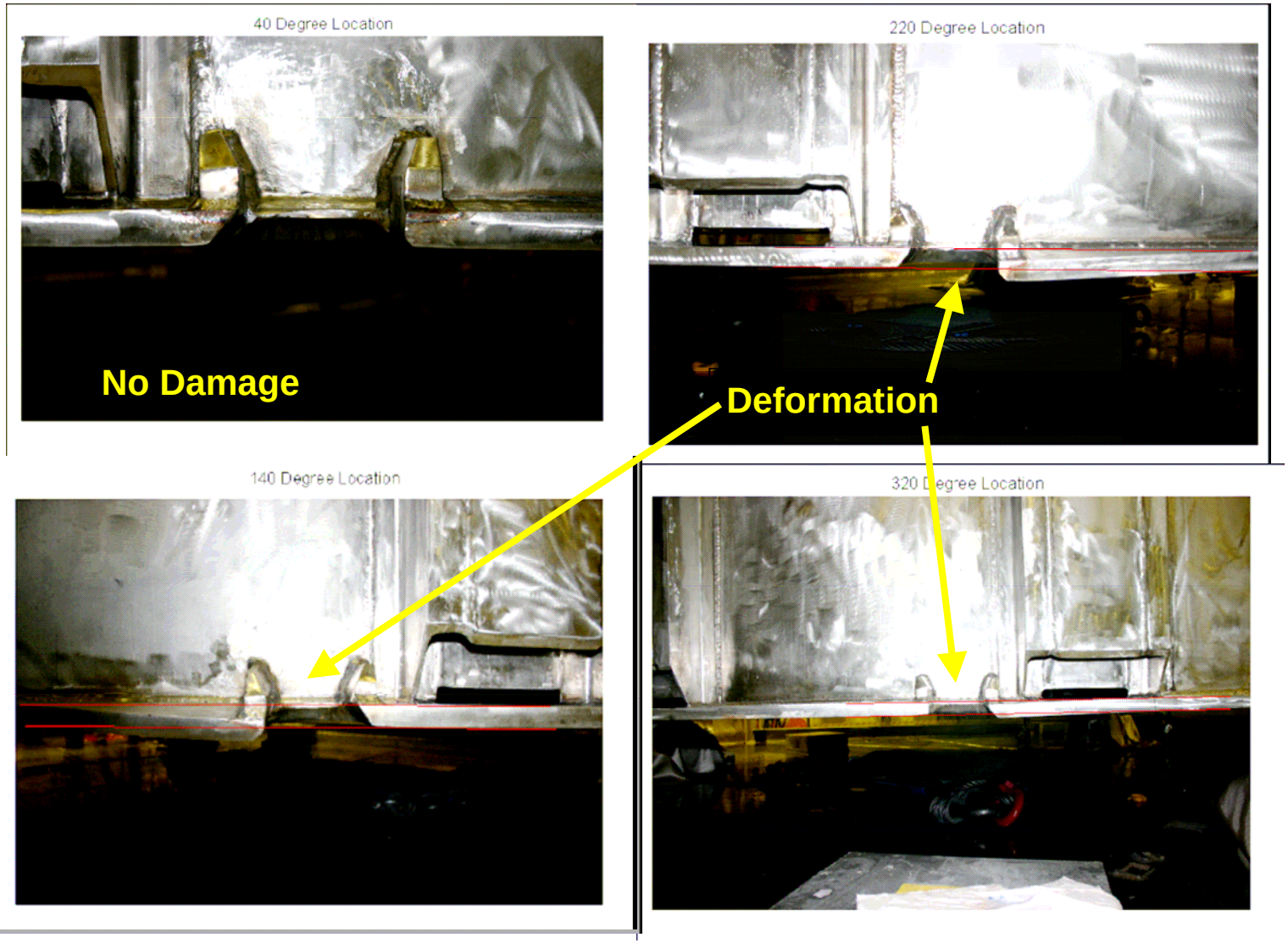


Background (cont.)

- QC2 replacement dryer was installed in May 2005
  - During fabrication some ovality was created in the skirt section of the dryer
- During the installation, an interference was encountered with the separator guide rods that prevented the dryer from fully seating
- During the removal of the dryer to correct the interference the dryer impacted the dryer support lugs that are attached to the inside of the reactor vessel at the 140°, 220°, and 320° locations
  - Cause: lack of clearance between the skirt base ring/reactor vessel support lugs and excessive clearance between dryer guide rods/dryer
- Indications of deformation at 140°, 220°, and 320° locations were observed at this time
- Subsequent inspections during the current refueling outage revealed additional indications at these locations
  - Deformation of the skirt base ring on the ID at 140° and 220° locations
  - Skirt panels dimpled at 140° and 220°
  - Neither of these conditions were observed at the 320° location

Background (cont.)

Original Deformation



Background (cont.)

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- Deformed areas were non-destructively (PT) examined on the OD and skirt base ring with no indications identified and dispositioned as acceptable for use for one cycle
- Repairs, modifications, and inspections of these areas were planned to be implemented during current refueling outage
- QC1 replacement dryer was installed in May 2005
  - Based on QC2 lessons learned avoided ovality and installation issues

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Dryer Inspection Results

Tim Hanley
Director Midwest Operations Projects

Dryer Inspection Results

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- QC2 dryer inspections have been completed
- Inspection scope encompassed and exceeded the requirements of BWRVIP-139
  - Inspections a combination of VT-1 and VT-3
  - General exterior visual examination
  - Locations potentially subject to fatigue
  - Outer structural welds including:
    - Hoods, vanes, skirt, upper support ring, skirt base ring
  - Inner structural welds including:
    - Cross beams (to upper support ring and support castings)
  - Drain channels and tie bar welds
- Scope expansion:
  - Skirt plates
  - Skirt base ring cut-outs, gussets
  - Latch boxes

Dryer Inspection Results (cont.)

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- 14 total indications documented in Indication Notification Reports (INRs)
  - 7 indications were minor in nature with no structural significance:
    - 2 documented the re-inspection of the deformed areas at the 220^{o} and 320^{o} location with no changes noted
    - 2 documented surface anomalies that were classified as non-relevant
    - 1 documented a small piece of debris that is captured in the dryer internals (less than 2/10” in length)
    - 1 documented damage to the 20^{o} area at the separator guide rod cut out that required minimal repair
    - 1 documented deformation to perforated plates

Dryer Inspection Results (cont.)

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- The following 7 indications will be discussed:
  - 3 documented small cracks in the end vane in three vane assemblies (INRs 06-06, 06-08, and 06-10)
  - 1 documented the rotation of the lifting eyes and damage to the lifting rod threads (INR 06-01)
  - 1 documented a crack in the latch box located at the 220^{o} location (INR 06-29)
  - 1 documented a crack in the vane assembly end plate near the 320^{o} location (INR 06-04)
  - 1 documented a large crack in the dryer skirt and base plate at the 140^{o} location (INR 06-02)

Dryer Inspection Results (cont.)

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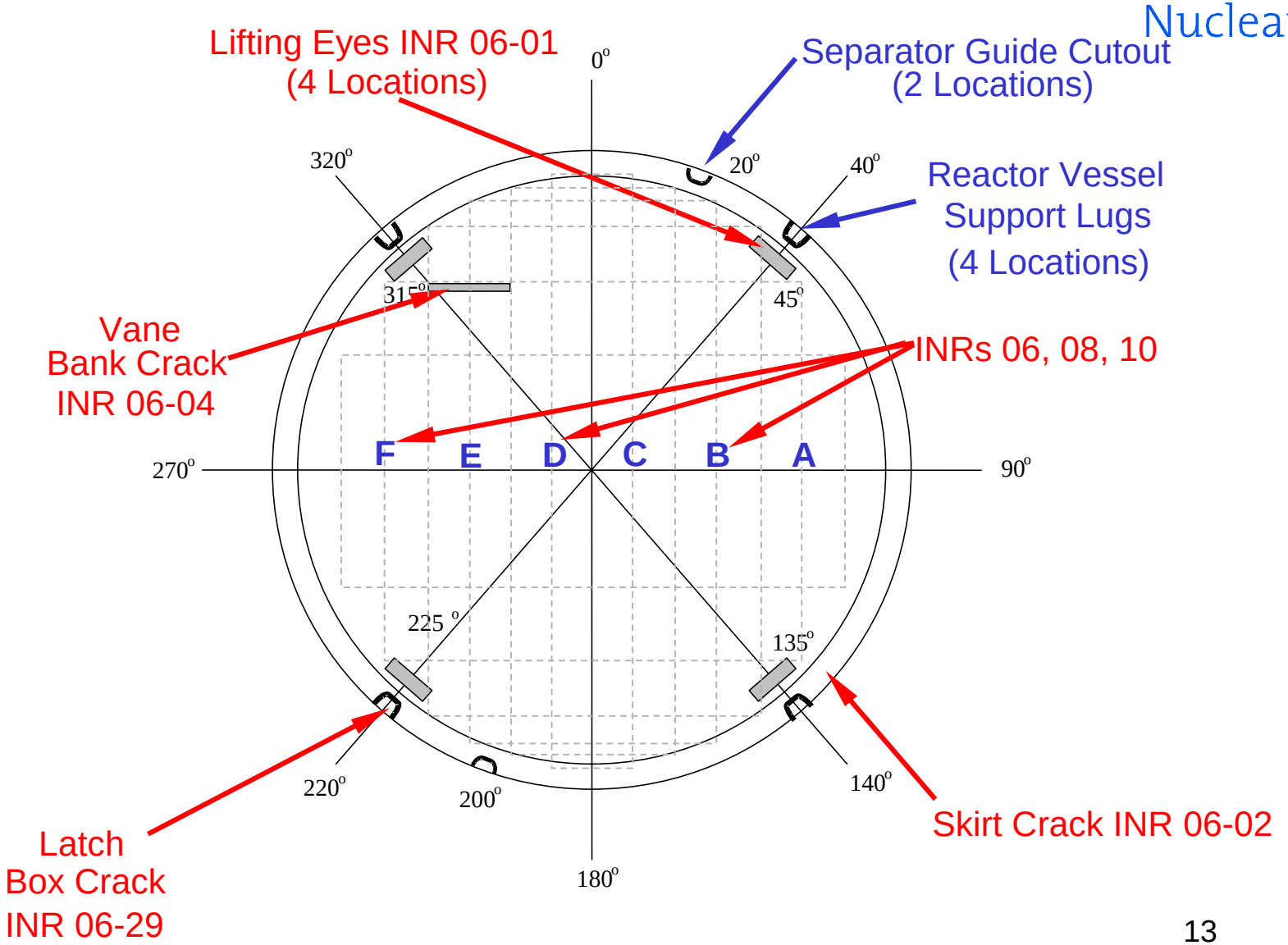

Dryer Inspection Results (cont.)

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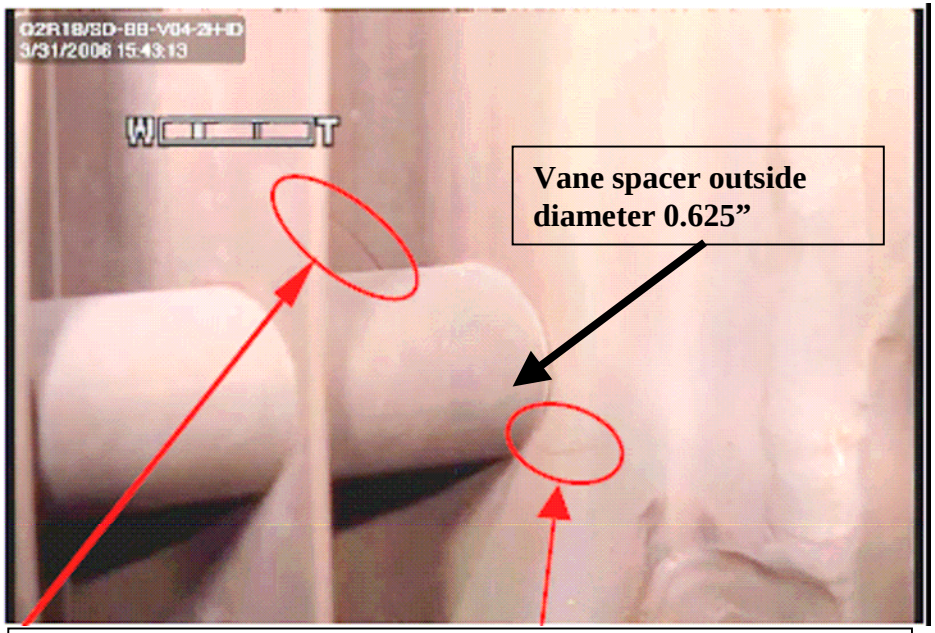
Dryer Vane Bank Assembly

- INRs 06-06, 06-08, and 06-10 document minor indications in the vane bank assemblies for dryer banks F, D, and B, respectively



Arrows indicate areas of cracking

Dryer Inspection Results (cont.)

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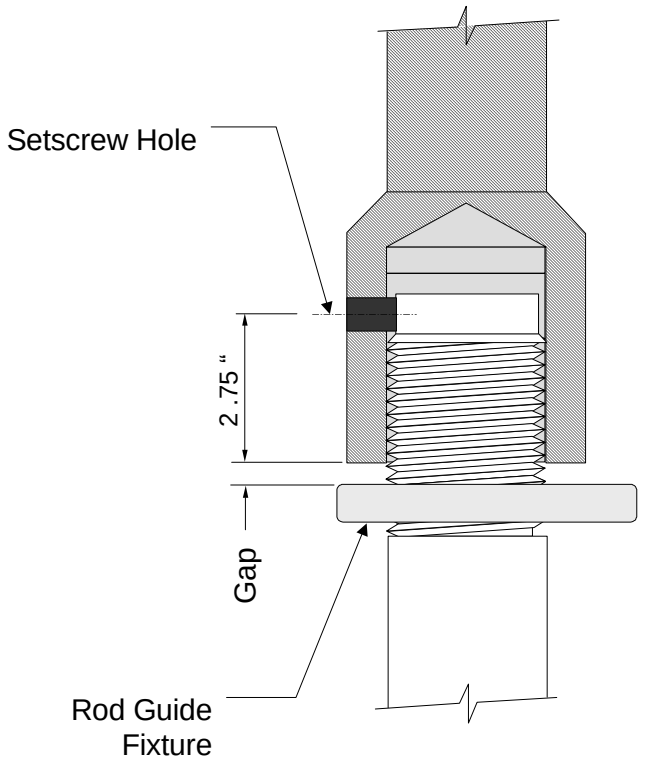
- Small cracks in the end vane in various vane assemblies (INRs 06-06, 06-08, and 06-10)
  - Characterized as fatigue cracking
  - Located in the end vane in their respective vane assembly which is wrapped around and welded to the end plate (non-structural)
  - Indications appear to have initiated from the hole in vane that accepts 5/8” tie rod protector
  - Dispositioned as no repair required - will be inspected during the next refueling outage
  - Missing material cannot be confirmed to be lost in the vessel – conservatively captured by lost parts program
- Applicability to QC1
  - Not a concern due to the small size of the cracks and lack of a driving force at that location
  - Cracks expected to be self relieving
  - Will be inspected during the upcoming planned outage

Dryer Inspection Results (cont.)

Dryer Lifting Eye Assembly

- INR 06-01 documented lifting eye rotation and lifting rod thread damage



Dryer Lifting Eye Assembly

Dryer Inspection Results (cont.)

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- Rotation of the lifting eyes and damage to the lifting rod threads (INR 06-01)
  - Four lifting eyes were found rotated out of alignment
  - Damage to the threads in the lifting rod at the 45º location
- Cause – installation issues with the setscrew in addition to an inadequate setscrew design that allowed the eyes to rotate with setscrew in place and tack weld intact
- Corrective action – unthreaded stock at the top of the lifting rod is being ground flat and a longer set screw is being added to ensure positive engagement
- Applicability to QC1
  - Lifting eyes on QC2 dryer were removed after initial attempt to engage lifting rig and reinstalled - not required on QC1
  - Lifting eye unlikely to separate from lifting rod due to unthreaded area at the top of lifting rod
  - In the unlikely event the lifting eye came off of the lifting rod, lost parts analysis has concluded that it would not prevent a safety function
  - Will be inspected during the upcoming planned outage

Dryer Inspection Results (cont.)

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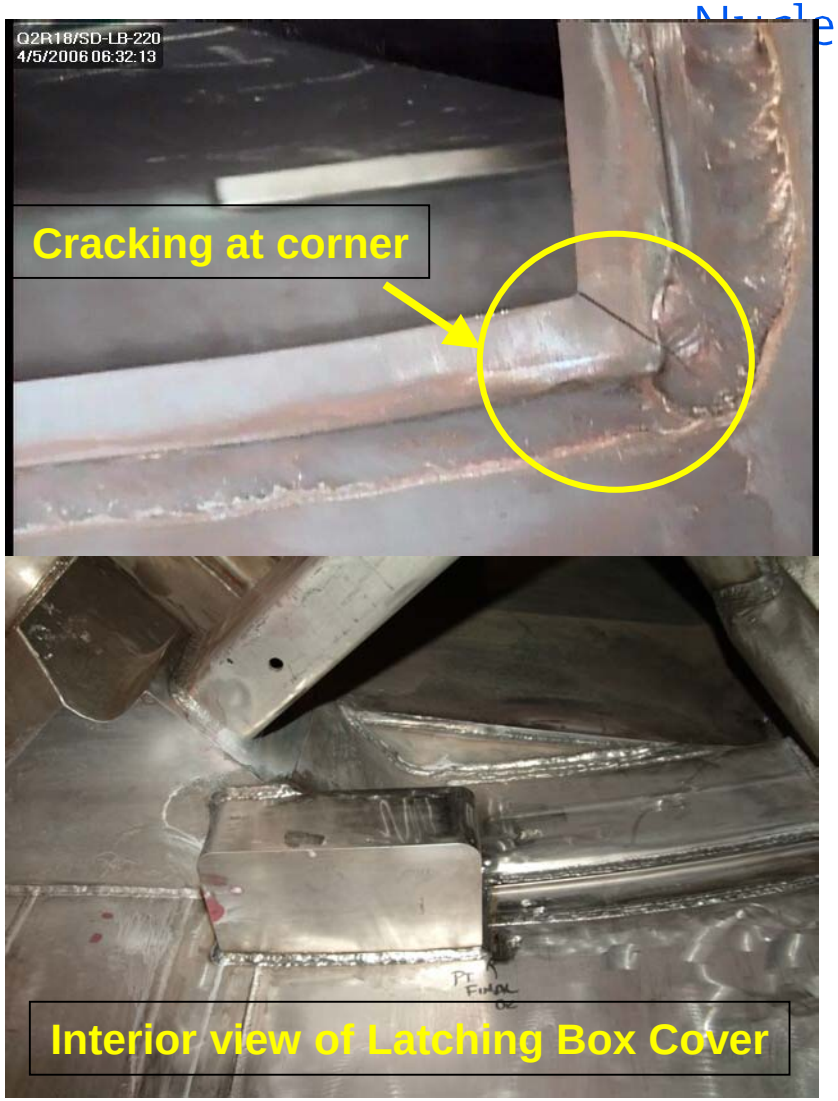
Latch Box

- INR 06-29 identified crack in latch box



Dryer Inspection Results (cont.)

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- Crack in the latch box at 220^{o} location (INR 06-29)
  - Function of the latch box is to limit bypass flow from the inside of the dryer skirt to the downcomer region
    - Non-structural component
  - Located on the same azimuth that was stressed during the impact event
  - Characterized as fatigue cracking
  - Other three latch boxes and welds were inspected with no issues identified
  - Repair consists of excavating cracked area and re-welding
- Applicability to QC1
  - QC1 dryer did not experience an impact event
  - Non-structural
  - Will be inspected during the upcoming planned outage

Dryer Inspection Results (cont.)

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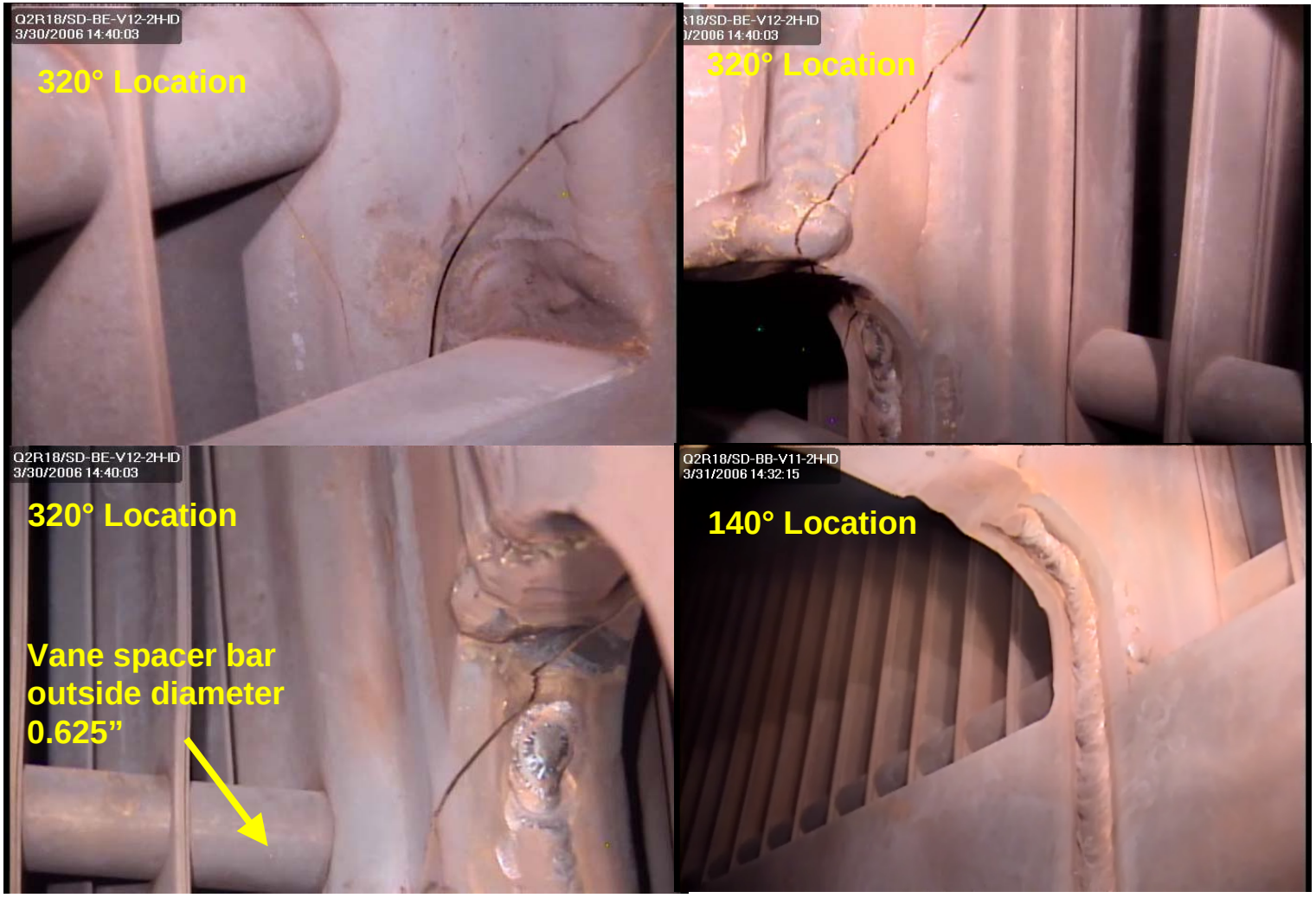
INR 06-04

Vane Assembly



Dryer Inspection Results (cont.)

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- Crack in the vane assembly end plate near the 320° location (INR 06-04)
  - Located on same azimuth of the dryer that experienced skirt base ring damaged during the impact event
  - Crack is in the bottom 2 inches of a ~6 foot weld
  - Characterized as fatigue cracking with a combination of bending and torsional loading
  - Inspection identified an abrupt change in weld thickness at the crack location
  - Similar locations inspected with no cracks identified nor were any other cases of abrupt changes in weld thickness identified
  - Not a loose parts concern due to attachment to other dryer members
  - Dispositioned as no repair required - re-inspect during the next refueling outage
- Applicability to QC1
  - QC1 dryer did not experience an impact event
    - Isolated to this one location in QC2
  - Not a lost parts concern
  - Will be inspected during the upcoming planned outage

Dryer Inspection Results (cont.)

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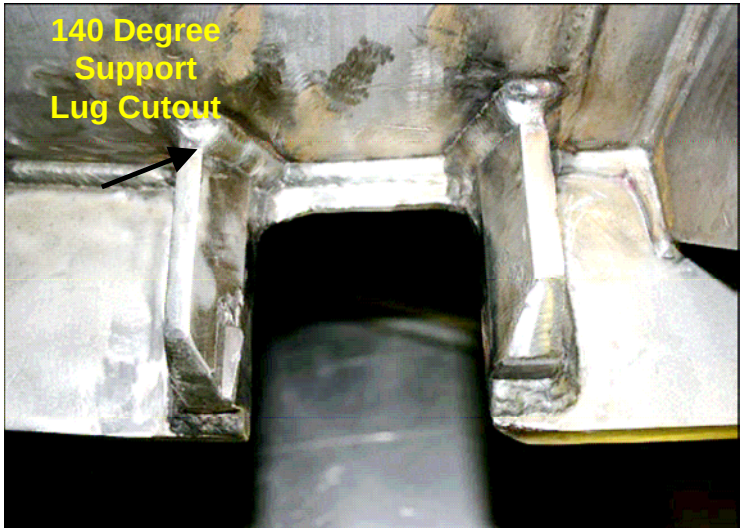
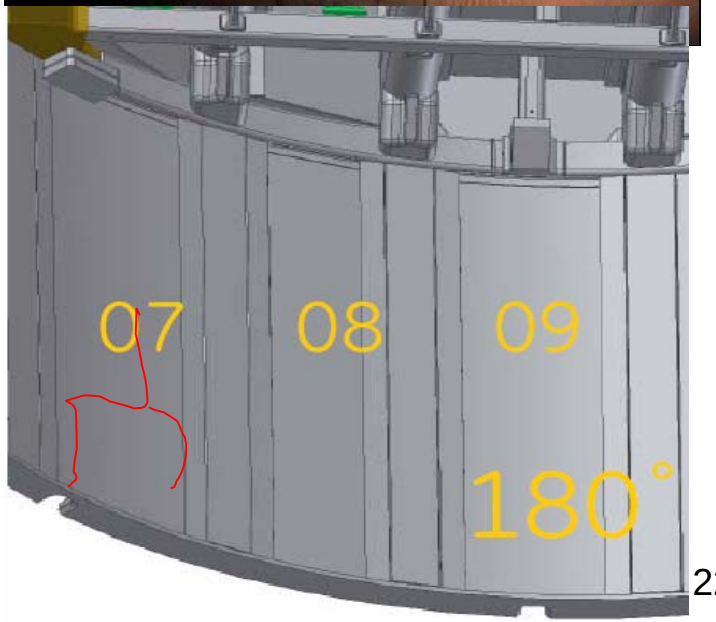
INR 06-02

Dryer Skirt





Dryer Inspection Results (cont.)

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- Crack in the dryer skirt and base ring at the 140° location (INR 06-02)
  - Approximate 6 foot crack extends from a cutout in the base ring into the adjacent skirt
    - Crack affected area was below the normal reactor water level
  - Boat samples taken in four locations for analysis
    - Preliminary cause indicates impact event key contributor
- Applicability to QC1
  - QC1 dryer did not experience an impact event
    - Ovality issues were addressed prior to manufacturing
  - Lost parts analysis concluded that if a lost part were generated would not compromise a safety function

Preliminary Cause

Roman Gesior

Corporate Programs Director

Preliminary Cause

- Multi-disciplined team used to determine cause of dryer damage
- Tools being used to determine cause of failure
  - Metallurgical failure analysis
  - Dryer inspection results and observations
  - Stress analysis
  - Failure Modes and Effects Analysis (FMEA)
  - Event and causal factor chart
- Conclusions
  - Load on skirt base ring during impact event induced damage while plastically deforming skirt base ring and skirt plate
    - Reduced the fatigue endurance
    - Residual stresses from fabrication were also a contributor
  - Operating pressure oscillation loads from Main Steam Line (MSL) acoustics resulted in skirt/base ring stresses that when combined with the reduced fatigue endurance was adequate to propagate cracking

Preliminary Cause

- Other causes investigated:
  - Design
    - Adequacy of FEA
    - Applied Loads/damping
    - New design
    - Base ring cutouts
  - Fabrication
    - Fit-up/sequence of fabrication
    - Base ring distortion
    - Materials issues
  - Installation
    - Decision making after fit-up
    - Impact with separator guide pins
    - Load cell not functioning
  - Operating transients

Preliminary Cause (cont.)

Metallurgical Analysis

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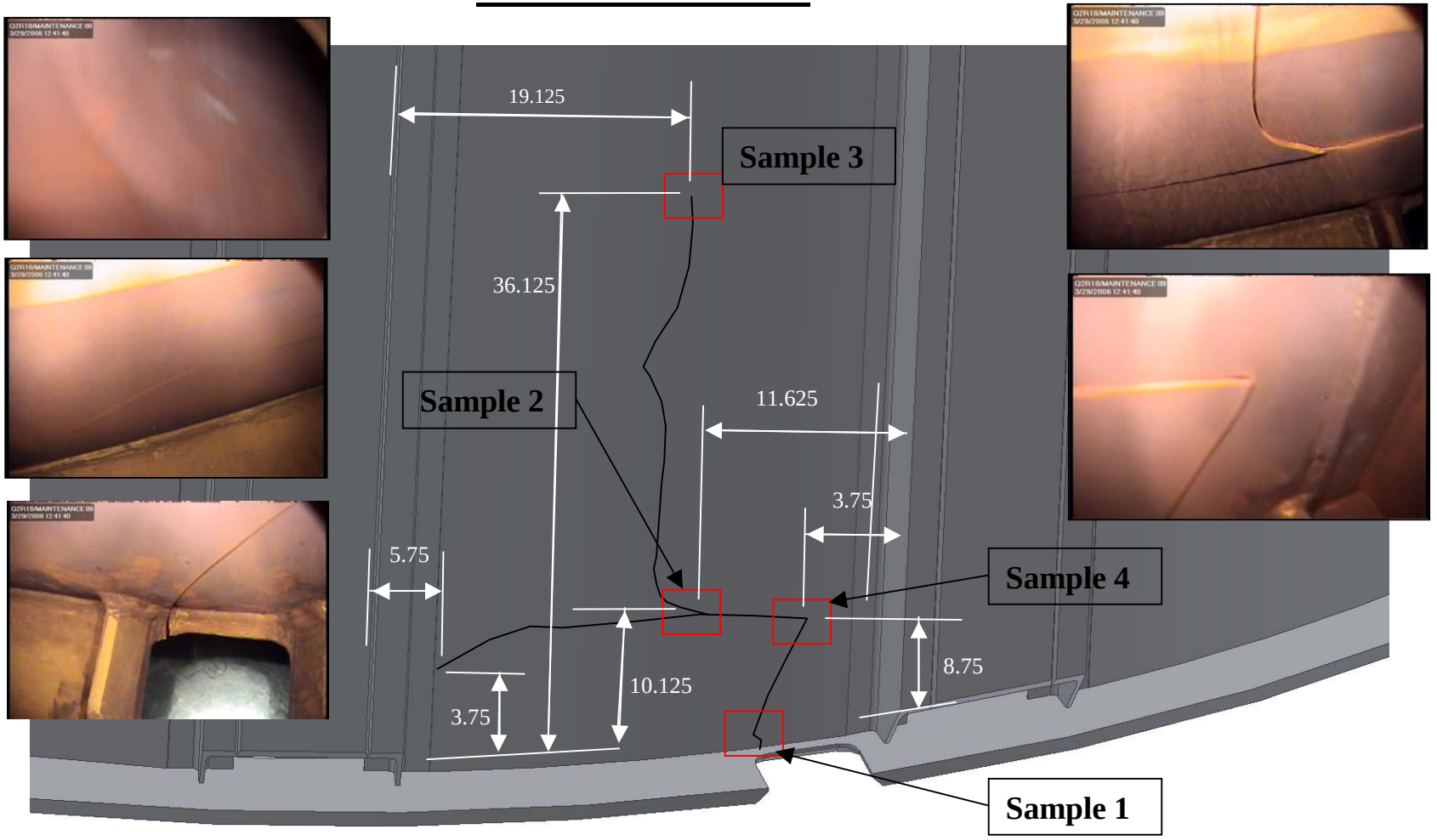
140° Location



Preliminary Cause (cont.)
Metallurgical Analysis

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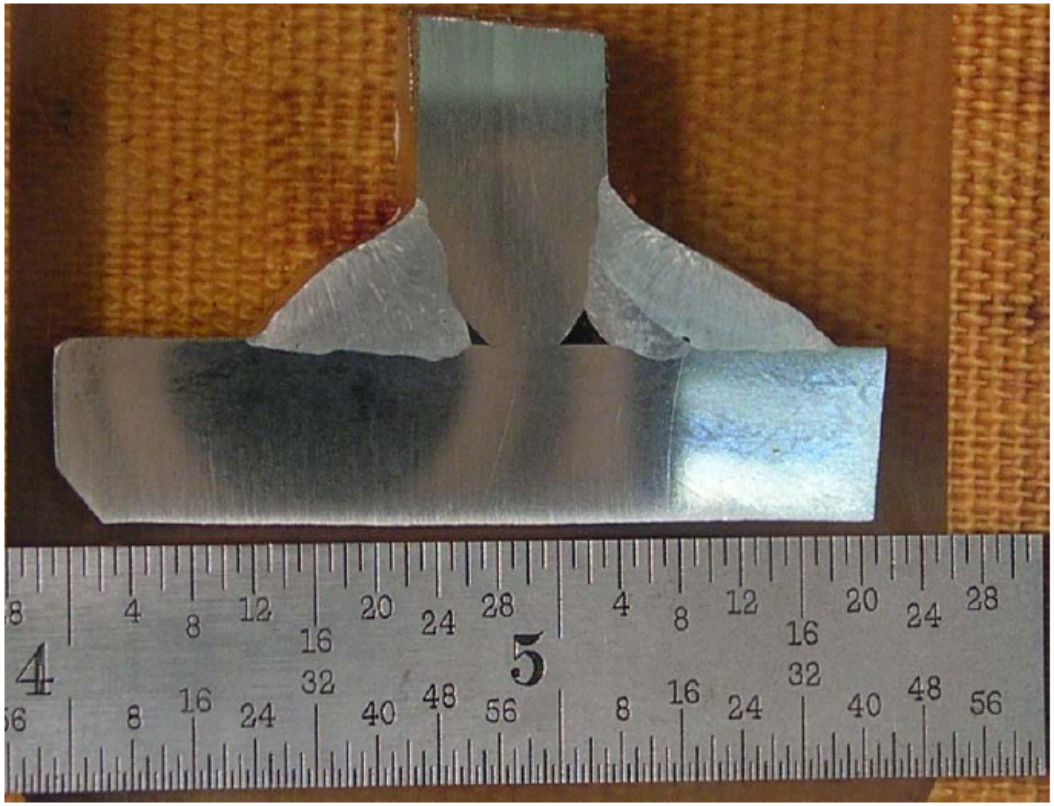
- Sample analysis results
  - Scanning Electron Microscope (SEM) results show surfaces are characteristic of fatigue
  - Fracture surface near the ID of the skirt base ring is consistent with torsional fatigue
  - No evidence of cold work induced stress corrosion cracking
  - No evidence of ductile tearing
  - Initiation site has not been identified
  - Secondary cracks that connect with the main fracture emanate out of weld root

Preliminary Cause (cont.)
Metallurgical Analysis

- Weld details require ID and OD penetration of 0.16” with 0.1” fillet reinforcement
- As built configuration has significant fillet reinforcement and weld size not cause of failure

Figure 2: Weld cross section of Sample 1-1 (in cut-out)
(~2 inches from fracture)



Preliminary Cause (cont.)
Metallurgical Analysis

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- Crack in the dryer skirt and base ring (140° location)
  - Impact event induced a large torsional load (>47,000 pounds) in the skirt base ring and bending load in skirt plate
    - Load on base ring at reduced section (due to cut-out area) resulted in localized high stress
  - The load resulted in plastic deformation of skirt base ring and skirt plate (dimples on skirt plate)
  - The plastic deformation of the base ring and skirt plate reduced the fatigue endurance limit of the material
  - Pressure oscillation loads from MSL acoustics provided cyclic stress necessary to propagate crack
    - The operating loads would also produce a torsional load on the base ring through the support gusset

Preliminary Cause (cont.)
Dryer Pressure and Strain Measurements

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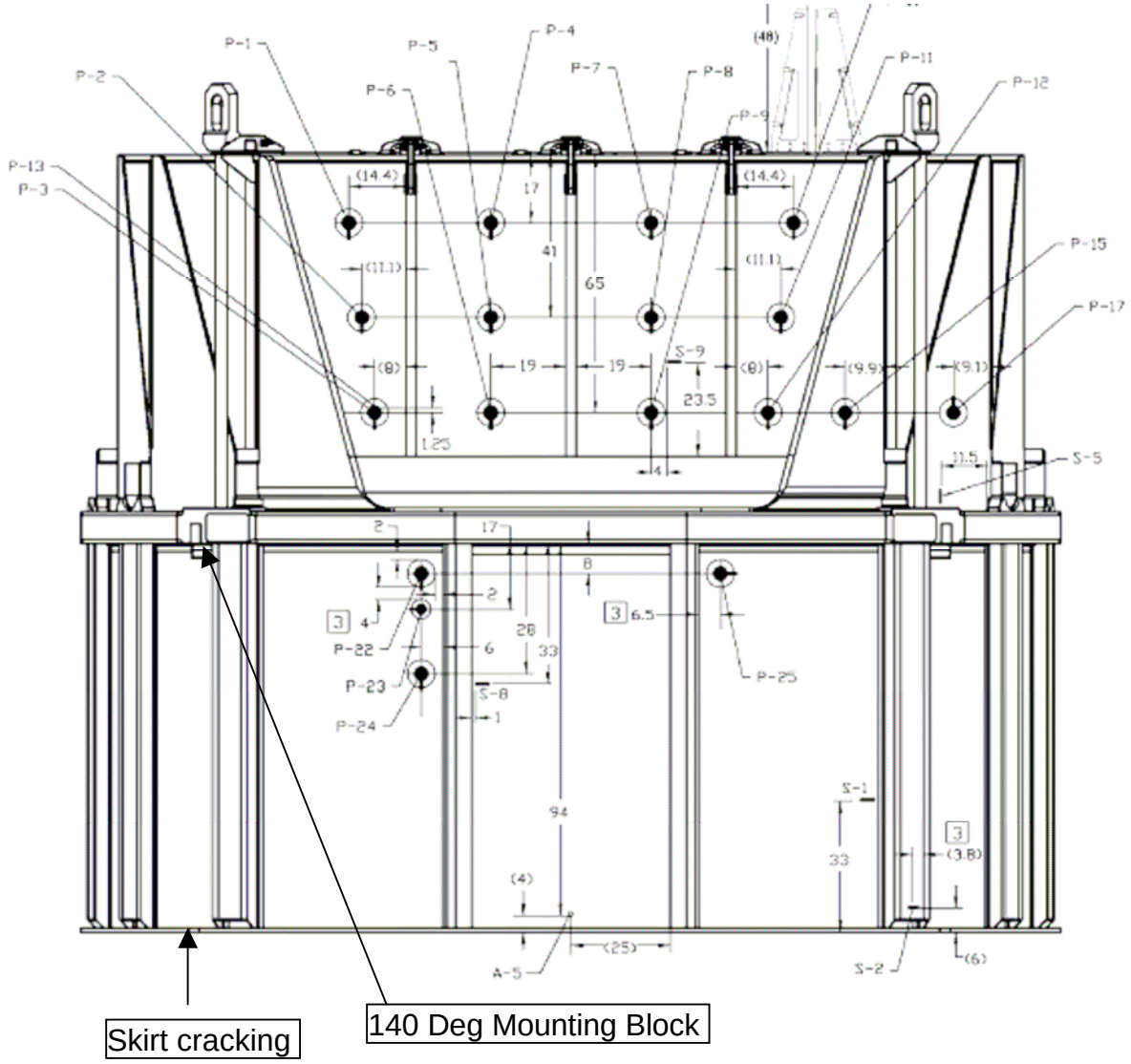
- Pressure oscillation loading alone at 140° location would not have initiated a fatigue crack
  - Other azimuths of dryer (MSLs C and D) with less plastic deformation had no cracking
    - Similar configuration
    - Higher pressure loading than the side that cracked (MSL B)
  - Skirt flat plate adjacent to MSLs has significantly higher pressure loads - however no cracking
    - Based upon in plant measurements
- Area of skirt base ring cracking was the most significantly deformed during the impact event
- Examination of the skirt at this location indicates dimpling
- The impact event resulted in residual stresses that reduced the endurance of the dryer skirt/base ring plate

Preliminary Cause (cont.)

Dryer Pressure and Strain Measurements



Skirt pressure transducers
- P22, P24, and P25

Skirt strain gages
- S8, S1, and S2

"A" Hood pressure transducers
P3, P12, P15, and P17

"B" Hood pressure transducers
P20 and P21

Instrument	psi (rms)	Max-Min psi
P3 (90°)	0.631	3.704
P12 (70°)	0.690	3.976
P15	0.547	3.192
P17	0.232	1.550
P20 (250°)	0.499	3.201
P21 (290°)	0.883	4.360
P22	0.422	2.622
P24	0.225	1.595
P25	0.344	2.436

Preliminary Cause (cont.)

Dryer Pressure and Strain Measurements

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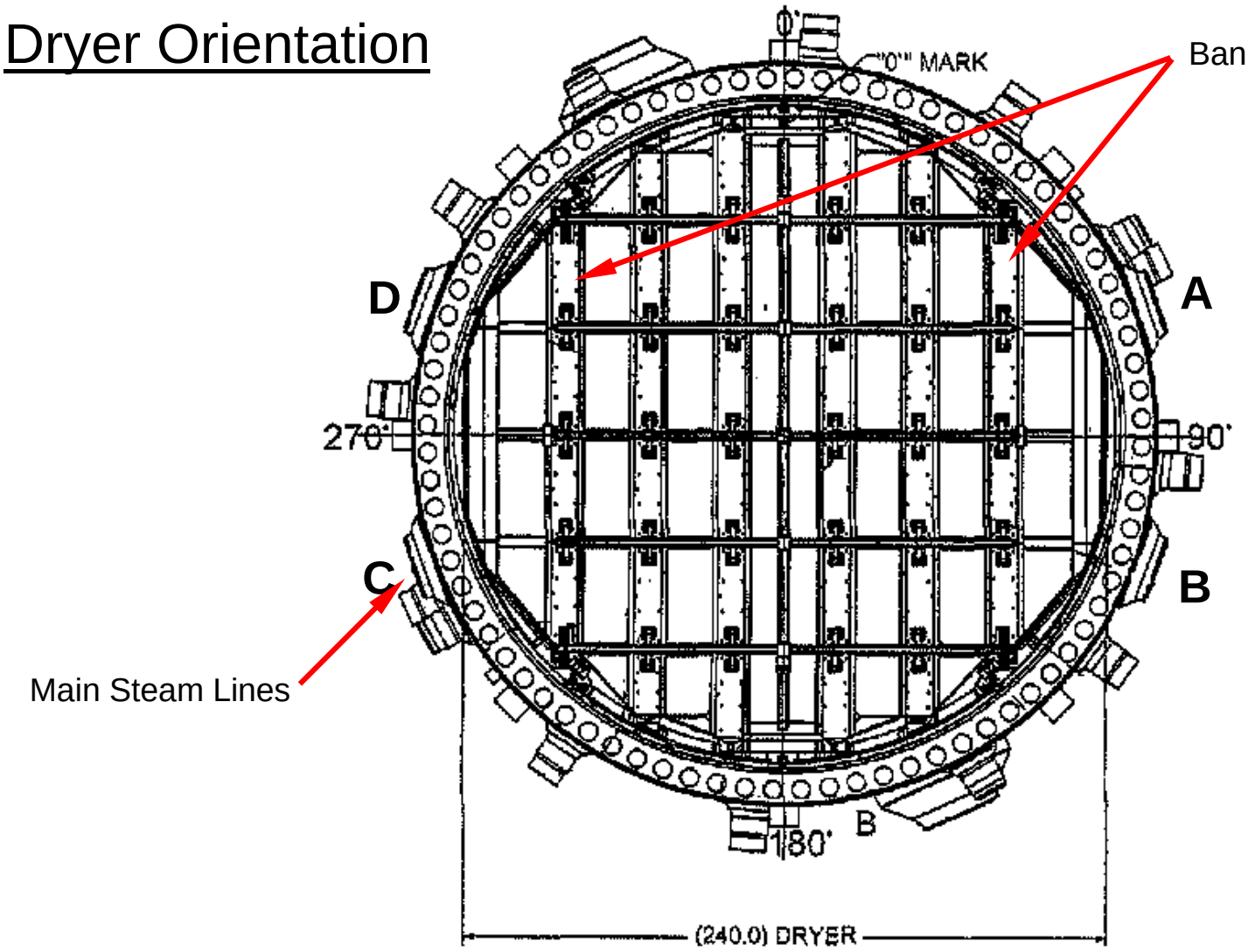
Dryer Orientation



Preliminary Cause (cont.)
Dryer Pressure and Strain Measurements

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- Dryer pressure load becomes smaller moving down from steam nozzles
  - Lowest outer hood pressure of 3.2 psi is greater than largest skirt pressure of 2.6 psi
  - Skirt pressure drops from 2.6 psi to 1.6 psi from P22 to P24 lower on skirt
- Pressure loads also drop when moving circumferentially away from the nozzles
  - Circumferential trend away from MSL P12 = 3.98 psi to P15 = 3.19 psi to P17 = 1.6 psi
- Pressure is lower on 140° (MSL B) dryer side than 40° (MSL A) or 320° (MSL D) dryer side
  - P3 (MSL B) = 3.7 psi is less than P12 (MSL A) = 3.98 psi and P21 (MSL D) = 4.36 psi

Preliminary Cause (cont.)
Dryer Pressure and Strain Measurements

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- Pressure measurements alone would indicate that the skirt is more susceptible at a different location
  - Cracking occurred at location of low measured pressure
  - Indicates that the residual stress due to impact event is a larger contributor than the acoustic pressure oscillation
  - Therefore, cracking occurred at 140° location due to increased plastic deformation and residual stress
- Condition of high stress locations on dryer with no cracks supports applied loads are conservative
- Number of fatigue cycles at EPU operation (>200 days) with 155 Hz load would have resulted in cracks at this location if stresses exceeded endurance limit
- No dryer degradation at 40° azimuth where dryer did not get hung up on RPV wall support

Preliminary Cause (cont.)
Finite Element Model

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- 2005 evaluation of impact event
  - Stress identified in the evaluation was extremely low and therefore the deformation residual stress was not considered an issue
  - Stress levels under-predicted due to simplistic modeling of dryer skirt base ring plate
    - Cutout not included
    - Skirt base ring support gusset was not included
  - Recent model update with solid elements including cut-out and gussets indicate that the cycle operating stresses are low (<30% of endurance limit)
  - PT inspections of the deformed areas did not include the dryer ID
  - An analysis was not performed to characterize the stress level or dryer loading due to the dryer being hung up
    - PT inspection results provided condition assessment that material tensile stresses were not exceeded

Preliminary Cause (cont.)
Conclusions

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- Load on skirt base ring during impact event induced damage while plastically deforming skirt base ring and skirt plate
  - Reduced the fatigue endurance
  - Residual stresses from fabrication were also a contributor
- Operating pressure oscillation loads from MSL acoustics resulted in skirt/base ring stresses that when combined with the reduced fatigue endurance was adequate to propagate cracking

Repair Strategy

Tim Hanley
Director Midwest Operations Projects

Repair Strategy

- 140^{o} and 220^{o} locations
  - Removed a portion of skirt base ring and skirt panel and replaced with plates of the original dimensions
  - Cutout size: ~26” by ~40” for the 140^{o} skirt section
  - Similar repair was made at the 220^{o} location; however, height is only 12 inches, which removes all deformation that was measured in the dryer skirt
  - Restores dryer to as close to original design configuration as possible
- 320^{o} location
  - Major portion of the deformed base plate was already being removed at the 320^{o} location as part of the original modification to address the cause of the impact event
- Removing skirt ring gussets at all four locations
- These changes to the dryer have been independently reviewed by a third party

Conclusions/Outage Status

Randy Gideon

Plant Manager

Conclusions

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- Replacement dryer design is robust
- Cracking that occurred in the skirt and base ring would not have occurred without the impact event
- Remainder of indications are not structurally significant
- Design enhancements and repairs have been analyzed and independently reviewed
- Dryer inspection results demonstrate replacement dryer design is sufficient to accommodate EPU operation