

**NRC Regulatory Conference
January 11, 2012**

**Palisades Nuclear Plant
Service Water Pump P-7C
Coupling Failure**



Entergy Nuclear Operations

ENTERGY NUCLEAR

Tony Vitale
Site Vice President
Entergy - Palisades



Agenda

- Introduction Tony Vitale
- Objectives Tony Vitale
- Apparent Violation Tony Vitale
- Root Cause Alan Blind
- Key Learnings Alan Blind
- Key Corrective Actions Alan Blind
- Common Cause Alan Blind
- Significance Brian Brogan
- Conclusions Tony Vitale

Objectives

- Discuss apparent violations and Entergy's acceptance of the finding
- Review the causal analysis of the event
- Review corrective actions
- Provide additional insights into the safety significance of the finding
- Address common cause failure probability

Complex Technical Issue

- Thorough investigation and cause analysis
- Robust corrective actions
- Different material properties between pumps
- P-7A and P-7B had lower susceptibility
- Material toughness not recognized as critical

Apparent Violation

- Entergy concurs with the apparent violations.
- Entergy has additional information for consideration regarding the safety significance of the finding.

Palisades Performance Recovery Plan

- **Plan Area**
 - Major divisions of culture or processes in need of improvement
 - Five major plan areas including
 - condition problem statement
 - future condition vision statement
 - Sixth plan area is Communications
- **Plan Elements**
- **Plan Actions**
- **Plan Metrics**

Palisades Performance Recovery Plan

- Plan Areas
 - Leadership Effectiveness
 - Safety Culture
 - Corrective Action Program
 - Equipment Reliability
 - Refueling Outages
 - Communication Plan

Alan Blind

Engineering Director

Entergy – Palisades



2011 SWP P-7C RCE Causal Analysis

- Scope Elements
 - Pump Operation
 - Maintenance Procedures and Practices
 - Organizational and Programmatic Factors
 - Metallurgical Analysis

2011 SWP P-7C RCE Causal Analysis

- Root Causes:
 - In 2006, the ASTM specification selected lacked specificity to ensure all critical material testing requirements for use in the service water operating environment (RC2) (O&P)
 - The 2009 and 2011 line shaft coupling failures were due to IGSCC (RC1) (Metallurgical)

2011 SWP P-7C RCE Causal Analysis

- Contributing Causes:
 - Increased susceptibility to IGSCC caused by tempering embrittlement (CC1) (Metallurgical)
 - Insufficient use of qualified metallurgical expertise (CC2) (Criterion XVI) (O&P)
 - Ineffective use of operating experience (CC3) (O&P)

Key Organizational Learnings

1. 2009 – Installing ASTM conforming material; other possible factors were not investigated (O&P)
2. Use of all available resources including operating experience and third party reviews (O&P)

Service Water Pump Teams

	2006/2007 Modification	2009 RCE	2010 Operating Experience Review	2011 RCE / Modification (Criterion XVI) (Criterion III)
Failure Analysis: Lucius Pitkin, Inc				X
Pumps: Mancini Consulting Services				X
Organizational Factors: Seastate Group				X
Technical Review: Structural Integrity		X	X	X
Palisades Engineering	X	X	X	X
Palisades Maintenance		X		X
Palisades Training				X
Entergy Fleet Challenge		X		X
OEM: Hydro Aire	X	Supplier RCE		X

Corrective Actions Technical

- New coupling material installed on all SWPs (RC1, CC1) (Metallurgical)
 - ASTM A564 type 630 SS Condition H1150 commonly referred to as 17-4PH (RC1, CC1)
 - Mechanical testing requirements include:
 - hardness
 - toughness
 - For additional assurance, an effectiveness review will be completed on the P-7C couplings by removal and inspection.

Corrective Actions

Organizational and Programmatic

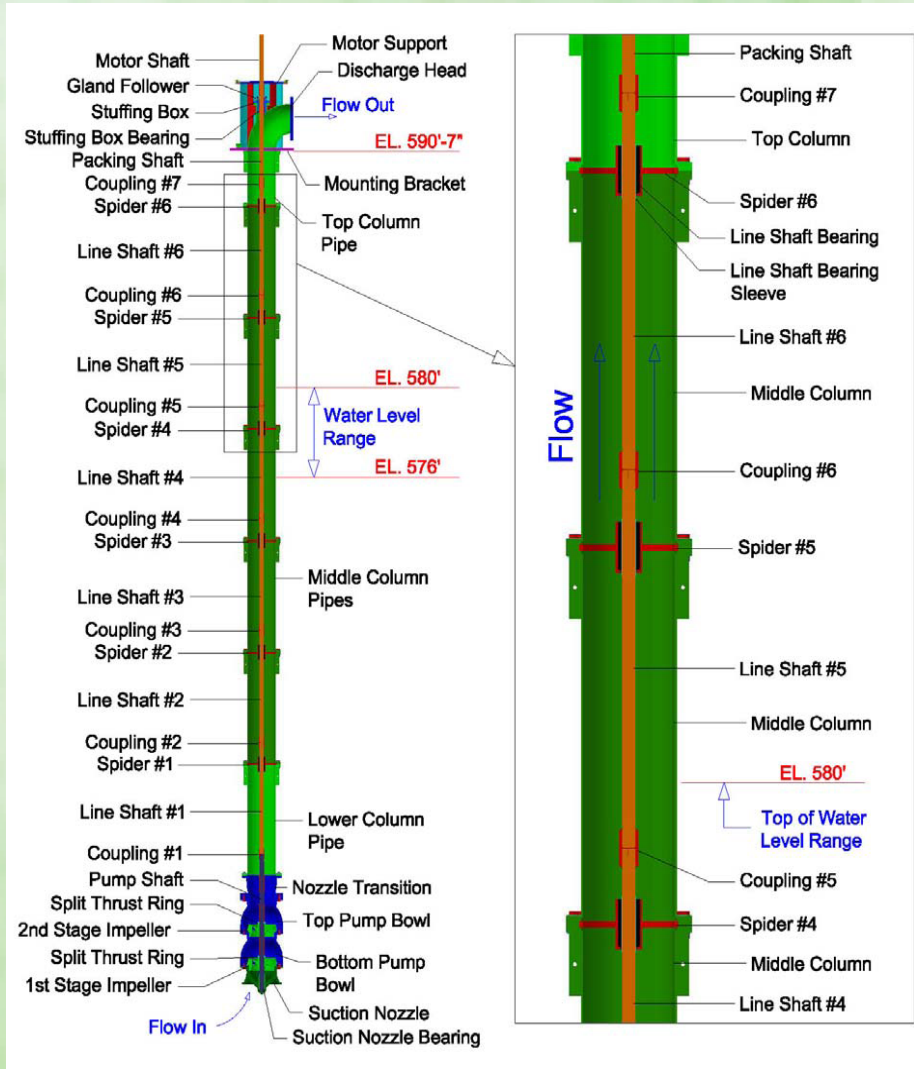
To address the 2006 modification issue:

- 2007 implemented EN-HU-104, “Technical Task and Rigor,” requires an Independent Technical Review for complex, high risk modifications (CC2) (Criterion III)
- 2007 implemented EN-DC-115, “Engineering Change Development,” requires a review of operating experience (CC3) (Criterion III)
- 2012 implemented EN-MS-S-037-L, “Requirements and Expectations for Material Change Design Changes,” identifies requirements and expectations for material changes affecting installed plant equipment (RC1, RC2, CC1, CC2, CC3) (Criterion III)

Common Cause Susceptibility Analysis

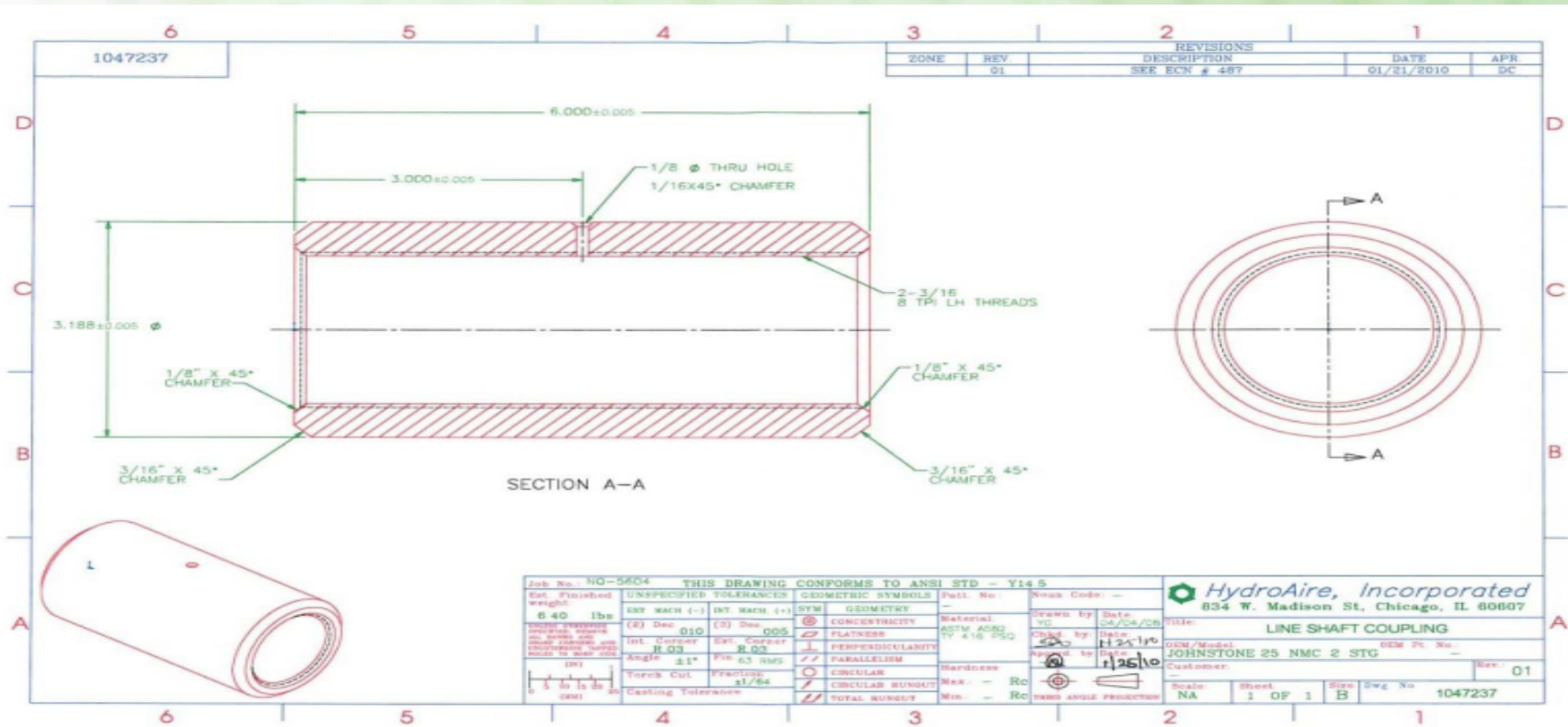
Common Cause Susceptibility Analysis

- SW Pumps (P-7A, B, C)
 - Pumps are two stage vertical shaft with 350 HP motor, each rated 8000 gpm at 140 ft of TDH.
- Local Coupling Environ
 - Nos. 1-4 continuously submerged in lake water
 - Nos. 5-7 experience wet/dry cycles
 - No. 8, near motor, is dry



Common Cause Susceptibility Analysis

- Shafts are connected by 8 threaded couplings
 - Coupling material was specified as ASTM A582 Type 416 SS



Common Cause Susceptibility Analysis

- 2011 service water pump (SWP) P-7C failed coupling: **cracks originated at thread roots and propagated to the outer diameter**
- Slanted fracture of remaining ligament is evidence of an overload event



Fracture Surface of 2011 Failed Coupling No. 6 in P-7C

Common Cause Susceptibility Analysis

- Failed couplings were all located in wet/dry region
 - Failed 2009 coupling P-7C #7
 - Failed 2011 coupling P-7C #6
 - Cracked 2011 coupling P-7C #7
 - Cracked 2011 couplings P-7B #5, 6 & 7
- P-7A - No indications found
- P7B - 40 days minimum from “as removed condition” to failure

Common Cause Susceptibility Analysis

- 2006 - ASTM A582 Type 416 SS Design Conformance. Hardness range for intermediate temper 24 to 32 HRC
 - 2006 - 2009 First P-7C Failure
 - Failed coupling hardness ranged from 34.8 to 37.1 HRC
 - 2009 - 2011 Second P-7C Failure
 - Failed coupling hardness ranged from 24.0 to 33.6 HRC

Common Cause Susceptibility Analysis

- Additional 2011 Testing:
 - Tensile Testing
 - The yield strength and elongation were found to be in the expected range for the specified intermediate temper condition
 - Charpy V-Notch Impact Energy
 - Low absorbed energy found: indicates low fracture toughness; which correlates with increased SCC susceptibility
- No correlation with coupling hardness and couplings that were cracked or failed

Common Cause Susceptibility Analysis

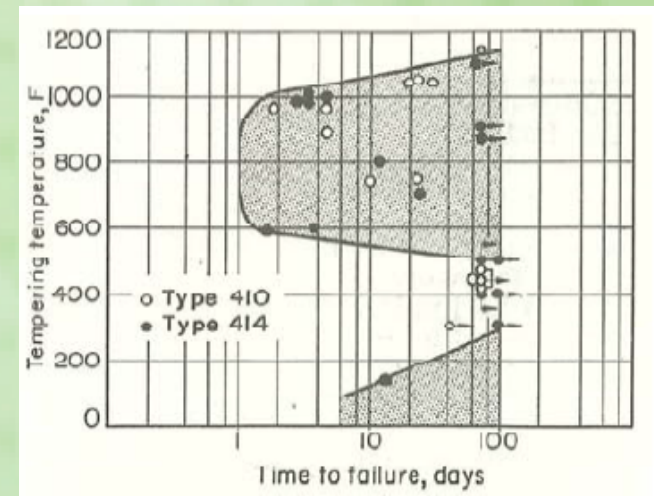
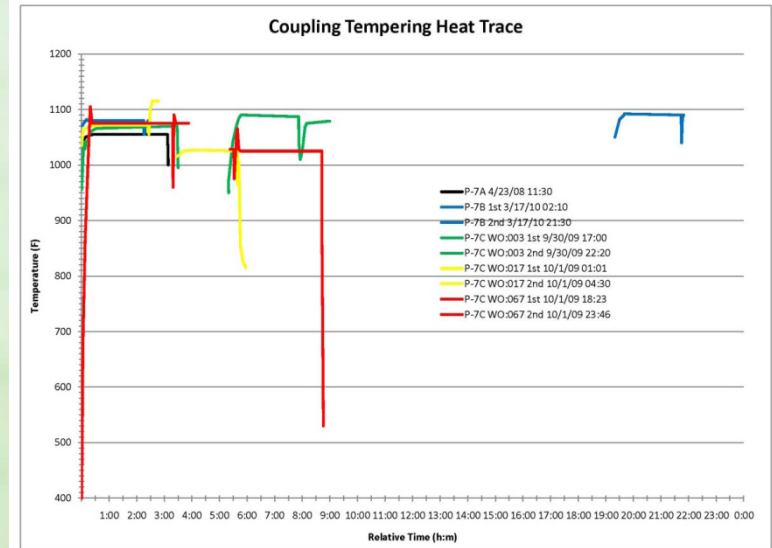
Stress Corrosion Cracking

- SCC is a failure process that requires each of the following:
 1. Susceptible Material
 2. Corrosive Environment
 3. Tensile Stress

Common Cause Susceptibility Analysis

1. Susceptible Material

- P-7C most susceptible
- Type 416 SS can be more or less susceptible to SCC depending on heat treatment
 - Couplings installed on P-7C SWP in 2009, were tempered in the range of 1025°F – 1090°F to achieve the specified hardness (28-32 HRC).
 - Tempering in critical range made the P-7C couplings less tough and more susceptible to SCC



ASM Metals Handbook, 8th Ed., Vol. 2

Common Cause Susceptibility Analysis

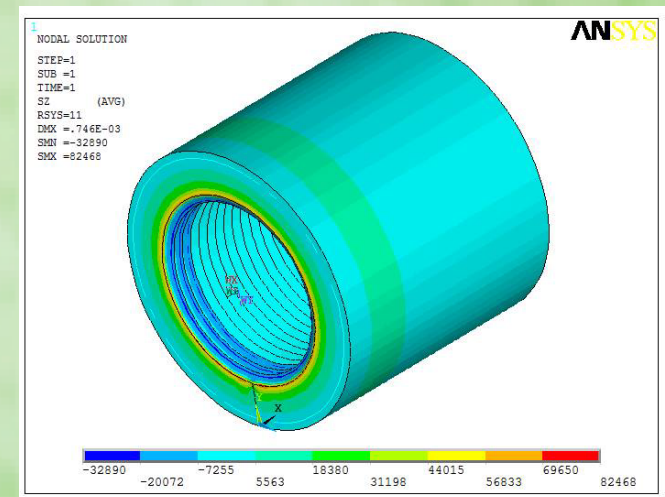
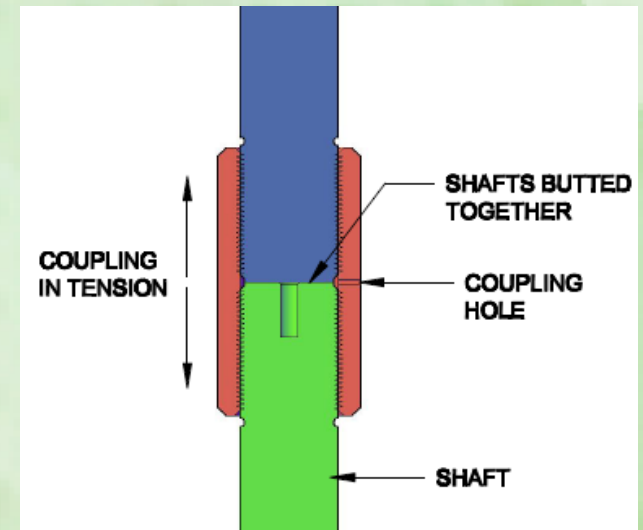
2. Corrosive environment

- Palisades intake water is chlorinated
- Chlorine was present on fracture surfaces
- Couplings 5, 6, and 7 in wet/dry zone

Common Cause Susceptibility Analysis SWP P-7C

3. Tensile Stress

- Threaded shaft and coupling design translate the motor torque to tensile stress across the coupling



Common Cause Susceptibility Analysis

Stress Corrosion Cracking Common Cause Evaluation Summary

	SWP 7A	SWP 7B	SWP 7C
Susceptibility:			More
Single Temper	X		
Double Temper		X	X
Critical Temper Range			X
Corrosive Environment	X	X	X
Tensile Stress	X	X	X
Wet / Dry Environment	X	X	X
2009 Nominal Run Time To Failure			2,414 hr
2011 Nominal Run Time To Failure			14,155 hr
Nominal Run Time To Replacement	16,259 hrs	9,073 hrs	

Technical Conclusion

- No common cause failure
 - P-7A – highest inservice time, least susceptible to SCC
 - P-7B – capable of meeting 30-day mission time
 - P-7C failure – P-7A and P-7B continued to provide two operable service water pumps

Brian Brogan
Sr. Staff Engineer
Entergy - Palisades



Significance Determination Overview

- Present the key input/assumption differences that affect the safety significance determination
- Show differences between:
 - NRC Inspection Report for P-7C Coupling Failure Preliminary White Finding
 - Entergy Calculation No: EA-PSA-SDP-P7C-11-06, “SDP Assessment of P-7C Coupling Failures”

Significance Determination Key Factors

- Service Water Pump Failure Rates
 - Independent Failure Rate
 - Common Cause Failure Rate
- Loss of Service Water (LOSW) Initiating Event (IE) Frequency
- Service Water System Unavailability in Response to Initiating Events

Service Water Pump Independent Failure Rate

- The service water pump failure-to-run basic event (BE) probability was updated
- Entergy concurs with the value derived for this probability in the inspection report

Common Cause Failure Rate

- Entergy common cause analysis includes:
 - Independent engineering analysis performed
 - Timing of the failures (based on NUREG/CR-6268)
 - Conservative statistical analysis of failure probability based on projected failure date from metallurgical analysis
 - Independent metallurgical analysis performed
 - No indications of cracking in the P-7A couplings

Entergy LOSW-IE

- Specific initiating event model to evaluate the increase in the LOSW-IE due to pump failures
- Conservative treatment of the common cause term in the initiating event model
- Method consistent with ASME/ANS PRA Standards for Capability Category II

Entergy LOSW-IE

$$F(\text{LOSW-IE})/\text{yr} = 8766\lambda_{\text{LOSWIE}}A$$

$$\lambda_{\text{LOSWIE}} = \lambda_{\text{CCFR}}(\lambda_S + \lambda_{\text{FR}} T_{\text{CCF}} + Q_{\text{MSP}}) + 2\lambda_{\text{IFR}}(\lambda_{\text{FR}} T_{\text{IF}})(\lambda_S + \lambda_{\text{FR}} T_{\text{IF}} + Q_{\text{MSP}})$$

- A SWP-induced loss of service water can be caused by:
 - Failure of the two normally running pumps and failure or unavailability of the standby pump
 - Failure of the two normally running pumps during the time frame when the first pump is out of service (OOS) for repairs
 - The standby pump can fail to start or fail to continue running while both of the normally operating pumps are OOS for repairs

Entergy LOSW-IE

$$\lambda_{\text{LOSWIE}} = \lambda_{\text{CCFR}}(\lambda_{\text{S}} + \lambda_{\text{FR}} T_{\text{CCF}} + Q_{\text{MSP}}) + 2\lambda_{\text{IFR}}(\lambda_{\text{FR}} T_{\text{IF}})(\lambda_{\text{S}} + \lambda_{\text{FR}} T_{\text{IF}} + Q_{\text{MSP}})$$

$\lambda_{\text{CCFR}} = \beta_{\text{FR}} \lambda_{\text{FR}}$	Failure rate for common cause failures of the two normally running pumps
$\lambda_{\text{S}} =$	Failure rate for failure of the standby pump to start on demand
$\beta_{\text{FR}} =$	Common cause beta factor for failure to run of two normally operating pumps. This factor is conservative as it accounts for all failure modes (not just the failure mode introduced by increasing the potential of IGSCC). The quantitative failure probability analysis supports the conservatism in this value.
$\lambda_{\text{FR}} =$	Failure rate for failure of the standby or operating pump to run
$\lambda_{\text{IFR}} = (1 - \beta_{\text{FR}}) \lambda_{\text{FR}}$	Failure rate for independent failure to run for each normally running pump
$T_{\text{CCF}} =$	Mean time to repair of at least one pump after a common cause failure to run
$T_{\text{IF}} =$	Mean time to repair of a normally operating pump after an independent failure to run
$Q_{\text{MSP}} =$	Maintenance unavailability of a Standby pump while plant in operation

Comparison of LOSW-IE Changes

Time Period	Inspection Report Increase in LOSW-IE	Entergy Increase in LOSW-IE
P-7C In Service	3.23	1.3
P-7C Out of Service	1590	30

Delta CDF Summary

Model	Inspection Report Δ CDF/yr	Entergy Δ CDF/yr
Full Power Internal Events	4.7E-6	4.3E-7
Flooding	(screened out)	1.0E-8
Fire	3.0E-7	7.0E-9
Seismic	3.5E-7	ϵ (not significant)
Total	5.4E-6 (White)	4.5E-7 (Green)

Significance Determination Conclusion

- The P-7C failures were determined to be repeated independent failures of a single component
- LOSW-IE is dominant impact on the results
- Impact of this condition on service water as a mitigating system yields results consistent with “very low” risk

Tony Vitale
Site Vice President
Entergy - Palisades



Summary

- Entergy concurs with the violations
- A thorough review of the event was performed to identify all related causes
- Entergy has developed effective corrective actions and root and contributing causes
- Entergy has performed a rigorous analysis consistent with ASME/ANS PRA standards
- Entergy's determination of the safety significance is "very low"