Relief Request for Reactor Vessel Head Nozzles Peened at Byron Station Unit 2

NRC/Exelon Meeting, NRC Headquarters

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Exelon Generation®

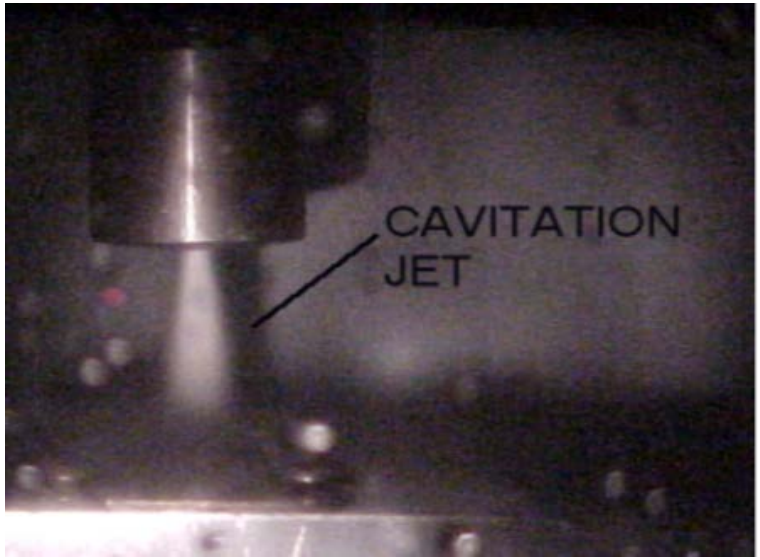
Agenda

- Introductions and Opening Remarks
- Background and Objective
- Relief Request Overview
- Byron Unit 2 Peening Application
- Peening Parameters
- Technical Rigor for Peening Process
- Deterministic Technical Basis
- Summary
- Schedule

Background

- Exelon utilized the AREVA UHP cavitation peening system to perform peening of the outside diameter and inside diameter of the Byron Unit 2 reactor vessel closure head vent line, penetration nozzles and J-groove welds

- The cavitation bubbles generated by the 55,000 psi jet provides compressive forces to reduce the existing residual tensile stresses from the J-groove welding process to a compressive stress state



Objective

- Application of UHP Peening technology on the Braidwood and Byron RPV head nozzles proactively mitigates PWSCC
  - Improves health and safety by reducing the potential risk of nozzle cracking and associated leakage
  - Significantly reduces dose related to reactive repairs
  - Preserves RPV head for safe prolonged life
- Delineate Exelon's strategy in following MRP-335 prescribed peening processes and inspection relief for mitigated Reactor Heads
- Detail technical rigor and extensive margins in Exelon's application of the RPV head nozzles peening process
  - Minimize post-peening stress to be zero or compressive
  - Applied increased peening coverage area and higher depth of compression
  - Additional detailed corrosion testing accuracy

Relief Request Overview

- Separate submittals for each peened head
- Exelon requests relief consistent with MRP-335 SE for follow up inspection in N+2 and subsequent 10-year ISI interval
- Additional relief requested from N+1 inspection based on actual peening application meeting or exceeding MRP-335 SE requirements
- Nozzles previously repaired that were peened are included as part of this request
- Nozzles that did not receive ID peening will not be included as part of this request

Relief Request Overview - Basis

- Exelon achieved post-peening residual plus operating stresses significantly less than the required **10 ksi**:
  - ≤ **0 ksi** on all **ID surfaces**
  - ≤ **-11.1 ksi** on all **OD weld surfaces**
  - ≤ **-22.1 ksi** on all **OD nozzle surfaces**

- Exelon peened the full code case N-729-1 inspection area instead of the MRP-335 required 20 ksi region and FEA model analysis showed the **actual 20 ksi region was significantly smaller** than that specified in the peening coverage requirements

- Exelon achieved:
  - **1-1.5 times** the required OD depth of compression
  - **1-5 times** the required ID depth of compression

Relief Request Overview – Basis (continued)

- Exelon utilized a more sensitive XRD methodology that provided highly accurate and repeatable results, supporting the stress measurements that were qualified in the SPQR
- Performed testing to confirm peening doesn't damage the nozzles or adversely affect flaw detection
- Deterministic crack-growth rate analysis demonstrates acceptability of 36 month interval, thus, inspection during N+1 is not required

Peening Parameters

- The following are areas where margin exists between the Byron Unit 2 results and the MRP-335 SE peening requirements:
  - Post Peening Stress
  - Peening Coverage Area
  - Depth of Compression
  - Post Peening Stress Accuracy
- Repaired nozzle was peened
- Additional testing performed verified technical rigor of the peening process:
  - Erosion Testing
  - Corrosion Testing
  - EPRI Coupon Testing
- Deterministic analysis for crack-growth rate

Peening Parameter Margins – Post Peening Stress

- The post peening residual plus operating stress achieved is significantly below the MRP-335 SE required **10 ksi**
  - The nozzle post peening OD residual plus operating stress range is -22.1 to -47.3 ksi for a margin of 32.1 to 57.3 ksi (29.1 to 54.4 ksi*)
  - The weld material post peening OD residual plus operating stress range is -11.1 to -41.6 ksi for a margin of 21.1 to 51.6 ksi (8.1 to 38.6 ksi*)

Location ID	Surface ID or OD	MRP Req'd Stress (ksi)	Post Peened Stress (ksi)	Margin with MRP (ksi)
7	OD	+10	-41.6	51.6
8	OD	+10	-28.4	38.4
15	OD	+10	***-11.1***	***21.1***
16	OD	+10	-32.7	42.7

** with worst case XRD accuracy*

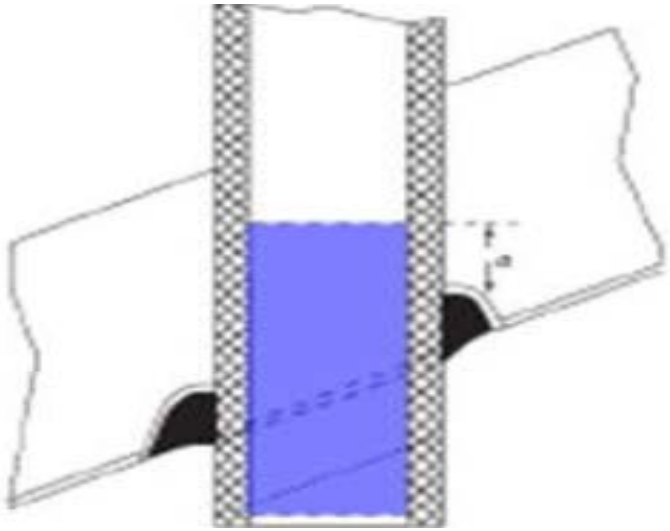
Peening Parameter Margins – Post Peening Stress

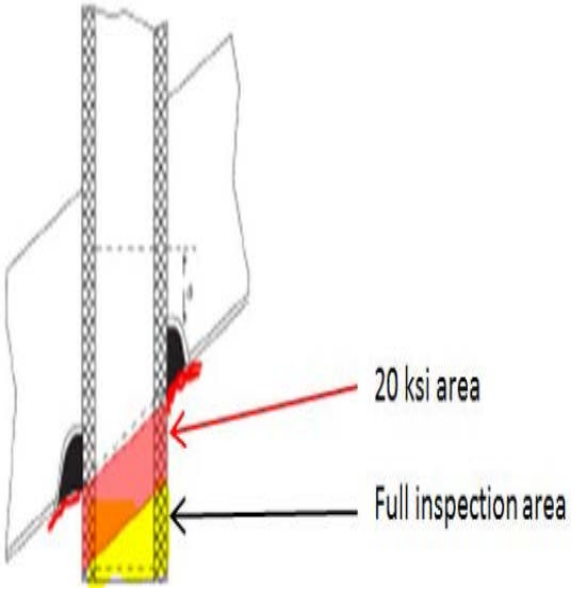
- The post peening ID residual plus operating stress range is 0 to -34 ksi for a margin of 10 to 44 ksi (7 to 41 ksi margin based on worst case XRD accuracy)

Location ID	Surface ID or OD	MRP Req'd Stress (ksi)	Post Peened Stress (ksi)	Margin with MRP (ksi)
1	ID	+10	-5.5	15.5
2	ID	+10	-16.7	26.7
3	ID	+10	-27.6	37.6
4	ID	+10	-31.5	41.5
5	ID	+10	-33.5	43.5
6	OD	+10	-47.3	57.3
7	OD	+10	-41.6	51.6
8	OD	+10	-28.4	38.4
9	ID	+10	-28.7	38.7
10	ID	+10	-20.2	30.2
11	ID	+10	-3.0	13.0
12	ID	+10	***0.0***	***10.0***
13	ID	+10	-13.3	23.3
14	OD	+10	-44.0	54.0
15	OD	+10	***-11.1***	***21.1***

Peening Parameter Margins – Coverage

- Exelon peened the full code case N-729-1 OD inspection area instead of the smaller MRP-335 SE 20 ksi region, providing **significant margin** beyond the required coverage area
  - The CETC nozzle funnels were machined to expose the downhill side 20 ksi peening area by a margin of **0.50 to 0.77 inches**
  - The ID peening coverage area was performed as required since the MRP-335 SE and code Case N-729-1 coverage areas are identical





Peening Parameter Margins – Coverage

- A FEA model was developed that identified the actual location of the 20 ksi residual stress region on the OD and ID of the nozzles was significantly smaller than the MRP-335 specified region
  - The OD actual 20 ksi stress downhill side location is 0.44” to 0.48” below the J-groove weld
  - The OD actual 20 ksi stress uphill side location is 0.46” to 0.61” below the J-groove weld

			Downhill Side Nozzle OD			Uphill Side Nozzle OD		
Tier	Pen No.	Incidence Angle	Required Coverage MRP-335 "a" (inches)	FEA Model 20 ksi Location (inches)	FEA Model 20 ksi Margin (inches)	Required Coverage MRP-335 "b" (inches)	FEA Model 20 ksi Location (inches)	FEA Model 20 ksi Margin (inches)
1	1	0°	1.5	0.46	1.04	1.5	0.46	**1.04**
7	22 thru 29	25.4°	1.5	0.45	**1.05**	1.5	0.61	**0.89**
13	62 thru 65	42.8°	1	0.48	**0.52**	1.5	0.61	**0.89**
14	66 thru 73	43.8°	1	0.47	0.53	1.5	0.61	**0.89**
15	74 thru 78	47.0°	1	0.44	0.56	1.5	0.56	0.94

Peening Parameter Margins – Coverage

- The FEA model showed actual 20 ksi residual stress region for the ID locations downhill (below) and uphill (above) side locations are bounding
  - The ID below toe of weld actual 20 ksi stress downhill side location is 0.47” to 1.26” below the J-groove weld
  - The ID above toe of weld actual 20 ksi stress uphill side location is 0.93” to 1.22” above the J-groove weld

			Downhill Side Nozzle ID (Below Lower Toe of Weld)			Uphill Side Nozzle ID (Above Upper Toe of Weld)		
Tier	Pen No.	Incidence Angle	Required Coverage MRP-335 "a" (inches)	FEA Model 20 ksi Location (inches)	FEA Model 20 ksi Margin (inches)	Required Coverage MRP-335 "a" (inches)	FEA Model 20 ksi Location (inches)	FEA Model 20 ksi Margin (inches)
1	1	0°	1.5	1.26	**0.24**	1.5	1.22	0.28
7	22 thru 29	25.4°	1.5	0.95	**0.55**	1.5	1.03	**0.47**
13	62 thru 65	42.8°	1	0.65	0.35	1	0.96	**0.04**
14	66 thru 73	43.8°	1	0.60	0.40	1	0.94	0.06
15	74 thru 78	47.0°	1	0.47	0.53	1	0.93	0.07

Peening Parameter Margins – Coverage

- The peening application for the OD locations covered the larger inspection area as defined per N-729-1
  - The OD downhill side peening process margin is 0.89” to 1.28”
  - The OD uphill side peening process margin is 1.28” to 5.12”

			Downhill Side Nozzle OD			Uphill Side Nozzle OD		
Tier	Pen No.	Incidence Angle	FEA Model 20 ksi Location (inches)	Distance Peened Below Toe of Weld (Inches)	Total Margin (inches)	FEA Model 20 ksi Location (inches)	Distance Peened Below Toe of Weld (Inches)	Total Margin (inches)
1	1	0°	0.46	1.74	**1.28**	0.46	1.74	**1.28**
7	22 thru 29	25.4°	0.45	1.59	1.14	0.61	3.74	3.13
13	62 thru 65	42.8°	0.48	1.40	0.92	0.61	5.59	4.98
14	66 thru 73	43.8°	0.47	1.38	0.91	0.61	5.73	**5.12**
15	74 thru 78	47.0°	0.44	1.33	**0.89**	0.56	5.51	4.95

Peening Parameter Margins – Coverage

- The peening application for the ID covered beyond the larger inspection area as defined per N-729-1
  - The ID below toe of weld downhill side peening process margin is 0.71”to 1.05”
  - The ID above toe of weld uphill side peening process margin is 0.83” to 5.82”

			Downhill Side Nozzle ID (Below Lower Toe of Weld)			Uphill Side Nozzle ID (Above Upper Toe of Weld)		
Tier	Pen No.	Incidence Angle	FEA Model 20 ksi Location (inches)	Distance Peened Below Toe of Weld (inches)	Total Margin (inches)	FEA Model 20 ksi Location (inches)	Distance Peened Above Toe of Weld (inches)	Total Margin (inches)
1	1	0°	1.26	2.12	0.86	1.22	7.04	**5.82**
7	22 thru 29	25.4°	0.95	1.66	**0.71**	1.03	1.94	0.91
13	62 thru 65	42.8°	0.65	1.50	0.85	0.96	1.93	0.97
14	66 thru 73	43.8°	0.60	1.65	**1.05**	0.94	2.18	1.24
15	74 thru 78	47.0°	0.47	1.42	0.95	0.93	1.76	**0.83**

Peening Parameter Margins – Depth of Compression

- The depth of compression achieved was more than the MRP-335 required OD of 0.04 and ID of 0.01 inches
  - The depth of OD compression was from 0.04 to 0.06 inches for all nozzles and the vent line
  - The depth of ID compression for open nozzles was from 0.01 to 0.05 inches
  - The depth of ID compression for annulus nozzles with thermal sleeves was from 0.01 to 0.02 inches
  - The depth of ID compression for the vent line was from 0.01 to 0.02 inches

Peening Parameter Margins – Post Peening Stress Accuracy

- A total of 18 coupons were OD and ID peened (with maximum, median, and minimum critical parameters) and were analyzed for stress, depth of compression and repeatability
- XRD was performed using the multiple exposure technique with a minimum of 22 Ψ (psi) angles to increase accuracy of results per SAE HS784 with the best accuracy on the surface of the nozzle (alloy 600)
- Independent third party laboratory performed review of XRD methodology to validate process repeatability and reproducibility

Peening Parameter Margins – Post Peening Stress Accuracy

- The post peening stress accuracy was typically maintained within ±1 to ±3 ksi for the nozzle material (alloy 600) and ± 5 ksi to ± 13 ksi for the J-Groove Weld Material (alloy 182) with repeatability and reproducibility as shown

	Alloy 600		Alloy 182 Weld Metal	
	Repeated Stress (ksi)	Reproduced Stress (ksi)	Repeated Stress (ksi)	Reproduced Stress (ksi)
Standard Deviation	±0.9	±0.3	±0.7	±0.3

Repaired Nozzles

- History of Byron U2 crack locations:
  - Nozzle 68 (Spring 2007)
  - Nozzle 6 (Fall 2014)
- These cracks were mitigated using the EFR method
- During spring refueling outage of 2016 (B2R19), the OD below the EFR weld material of nozzle 6 was peened to the top of the threads
- There was no OD area below the EFR weld material for nozzle 68
- The ID of the nozzle 6 was peened consistent with the N-729-1 inspection area
- The ID of nozzle 68 has not yet been peened
- Therefore, nozzle 6 has been completely mitigated and will be included in this relief request

Technical Rigor for Peening Process – Erosion Testing

- A test was developed that performed repeated peening of the same coupon to determine the amount of peening required to cause detrimental surface conditions
- Results showed that continuous peening of a location would be required for over 8 hours prior to experiencing any detectable detrimental surface conditions
- Normal peening time in any one location is a small fraction of the 8 hour exposure time
- Process controls are in place to prevent over peening

Technical Rigor for Peening Process – Corrosion Testing

- Tests were performed to validate that peening and EDM did not affect the corrosion resistance of the peened materials of the nozzle and J-groove weld
  - ASTM G28-02 method A testing was completed on 3 specimens for each material using ferric sulfate-sulfuric acid for 24 hours
  - The results were reviewed at 10x and 250x magnification and determined that there were no adverse change in the grain boundary as a result of peening and EDM
- Therefore, the peening process does not adversely affect the RPV head

Technical Rigor for Peening Process – EPRI Coupon Testing

- A test was performed to verify that peening would not affect flaw detection using qualified NDE UT methods
- An EPRI provided test coupon was peened that contained mock-up flaws
- The coupon was analyzed with site specific time of flight diffraction NDE and determined that there was no adverse affect on flaw detection using qualified NDE UT methods

Deterministic Technical Basis

- A fully deterministic technical basis paper (ASME PVP2016-64032) has been published supplementing MRP-395 with additional deterministic crack growth analyses, demonstrating the acceptability of a 36-month UT interval for heads with previously detected PWSCC that operate at T_{cold}
- This new analysis extends the deterministic analysis in MRP-395 by applying the 95th percentile factor, rather than the standard 75th percentile per ASME Section XI. This new analysis exceeds the ASME approach considerably and supports the 36-month inspection interval without credit for peening
- On the basis of this technical analysis, a 36 month interval would continue to ensure that the nuclear safety and leakage (for defense in depth) concerns are conservatively addressed in reference to SE Condition 5.4
- In addition to the technical analysis included in the ASME PVP paper, the SE states that the NRC ‘s independent calculation shows that a shallow pre-existing flaw would not grow to a detectable size until the 2nd refueling outage after peening at the earliest, and is in agreement with the above ASME position

Summary

- Exelon requests relief consistent with MRP-335 to include all peened nozzles
- Due to additional margin in peening application and independent calculations/analyses, relief from N+1 inspection is also requested
- N+1 inspection relief request is justified based on:
  - Meeting or significantly exceeding the requirements of the MRP-335 SE
  - Additional technical rigor in XRD accuracy and testing
  - Deterministic technical analysis concluding pre-existing flaw would not grow to a detectable size until the second refueling outage at the earliest

Schedule for Submittal

- Exelon plans to submit the post peening inspection relief requests per the following schedule:
  - Byron Unit 2 - December 2016
  - Braidwood Unit 1 - 1Q2017

- Byron Unit 1 and Braidwood Unit 2 relief requests will be submitted following the Spring 2017 peening application

Questions?

Acronym Key

- ASTM – American Society for Testing and Materials
- CETC- Core Exit Thermocouple
- EDM- Electro Discharge Machining
- EFR- Embedded Flaw Repair
- EPRI- Electric Power Research Institute
- FEA Finite Element Analysis
- ID- Inner Diameter
- ISI- Inservice Inspection Interval
- Ksi- kilopounds per square inch
- MRP 335- Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP 335, Revision 3)
- MRP 395- Materials Reliability Program: Reevaluation of Technical Basis for Inspection of Alloy 600 PWR Reactor Vessel Top Head Nozzles (MRP-395, 2014 Technical Report)
- NDE- Non-Destructive Examination
- OD- Outer Diameter
- PWSCC- Primary Water Stress Corrosion Cracking
- RPV- Reactor Pressure Vessel
- SAE - Society of Automotive Engineers
- SE - Safety Evaluation
- SPQR - Special Process Qualification Report
- XRD- X-Ray Diffraction