Exelon Generation Alloy 600 PWSCC Mitigation Plan for Reactor Vessel Head Penetration Nozzles Utilizing Cavitation Peening at Byron and Braidwood

NRC/Exelon Meeting, Warrenville, IL

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July 30, 2015

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Agenda

- Introductions and Opening Remarks
- Objective
- Braidwood / Byron PWSCC History
- AREVA RPV Head Penetration Peening Technology
- RPV Head Penetration Peening Benefits
- Peening Technical Basis
- Exelon Peening Mitigation Implementation Plan
- Implementation of Peening via 50.59 Process
- Post Peening Inspection Relief Requests
- NRC Interaction
- Summary

Objective

- Present Exelon's initiative for reactor pressure vessel (RPV) head PWSCC mitigation
  - Introduce AREVA Peening process
  - Provide benefits of Peening process
  - Discuss 10 CFR 50.59 approach
  - Discuss Exelon's integrated implementation plan including future inspection relief requests

- Obtain NRC feedback on Exelon's initiative and identify technical and regulatory challenges
  - Achieve an understanding of questions or concerns
  - Discuss approach for resolving questions or concerns

Braidwood / Byron PWSCC History

- Braidwood and Byron RPV heads are B&W T-Cold Heads with the RPV head penetration nozzles fabricated using B&W tubular product
- Inspections to date have identified the following flaws:
  - Byron Unit 2 – two nozzles (Spring 2007, Fall 2014)
  - Byron Unit 1 – four nozzles (Spring 2011)
  - Braidwood Unit 1 – one nozzle (Spring 2012)
- Each flaw has been repaired using an NRC approved embedded flaw overlay
- Under the current regulatory requirements, the three repaired RPV heads require ultrasonic examinations and bare metal visual inspections every refueling outage
- To date the inspection program has not detected cracking symptoms on the Braidwood Unit 2 RPV head

Braidwood / Byron PWSCC History

- History of crack locations are shown below

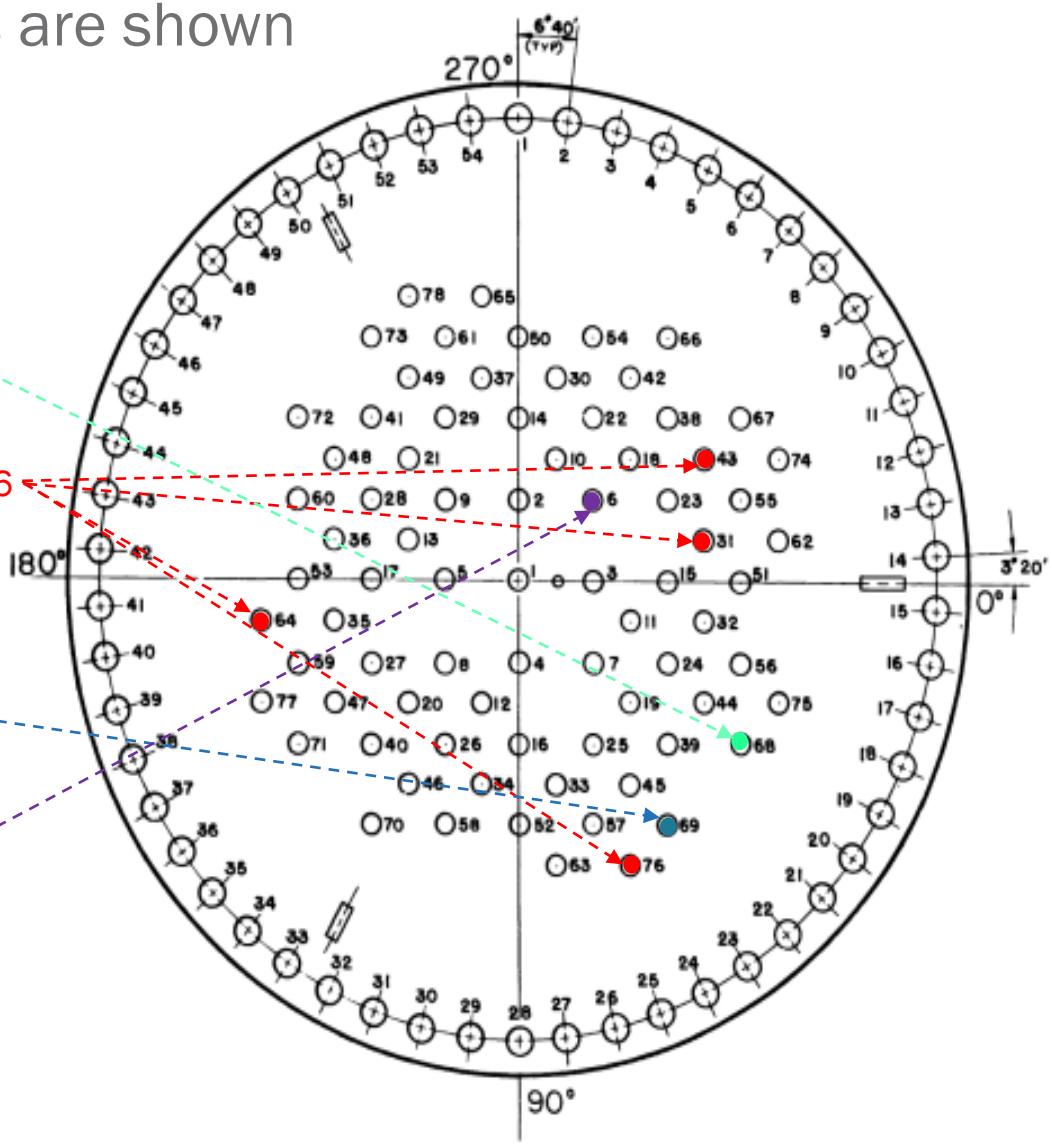
<u>Existing Flaw / Repair Locations</u>

Byron Unit 2 (Spring 2007) #68

Byron Unit 1 (Spring 2011) #31, 43, 64, 76

Braidwood Unit 1 (Spring 2012) #69

Byron Unit 2 (Fall 2014) #6



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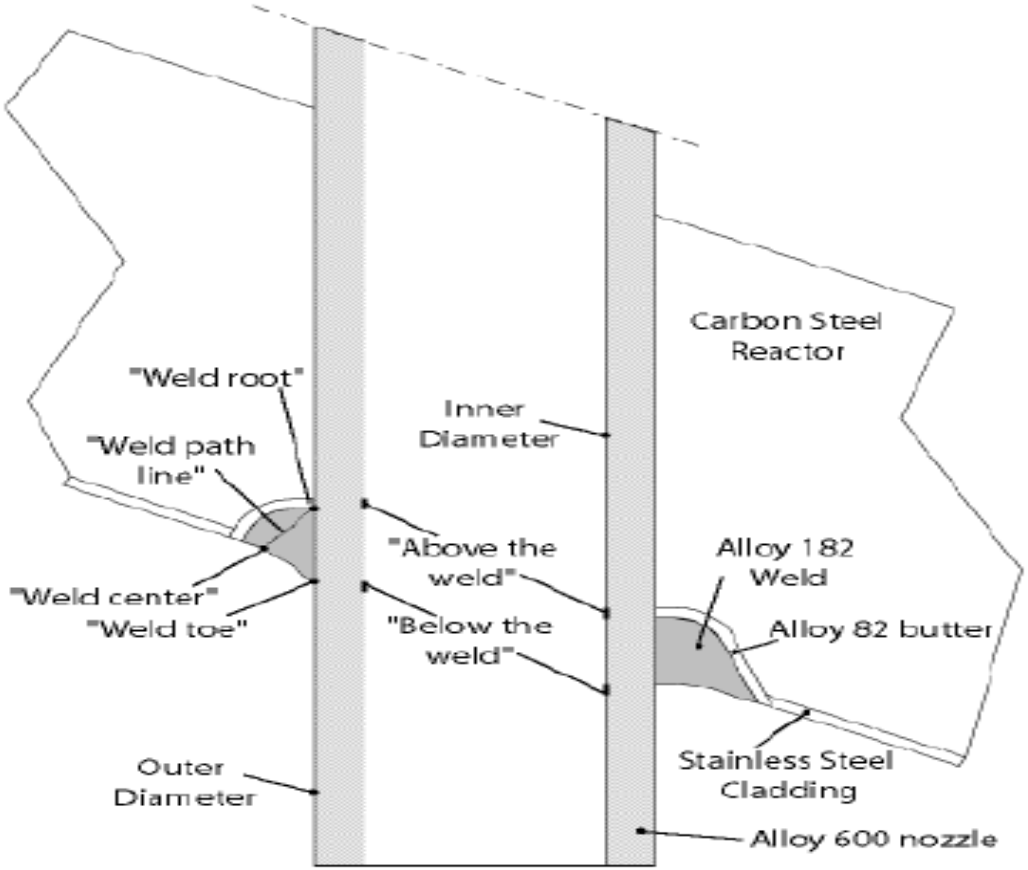
Braidwood / Byron PWSCC History

- All cracks were outside diameter (OD) axial (toe of weld and below and propagated upwards, behind weld), with no leakage identified

  - CRDM nozzle is nominally 4” inches OD and 2 ¾” ID with 5/8” wall thickness



Braidwood / Byron PWSCC History

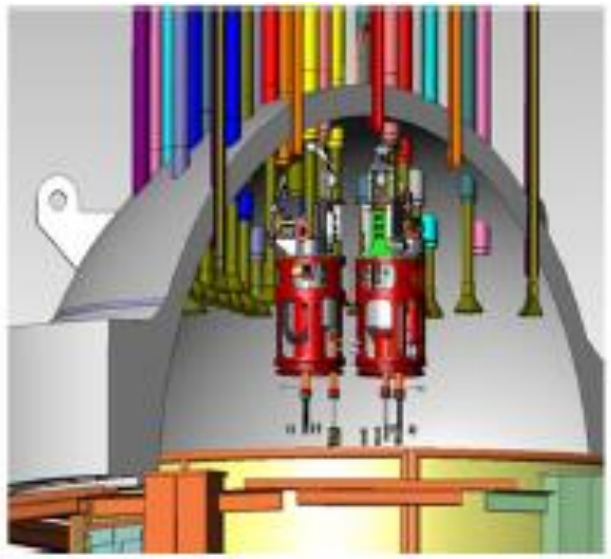
- Exelon's current method for addressing RPV head PWSCC induced flaws is to implement an embedded flaw weld overlay
  - Reactive due to unknown scope prior to outage
  - Significant dose, outage extension, and cost
  - Fails to provide a complete solution for long term asset (i.e., RPV) management or improve reliability of non-repaired penetrations

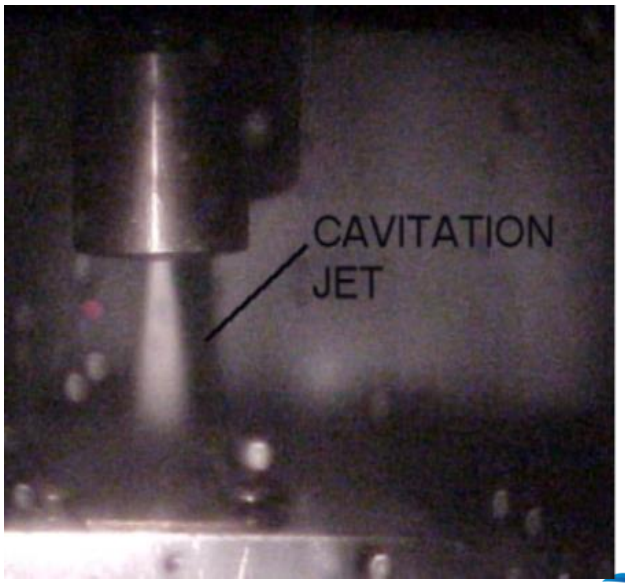
- Anticipated discovery of new PWSCC induced flaws in the RPV head penetrations over the next 33 years (assuming License Renewal) is between 11 (best case) and 84 (worst case)

- Therefore, Exelon is pursuing proactive RPV head penetration Peening technology with AREVA to improve the RPV head penetration integrity and mitigate PWSCC to reduce vulnerabilities that could impact public health and safety

AREVA RPV Head Penetration Peening Technology

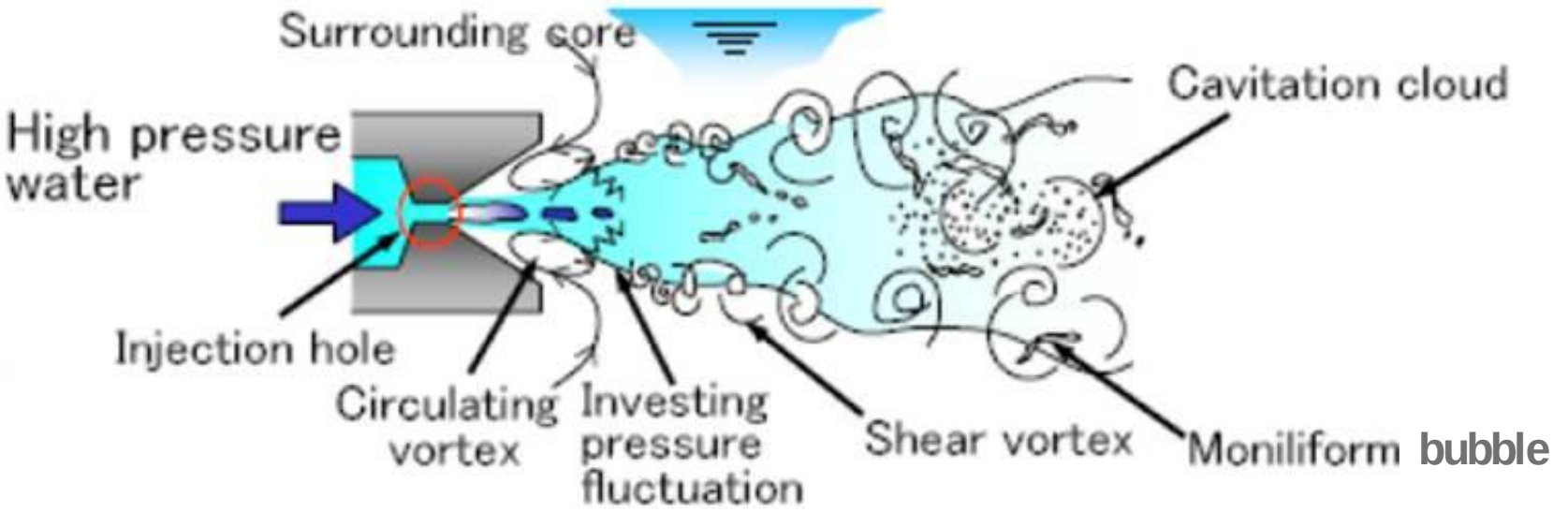
- Ultra high velocity jet results in pressure below vapor pressure in water resulting in vapor bubbles forming in the water - **Cavitation**
- Cavitation bubbles collapse at surface generating high pressures on the material
- The shockwaves caused by collapsing voids imparts compressive stresses in the surface layer of material
  - The water-jet force does NOT perform the Peening
  - The Peening is performed by the collapse of the vapor bubbles

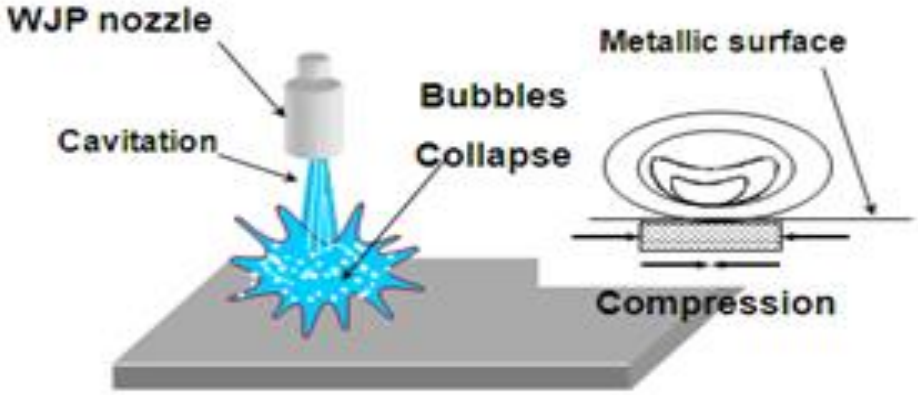


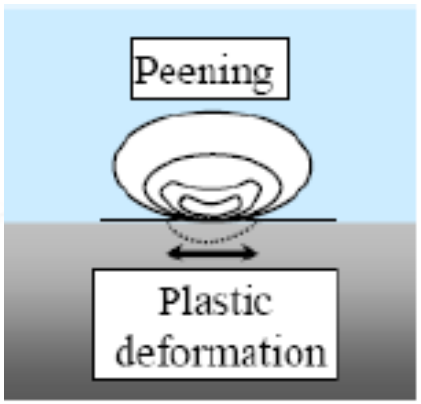


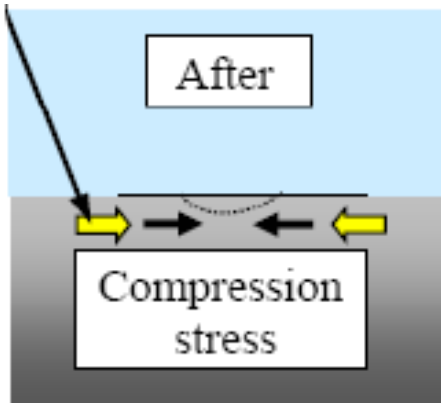
AREVA RPV Head Penetration Peening Technology

– Cavitation Peening Process Diagram









AREVA RPV Head Penetration Peening Technology

- Demonstration Video

AREVA RPV Head Penetration Peening Technology

- Extensive testing has shown cavitation Peening is an effective process that provides broad coverage in its application and extreme flexibility with applied geometries and process flow rates
  - Given it is **NOT** the water-jet that is doing the Peening but the cavitation bubbles, the process ensures coverage overlap with wide tolerances on geometry length and flow-rates
  - Documented test results confirm:
    - Testing over a variety of flow-rates and distances to target provide the same beneficial results
    - Post peening benefits show final “as left” stresses are reduced regardless of initial residual stress state
    - Testing has shown higher tensile stresses reduce and respond faster than to a lessor initial residual tension state
    - Peening is effective over a wide applied angle between the water-jet and material being peened showing appropriate coverage on complicated geometries
    - Documented test results are available for review

AREVA RPV Head Penetration Peening Technology

– Cavitation Peening Surface Finish

- Visual inspection can be used to confirm Peening coverage
- Testing shows the as left surface finish does not impact NDE inspection results
- Aggressive high temperature corrosion testing has validated resistance to PWSCC initiation

Peened **Non-Peened**

RPV Head Penetration Peening Benefits

- Primary Safety Benefit
  - Reduction in nozzle tensile stresses significantly diminishes the potential for future PWSCC induced cracks and associated leakage paths
  - RPV head is in a safer condition and more effectively protects the health and safety of the public
  - Reduction in cumulative dose/exposure by not performing reactive repairs - ranges from 731 to 2181 Rem
- Primary Commercial Benefit
  - Extend life and improve reliability of RPV head
  - Eliminate need for reactive repairs - cost savings
  - Eliminate outage extensions for reactive repairs – dose savings
- Secondary Benefits include additional dose and outage savings related to reduced future periodic inspections

Peening Technical Basis

- Initiation of PWSCC flaws requires tensile stress at the surface
- Peening techniques mitigate PWSCC by reversing the tensile stress at the surface, exposed to reactor coolant, to compressive residual stress
- Peening vendors and EPRI performed separate verification experiments, including corrosion cracking and stress relaxation tests, to confirm the effectiveness and sustainability of peening treatments
- Evaluations were conducted related to peening performance methods and effects
  - Coverage, magnitude and depth of compression stresses
  - Retention of compressive stresses throughout plant life
  - Verification of no unacceptable side effects
  - Precludes the initiation of PWSCC

Peening Technical Basis

- Key supporting EPRI-MRP reference documents
  - MRP-335, Revision 1, 2013, Topical Report for PWSCC Mitigation by Surface Stress Improvement
  - MRP-2014-027, 2014, Supplemental Technical Basis for Peening of Alloy 600 RPVHPNs
  - MRP-267, Revision 1, 2012, Technical Basis for PWSCC Mitigation by Surface Stress Improvement

Exelon Peening Mitigation Implementation Plan

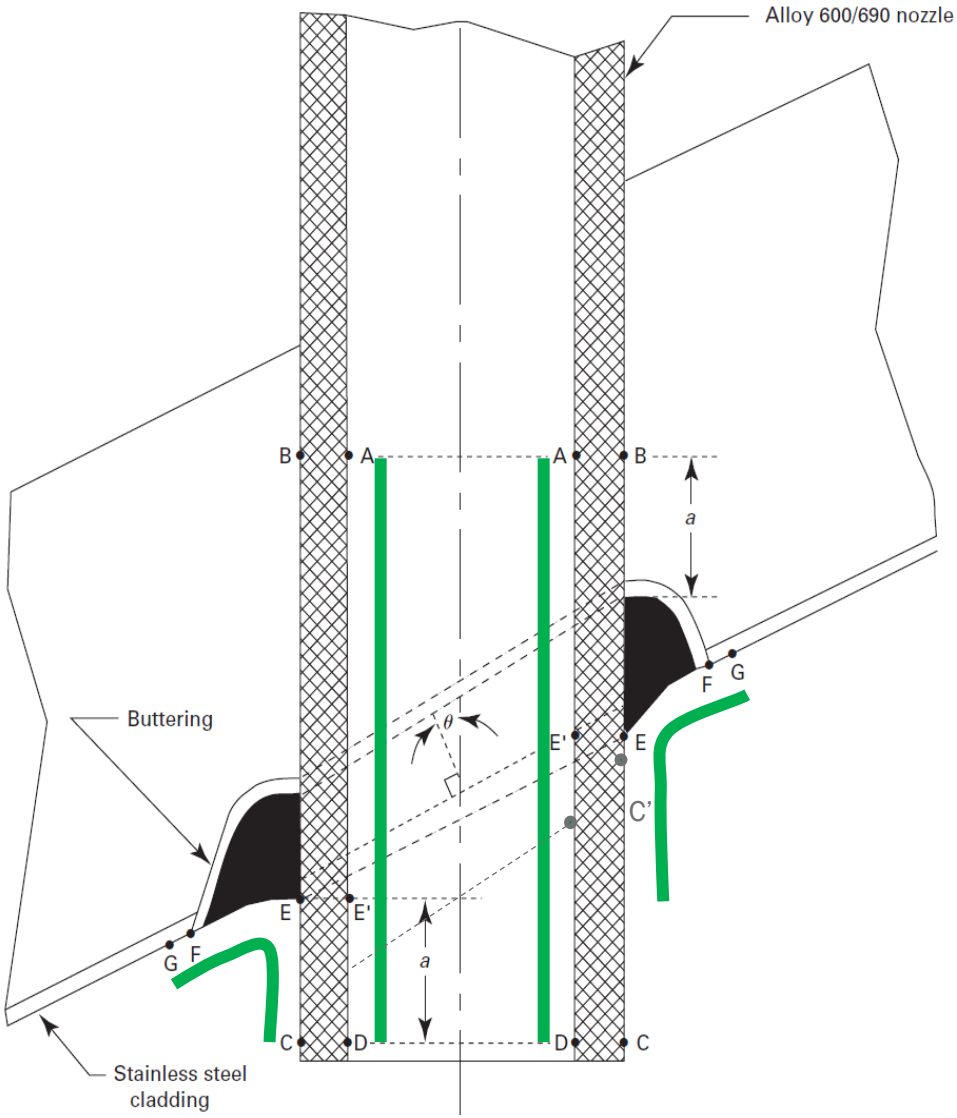
- Exelon will mitigate RPV head penetrations using cavitation water jet Peening
  - Contract has been awarded to AREVA with field development in progress
- Exelon will implement Peening during the 2016 and 2017 refueling outages
  - Byron Unit 2 - Spring 2016
  - Braidwood Unit 1 - Fall 2016
  - Byron Unit 1 - Spring 2017
  - Braidwood Unit 2 - Spring 2017
- Peening will be implemented as a “special process” in accordance with 10 CFR 50, Appendix B, Criterion IX
- Peening of the RPV head penetrations will be assessed in accordance with 10 CFR 50.59

Exelon Peening Mitigation Implementation Plan

- Scope of work includes the outer and inner surfaces of the susceptible Alloy 600 and 182/82 material in all the 79 nozzles in each of the Byron and Braidwood RPV heads:
  - 53 CRDM nozzles
  - 5 thermocouple nozzles
  - 2 reactor vessel level indicating system (RVLIS) nozzles
  - 18 spare nozzles
  - 1 RPV head vent nozzle

Exelon Peening Mitigation Implementation Plan

- The minimum peened coverage areas:
  - The Peening shall extend at least .25” beyond all PWSCC susceptible material
  - PWSCC susceptible material is defined as Alloy 182/82 and the heat affected zone of the Alloy 600 nozzles that are in contact with the primary water



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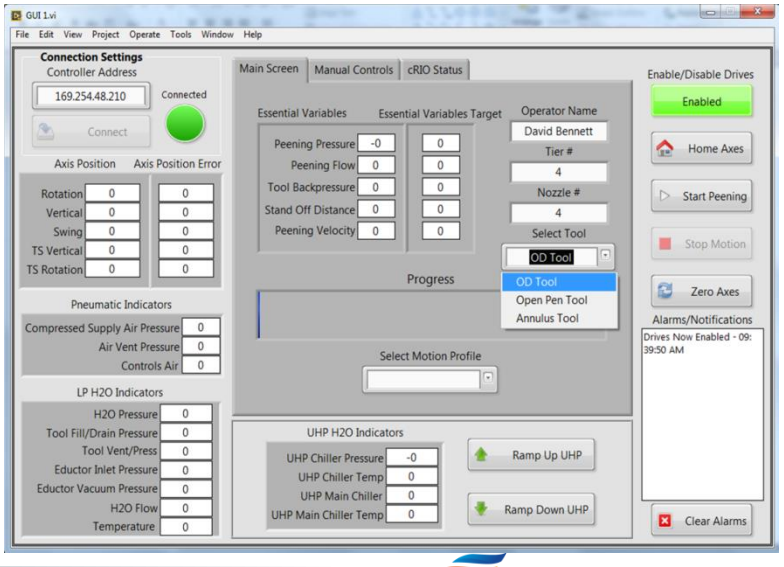
Exelon Peening Mitigation Implementation Plan

- Applying 10 CFR 50, Appendix B, Criterion IX Process

  - Essential variables will be bounded (e.g., high pressure, nozzle stand off distance, back pressure, nozzle position, nozzle speed)

  - Training and qualification will be conducted by process demonstration
    - The qualification will include testing on mockups at the boundary extremes to demonstrate that the required results can be obtained even at the 'limits' of the essential variables
    - The qualification will be performed on full scale mockups with material and geometry constraints

  - During implementation essential variables will be controlled/monitored to ensure acceptable results are achieved



Implementation of Peening via 10 CFR 50.59 Process

- Exelon intends to implement Cavitation Peening in accordance with 10 CFR 50.59
  - AREVA testing has confirmed that cavitation peening does not cause damage to the RPV head
    - Exposure time testing revealed that plate surface does not start to break down until 16 times the exposure time that is necessary to obtain the maximum UHP cavitation peening compressive stress
    - Even 8 times the exposure time still produces successful surface inspections
  - Cavitation Peening does not affect SSCs nor their associated performance, FSAR design basis, or Technical Specifications
  - Extensive testing has shown Cavitation Peening is less invasive than original grinding activities performed during fabrication and the Peening application process energy levels remain low
  - Exelon will make 10 CFR 50.59 evaluation available for NRC review in advance of Peening implementation

Post Peening Inspection Relief Requests

- Exelon plans to submit two separate relief requests to obtain inspection frequency relief
  - One relief request will cover the non-repaired nozzles
    - Nozzles covered under MRP-335 and Code Case N-729-5
  - One relief request will cover the repaired nozzles
    - Westinghouse Embedded Flaw Repair (EFR)
    - AREVA Inside Diameter Temper Bead (IDTB) Half- Nozzle
      - Half-Nozzle Rotary Peening
      - Half Nozzle Cavitation Peening
- Exelon will also submit a relief request to utilize the AREVA IDTB half-nozzle repair method
  - In lieu of embedded flaw repair
  - Approval requested prior to Byron Unit 1 refueling outage in fall 2015 (B1R20)

NRC Interaction

- Exelon is moving forward with Cavitation Peening technology due to the safety and long term asset preservation benefits
- Since this will be the first application of RPV head penetration Peening to mitigate PWSCC in United States, there are regulatory uncertainties that Exelon wants to identify/clarify
- Exelon supports open dialogue with NRC to understand and proactively resolve regulatory questions and issues
  - Peening evaluated in accordance with 10 CFR 50.59, which will be made available to NRC for review prior to implementation
  - Requirements during the Peening activity to support potential future relief requests related to post Peening periodic inspection frequency

Summary

- Application of the Peening technology on the Braidwood and Byron RPV head penetrations is a proactive approach to mitigate PWSCC
  - Improves safety by reducing the potential for nozzle cracking and associated leakage
  - Results in significant reduction in dose related to reactive repairs

- Exelon has confidence in the Peening technology based on industry testing, EPRI/MRP published documents and the process controls being implemented

- Exelon proactively supports resolution of NRC questions and ensure NRC remains informed of implementation and submittal plans