(via email)

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Document Control Desk
U. S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852

Subject: Response to the NRC Request for Additional Information (RAI) related to Electric Power Research Institute (EPRI) MRP-335, Revision 1, "Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement [Peening]" (TAC No. MF2429)

References:

1. U.S. NRC, Request for Additional Information Related Electric Power Research Institute MRP-335, Revision 1, "Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement [Peening]" (TAC No. MF2429), ADAMS ML14181A025, September 8, 2014
2. *Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 1),* EPRI, Palo Alto, CA: 2013. 3002000073.
3. *Materials Reliability Program: Technical Basis for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-267, Revision 1)*, EPRI, Palo Alto, CA: 2012. 1025839.

This letter transmits two copies of the responses to the Requests for Additional Information (RAI) received in Reference 1. Attachment 1 is a table with the responses to individual RAI questions. Attachment 2 is additional technical material cited in several of the RAI responses that supports the NDE approach of the MRP-335R1 topical report (Reference 2) for the case of reactor pressure vessel head penetration nozzles (RPVHPNs). The topical report is supported by technical basis detailed in MRP-267R1 (Reference 3).

EPRI, MRP members and the other Industry representatives would like to thank the NRC staff for holding the public meeting on September 9, 2014, to discuss the NRC review of the topical report and supporting information. We found the exchange of perspectives at the meeting to be productive and useful in further understanding the RAI. As a result of those discussions, EPRI MRP provides further information on several general topics that were discussed below.

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Benefit of Peening Vendor Visits and Follow-up Public Meetings

EPRI believes that NRC site visits at peening vendor facilities and follow-up meetings, including presentations by the peening vendors of additional data, would have significant benefits for the NRC Safety Evaluation (SE) peening team. EPRI and other Industry organizations are ready to support these activities now. We believe that such activities would provide information to the staff that may address many of the RAI questions regarding how to ensure that peening mitigation is implemented in an effective manner with a high assurance of quality.

Schedule Request

Plant owners have an urgent need for NRC to provide the requirements for inspection credit of peening mitigation of Alloy 82/182 piping butt welds and Alloy 600/82/182 RPVHPNs in PWRs. This information is needed by utilities to support decision making regarding application of peening mitigation of primary water stress corrosion cracking (PWSCC). Two U.S. PWRs have announced plans to peen piping welds and reactor vessel bottom-mounted nozzles starting in 2016. Multiple other plants have reviewed competitive bids for peening of RPVHPNs and are in the final stages of their procurement decisions. Contracts have now been awarded for peening mitigation of the reactor vessel heads at four U.S. PWR units.

In February 2013, EPRI formally submitted the peening topical report for NRC review and requested finalized requirements for inspection credit to be provided as soon as possible. The NRC's current schedule does not reflect an advanced finalization of requirements for inspection credit and shows the draft SE being ready in the summer of 2017 after confirmatory testing. Plant owners are concerned that the results of the confirmatory testing currently planned by NRC could be delayed beyond this schedule. The current NRC plan for confirmatory testing involves many steps including fabrication of test specimens, peening of test specimens by as many as five different peening vendors, and long-term corrosion testing of peened specimens. Industry organizations have conducted thorough research on the application of peening that is backed by operating experience in PWR systems and holds the position that further testing is not needed to finalize requirements for inspection credit. Research schedules and the completion of data analysis of research results are often unpredictable.

EPRI MRP requests that the NRC finalize requirements for inspection credit of peening mitigation by mid-2015. Without the availability of a formal SE, plant owner decisions on peening mitigation implementation may be adversely impacted. Precedent supports the NRC issuing SE on topical report submittals of this nature prior to completing independent regulatory sponsored research confirmation work.

Confirmatory Testing Approach Request

In Reference 1 the NRC staff states, "EPRI has provided sufficient information to demonstrate that the peening process, if properly implemented, is an effective mitigation to address primary water stress corrosion cracking." Thus, NRC has indicated that its planned confirmatory testing is intended to address its concerns regarding the range of implementation parameters that will be used across the PWR fleet. With regard to peening implementation, we understand that the key NRC questions and concerns are the following:

- What is the envelope of essential variables for each process that results in effective peening and peening that does not cause unacceptable damage? How difficult is it to obtain conditions within the envelope (i.e., how sensitive is effective peening and not causing unacceptable damage to the essential variables) and how sensitive is the envelope to surface condition, accessibility, and cold work?
- Does the existing peening qualification work by the vendors adequately cover the full range of plant geometries, peening accessibility, surface conditions, cold work, and pre-existing residual stresses?
- What are the process controls that ensure 100% coverage, effective peening, and no unacceptable damage or side effects?

EPRI MRP believes that site visits to peening vendor facilities and follow-up public meeting discussions with peening vendors is the best approach to provide information beyond that in Reference 3 and the RAI responses in Attachment 1 to address these. We respectfully request that the staff consider the information to be provided directly by the peening vendors in your assessments of your concerns related to effective peening implementation. The peening vendors are best positioned to discuss acceptable essential variable ranges for each process, how the beneficial effects of peening vary as a function of the essential variable values and how they control these, including proprietary data as necessary. Existing peening vendor testing has addressed the relevant plant geometries, surface conditions, and component accessibilities.

EPRI MRP concludes that there are sufficient controls and sufficient information today to conclude that the types of peening mitigation covered in the topical report will be effectively implemented under 10 CFR 50, Appendix B, Criterion IX requirements and that appropriate inspection credit should be given:

- Peening will be implemented as a "special process" in accordance with the quality assurance requirements of 10 CFR 50, Appendix B, Criterion IX. Controlled special process procedures will be submitted for licensee pre-implementation approval.
- Satisfaction of an appropriate set of performance criteria, such as Appendix I of ASME Code Case N-770-4 (approved by ASME on May 7, 2014), under the 10 CFR 50 Appendix B criteria, will result in an effective peening mitigation that supports appropriate long-term inspection credit. Peening is effective for mitigation if the intended residual stresses (prescribed by compressive magnitude, depth, and wetted surface coverage) are achieved regardless of the peening technology process used to produce those stresses.
- Advanced peening methods are a mature technology regularly applied in other industries such as commercial and military aerospace, as well as peening of turbine blades.
- There is over a decade of experience with peening mitigation in dozens of Japanese PWRs and BWRs.
- MRP's technical basis (Reference 3) includes both peening vendor testing and validation testing sponsored by EPRI independent of the peening vendors. The testing includes

corrosion testing with and without pre-existing surface flaws, as well as testing in simulated PWR primary water.

For the reasons listed above we do not believe confirmatory research testing is mandatory. However, if the NRC does proceed with a program of confirmatory research testing, given the precedence for defining SE requirements prior to completion of NRC confirmatory research, EPRI MRP respectfully requests that any confirmatory NRC research testing not delay NRC's issuance of an SE specifying requirements for inspection credit for peening mitigation of PWR Alloy 82/182 piping butt welds and Alloy 600/82/182 RPVHPNs. The SE and confirmatory testing schedules should be decoupled.

There is widespread agreement that initiation of stress corrosion cracks is precluded if the surface stress (including residual stress and normal operating stress) is shown to be compressive. Thus, it is clear that the benefit of expeditious action of NRC on requirements for peening inspection credit would outweigh delays to complete confirmatory testing prior to issuance of such requirements.

If NRC does proceed with a program of confirmatory research testing, EPRI MRP requests an opportunity to provide suggestions for consideration before the program is implemented. The technical perspectives of EPRI, MRP members and the peening vendors may be helpful in this regard.

<u>EPRI MRP Approach to NDE Requirements for RPVHPNs</u>

Another topic of discussion at the September 9 public meeting was the set of inspection requirements for use with peening mitigation of PWR RPVHPNs. The topical report (Reference 2) and Supplemental Technical Basis document (Attachment 2) propose such an appropriate set of inspection requirements for RPVHPNs. Applying peening processes results in the material susceptible to PWSCC in an improved condition that prevents initiation of new stress corrosion cracks and arrests any shallow pre-existing surface flaws that are located in the surface compressive stress zone. EPRI MRP proposes a robust set of ongoing inspections for peened RPVHPNs, with the following components:

- Pre-peening UT exam
- Follow-up UT exams at specific outages following the peening application
- Continuing long-term in-service inspection (ISI), with 100% of the RPVHPNs
- Detailed bare metal visual examinations of each intersection of nozzle and the upper head surface for evidence of pressure boundary leakage on the same basic schedule as for unmitigated heads as a substantial conservatism

Consistent with the current inspection requirements for unmitigated heads (per ASME Code Case N-729-1 as conditioned by 10 CFR 50.55a(g)(6)(ii)(D)), surface examinations (using for example eddy-current testing (ET)) of the J-groove weld are not necessary to maintain reasonable assurance of safety. Considering the improved condition of the peened nozzle and J-groove weld, surface examination of the J-groove weld continues to be unnecessary for

RPVHPNs. (Further, plant owners find ET surface examinations of J-groove welds to be impractical considering the potential for false calls, detection of acceptable fabrication flaws, and high radiation worker dose associated with supplemental PT exams to characterize ET indications; this imposes unnecessary and unwarranted radiation dose to NDE inspection and repair personnel who prepare surfaces for examination and implement repairs.) The Topical Report does not take credit for detection of all flaws prior to peening. Instead, in a similar manner as for the case for unmitigated heads, a robust program of ongoing examinations addresses the possibility of pre-existing stress corrosion cracks that were not detected by the pre-peening examination and that were too deep to be arrested by the peening application. Attachment 2 provides further details on the basis for this conclusion that surface examinations are unnecessary for the case of peened RPVHPNs, as well as unmitigated RPVHPNs.

The proposed inspection regime in combination with the supporting technical bases provides assurance that plant safety is maintained. Plant experience has demonstrated that the current inspection requirements for unmitigated heads are sufficient to maintain a low probability of pressure boundary leakage due to PWSCC of RPVHPNs. The improved condition of peened RPVHPNs and ongoing UT and visual examinations prescribed in the Topical Report result in a reduced concern for pressure boundary leakage. Completion of the SE process will provide utilities the remaining information needed to evaluate the peening mitigation option, and thus should not be unnecessarily delayed.

If you should have any questions concerning this response, please contact Paul Crooker, EPRI MRP Project Manager, at (pcrooker@epri.com) or 650-855-2028.

Sincerely,

B. C. Rudell
MRP Chairman
Exelon

Anne Demma
MRP Program Manager
EPRI

Attachment 1: Table of RAI Responses

Attachment 2: Supplemental Technical Basis for Peening of Alloy 600 RPVHPNs

cc: Paul Crooker, EPRI
Anne Demma, EPRI
Joseph J. Holonich, U.S. NRC
William Sims, Entergy

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
1	Intro	General	By letter dated May 1, 2013 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML13126A009), the EPRI submitted to the NRC the "Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement" (MRP-335, Revision 1) for review. The NRC staff has initiated its review of the document, and finds EPRI has provided sufficient information to demonstrate that the peening process, if properly implemented, is an effective mitigation to address primary water stress corrosion cracking. Due to the shallow depth of penetration of the peening technique, the NRC staff has concerns for the implementation process controls to ensure an effective mitigation is provided for all in-service surface conditions for which application is proposed. As such, the NRC staff provides the following requests for additional information to complete the review.	We appreciate the finding that "EPRI has provided sufficient information to demonstrate that the peening process, if properly implemented, is an effective mitigation to address primary water stress corrosion cracking."

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
2	General	General	The NRC staff believes that the peening process should be treated as a controlled process similar to welding to ensure consistent application across the US nuclear fleet in order to justify generic regulatory relief from the current inspection requirements. Without a general standard for peening application, the NRC staff is concerned with the reliance on each individual owner to develop a technical justification document as the only implementation control at an individual plant.	The peening process will be considered a controlled "special process" in accordance with 10 CFR 50, Appendix B, Criterion IX, similar to welding, heat treating and NDE, with qualified personnel using qualified procedures. Satisfaction of the performance criteria already being placed in ASME Code Cases, such as Appendix I of ASME Code Case N-770-4, will result in an effective peening mitigation that supports the ISI inspection credit identified in the Topical Report. Each vendor must have technically qualifying data specific to its process that confirms the Code Case performance criteria are met by controlling certain "essential" parameters. The qualified procedures demonstrate that those parameters are effectively controlled by the vendor peening system and system-specific process controls specified in the vendor specific procedure(s) under an approved Quality Assurance program. The applicable performance criteria require the peening vendor to perform laboratory demonstration testing and analysis work showing that the peening is effective: • The steady-state operating axial and hoop direction stresses combined with residual stresses are compressive at the inside surface • Unless alternative requirements are satisfied, the nominal depth of the compressive residual stress produced by the peening technique is at least: – 0.04 in. (1.0 mm) for the ID of Alloy 82/182 piping butt welds – 0.04 in. (1.0 mm) for the outer surfaces of RPVHPNs – 0.01 in. (0.25 mm) for the inner surfaces of RPVHPNs • The compressive surface stress condition is maintained for the remaining service life of the component • The peening coverage results in compressive stress in the susceptible material along the entire wetted surface: – Weld and butter material of Alloy 82/182 piping butt weld – Inner and outer surfaces of Alloy 600 RPVHPN tube in susceptible region with high weld residual stresses as evaluated by MRP-95R1 – Weld and butter material of Alloy 82/182 RPVHPN J-groove weld

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
				EPRI MRP requests that NRC approve these stress improvement and coverage requirements as defined above, in the responses to RAI 4-3 and RAI 4-6C, and in Appendix I of ASME Code Case N-770-4. The 10 CFR 50, Appendix B Quality Assurance requirements including those for "special processes" in accordance with Criterion IX will ensure that the peening process at each application will satisfy the applicable performance criteria such that the stress improvement and coverage parameters are met. In addition, unlike the situation for welding, the peening process will not be routinely applied at all nuclear facilities. Many of the Alloy 82/182 reactor vessel inlet/outlet nozzle locations are accessible for mitigation performed from outside of the piping and are being mitigated using other techniques, and the reactor vessel top heads in almost two-thirds of the PWRs operating in the U.S. have been replaced with heads having PWSCC-resistant materials. Furthermore, weldments constitute a fundamental part of the load-carrying reactor coolant pressure boundary, whereas peening mitigation merely improves the surface stress condition.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
3	General	General	Further, the NRC staff is concerned about the range of implementation parameters that will be used across the fleet, if a general standard is not developed or available for independent owner use. Therefore, the NRC staff has determined that our primary request from EPRI will be for the identification of essential variables for each peening process. Additionally, the NRC staff requests that the range of each of these essential variables is identified. As part of a validation program, the NRC staff will request EPRI to facilitate the peening of several materials using the minimum range of each of the essential variables. The NRC, through Pacific Northwest National Laboratory, will then perform non-destructive evaluation, weld residual stress measurements and crack initiation testing on the peened specimens to verify the effective implementation of each peening process within the range of identified essential variables.	Peening mitigation is a special process to be controlled in accordance with 10 CFR 50, Appendix B, Criterion IX. The process must be identified, essential variables and limits must be clearly defined for each process, and a QA program for control of the essential variable values must be in place for implementation. However, peening is effective for mitigation if the expected residual stresses are achieved regardless of the process used to produce those stresses. The peening vendors will be required to meet peening compressive stress magnitude and depth requirements and peening coverage requirements. The peening vendor will be required to establish and provide essential variables with associated ranges of acceptable application-specific values as part of its controlled special process procedure qualification. These essential variable values will ensure that the specified stress and coverage requirements are met. The essential variables will be unique to the peening technology offered and will be submitted as part of the controlled special process procedures for licensee pre-implementation approval. The acceptable values of the essential variables are specific to each vendor and type of component being peened considering the detailed process and equipment differences among the vendors (e.g., laser power, water jet nozzle design, direction of nozzle travel). Each vendor determines an acceptable envelope of essential variable values through mockup testing and stress measurements, but does not exhaustively determine the entire range of essential variables that results in effective peening. By confirming that the process in fact was performed with an acceptable set of essential variable values, it is demonstrated that the required stress and coverage parameters are met or exceeded and consequently that the peening mitigation is effective. The MRP supports the use of the performance criteria of Appendix I of ASME Code Case N-770-4 to ensure effective peening mitigation and finds that supports appropriate ISI inspection credit. The peening process will be considered a controlled "special process" in accordance with 10 CFR 50, Appendix B, Criterion IX. This is synonymous to a vendor submitting welding program procedures and specific welding procedure qualification record(s) to a licensee for pre-implementation approval.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
				As discussed in MRP-267R1, the compressive stress obtained by peening is insensitive to the magnitude of the tensile residual stresses that are present prior to peening. The compressive stress developed in response to peening is mostly governed by the material properties and not by the starting residual stress condition. The initial residual stress distribution is not an essential parameter. Furthermore, the effectiveness of the peening performed is not dependent on the precise level of compressive residual stresses produced by the peening, provided that they are greater in magnitude than the applied stress. The control by the peening vendor of the essential variables particular to the peening technology utilized and the satisfaction of the performance criteria result in a robust mitigation process. Based on the experience with peening of PWRs and BWRs in Japan, and the extensive work documented in MRP-267R1, including testing sponsored by EPRI independent of the peening vendors, MRP believes that additional validation testing is unnecessary and may unnecessarily delay industry implementation.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
4	1-1A	Section 1	Table 1.1 states the following under Quality Assurance Considerations, "...since peening is a special process, it shall be controlled in a manner consistent with Criterion IX, "Control of Special Processes," of Appendix B and any applicable plant specific commitments. As stated in that criterion, this requires that the personnel and procedures involved need to be appropriately qualified. Since there are no industry standards that apply to peening, these qualifications shall be done to vendor requirements developed and documented per their 10 CFR [Part] 50 [Title 10 of the Code of Federal Regulations] Appendix B quality assurance program and to utility requirements and commitments applicable at the plant site...." The NRC staff is concerned that no generic industry standards are available for the various peening techniques to be applied. To ensure consistent and effective application, the NRC requests the following: A. Submit reference document MRP-336, "Materials Reliability Program: Specification Guideline for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement."	As discussed above and in more detail below in the response to RAI 1-1B, the effectiveness of peening mitigation will be ensured through applicable ASME Code approved performance criteria and by controlling the peening as a "special process" in accordance with 10 CFR 50, Appendix B, Criterion IX. The applicable ASME Code approved performance criteria are Appendix I of ASME Code Case N-770-4 for Alloy 82/182 piping butt welds and an Appendix II of a planned revision of ASME Code Case N-729 for Alloy 600 reactor vessel top head penetration nozzles. If a version of N-729 incorporating peening mitigation of Alloy 600 RPVHPNs has been published by ASME at the time MRP-335 is revised, the revised version of MRP-335 will reference the performance criteria requirements of that code case. Otherwise, performance criteria requirements for RPVHPNs will be included in the revised topical report itself. It is emphasized that each peening vendor is required to meet the stress and coverage parameters defined in response #2 above regardless of the essential variables particular to the vendor. Peening is effective for mitigation if the expected residual stresses and coverage are achieved regardless of the process used to produce those stresses. The stress and coverage requirements in response #2 above will be incorporated into the revised topical report. The MRP-336 report (EPRI 1025841, published July 2012) is a proprietary document that was not published in a format for public release. MRP-336 is not part of the technical basis for the MRP-335R1 topical report, and it is not referenced in MRP-335R1 or MRP-267R1. Instead, MRP-336 was produced for MRP members to provide general guidance regarding the issues that are expected to be encountered when procuring advanced peening services for PWSCC mitigation. If there are specific technical issues that are relevant to the NRC safety evaluation and requirements for peening mitigation, please provide those specific requests. MRP can better determine which content may be needed to address the issue based on a specific question/request for additional information.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
5	1-1B	Section 1	The NRC staff is concerned that no generic industry standards are available for the various peening techniques to be applied. To ensure consistent and effective application, the NRC requests the following: B. Identify all essential variables and associated ranges for each peening method. Identify any additional limitations for various surface conditions or access limitations of the proposed components.	Section 2.11 of MRP-335R1 lists the key process application variables for water jet peening and underwater laser peening technologies. The peening vendor will be required to provide essential variables with associated ranges of acceptable application-specific values as part of its controlled special process procedures submitted for licensee pre-implementation approval. The MRP supports the use of the performance criteria of Appendix I of ASME Code Case N-770-4 to ensure effective peening mitigation that supports appropriate ISI inspection credit. The peening process will be considered a controlled "special process" in accordance with 10 CFR 50, Appendix B, Criterion IX. Peening is effective for mitigation if the expected residual stresses are achieved regardless of the process used to produce those stresses. Each vendor is required to demonstrate that its envelope of acceptable essential variable values documented in the application-specific procedures will result in coverage and compressive stress magnitude and depth parameters meeting the requirements of response #2 above, as well as the full set of applicable performance criteria. The vendor will demonstrate satisfaction of these requirements through representative mockup testing. This testing and the proof of peening effectiveness will be documented in a site-specific report. EPRI MRP requests that NRC approve the stress improvement and coverage requirements defined above in response #2, in the responses to RAI 4-3 and RAI 4-6C, and in Appendix I of ASME Code Case N-770-4. EPRI MRP requests that NRC-approved stress improvement and coverage parameters be incorporated into the finalized peening requirements for inspection credit, and not the vendor-specific envelopes of essential variable values. As utilities begin to peen their susceptible locations, other vendors may enter the market and offer laser peening or water jet peening processes with identified envelopes of acceptable essential variable values that are unique due to detailed process and equipment differences. Moreover, existing vendors may improve certain aspects of their processes, resulting in changes to the acceptable envelope of essential variable values. It is important that the regulatory oversight structure allow the vendors the flexibility to improve their products without unnecessarily limiting the essential variables and techniques.

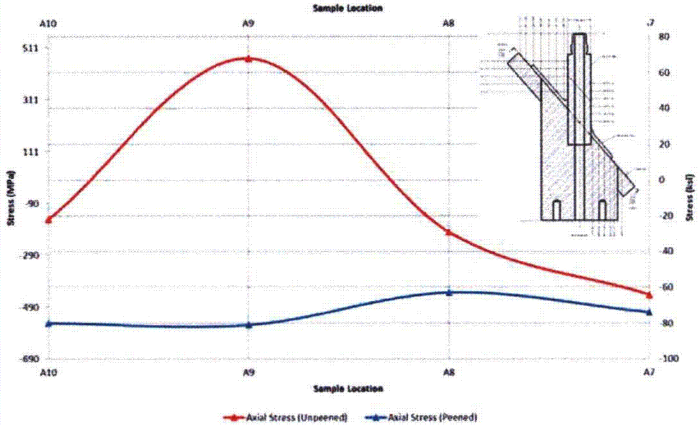
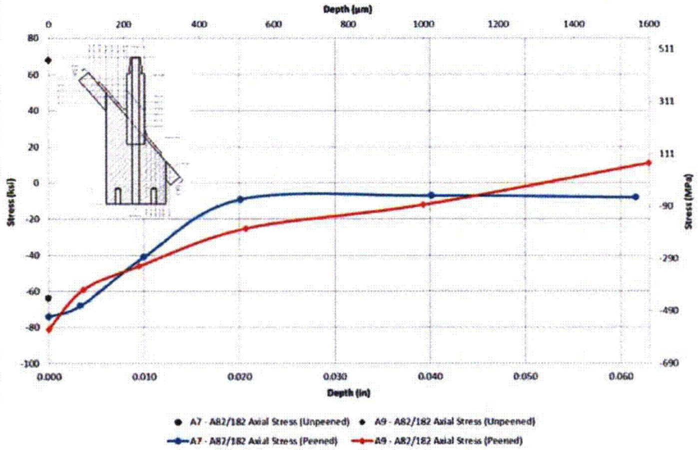
#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
				Section 2.8 of MRP-335R1 discusses the potential for surface condition limitations. There are no known limitations imposed by surface conditions on the peening applications covered in MRP-335R1. Section 2.7 of MRP-335R1 addresses potential geometric application limitations, noting that the particular air laser peening (ALP) process described in MRP-267R1 is applicable to the outer surfaces of reactor vessel head penetration nozzles, i.e., not the ID surface of the nozzle tube. Subsequent to publication of MRP-335R1, an approach has been developed to apply ALP to the nozzle ID surface. Currently, there are multiple peening techniques available to peen both the nozzle OD/weld and ID surfaces of the reactor vessel top head nozzles. Due to geometry, it is noted that some peening techniques of interest cannot be used to peen the threaded areas that are present in some cases near the bottom of the reactor vessel head nozzle tube. Because any such threaded areas are located below the weld toward the end of the nozzle and inboard of the pressure boundary, it is not necessary that peening be performed of the threaded regions when present.
6				*#6 not used*
7	1-3	Section 1	The NRC staff has the option to include lower reactor vessel penetration nozzles (i.e., reactor vessel bottom mounted instrumentation nozzles) and associated welds in the validation testing. However, these areas have not been identified for potential relief from current inspection requirements. Please verify that the NRC does not need to validate the peening of the bottom mounted instrumentation nozzles to support the review of MRP-335.	Bottom mounted nozzles (BMNs) are outside the scope of MRP-335R1. The current ISI inspection requirement for BMNs, per 10CFR50.55a and ASME Code Case N-722-1, is for visual examinations from the exterior of the vessel for evidence of leakage. Peening of BMNs may be performed for asset management purposes through the 10 CFR 50.59 process with no relaxation of this examination requirement. It is the position of MRP that generic relaxation, and associated approval through a Topical Report approval process, of inspection requirements for peened BMNs is not needed.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
8	2-1	Section 2	Section 2.0 of MRP-267, Revision 1, "Materials Reliability Program: Technical Basis for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement," provides essential variables for the three peening processes (described below) and these variables affect the mechanical properties of the peened weld surface. The peening processes include; Water jet peening, Laser shock peening, and Fiber laser peening. The NRC staff believes that in addition to the essential variables identified by EPRI, the following variables would be important in affecting the quality of the peened surface. Therefore, the staff requests that the MRP address each and determine whether to include these variables in the procedure qualifications. (a) type of machine (e.g., model) used for any given process. (b) type of base metal and the thickness. (c) number of peening layers.	The peening vendor will be required to provide essential variables with associated ranges of acceptable values for the specific application as part of its controlled special process procedures submitted for licensee pre-implementation approval on an application-specific basis. With regard to the variables listed in this question, MRP notes the following: • The type of machine is not applicable to water jet peening (WJP). For laser peening, the essential variables are specified such that the type of laser "machine" (i.e., laser oscillator) is unnecessary. • MRP-335R1 only needs to consider Alloy 600 and its weld metals Alloy 82, Alloy 182, and Alloy 132. These are the susceptible alloys that are addressed by peening mitigation of PWSCC. • The thickness of the material is only important to the extent it is required to constrain the plastic deformation caused by peening and hold the treated surface in compression. All of the locations covered by MRP-335R1 have much more than sufficient thickness. • For WJP, the number of peening layers (interpreted as number of passes) is not an essential variable. The total time of peening at one location or rate of peening in meters or square meters per hour is the essential variable and is independent of whether the jet is moved over an area once at a slow speed or several times at a higher speed. Peening mitigation is a special process to be controlled in accordance with 10 CFR 50, Appendix B, Criterion IX. The process must be identified, essential variables and limits must be clearly defined for each process, and a QA program for control of the essential variable values must be in place for implementation. However, peening is effective for mitigation if the expected residual stresses are achieved regardless of the process used to produce those stresses.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
9	3-1	Section 3	Pages 3-2 and 3-4 in Section 3.2.1 of MRP-335, Revision 1, describe that – • "Alloy 600 base material with good access (large radius or flat surface) – ULP (Toshiba): Surface stress -450 to -900 MPa (-65 to -130 ksi), compressive to depths of more than 1.0 mm. – WJP (MHI): Surface stress ranging from -267 to -411 MPa (-39 to -60ksi), compressive to depths of more than 1.0 mm. – ALP (MIC): Shallow surface layer with tensile stress of about +400 MPa, dropping to zero at a depth of about 20 µm and decreasing to -400 to -660 MPa (-58 to -96 ksi) at depths of about 35 to 70 µm stress remains compressive to depths of more than 1.5 mm. In this regard, it is expected that the ALP process parameters selected for use at RPVHPN [reactor pressure vessel head penetration nozzle] J-groove welds will result in compressive stress fields to depths of more than 3 mm. • Alloy 82/182 weld metal with good access – ULP (Toshiba): Surface stress ranging from -500 to -1000 MPa (-73 to -145 ksi), compressive to > 1.0 mm. – WJP (MHI): Surface stress ranging from -293 to -414 MPa (-42 to -60 ksi), compressive to > 1.0 mm. – ALP (MIC): No data available for the stress depth profile for Alloy 82/182 welds; assumed to be similar to data for Alloy 600 given above. This assumption is justified by the capability of ALP to produce compressive residual stress depth as great as 8 mm depending on the treated material and chosen process parameters. • Alloy 600 base material at ID [inside diameter] of small diameter tube – ULP (Toshiba): Surface stress ranging from -300 to -500 MPa (-44 to-73 ksi), compressive to > 1.0 mm (after peening both ID and OD). – WJP (MHI): Surface stress of -210 to -470 MPa (-30 to -68 ksi), compressive to -0.5 mm. – WJP (Hitachi-GE): Surface stress of -500 to -670 MPa (-73 to -97 ksi), compressive to -0.5 mm."	The mockup testing presented in MRP-267R1 was used by the peening vendors to demonstrate that the effect of peening is sufficient for effective mitigation of PWSCC. The vendors determined the ranges of essential variables that produced sufficient peening effects. The test results of the peening vendors reflect variability in the test conditions, including the extreme ranges of the essential variables, different material types, prior cold work conditions, and different pre-peened stress conditions. For the reasons discussed below in the response to Item 3-2C, the effectiveness of peening mitigation is insensitive to the precise magnitude of the peening compressive residual stress obtained (provided that it is greater in magnitude than the applied stress). It is not necessary that the peening compressive stress magnitudes summarized in Section 3.2.1 of MRP-335R1 be bounding. In addition, it is not necessary that the compressive stresses from peening be uniform for peening to be effective, although the peening compressive stresses do tend to be relatively uniform due to the self-normalizing behavior as described in Section 4.5 of MRP-267R1. Inserted below in this response to RAI 3-1 are example laboratory data demonstrating such self-normalizing behavior in which the peening compressive residual stress magnitude is insensitive to the initial residual stress prior to peening. The considerations of surface condition, cold worked condition, and limited access areas are each addressed in detail in MRP-267R1: • The testing documented in MRP-267R1 included heavily ground specimens, as well as welded plate specimens and J-groove weld mockups. • Section 4.6 of MRP-267R1 is a detailed assessment of the issues related to cold work, including of the effect of prior cold work. The testing documented in MRP-267R1 includes U-bend specimens with aggressive strain conditions (e.g., 20% pre-strain plus an estimated 10% additional strain due to bending per page A-81 of MRP-267R1), as well as 20% cold-worked specimens of austenitic stainless steel (which behaves similarly to Alloy 600 in terms of the stress effect of peening). Further, shot peening mitigation of PWSCC of Alloy 600 steam generator tubes in areas that were significantly cold worked, e.g., roll overlaps and roll transitions, has been observed to be highly effective as discussed in Section 4.6.5 of MRP-267R1.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
			While the information provided by EPRI in support of MRP-335 clearly shows compressive stresses are provided, it is not clear to the NRC staff that these results are bounding for the full range of essential variables that could be implemented at an individual plant. The NRC staff believes that additional information is needed to show the effectiveness of maintaining uniform levels of compressive stresses from peening (adjusted for temperature and load cycling induced relaxations) with the following considerations; surface condition, cold worked condition, and limited access areas. Provide information, either new results or clarify existing testing, to show that uniform levels of compressive stresses from peening (adjusted for temperature and load cycling induced relaxations) are maintained along the region of concern in these nozzles and welds at the surfaces that are susceptible to primary water stress corrosion cracking (PWSCC) and are being treated. This information, including analysis, should consider application of peening that meets the minimum generic qualification requirements. Further, the analysis should consider and include surfaces that are cold worked (up to 15%), as welded weld surfaces, limited access to surfaces and other potential surfaces found as the surface condition for in-service components.	• As summarized in Section 2.7 of MRP-335R1, there are no access limitations that have been identified that preclude effective peening from being performed. Section 2.7 of MRP-335R1 notes that the particular air laser peening (ALP) process described in MRP-267R1 is applicable to the outer surfaces of reactor vessel head penetration nozzles, i.e., not the ID surface of the nozzle tube. Subsequent to publication of MRP-335R1, an approach has been developed to apply ALP to the nozzle ID surface. Currently, there are multiple peening techniques available to peen both the nozzle OD/weld and ID surfaces of the reactor vessel top head nozzles. Finally, Sections 4.3 and 4.4 of MRP-267R1, which evaluate the long-term effectiveness of peening mitigation based on experimental testing and analysis work, conclude that peening mitigation is effective for more than 60 years of operation. This conclusion is based on thermal relaxation and load cycling tested performed by the peening vendors, as well as independent testing sponsored by EPRI. The extensive data documented in MRP-267R1 demonstrates the long-term effectiveness of peening mitigation of the plant components addressed by MRP-267R1 and MRP-335R1, including the applicable material (including cold work up to 15%), surface (welds and heavy grinding), and accessibility conditions. MRP-267R1 provides sufficient test data to bound the conditions relevant to the plant locations of interest.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
				<u>Example Stress Measurements Illustrating the Insensitivity of the Peening Compressive Residual Stress to the Pre-Peening Residual Stress State</u> A study was performed by AREVA to verify that the unpeened residual stress state of the material does not have a significant effect on the final peened surface compressive stress and depth of compression. A surface that is in high tension relaxes more when it is peened vs. a surface that has low tension. Likewise a material that is already in compression does not relax as much when it is peened. The conclusion is peening on a material has about the same final result regardless of the initial residual stress state of the material. (In fact, the results presented below show the material in highest tension to have the highest compression after peening.) X-ray diffraction was used to measure the residual stress state of an unpeened bottom mounted nozzle OD mockup. The surface axial stresses on the Alloy 82/182 material ranged from -64 ksi to +68 ksi (-441 MPa to +469 MPa). The weld was an "as welded" fillet (no grinding), the surface residual stress was measured approximately every 0.5 in. (12.7 mm). Typically, the fillet "hills" were in tension and the "valleys" were in compression. Peening was performed on the mockup and the precise same locations were measured on the surface after peening. Two locations (A7 and A9) had depth residual stress measurements taken: • Location A7 was at -64 ksi (-441 MPa) before peening and went to -74 ksi (-510 MPa) after peening. • Location A8 was at -29 ksi (-200 MPa) before peening and went to -63 ksi (-434 MPa) after peening. • Location A9 was at +68 ksi (469 MPa) before peening and went to -81 ksi (-558 MPa) after peening. • Location A10 was at -22 ksi (-152 MPa) before peening and went to -80 ksi (-552 MPa) after peening. The data show the greatest peening response occurred with the highest amount of initial tension. Regardless of the initial state, high tension or high compression, the final compressive stresses ended up within a -63 ksi to -81 ksi (-434 MPa to -558 MPa) range. The results are shown in the figures below.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
				AREVA UHP Cavitation Peening **BMN Nozzles: W4 Loop OD Periphery Geometry - Before / After** **Surface Map**  **AREVA UHP Cavitation Peening** **BMN Nozzles: W4 Loop OD Periphery Geometry - Before / After** 

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
10	3-2A	Section 3	Page 3-4 in Section 3.3.1 of MRP-335 states that: "...Based on extensive previous weld residual stress FEA [finite element analyses] work performed by the authors for CRDM/CEDM nozzles in many PWRs (see, e.g. [12]), the peak applied stresses at the ID [inner diameter] surfaces of RPVHPNs are relatively low, between 15 and 25 ksi (103-172 MPa) or less. The expected initial surface compressive stresses generated by peening are at least about 300 MPa (44 ksi), but can decrease to about 200 MPa (29 ksi) as a result of temperature and load cycle effects. The total stress at the surface thus will be below zero. Thus, crack initiation is prevented...." and "...Based on extensive previous weld residual stress FEA work performed by the authors for CRDM/CEDM [control rod drive mechanism/control element drive mechanism] nozzles in many PWRs (see, e.g. [12]), the peak applied stresses at the OD [outer diameter] surfaces of RPVHPNs, at either the weld or base material, are relatively low, less than 5 ksi (35 MPa) or less. The expected initial surface stresses generated by ALP (without an ablative layer) are about +450 MPa (65 ksi), but with compressive stresses developing just below the surface at about -450 MPa (-65 ksi), i.e. zero stress at 15 μm and -450 MPa at 35 μm. The high tensile surface stresses could result in local initiation of very shallow cracks but the high subsurface compressive stresses limit their growth to less than about 20 or 30 μm according to a stress-intensity-factor based crack growth calculation. Thus, the initiation of cracks with depths that are of engineering significance is prevented. Similarly, the use of ULP or WJP on the OD surfaces of RPVHPNs would preclude future PWSCC initiation at this location...." Ref. [12] of MRP-335-Rev-1 (Page 7.2): D. Rudland, J. Broussard, et al., "Comparison of Welding Residual Stress Solutions for Control Rod Drive Mechanism Nozzles," Proceedings of the ASME 2007 Pressure Vessels & Piping Division Conference: PVP2007-26045, July 2007.	The peak applied (i.e., operating) stress values cited in Section 3.3.1 are based on a review of FEA cases performed by Dominion Engineering, Inc. for many PWR reactor vessel heads. The results in Figures 6 and 8 of Ref. [12] actually show a very similar peak operating stress for the two organizations of about 170 to 175 MPa on the ID surface of the nozzle tube (for the hoop stress component in each case). Figures 7 and 9 of Ref. [12] show operating stresses on the nozzle OD, but at or above the triple point, which is well above the wetted surface that is treated by peening. Despite the differences in boundary condition modeling and in assumed interference fit discussed in Ref. [12], the peak applied stress for the two organizations is very similar for the nozzle ID surface. Furthermore, it is noted that the applied stress values are not dependent on the inservice material properties (i.e., such as yield strength). As stated in Ref. [12], the operating conditions result in elastic analyses, so the applied stress values are not dependent on material heat-specific properties such as the yield strength. Lastly, it is emphasized that the effectiveness of peening mitigation is insensitive to the magnitude of the applied stresses for the reasons discussed below in the response to Item 3-2C (provided that the magnitude of the peening compressive stress is greater than the applied stress). As discussed on page 8 of Ref. [12], there are some sizable differences in the weld residual stresses (excluding applied stresses) calculated by the two independent organizations for particular locations in the nozzle and weld (e.g., as shown in Figures 12 and 14 of Ref. [12]). However, both organizations show the potential for peak weld residual stresses similar to the assumed yield strength of the material. As discussed below in the response to RAI 3-2C, the magnitude of the compressive residual stress that is produced by peening is insensitive to the magnitude of the residual stresses present prior to peening.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
			The FEAs presented in Ref. [12] by the two independent organizations gave considerably different results for the peak stresses (hoop and axial) at the inside diameter (Figures 12 and 14, respectively) along the triple point – welding residual stress only comparison and in Figure 7 (hoop stress along the tube OD-operating loads only) and also in Figure 8 (axial stress along the *tube ID – operating loads only) for the CRDM analysis models.* The NRC staff believes that other plant- specific analyses show a range of values for use as the peak applied stresses at the ID and the OD surfaces than presented in the Section 3.3.1. Therefore NRC staff requests EPRI to:– A. Provide a survey of ranges of peak applied stress values determined with use of in-service material properties.	

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
11	3-2B	Section 3	The FEAs presented in Ref. [12] by the two independent organizations gave considerably different results for the peak stresses (hoop and axial) at the inside diameter (Figures 12 and 14, respectively) along the triple point – welding residual stress only comparison and in Figure 7 (hoop stress along the tube OD-operating loads only) and also in Figure 8 (axial stress along the tube ID – operating loads only) for the CRDM analysis models. The NRC staff believes that other plant- specific analyses show a range of values for use as the peak applied stresses at the ID and the OD surfaces than presented in the Section 3.3.1. Therefore NRC staff requests EPRI to:– B. Clarify or submit additional supporting justification to assume that all subsurface stresses under the conditions discussed here would not permit flaw propagation. NRC staff disagrees with the assessment made in the statement, "the peak applied stresses at the ID surfaces of RPVHPNs are relatively low, between 15 and 25 ksi". Many sources, including MRP-95R1, "Generic Evaluation of Examination Coverage Requirements for Reactor Pressure Vessel Head Penetration Nozzles, Revision 1," have found inside diameter stresses in excess of 60 ksi. NRC staff is also concerned about heavily cold worked surfaces and craze cracking on surfaces. Therefore, a process that may only generate 29 ksi of compression may not result in surface stresses below zero ksi.	The question confuses *applied* (i.e., operating) stresses and *residual* stresses. The peak applied stresses (i.e., operating stresses due to operating pressure and temperature) at the ID surfaces of RPVHPNs are in fact relatively low, between 15 and 25 ksi. It is agreed that stress modeling for RPVHPNs, including in MRP-95R1, often shows total stresses (residual plus applied) in excess of 60 ksi. However, the effectiveness of the peening only requires the magnitude of the compressive residual stress initially produced by peening to exceed the magnitude of the tensile *applied* stress at steady state operating conditions. The peening process involves application of plastic strains that eliminate the pre-existing tensile residual stresses present at the treated surface. As discussed below in the response to RAI 3-2C, the magnitude of the compressive residual stress that is produced by peening is insensitive to the magnitude of the residual stresses present prior to peening. This behavior is illustrated in the example laboratory data presented above in the response to RAI 3-1. These data show that the areas initially with the highest tensile residual stresses tend to have the greatest response to the peening and highest resulting compressive stress magnitude. Furthermore, as also discussed below in the response to RAI 3-2C, the thermal stress relaxation acts on the total stress during steady state operation, including the effect of the tensile operating stress due to pressure and temperature loading. Thus, regardless of the amount of stress relaxation that occurs due to thermal relaxation, the total stress near the surface including operating stresses must remain compressive. In addition, as discussed in detail in Section 4.6.4 of MRP-267R1, peening mitigation is effective regardless of the presence of a surface cold-worked layer (e.g., due to grinding). Finally, the concern for surface craze cracking is addressed by peening mitigation in the same manner that other potential shallow surface flaws are addressed, i.e., through stress improvement and the NDE required to be applied in combination with peening mitigation.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
12	3-2C	Section 3	The FEAs presented in Ref. [12] by the two independent organizations gave considerably different results for the peak stresses (hoop and axial) at the inside diameter (Figures 12 and 14, respectively) along the triple point – welding residual stress only comparison and in Figure 7 (hoop stress along the tube OD-operating loads only) and also in Figure 8 (axial stress along the tube ID – operating loads only) for the CRDM analysis models. The NRC staff believes that other plant- specific analyses show a range of values for use as the peak applied stresses at the ID and the OD surfaces than presented in the Section 3.3.1. Therefore NRC staff requests EPRI to:– C. Evaluate the effectiveness of each peening technique considering the effect of peening at the minimum range of the essential variables for each technique. If not, provide justification.	The mockup testing presented in MRP-267R1 was used by the peening vendors to demonstrate that the effect of peening is sufficient for effective mitigation of PWSCC. The vendors determined the ranges of essential variables that produced sufficient peening effects. As documented in MRP-267R1 and MRP-335R1, peening performed per the procedures of the peening vendors produces a large compressive residual stress at the treated surface. The magnitude of the compressive residual stress that is produced by peening is insensitive to the magnitude of the residual stresses present prior to peening. Furthermore, as long as the magnitude of the compressive residual stress is greater than the magnitude of the applied stress, the effectiveness of the peening mitigation is insensitive to the precise magnitude of the applied stresses. Following are key technical points that support the robustness of the peening process to provide long-term effective mitigation of PWSCC: 1. As discussed in Section 4.5 of MRP-267R1 (and illustrated in the laboratory data presented above in the response to RAI 3-1), areas initially in tensile residual stress will experience a greater response to treatment since these areas are statically biased higher up on the stress-strain curve, so they will achieve more plastic deformation upon relaxation. In a related way if an area is initially compressively pre-stressed, the peening induced pressure has to overcome more elastic resistance before achieving plastic deformation that leads to compressive residual stress. Therefore the process is somewhat self-normalizing in that regions with higher tensile pre-stress will attain a more effective peening than regions of neutral stress, and areas with a pre-existing compressive stress will show less response to the peening. The net result is that the variability in the post-peening stresses is relatively small, and much less than the variability that can be present in pre-peening residual stresses. 2. The thermal stress relaxation that acts to reduce the magnitude of the compressive residual stress at the peened surface in the long term (see Sections 4.3 and 4.4 of MRP-267R1) acts on the total stress during steady state operation, including the effect of the tensile operating stress due to pressure and temperature loading. Thus, regardless of the amount of stress relaxation that occurs due to thermal relaxation, the total stress near the surface including operating stresses must remain compressive. 3. As discussed in Section 3.1 of MRP-335R1, initiation of PWSCC will not occur during plant lifetimes if the peak stress at the wetted surface during normal operation is below the practical "threshold" tensile stress of about 20 ksi (138 MPa).

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
13	4-1A	Section 4	Page 4-3, Footnote number 4 (the same as Table 4-1 footnote number 2) states that "...The pre-mitigation examination may be delayed to after the mitigation outage provided that the inspection requirements for unmitigated component apply until the examination is performed and PWSCC must not be detected during the delayed examination for the relaxed inspection requirements to apply...." (a) The NRC staff assumes that the mitigation outage referenced above is the outage during which peening will be performed. In this case, clarify how and why an examination performed after peening is applied to a component (i.e., after a mitigation outage) may be considered as a pre-mitigation examination. How can a pre-mitigation examination be completed after the mitigation has been applied, especially in light of the fact that flaws detected prior to peening shall be removed.	Yes, the mitigation outage here refers to the outage that peening is performed. The point is that if the delayed pre-mitigation examination does not detect any flaws that would have been required to have been removed or repaired prior to peening, then it can be concluded that the examination would also not have detected any such flaws just prior to peening being applied if it were performed then. Thus, in this alternative approach, peening mitigation would be credited for inspection credit only subsequent to the delayed pre-mitigation examination being completed and only in the case that no flaws that would have required removal or repair are detected. It is noted that ASME Code Case N-770-4, which addresses inspection credit for peening mitigation of PWR Alloy 82/182 piping butt welds, does not include this type of option to delay the pre-peening examination. EPRI MRP accepts the approach in Code Case N-770-4, and EPRI MRP agrees to remove the subject footnotes regarding this option from a revised version of MRP-335R1.
14	4-1B	Section 4	Page 4-3, Footnote number 4 (the same as Table 4-1 footnote number 2) states that "...The pre-mitigation examination may be delayed to after the mitigation outage provided that the inspection requirements for unmitigated component apply until the examination is performed and PWSCC must not be detected during the delayed examination for the relaxed inspection requirements to apply...." (b) The NRC staff interpreted the intent of the phrase, "...the inspection requirements for unmitigated component apply until the examination is performed....", as that the inspection requirements for the unmitigated component in Code Case N-770-1 will be applied to the candidate component that has not yet been peened. Discuss whether this is the correct interpretation.	No, as clarified in the response to Question 13, the inspection requirements for an unmitigated component would apply until the time that the delayed pre-peening examination is performed subsequent to peening. The inspection requirements for a peened component could be applied thereafter only in the case that no flaws that would have required removal or repair are detected.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
15	4-1C	Section 4	Page 4-3, Footnote number 4 (the same as Table 4-1 footnote number 2) states that "...The pre-mitigation examination may be delayed to after the mitigation outage provided that the inspection requirements for unmitigated component apply until the examination is performed and PWSCC must not be detected during the delayed examination for the relaxed inspection requirements to apply...." (c) Clarify the phrase: "...PWSCC must not be detected during the delayed examination for the relaxed inspection requirements to apply...." The NRC staff understands that if PWSCC is detected, then the relaxed inspection requirements will not be applied. The NRC staff assumes that the relaxed inspection requirements are those requirements for the mitigated components as specified in Code Case N-770-1. However, if PWSCC is detected during the pre-mitigation examination, discuss whether the peening is permitted to be applied to the candidate component.	The peening would have already have been applied when the delayed pre-peening examination is performed. As documented in MRP-267R1 (see Section 4.5), peening performed per the vendor requirements does not introduce flaws into the wall, nor does it cause growth of pre-existing flaws. Thus, it is permissible to perform peening with the pre-peening examination delayed. However, as noted above in the response to Question 13, such an option is not included in ASME Code Case N-770-4.
16	4-1D	Section 4	Page 4-3, Footnote number 4 (the same as Table 4-1 footnote number 2) states that "...The pre-mitigation examination may be delayed to after the mitigation outage provided that the inspection requirements for unmitigated component apply until the examination is performed and PWSCC must not be detected during the delayed examination for the relaxed inspection requirements to apply...." (d) Revise Footnote number 4 on page 4-3 (and footnote 2 in Table 4-1) in its entirety for clarification.	As discussed above in the response to RAI 4-1A, ASME Code Case N-770-4, which addresses inspection credit for peening mitigation of PWR Alloy 82/182 piping butt welds, does not include this type of option to delay the pre-peening examination. EPRI MRP accepts this approach in Code Case N-770-4, and EPRI MRP agrees to remove these footnotes from a revised version of MRP-335R1.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
17	4-2	Section 4	Page 4-4, first paragraph states that "a post-mitigation inspection (a.k.a. pre-service inspection) **may be** performed just after the application of peening and before the unit begins to operate." If a licensee wishes to take credit for the peening so that the inspection interval of Alloy 600/82/182 components in accordance with ASME Code Case N-770-1 could be extended, the licensee needs to follow the pre-service inspection requirements of the ASME Code, Sections III and XI. The NRC staff finds that the pre-service inspection (i.e., post-mitigation inspection) is a requirement of the ASME Code Sections III and XI, and therefore should be performed before the peened component can be placed in service. The NRC staff notes that a UT, eddy current and liquid penetrant testing should be performed after peening is applied and before the component is placed in service. (a) Justify why the pre-service inspection "may be performed" instead of "must be performed." (b) Discuss the examination techniques that will be used in the pre-service inspection.	(a) As documented in MRP-267R1 (see Section 4.5), peening performed per the vendor requirements does not introduce flaws into the wall, nor does it cause growth of pre-existing flaws. In addition, the peening process does not introduce any significant geometrical changes of the treated component, and work by EPRI and the peening vendors shows that peening does not affect the inspectability of the peened component. Hence, it is appropriate that the pre-peening examination be considered the preservice baseline examination. For the case of Alloy 82/182 piping butt welds, ASME Code Case N-770-4, which was approved by ASME on May 7, 2014, states that pre-peening examination shall be considered the preservice baseline examination. ASME Section III does not include preservice inspections applicable to repair/replacement activities or mitigation work, and peening as a surface stress improvement is not addressed in Section III. ASME Section XI requires preservice examinations following repair/replacement activities, but peening is not a repair/replacement activity; therefore, the preservice examination provisions of IWA-4000 do not apply. (b) The examination techniques to be used in the pre-peening examination, which is considered the preservice examination, are UT and, in the case of Alloy 82/182 piping butt welds, also ET. With regard to reactor vessel head penetration nozzles, please see the separate "Supplemental Technical Basis" document for additional discussion of the basis for the pre-peening inspection approach of MRP-335R1. Note that PT is not a practical option for the piping locations since peening at such locations is performed underwater and remote PT is not available.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
18	4-3	Section 4	Page 4-4, third paragraph states that the extent of the required surface to be peened in the case of RPVHPN is defined by the examination volume/area of Figure 2 of ASME Code Case N-729-1. Footnotes of figure 2 in Code Case N-729-1 may allow licensees to only peen to the boundary of the J-groove weld which the NRC staff finds insufficient. For clarity, include a figure in MRP-335 that is similar to Figure 2 of Code Case N-729-1 and eliminate any potential footnotes that may allow a reduction in surface area application. The figure should identify and therefore define the maximum surfaces of the RPVHPNs including the J-groove weld surface that are qualified and permitted to be peened based on the calculations and/or mockups and the surfaces that are to be examined as part of the peening effort.	A figure similar to Figure 2 of ASME Code Case N-729-1 will be included in the revised version of MRP-335R1. The figure will make clear that the surface to be peened shall include at least 1/4 inch beyond the theoretical point "F" (intersection of weld butter and stainless steel cladding on wetted surface). There is no limit on peening a larger surface than the minimum to be defined in the figure to be added to MRP-335R1. Additional material on the cladding and on the nozzle tube ID may be peened without any concerns because the wall thickness of the head and tube and are nominally the same in the areas extending just beyond the minimum peening surface. Note that for peening on the nozzle OD, the peening coverage can be limited to the distance "a" below the weld toe at each azimuthal position around the nozzle. The FEA stress results presented in MRP-95R1 (the technical basis for the ASME Code Case N-729-1 inspection coverage) demonstrate that peening of the nozzle tube OD outside this zone only increases the implementation time for no added technical benefit. As an alternative, similar to the approach defined in Appendix I of Code Case N-729-1, it is appropriate to permit head-specific stress calculations to be used to define the peening coverage zone for a specific head, considering the minimum 20 ksi threshold for crack initiation over plant time scales. Further, note that, due to geometry, some peening techniques of interest cannot be used to peen the threaded areas that are present in some cases near the bottom of the nozzle tube. Because any such threaded areas are located below the weld toward the end of the nozzle and inboard of the pressure boundary, it is not necessary that peening be performed of the threaded regions when present. The inspection volume/surface defined in N-729-1 is appropriate for use with peening. Inspections of the susceptible Alloy 600, 82, and 182 material are performed to detect PWSCC flaws. As documented in MRP-267R1 (see Section 4.5), peening performed per the vendor requirements does not introduce flaws into the component, nor does it cause growth of pre-existing flaws. Thus, it is not necessary for the inspections performed to cover the entire surface that was actually peened.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
19	4-4A	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (a) Describe the details of the evaluation to identify susceptibility of adjacent areas to flow induced vibration.	The first bullet in Section 6.2 of MRP-335R1 notes that there have been flow induced vibration (FIV) failures of nozzles and instrument lines located close to water jet peened (WJP) areas in Japanese BWRs. This bullet refers to MRP-335R1, which provides references for these events. As discussed in MRP-335R1 and MRP-267R1, and in the referenced documents, the failures in the Japanese BWRs were of small nozzles and instrument lines located close to areas that were water jet peened, and did not affect the thick-wall parts that were peened. It also did not affect thick-wall parts adjacent to the peened areas. Based on this experience, MRP-335R1 (Section 4.2) recommends an evaluation prior to water jet peening to identify any susceptibility of adjacent areas to flow induced vibration (FIV). The evaluation should primarily rely on a review of the applicable drawings such as vessel and vessel attachment drawings to verify that there are no small-diameter parts such as instrument lines or nozzles in locations where they could be adversely affected by flow from the peening operation. It is emphasized that peening mitigation has been extensively applied at Japanese PWRs, including for many RPV nozzle dissimilar metal welds, BMN ID surfaces, and BMN J-groove welds. There is no operating experience that indicates that flow induced vibrations from WJP are an issue in PWRs. With regard to reactor vessel top head penetration nozzles, mockup testing has demonstrated that there is no harm to the nozzle or thermal sleeve (when present) when the nozzle inner and outer surfaces are peened via water jet. The process does not trigger any resonance with the natural frequency of the thermal sleeve.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
20	4-4B	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (b) Discuss the experience and any lessons learned from the Japanese peening experience that could be adopted and included as guidance for the domestic nuclear plants in MRP-335.	As noted in the response to RAI 4-4(a), and in more detail in MRP-335R1 Section 6.2 and in MRP-267R1 Section 3.1.4, there have been reports of two occurrences of flow induced vibration problems induced by water jet peening in Japanese BWRs. The descriptions of these experiences in MRP-267R1 are reproduced below: • "In 2006, at the Shimane-2 BWR, damage was detected of deflectors and 2-cm (0.8 in.) diameter nozzles of the high pressure core spray system [37]. It was concluded that these problems were caused by flow induced vibration of these parts that occurred as a result of WJP of adjacent areas of the reactor internals. The Japanese safety authority, NISA, ordered Japanese utilities who have ever applied WJP to visually inspect surrounding components. NISA also published instructions that require evaluation of the possibility of FIV problems prior to application of WJP and inspection of surrounding components after WJP." • "In 2010, at the Kashiwazaki Kariwa-2 BWR, it was found during post-inspection of WJP of the core shroud that a 14 mm (0.55 in.) diameter jet pump sensing line was damaged [38]." The wall thickness for the sensing line was only 0.051 in. (2 mm). In both of the above cases, the failures were of small-diameter parts that experienced flow induced vibration as a result of water jet peening of adjacent thick-wall parts. There have been no reports of flow induced vibration of the thick-wall parts that were peened or of adjacent thick-wall parts. The guidance that was developed based on this experience is summarized in the first bullet of MRP-335R1 Section 6.2 and reads as follows: "Based on this experience, this document requires evaluations to identify susceptibility to FIV, and if susceptible, require post-peening inspections to verify that problems did not occur." The requirements for the evaluations are also discussed in several other locations in MRP-335R1, especially on page 4-4 of Section 4.2. Section 4.2 requires a post-mitigation visual examination (VT-1 or VT-3) if the evaluation to identify any susceptibility of adjacent areas shows susceptibility to damage from the peening process. In summary, based on the Japanese experience, there is no concern regarding flow induced vibration of the thick-wall parts that are being peened by WJP, but the possibility of flow induced vibration damage of small-diameter adjacent parts needs to be considered and addressed. The evaluation of FIV is a conservative defense-in-depth action to ensure that the area to be peened is evaluated for the potential of FIV.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
21	4-4C	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (c) The NRC staff finds that a post-mitigation ultrasonic testing, penetrant testing and eddy current testing must be performed on the peened component regardless the outcome of the evaluation of susceptibility to flow induced vibration. The visual examination will not have the capability of detecting embedded flaws. As such, discuss why a visual examination is sufficient to determine whether a peened component is acceptable for service.	No theoretical analyses, test results, or plant experiences have been found that indicate that flow induced vibration from peening could induce defects in the thick-wall parts of the type being considered for peening in MRP-335R1. Test results for reactor vessel top head nozzle mockups show that there is no harm to the nozzle or thermal sleeve (when present) when the nozzle inner and outer surfaces are peened via water jet. The process does not trigger any resonance with the natural frequency of the thermal sleeve. It is considered that the only parts at risk of experiencing flow induced vibration damage are those of the type that have been damaged in Japanese BWRs as discussed in the above responses to RAI(a) and RAI(b), i.e., adjacent small-diameter parts such as instrument lines or nozzles that can be excited by the flows associated with WJP. Thus, based on flow induced vibration concerns there is no need to inspect the thick-wall parts that have been peened. However, if adjacent small-diameter parts are present in locations that could be subject to flow induced vibrations caused by WJP of thick-wall parts, these small-diameter parts should be inspected as recommended in MRP-335R1 (using VT-1 or VT-3). Japanese experience was that visual inspection was appropriate for detecting damage of such small-diameter parts when it had occurred as a result of WJP.
22	4-4D	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (d) Discuss why peening is permitted for a component that is susceptible to flow induced vibration.	Peening is not permitted by MRP-335R1 of parts that are subject to flow induced vibration caused by water jet peening. MRP-335R1 addresses peening of Alloy 82/182 piping butt welds and of reactor vessel top head penetration nozzles. These thick-wall parts are not subject to flow induced vibration caused by water jet peening. Furthermore, the evaluation is intended to validate that there are no components in adjacent areas that are susceptible to FIV and thus to preclude the potential for FIV damage to susceptible adjacent areas.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
23	4-4E	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (e) The NRC assumes that the evaluation to identify susceptibility of adjacent areas to flow induced vibration is based on analyses. The NRC staff has reservations about the adequacy of using analyses in this regard. The NRC staff believes that a mockup could also be used to identify susceptibility of adjacent areas to flow induced vibration. Discuss whether a mockup will be used to identify susceptibility of adjacent areas to flow induced vibration and to demonstrate that peening will not affect structural integrity of the candidate component. Discuss the acceptance criteria that determine susceptibility of flow induced vibration. If not, discuss why an analytical evaluation by itself is adequate.	The assumption stated in the question that evaluations of adjacent areas for susceptibility to flow induced vibration would be based on analyses is not correct. It is intended that such evaluations will be based on review of design drawings and on a review to make sure that there are no small-diameter parts such as instrument lines that are close enough to be damaged by flows from water jet peening. In this regard, it is considered unlikely in PWRs that there will be susceptible small-diameter parts near the locations considered for water jet peening. It should be noted that flow induced vibration problems of small-size parts in Japan have only occurred in BWRs, and not in PWRs. Finally, the use of mockups is not warranted for these same reasons.
24	4-4F	Section 4	Page 4-4, fourth paragraph states that "...An evaluation shall be performed prior to water jet peening to identify susceptibility of adjacent areas to flow induced vibration. A post-mitigation visual examination (VT-1 or VT-3) shall be performed if the evaluation shows susceptibility to damage from the peening process. Such evaluations need to consider the experience of the extensive peening performed in Japan, the specific peening process performed, and whether there is any potential for inadvertent damage to components adjacent to the target peening area...." (f) It is not clear to the NRC staff whether the concern on page 4-4 is regarding the susceptibility of adjacent areas (surrounding the peened region) to the flow induced vibration in the component itself (e.g., vibration caused by the fluid flow inside the pipe during the peening process), or susceptibility of adjacent areas to the mechanical vibration of the candidate component during the peening process (i.e., generation of the harmonic excitation of the candidate component during the peening). Clarify what is meant by the flow induced vibration.	As discussed in responses to earlier parts of RAI 4-4, the flow induced vibration problems that have occurred in Japan were of small-diameter BWR parts such as instrument lines and flow nozzles that were subjected to high flow rates from the WJP. Flow induced vibration damage has not been observed of the part being peened, the adjacent directly connected thick-wall parts, or the thermal sleeve sometimes located inside the reactor vessel top head nozzle. Thus, what is meant by flow induced vibration is excessive vibration of small-diameter parts caused by the water jet peening.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
25	4-5	Section 4	Page 4-4, fourth paragraph states that "...It is not necessary that volumetric or surface examinations be performed post-peening as the peening process does not introduce any significant geometrical changes of the treated component, and because flaws detected prior to peening shall be removed, repaired, or mitigated prior to or after peening..." The NRC staff notes that operating experience has shown that ultrasonic examinations missed detecting service-induced flaws. The NRC staff finds that a post-peening examination using ultrasonic and eddy current testing techniques must be performed to verify that no new flaws are introduced and flaws undetected during the pre-peening examination have not grown as a result of the peening. Justify why volumetric and eddy current examinations are not necessary after peening is applied.	As documented in MRP-267R1 (see Section 4.5), peening performed per the vendor requirements does not introduce flaws into the wall, nor does it cause growth of pre-existing flaws. Section A.2.2.1 of MRP-267R1 contains experimental results from Toshiba and MHI showing that laser peening and water jet peening do not cause crack growth during application. Hence, it is appropriate that the pre-peening examination be considered the preservice baseline examination. For the case of Alloy 82/182 piping butt welds, ASME Code Case N-770-4, which was approved by ASME on May 7, 2014, states that pre-peening examination shall be considered the preservice baseline examination. In March 2012, UT missed deep axial PWSCC flaws in a steam generator Alloy 82/182 inlet nozzle dissimilar metal weld. In response to this event, the industry established a program called the NIFG (NDE Implementation Focus Group). This has resulted in three EPRI reports published in 2013 that address how to improve the reliability of UT inspections of piping dissimilar metal butt welds (EPRI 3002000041, EPRI 3002000091, EPRI 3002000204). These reports are publicly available on the EPRI website. The actions required of utilities by the NIFG include evaluation of the condition of all piping dissimilar metal butt welds and determination which of them require re-inspection using improved procedures. Finally, it is noted that MRP-335R1 and N-770-4 each include ET as a second inspection method as part of the pre-peening examination for Alloy 82/182 piping butt welds. In this case, the ET examination was included in the topical report and Code Case N-770-4 because it is already included in the standard examination process. As shown in the topical report, ET examinations are not necessary for peening to be effective. They were included as a secondary measure to provide additional assurance. In the case of Alloy 600 RPVHPNs, it is not necessary that ET be included in the examinations. The basis for this approach is presented in the MRP-335R1 Supplemental Technical Basis document.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
26	4-6A	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (a) ASME Code, Section XI, Appendix VIII, Supplement 10 limits flaw depths in qualification mockups to the range of 10 - 100% of wall thickness. Please clarify how the existing qualification mockups and thus qualifications may be applied to the pre-peening ultrasonic examination, especially for very shallow flaws.	As discussed in its Section 4.2, MRP-335R1 includes a follow-up inspection to be performed a certain number of cycles after the peening application. The follow-up inspection addresses the possibility of flaws that were neither detected in the pre-peening examination nor sufficiently shallow to have been arrested by the peening process. In addition, the pre-peening examinations per Section 4.2.1 also include a surface examination as a secondary method intended to provide additional assurance of flaw detection. The main probabilistic calculations of Appendix A do not credit the pre-peening ET, and Sensitivity Case 17 of Appendix A assumes that the POD for the UT examinations is zero for flaws below a depth of 10% of the wall thickness. Case 17 showed a relatively small effect on the leakage probability results for the peened reactor vessel outlet nozzle case of an increase of 22% (see Figure A-22 of MRP-335R1).
27	4-6B	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (b) Specify whether the pre-peening ultrasonic examination will be performed from the outer diameter or inner diameter of the pipe.	Consistent with ASME Code Case N-770-4, the pre-peening volumetric examination may be performed from either the inside or outside surface. Either approach requires the examination to be qualified per Appendix VIII of Section XI. In practice, it is very likely that the pre-peening volumetric examination will be performed from the inside surface. Peening is often expected to be applied to piping butt welds for which there is not good access to the exterior of the piping, and the requirement for an ID surface examination makes it very likely that the UT would also be applied from the ID.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
28	4-6C	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (c) Include in MRP-335 report examination diagrams of the pipe components that peening will be applied. The diagrams should indicate the exact volumes and surface areas of the pipe that are required to be examined. For example, a diagram similar to Figure IWB-2500-8 of the ASME Code, Section XI should be included in MRP-335 to clearly show the required examination volume and surfaces. The peened surface should also be shown in the diagrams as a reference.	It was the intention of MRP-335R1 that the examination volume and surface requirements be made consistent with those of ASME Code Case N-770-1 for unmitigated welds. ASME Code Case N-770-4, which was approved by ASME on May 7, 2014, defines using its Figure 1 the exact volumes and surface areas of the pipe that are required to be examined. The MRP concurs with Figure 1 of N-770-4 as the appropriate definition for the examination volume and surface. In accordance with the performance criteria of Appendix I of N-770-4, the peening process shall be performed to ensure that the entire wetted surface of susceptible material (i.e., Alloy 82 and/or 182 butter and filler metal) is peened. The appropriate required overlap distance of peening on the adjacent material not susceptible to PWSCC to ensure that the entire wetted surface of Alloys 82 and 182 is peened may depend on the particular peening process used. To resolve this comment, MRP will revise MRP-335R1 to cite Figure 1 of Code Case N-770-4 as the appropriate definition for the examination volume and surface. As necessary, the revised topical report will define minimum distances for overlap of adjacent non-susceptible material.
29	4-6D	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (d) Some of the Alloy 82/182 welds join components that are fabricated with cast austenitic stainless steel (e.g., pipe, safe end, and pump nozzles). Ultrasonic testing (UT) of cast austenitic stainless steel has not been qualified by the ASME Code, Section XI. Some of the Alloy 82/182 welds are situated with nearby obstructions such as small bore branch lines. As a result, pre-peening UT of the weld could not achieve essentially 100 percent examination coverage. As such, flaws located in the unexamined volume of the weld may not be detected. Discuss for these two situations (i.e., cast stainless steel and obstructions) whether peening could be applied to the Alloy 82/182 weld of the pipe. If yes, justify why peening could be applied to a component that UT or ET could not achieve essentially 100 percent examination coverage.	Subarticle -2500 of ASME Code Case N-770-4 addresses such UT examination coverage issues, including the concerns for cast stainless steel and permanent obstructions. The MRP concurs with the approach taken in N-770-4 to addressing these examination coverage concerns. Two additional points are made. First, the coverage obtained for the surface examinations required by N-770-4 for use with peening mitigation are not affected by the presence of cast stainless steel material adjacent to the susceptible Alloy 82 or 182 material. Second, the piping butt weld locations currently under consideration for peening mitigation are the reactor vessel outlet and inlet nozzles (plus the reactor vessel safety injection and core flood nozzles present at some plants). These locations are not affected by permanent obstructions such as small-bore branch lines. The presence of small-bore branch lines is a concern affecting some reactor coolant pump nozzle dissimilar metal weld locations. It is expected that ET will cover 100% of the RV inlet and outlet nozzle susceptible materials, which would identify surface breaking PWSCC flaws that could affect peening mitigation effectiveness. Also, as justified in MRP-335R1 and MRP-267R1 and in the responses to Questions 26 and 27, peening may be applied over existing surface breaking planar flaws, further justifying peening of welds joining cast austenitic materials.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
30	4-6E	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (e) The NRC staff finds that pre-peening UT must achieve 100 percent examination coverage (not essentially 100 percent) of the surface that will be peened and the volume that will be affected by peening. Also, the pre-peening surface examination must achieve 100 percent coverage (not essentially 100 percent) of the surfaces that will be affected by peening. The pre-peening and post-peening UT and surface examination must cover ½ inch on the either side of the peened surface. The ½ inch is a buffer zone that will not be peened but should be inspected with UT, eddy current testing and liquid penetrant testing before and after peening to ensure that peening would not adversely affect the buffer zone. Discuss whether these criteria could be included in MRP-335 as a requirement. If not, provide justification.	Figure 1 and Subarticle -2500 of ASME Code Case N-770-4 address the UT and ET examination coverage required for Alloy 82/182 piping butt welds, including those mitigated via peening. The volumetric and surface examination coverage pre- and post-peening are the same. The MRP concurs with the approach taken in N-770-4. The question expresses the concern that an examination is needed of the adjoining material not susceptible to PWSCC but affected by the peening process. As documented in MRP-267R1, peening performed per the requirements does not introduce flaws into the component, nor does it cause growth of pre-existing flaws. The purpose of the pre-peening UT and ET is to identify pre-existing flaws in the Alloy 82 and/or 182 material that could grow via PWSCC subsequent to application of peening. As shown by the analyses of the Topical Report, it is not necessary that the pre-peening NDE detect all pre-existing flaws that may be deeper than the compressive residual stress zone. Follow-up examinations are included that address the possibility of such flaws. Finally, it is noted that PT examination is not a practical option for piping locations mitigated by peening.
31	4-6F	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (f) If pre-peening examination detects a flaw in an Alloy 82/182 weld, MRP-335 stated that the flaw will be removed and the weld will be repaired before peening will be applied. (1) Discuss the maximum size (depth and length) of the flaw that will be removed and repaired before peening can be applied (i.e., specify the maximum flaw size beyond which the peening will not be applied). (2) Discuss whether some ligament of the flaw will remain in the component while peening is applied. If yes, discuss the maximum flaw size that can be remain in the component and peening can still be applied (e.g., flaw size, location with respect to the peened surface). For example, if peening is applied to the ID surface of a pipe weld and if the flaw is located near the outside diameter surface, would the flaw be permitted to remain inservice? If yes, what size of the flaw will be permitted?	MRP concurs with the detailed approach specified in ASME Code Case N-770-4, which was approved by ASME on May 7, 2014, regarding appropriate actions in response to detection of a flaw in the pre-peening examination. Any flaw found by pre-peening inspection may be evaluated and handled in accordance with Case N-770-4 Table 1, Notes 19(*b*) and 19(*c*). MRP-335R1 will be revised to allow peening over an existing flaw consistent with Case N-770-4 Table 1, Note 19(*c*)(*2*) and (*3*). Peening over an existing flaw may be important for hardship purposes while the flaw is being evaluated [Table 1 Note 19(*c*)(*2*)] or while another mitigation technique is being planned [Table 1 Note 19(*c*)(*3*)]. Peening is not a mitigation technique for accepting planar surface flaws deeper than the peening compressive layer nor for accepting embedded flaws. Planar surface flaws deeper than the peening compressive layer and embedded flaws are accepted by evaluation or corrected by repair/replacement activity or by stress improvement (i.e., MSIP®) as approved by previous regulation. The purpose of peening is to mitigate surface-breaking PWSCC flaws. Peening is not intended to address embedded flaws, which are evaluated per Section XI requirements.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
32	4-6G	Section 4	Page 4-5, Section 4.2.1 states that for piping, a pre-peening ultrasonic examination shall be performed of the dissimilar metal weld using a technique that has been qualified to the performance demonstration requirements of Appendix VIII of Section XI of the ASME Code. (g) Discuss whether the ultrasonic testing (UT) and eddy current testing (ET) are qualified to perform examination on the peened surface. If yes, discuss the industry codes and standards by which the UT and ET are qualified and provide qualification requirements for the UT and ET.	The UT and ET demonstration requirements cited by ASME Code Case N-770-4 (Section XI Appendix VIII for UT and Section XI Appendix IV for ET) apply to peened as well as unmitigated welds. MRP concurs with these requirements. MRP-267R1 and EPRI report 3002000656 (*Materials Reliability Program: Effects of Surface Peening on the Inspectability of Nondestructive Evaluation*, November 2013) show that UT and ET qualified for use on unmitigated welds is reliable for use on peened welds. Peening does not introduce any changes to the component geometry or surface that affect the inspectability of the component via UT or ET. Section A.4.1 of MRP-267R1 contains a detailed experimental procedure and the results for experiments performed by Hitachi-GE verifying that WJP does not affect the flaw sizing capabilities of UT. Similarly, MHI has performed tests in parts with EDM slits and confirmed that peening did not affect the detectability of the slits by either ET or UT.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
33	4-7A	Section 4	Page 4-5 Section 4.2.1 states that "...[prior to peening] an eddy current (ET) or liquid penetrant (PT) inspection shall also be performed of the weld ID [for RPV head penetration nozzles]. The ET or PT technique need not be qualified using formal performance demonstration techniques, but shall have been demonstrated by the inspection vendor per current practices (e.g., per ASME Section V)..." (a) The NRC staff believes that for the pre-peening examination, the ET or due to access limitations PT must be used. The eddy current technique must be qualified to detect flaws both on the surface and near surface volume that will be affected by peening to provide reasonable assurance of detecting flaws. The NRC staff does not consider the low rigor qualifications of Article 14 of ASME Code, Section V practices rigorous enough for this application. However, under some circumstances the NRC staff would entertain qualification demonstrations that meet the requirements outlined in Section V, Article 14, Intermediate Rigor. Please clarify what is meant by "demonstrated by the inspection vendor per current practices" and justify why the ET technique need not be qualified using formal performance demonstration techniques.	Section 4.2.1 includes the requirement for a surface examination (ET or PT) as part of the pre-peening inspection for Alloy 82/182 piping butt welds and not the reactor vessel head penetrations. As stated in Section 4.2.1, the surface (ET or PT) examinations that are required in MRP-335R1 for use prior to peening are not relied upon in the safety analyses described in Section 5 and Appendix A. Surface examination is not credited at all in the main probabilistic cases. Instead the required surface examination is a secondary method intended to provide additional assurance of flaw detection and removal. As a secondary method not relied upon in the safety analyses, it is not necessary that the pre-mitigation ET or PT examination meet the requirements of a Performance Demonstration qualification similar to Appendix VIII of Section XI for ultrasonic examinations. ASME Code Case N-770-4, which was approved by ASME on May 7, 2014, states that the ET for inspection credit of peening mitigation of Alloy 82/182 piping butt welds shall be in accordance with IWA-2223, which states that ET for detection of surface flaws shall be conducted in accordance with Mandatory Appendix IV of Section XI. Case N-770-4 specifically specifies ET in accordance with Appendix IV as the appropriate surface examination to detect the presence of planar surface flaws prior to peening. The performance demonstration for ET in accordance with Appendix IV and its applicable Supplement 2 requirements is sufficient for ET pre-peening examinations when combined with the required follow-up examinations and other requirements for peening in N-770-4. MRP concurs with ASME that Appendix IV is an appropriate set of requirements for demonstration of ET to be applied to Alloy 82/182 piping butt welds mitigated by peening and will revise MRP-335R1 to include this requirement in lieu of "demonstrated by the inspection vendor per current practices." It is noted that this question refers to Section 4.2.1 of MRP-335R1, which is specific to Alloy 82/182 piping butt welds. However, the question inserts "[for RPV head penetration nozzles]" in a quotation of Section 4.2.1. This insertion is understood by MRP to be an error.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
34	4-7B	Section 4	Page 4-5 Section 4.2.1 states that "...[prior to peening] an eddy current (ET) or liquid penetrant (PT) inspection shall also be performed of the weld ID [for RPV head penetration nozzles]. The ET or PT technique need not be qualified using formal performance demonstration techniques, but shall have been demonstrated by the inspection vendor per current practices (e.g., per ASME Section V)..." (b) MRP-335 states that the peening will be effective for 1 millimeter (mm) in depth into the component. The NRC staff finds that the pre- and post-peening ET should be capable of detecting a flaw within the 1 mm distance and beyond the 1 mm distance with certain margins so as to include the detection error and measurement uncertainty. ET should be qualified to that wall thickness (distance) with the margin. (1) Discuss the maximum wall thickness (distance) that ET can detect a flaw in a unmitigated component and in a peened component. (2) Discuss the wall thickness ET is qualified to detect in an unmitigated component and in a peened component with the margin. (3) Discuss whether ET's capability would change when examining a unmitigated component vs. a peened component. (4) Discuss the margin in terms of wall thickness. (5) How will surface condition affect ET performance? (6) Should there be a minimum surface roughness condition to ensure effective ET and peening coverage?	The NRC is requesting ET capability and qualification that does not exist in the industry and is not needed for peening of Alloy 82/182 piping butt welds performed in accordance with MRP-335R1 or ASME Section XI Code Case N-770-4. The pre-peening examinations, including ET surface examinations, are designed to identify pre-existing flaws that could grow subsequent to peening, but it is not a requirement that the pre-peening examination be 100% effective. The follow-up examination included in MRP-335R1 and required by CC N-770-4 is an effective way of finding flaws with depths, at time of peening, greater than 1 mm but less than 10% through wall, because the interval between peening application and the follow-up examination allows the flaw to grow to a depth that can be more reliably detected. The probabilistic analyses, which do not credit any surface examinations, show this follow-up examination is effective. Although the pre-peening ET helps to identify shallow flaws that could grow subsequent to peening, the follow-up examination is the primary means of finding flaws that were too deep to be mitigated and too shallow to be detected at the time of peening. The results of analyses in MRP-335R1 show that the strategy of a pre-peening examination and a follow-up examination is effective in assuring that no pre-existing flaws will grow to significant depth without detection. This eliminates the need for the NRC-requested ET capability and qualification requirements. In addition, for the case of Alloy 82/182 piping butt welds, the ET examination was included in the topical report and Code Case N-770-4 because it is already included in the standard examination process. As shown in the topical report, ET examinations are not necessary for peening to be effective. They were included as a secondary measure to provide additional assurance.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
35	4-9	Section 4	Table 4-1, under the Follow-Up Exams column, specifies that volumetric and visual examinations be performed for the peened Alloy 600 reactor vessel heads and Alloy 82/182 butt welds. The NRC staff notes that visual examination is not adequate to detect flaws embedded in the wall thickness which may be affected by peening. The NRC staff believes that volumetric, ET or PT should be performed as part of the follow-up examination. The NRC staff understands that PT may not be applicable to examining piping because in the follow-up examination, inside of piping would be filled with coolant. However, PT should be applicable to the reactor vessel head nozzle penetrations and J-groove welds. Discuss why ET or PT will not be performed in the follow-up inspections.	The purpose of the follow-up examination is to address the possibility of flaws not detected in the pre-peening examinations subsequently growing in size. Similar to the case of ISI examinations of unmitigated components, a volumetric examination is appropriate for this purpose. Shallow flaws on the examined surface would become detectable via UT if they were to grow in depth. The main probabilistic calculations of Appendices A and B of MRP-335R1, which do not credit any ET or PT examinations, show explicitly that the UT examinations are sufficient. In fact for the case of RPVHPNs, the probabilistic results show that the risk of nozzle ejection is maintained below the absolute acceptance criterion of 5×10^{-5} per year with no UT, ET, or PT examinations subsequent to a one-time follow-up UT examination. With regard to RPVHPNs, the separate "Supplemental Technical Basis" document discusses the basis for the inspection approach of MRP-335R1. PT examinations of the outer surfaces of RPVHPNs are dose-intensive because of their manual nature, typically resulting in multiple REM of exposure per nozzle examined. In addition, it is noted that peening performed per these requirements does not affect flaws located in the wall thickness of the peened component, i.e., embedded flaws. As documented in MRP-267R1, peening does not introduce flaws into the wall, nor does it cause growth of pre-existing flaws. Peening of thick-wall components also does not cause significant acceleration of growth of pre-existing flaws during subsequent operation.
36	4-10A	Section 4	(a) For the ISI examinations, discuss why ET is not needed for the Alloy 82/182 butt welds in piping.	MRP acknowledges the Case N-770-4 requirement for a surface examination as part of the ISI examinations for Alloy 82/182 piping butt welds, but this requirement is not necessary for the acceptability of peening mitigation. As is the case for unmitigated Alloy 82/182 piping butt welds, UT examinations are sufficient for the ISI requirement. Shallow flaws on the ID surface would become detectable via UT if they were to grow toward the OD surface. The main probabilistic calculations of Appendix A of MRP-335R1, which do not credit any ET examinations, show explicitly that the UT examinations are sufficient.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
37	4-10B	Section 4	(b) Table 4-1 provides examination requirements for the Alloy 82/182 hot and cold legs and reactor vessel head only. Discuss whether peening will be applied to bottom mounted instrumentation nozzles of the reactor vessel, piping other than the hot and cold legs (e.g., surge lines), and relief and safety valve nozzles and heater sleeve nozzles at pressurizer. If yes, discuss why Table 4-1 does not provide examination requirements for these components.	Bottom mounted nozzles (BMNs) are outside the scope of MRP-335R1. The current ISI inspection requirement for BMNs, per 10CFR50.55a and ASME Code Case N-722-1, is for visual examinations from the exterior of the vessel for evidence of leakage. Peening of BMNs may be performed for asset management purposes through the 10CFR50.59 process. Peening mitigation of Alloy 82/182 piping butt weld locations nominally operating at pressurizer temperature (pressurizer surge nozzle, safety and relief nozzles, and pressurizer spray nozzle) is not anticipated, and thus not within the scope of Table 4-1. The large majority of these locations have already been mitigated using weld overlays, and access to the ID surface of these locations is limited such that inspection and mitigation of these locations is performed from the OD. The topic of inspection credit for peening mitigation of pressurizer heater sleeve nozzles (Alloy 600 or stainless steel) is outside the scope of MRP-335R1.
38	4-11A	Section 4	The NRC staff notes that Section 4 and Table 4-1 do not provide guidance for the event when the follow-up and ISI examinations detect a new flaw or growth of an existing flaw in the peened component (assuming an existing flaw was permitted to remain in the component before peening). (a) Discuss how new flaws or growth of an existing flaw in the peened component would be dispositioned (e.g., what are the acceptance criteria).	Acceptance of flaws in peened components will be per ASME Code Section XI and applicable Code Case rules (e.g., Code Case N-770-4) as conditioned in 10 CFR 50.55a and applicable Regulatory Guides. ASME Code Case N-770-4, which covers peening mitigation of Alloy 82/182 piping butt welds, was approved by ASME on May 7, 2014.
39	4-11B	Section 4	The NRC staff notes that Section 4 and Table 4-1 do not provide guidance for the event when the follow-up and ISI examinations detect a new flaw or growth of an existing flaw in the peened component (assuming an existing flaw was permitted to remain in the component before peening). (b) Discuss under what criteria the peened component would be re-classified as the unmitigated component in accordance with ASME Code Case N-770-1 and Table 4-1.	The best forum for setting such criteria is the current effort within ASME Section XI to develop requirements for inspection credit of peening mitigation. ASME Code Case N-770-4, which covers peening mitigation of Alloy 82/182 piping butt welds, was approved by ASME on May 7, 2014. This code case includes appropriate detailed requirements in this area. A revised version of MRP-335R1 will reference the detailed requirements of N-770-4 in this area. If a version of N-729 incorporating peening mitigation of Alloy 600 RPVHPNs has been published by ASME at the time MRP-335R1 is revised, the revised version of MRP-335R1 will reference the detailed requirements of that code case in this area. Otherwise, the detailed requirements for RPVHPNs will be included in the revised topical report itself.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
40	4-11C	Section 4	The NRC staff notes that Section 4 and Table 4-1 do not provide guidance for the event when the follow-up and ISI examinations detect a new flaw or growth of an existing flaw in the peened component (assuming an existing flaw was permitted to remain in the component before peening). (c) Discuss whether peening can be re-applied to the peened component in which new flaws or growth of existing flaws has occurred.	There are no limitations in the peening processes that preclude re-application of peening to a previously peened component in which a new flaw has occurred. Post-repair peening of the entire surface may be repeated to address any repair-induced tensile residual stresses. If a new surface-connected flaw is found by the follow-up exam or ISI exam, ASME Code Case N-770-4 paragraphs -3132.2(d), -3132.3(e), and -3132.2(e), along with Table 1 Notes 20(b) and 21(e), specify the flaw resolution actions in the case of piping. Per the requirements of Code Case N-770-4, peening cannot be credited as a mitigation technique on a weld with a previously detected flaw that has not been removed. This conservative position was taken by ASME Section XI to preclude the need to have qualified depth sizing eddy current examination techniques to assure the flaw depth was less than the depth of the peening compressive zone. The "growth of existing flaws" portion of this question is not expected to be likely in practice since there would not be "an existing [previously detected] flaw" left in service from the previous peening. However, there is no limitation in the peening processes to preclude re-application of peening in such a case, but the re-peening would not be credited as a mitigation technique for the purpose of future inspection requirements unless the flaw was removed prior to the re-peening. If the indication can be excavated and still meet the ASME Code requirements, then the resultant area may be re-peened to mitigate any stresses induced by the excavation operation (such as grinding). Or if necessary, the flaw excavation to remove the flaw may be followed by a welded repair/replacement activity to build up the excavation area in accordance with IWA-4000. In both examples, Code Case N-770-4 would allow the component to be placed back into Item L (Uncracked butt weld mitigated by peening). However, if a mitigation method addressed in N-770-4 such as weld inlay, weld onlay, or weld overlay were applied to correct the flaw, the inspection requirements of N-770-4 for that mitigation would apply rather than the requirements of Item L for peened components. Peening could certainly be performed after such mitigations but would not be credited as the mitigation to be used in Case N-770-4 for setting subsequent inspection requirements.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
41	4-12A	Section 4	(a) NRC imposed additional conditions on Code Cases N-729-1 and N-770-1 in 10 CFR 50.55a. Table 4-1 should include a footnote to reference 10 CFR 50.55a for completeness.	It is agreed that such a footnote should be included. Note that the Section 4 text already discusses that 10 CFR 50.55a mandates N-729-1 and N-770-1, subject to NRC conditions.
42	4-12B	Section 4	(b) Clarify why Table 4-1 specifies Code Cases N-729 and N-770 instead of N-729-1 and N-770-1 as required in 10 CFR 50.55a.	The inspection requirements in the table are largely unchanged for the various revisions of these code cases. Nevertheless, it is agreed that it would be best to cite N-729-1 and N-770-1, since they are the currently mandated versions (as already discussed in the Section 4 text).
43	4-12C	Section 4	(c) 10 CFR 50.55a also imposed conditions on Code Case N-722-1 which is related to visual inspections of Alloy 600/82/182 components. Discuss why Code Case N-722-1 is not discussed in Section 4 and Table 4-1.	It is understood that the requirements of N-770-1 (as conditioned by 10 CFR 50.55a) bound the requirements of N-722-1 (as conditioned by 10 CFR 50.55a) for the case of Alloy 82/182 piping butt welds. It is also noted that N-722-1 excludes the RV top head nozzles. Nevertheless, a discussion of N-722-1 can be added to Section 4 and Table 4-1.
44	4-12D	Section 4	(d) ASME will likely to publish revisions to Code Cases N-722, N-729 or N-770 in the future. The NRC may approve the revisions. Include in Section 4 or Table 4-1 how the NRC-approved code case revisions will be used.	If future versions of these code cases crediting peening mitigation are approved by NRC in 10 CFR 50.55a, then licensees would normally be expected to apply those code cases including any NRC conditions. If the NRC approved these Cases in Reg. Guide 1.147, licensees would choose whether to adopt use of the Cases in accordance with the provisions for use of Cases, as specified in 10 CFR 50.55a and in the Reg. Guide. In some cases, licensees might request alternatives to the code cases as conditioned by NRC, perhaps with the latest version of MRP-335 as part of the technical basis for the request.
45	4-13	Section 4	Discuss whether after peening the surface of a component would become rough enough to adversely affect the post-peening UT and ET (e.g., the probe would not have good contact with the component surface). If yes, discuss how the roughness would be eliminated, what would be the final roughness of the surface, and whether the final surface finish would satisfy the surface conditioning requirement of the ASME Code, Section XI, Appendix D.	The effects of the types of peening covered by MRP-335R1 on surface roughness are discussed in Section A.1.7 of MRP-267R1. That section provides test results from the peening vendors. It shows that the peening has minor effects on surface roughness and that the surface roughness of peened parts is similar to that of inservice components. Moreover, UT and ET evaluations performed on plate coupons that had a surface roughness of 250 microinches RMS or better before peening showed no adverse effects on the data quality after peening was applied (EPRI report 3002000656). All of the peening vendors consider that the surface roughnesses produced by their peening processes will not adversely affect post-peening UT and ET. Hence, the small increase in surface roughness due to peening will have no impact on the inspection capabilities for UT or ET, and peening does not adversely affect the ability to perform UT or ET. Steps to improve the surface condition after peening are not necessary.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
46	4-14	Section 4	To assist in reviewing MRP-335, the NRC staff requests the following references: The NRC staff requests References (a), (b) and (c) because they are the eddy current testing (ET) specification sheets that would provide information to support the capability of ET. Reference (d) provides specific ET and UT technology for the examination of the bottom mounted nozzles in BWRs which will assist the NRC staff to understand the component-specific UT and ET technology. The NRC staff requests Reference (e) because the article provides information on the examination of Alloy 600 components. The NRC staff requests Reference (f) because the report will help the NRC staff to understand the guidance and qualification of Alloy 82/182 weld examination. This information will help the NRC staff to review the pre-peening examination of the Alloy 82/182 welds. (a) EPRI Eddy Current Examination Technique Specification Sheet, ETSS #20510.1, Rev. 7, October 2006 (available from EPRI NDE Center, Charlotte, NC). (b) EPRI Eddy Current Examination Technique Specification Sheet, ETSS #20501.2, Rev. 4, August 2006 (available from EPRI NDE Center, Charlotte, NC). (c) EPRI Eddy Current Examination Technique Specification Sheet, ETSS #21503.1, Rev. 4, July 2006 (available from EPRI NDE Center, Charlotte, NC). (d) Outline of Hitachi-GE GE Nuclear Energy (HGNE)'s ECT and UT technologies for nickel based weld lines of BWR bottom head, Hitachi-GE document E-TY-50521r1, Feb. 1, 2012. (e) M. Taniguchi and N. Hori, "Maintenance Technology Development for Alloy 600 PWSCC Issue," Proceedings of ICONE12 12th International Conference on Nuclear Engineering, April 25–29, 2004, Arlington, Virginia, USA. (f) *Dissimilar Metal Piping Weld Examination -- Guidance and Technical Basis for Qualification*, EPRI, Palo Alto, CA: 2003. 1008007.	The ETSS sheets ((a), (b), and (c)) are available for viewing at the EPRI NDE Center in Charlotte. (d) This document is a proprietary Hitachi-GE presentation made available to MRP to support MRP-335R1. However, the following publicly available conference paper has largely the same information: N. Kono, A. Nishimizu, Y. Nonaka, I. Yoshida, H. Ouchi, T. Yamada, K. Otani, and K. Hasegawa, "Development of Ultrasonic and Eddy Current Testing Systems for Ni-Based Alloy Welds at the BWR Reactor Bottom Head," *Proceedings of the 9th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components*, May 22-24, 2012, Seattle, Washington, USA. This paper is available to NRC. (e) This is a conference paper available in the open literature. (f) EPRI 1008007, which is a proprietary EPRI report published in 2003, is not part of the technical basis for the MRP-335R1 topical report and is not referenced in MRP-335R1 or MRP-267R1. If NRC has specific technical issues regarding NDE of Alloy 82/182 piping butt welds that are relevant to the NRC safety evaluation and requirements for peening mitigation, please provide those specific requests. MRP can better determine which content may be needed to address the issue based on a specific question/request for additional information.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
47	4-15	Section 4	Discuss the minimum pipe size and wall thickness that peening is permitted to be applied. Discuss and cite the calculations that support these limits in pipe size and wall thickness.	The question of pipe size is not pertinent to the scope of configurations included in MRP-335R1. The wall thickness applicable to the nozzles and welds in MRP-335R1 have been justified by the testing documented in MRP-267R1. The peening methods covered in MRP-335R1 may be permitted to be applied to thick-wall components, including RPVHPNs, as supported by the peening of mockups documented in MRP-267R1. The fact that the peening induces a compressive residual stress of large magnitude within a typical distance of 1.5 millimeters from the peened surface demonstrates that the wall thicknesses of the mockups are sufficient to support effective peening. For the case of piping butt welds, the geometry of large-diameter PWR main loop piping welds was represented by welded flat plates in the mockup testing, and there has been more than a decade of practical plant experience with implementation of peening mitigation for reactor vessel outlet and inlet nozzles and reactor vessel safety injection nozzles in Japanese PWRs. Thus the mockup test results presented in MRP-267R1 directly apply to large-diameter PWR main loop piping welds, including reactor vessel outlet and inlet nozzles.
48	5-1	Appendix A	Page A-58, Section A.4, Flaw Detection Model, states that "Hitachi-GE reported the ability to detect flaws with depths greater than 0.5 mm and lengths greater than 3.3 mm of BMNs [bottom mounted nozzles]" The NRC staff needs to understand the technical basis for flaw detection used for certain size flaws. (a) Confirm that flaw depth greater than 0.5 mm and lengths greater than 3.3 mm of BMN can be detected by either surface or volumetric examination. (b) Provide the document "Outline of Hitachi-GE GE Nuclear Energy (HGNE)'s ECT and UT technologies for nickel based weld lines of BWR bottom head, Hitachi-GE document E-TY-50521rl, Feb. 1, 2012".	(a) The NRC comment is referring to a specific example in Section A.8.4 of MRP-335R1, which discusses the flaw detection model development used in the MRP-335 probabilistic assessment. The description and basis in Section A.6 ("Examination models") and in Section A.8 ("Probabilistic model inputs") provide comprehensive information on the technical basis used in the probabilistic assessment related to examinations and flaw detection. (b) This document is a proprietary Hitachi-GE presentation made available to MRP to support MRP-335R1. However, the same information on ET detectability is available in a publicly available conference paper: N. Kono, A. Nishimizu, Y. Nonaka, I. Yoshida, H. Ouchi, T. Yamada, K. Otani, and K. Hasegawa, "Development of Ultrasonic and Eddy Current Testing Systems for Ni-Based Alloy Welds at the BWR Reactor Bottom Head," *Proceedings of the 9th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components*, May 22-24, 2012, Seattle, Washington, USA. This paper will be made available to NRC.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
49	5-2	Section 5	Page 5.3, Section: 5.2.2, Inspection and Detection, states that "...the median UT inspection POD curve used for cracking on DMW component ID is from MRP-262R1. In Section 5.2.2, Inspection and Detection, the second paragraph states that "...because the MRP-262 curve was developed using only circumferential cracks, and a review of the examination data suggests a generally lower POD for axial cracks, the POD predicted by the MRP-262 curve is reduced by 20% for axial cracks...." Page 43 of Reference 19 of MRP-335 "Materials Reliability Program: Development of Probability of Detection Curve for Ultrasonic Examination of Dissimilar Metal Welds (MRP-262, Revision 1) Typical PWR Leak-Before-Break Line Locations, EPRI, Palo Alto, CA: 2009.1020451" discusses the circumferential crack assessment, but there is no discussion on the axial crack limitation. While the NRC staff agrees that the POD will be lower for axial flaws due to the greater sound path through weld material and thus more difficult nature of the examination, this approach to determining POD for axial flaws seems to be very arbitrary. (a) Explain the technical basis and justify the applicability of creating POD cures for axial flaws by simply reducing the POD curves for circumferential flaws by 20%. (b) Discuss the accessibility inside the bottom mounted nozzle for peening.	(a) The approach to modeling the detectability of axial flaws by simply reducing the POD curves for circumferential flaws by 20% is not arbitrary. It is a clearly conservative approach given the specific detection test acceptance criteria included in Supplement 10 of Appendix VIII of ASME Section XI for UT performance demonstration. Supplement 10 specifies a minimum detection rate between 0.68 and 0.82, depending on the number of flawed grading units. (b) Bottom mounted nozzles (BMNs) are outside the scope of MRP-335R1.
50	5-3	Section 5	Page 5-28, Section 5.2.3.3, Validation Study for the Weight Function Method Stress Intensity Factor Calculation, states that "...Further details to demonstrate sound implementation of the stress intensity factor calculation methodology is withheld here. More rigorous stress intensity factor calculation validation has been performed and is documented internally...." The stress intensity factor calculation provides the technical basis of the peening application. It is not clear to the NRC staff why the stress intensity factor calculation is withheld from the subject report. Submit details on the rigorous stress intensity factor calculation methodology and validation.	It was simply decided not to publish the full stress intensity factor verification study in the report itself. Instead key verification results were included. The full verification study is available to be submitted to NRC.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
51	5-4	App A	Page A-58, Section A 8.4, Flaw Detection Model, states that "...experience indicates that there exists a minimum crack length below which cracks are very difficult to detect by ET. A deterministic input of 2 mm was selected for this length...." The NRC staff needs to understand the technical justification for the minimum crack length of 2 mm. Also, the NRC is concerned with limitations for detection of a minimum crack length for non-smooth surfaces (i.e. as welded). Provide the technical basis for eddy current testing capability of detecting a crack length of 2 mm (0.08-inches).	Rather than assuming that the POD is purely a function of crack depth, a length cutoff was added as a deterministic input. It was assumed that any crack with a length less than this cutoff is not detectable by ET regardless of the crack depth. The length cutoff was assumed to be 2 mm on the basis of what might generally be expected for ET methods. It is emphasized, as noted in other responses, that the effectiveness of peening mitigation is not dependent on ET examinations being included.
52	5-5	Section 5	Page 5-31, Section 5.3.2, Reactor Pressure Vessel Head Penetration Nozzles (RPVHPNs), states that "...the program predicted that the cumulative probability of leakage after peening would be reduced by a factor between 9 and 12...." Justify that the cumulative probability of leakage after peening can be reduced by a factor between 9 and 12.	The statement in question refers to the computational "program" developed to make probabilistic predictions for leakage of Alloy 82/182 piping butt weld components. The predictions of this program inform the conclusions of MRP-335R1, as is described throughout Section 5.3. It is believed that the use of the word "program" in the statement in question may be confused with "peening program" or "inspection program" used elsewhere in the main body of the report. Therefore, the statement will be revised to read "...it was predicted that the cumulative probability of leakage after peening would be reduced by a factor between 9 and 12." This revision applies also to the paragraph above in MRP-335R1.
53	5-6	App A	Page A-58, Section A.4, Flaw Detection Model, states that "For BMN J-weld surfaces, cracks 0.9 mm or deeper were detected (Ref 29)." Reference 29, M. Taniguchi and N. Hori, "Maintenance Technology Development for Alloy 600 PWSCC Issue," Proceedings of ICONE12 1 2nd International Conference on Nuclear Engineering, April 25-29, 2004, Arlington, Virginia, USA, does not appear to provide a discussion on cracks of 0.9 mm in length being detectable. Justify the conclusion that cracks of 0.9 mm in length can be detected.	Reference 29 includes a figure with signal-to-noise ratio detection data for the BMN inner surface as a function of SCC depth. Similar data for RV inlet/outlet butt welds and BMN J-groove weld surfaces were made available to MRP in the form of a proprietary response document. For BMN J-groove weld surfaces, four test pieces were examined by ET, machined, and then destructively examined to determine the actual SCC depth. MNES reported that for the four samples, eight cracks were identified with depths of 0.9 - 3.5 mm. This information shows that cracks of 0.9 mm in depth may be detectable although ET of J-groove welds is not yet sufficiently developed and qualified to enable field application. For RV inlet/outlet nozzle butt weld locations, over 10 test pieces were similarly examined. These tests indicated that all cracks with depths of at least 0.5 mm were detectable.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
54	5-7	App B	Page B-69, Section B.9, Results of probabilistic cases states: "...the magnitudes of the predicted risks for any given case may include a substantial bias error...." Provide details of substantial bias error in calculating the magnitudes of the predicted risks with respect to peening.	The peening probabilistic models take the standard approach of being best-estimate models with uncertainties treated using statistical distributions. However, due to the complexities of some aspects of the degradation process, some modeling simplifications are required. These simplifications are implemented in a conservative manner such that some conservative biases are introduced. For example, conservatively low POD curves are assumed in cases of limited data, and a zero stress intensity factor threshold is assumed for growth. For peening of top head nozzles, a leak is conservatively assumed to immediately result in a 30° circumferential flaw, and no credit is taken for the UT leak path examination. The point made in Section B.9 is that any such biases tend be canceled out when considering the relative differences in the results of different probabilistic cases.
55	5-8	App B	Page B-16 of MRP-335 states that "...a peening compressive residual stress to a depth of at least 3 mm is assumed for the wetted nozzle OD and weld surfaces of the RPVHPN....". Page B-66 states that "...the peening of the penetration nozzle OD and weld location is expected to be performed with ALP [air laser peening]...." It is also stated on Page B-66 that water jet peening (WJP) or underwater laser peening (ULP) was assumed to be applied to the nozzle inside diameter. (a) Clarify why the simulation was conducted with mixed peening processes. (b) Page 2-3 of MRP-335 states that the ALP process in nuclear power plants is not as developed as for WJP and ULP, and there has not been any experience with using this method in PWR or BWR reactor applications. Clarify why the simulation results of Appendix B to MRP-335 rely on this method.	(a) At the time MRP-335R1 was completed, the particular air laser peening (ALP) process described in MRP-267R1 was considered not to be applicable to the ID surface of the RPVHPN tube. Subsequent to publication of MRP-335R1, an approach has been developed to apply ALP to the nozzle ID surface. Currently, there are multiple peening techniques available to peen both the nozzle OD/weld and ID surfaces of the reactor vessel top head nozzles. (b) In 2012, the ALP process was the only process being seriously considered for peening of the outer surfaces of RPVHPNs. The ALP process has been extensively applied to critical aerospace applications and can readily be applied to effectively peen the outer surfaces of RPVHPNs. Today there are multiple peening vendors and processes being actively considered for peening of the outer and inner surfaces of RPVHPNs. Sensitivity Case 19 of Appendix B shows that the effectiveness of peening of RPVHPNs is not dependent on the use of the ALP process. The MRP-335R1 Supplemental Technical Basis document submitted with this RAI response applies the analyses of the existing MRP-335R1 topical report to address the specific peening methods that are now available to be applied to the outer and inner surfaces of RPVHPNs. The probabilistic cases presented in this supplemental document are particular to the capabilities of these peening methods.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
56	5-9	Section 5	MRP-262 contains POD curves only for pressurizer surge, reactor pressure vessel nozzle, and steam generator nozzle dissimilar metal welds. No POD curves for the head penetrations were included in the MRP-262 report. As such, where does the POD curve for RPVHPN and outside diameter locations shown in Figure 3 come from? The NRC staff notes that the caption is titled "assumed". What does this mean? What data was used and how was that data used to generate the curve in Figure 5-3?	The curve was conservatively defined recognizing that 10CFR50.55a(g)(6)(ii)(D)(*4*)(*iv*) specifies detection test acceptance criteria corresponding to a minimum detection rate between 0.68 and 0.82. Regardless of how large the simulated crack becomes, the POD that is assumed is no greater than 0.95. A sensitivity case is included in Appendix B that assumes a maximum POD of 0.90 regardless of crack size. Further description on how Figure 5-3 was generated is included in Section B.8.4.2 of MRP-335R1.
57	5-10	Section 5	Figure 5-2 on page 5-5 presents linear POD curves for dissimilar metal welds examined from the inside diameter. Please address why the POD curves are linear and are extrapolated to the baseline (even though the Performance Demonstration Initiative (PDI) samples contain no flaws that are less than 10 percent of full wall thickness).	The linear dependence of POD on flaw depth for depths less than 10% of the wall thickness evaluated in the probabilistic calculations of MRP-335R1 is the same as the approach taken by the xLPR Program, as described in EPRI 1022528 (*Models and Inputs Selected for Use in the xLPR Pilot Study*, EPRI, Palo Alto, CA: 2010. 1022528. [freely downloadable at www.epri.com]). The xLPR POD model includes parameterization to allow the user to specify the POD at zero depth and a small flaw threshold at which to begin the linear approximation, but recommends the use of 0 and 10% for these parameters, respectively. In addition, it is emphasized that Sensitivity Case 17 was applied in Appendix A to investigate the effect of a zero POD for flaws with depths less than 10% through-wall. This had a relatively small effect on the leakage probability results for the peened reactor vessel outlet nozzle case of an increase of 22% (see Figure A-22 of MRP-335R1).

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
58	5-11	Section 5	Page 5-4 states that "...The median ET [eddy current testing] inspection POD curve used for cracking on DMW [dissimilar metal weld] and RPVHPN ID locations is shown in Figure 5-4. In the absence of a rigorous experimental investigation, this curve was derived based on a review of ET POD for various probe types and locations, as detailed in Appendix A.8.4.3...." Please provide all the references listed on page A-58 related to the ET POD curves. Please explain in detail how these curves were generated, especially in light of the lack of "rigorous experimental" data.	The RAI first requests that all the references listed on page A-58 of MRP-335R1 be provided. These references are as follows: • M. Taniguchi and N. Hori, "Maintenance Technology Development for 600 PWSCC Issue," *Proceedings of ICONE12 12th International Conference on Nuclear Engineering*, April 25–29, 2004, Arlington, Virginia, USA. • Outline of Hitachi-GE GE Nuclear Energy (HGNE)'s ECT and UT technologies for nickel based weld lines of BWR bottom head, Hitachi-GE document E-TY-50521r1, Feb. 1, 2012. [The relevant information is now available in a publicly available conference paper: N. Kono, A. Nishimizu, Y. Nonaka, I. Yoshida, H. Ouchi, T. Yamada, K. Otani, and K. Hasegawa, "Development of Ultrasonic and Eddy Current Testing Systems for Ni-Based Alloy Welds at the BWR Reactor Bottom Head," *Proceedings of the 9th International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components*, May 22-24, 2012, Seattle, Washington, USA.] • Eddy Current Examination Technique Specification Sheets (ETSSs) (as listed in MRP-335R1), EPRI NDE Center, Charlotte, NC. The second part of the RAI asks for a detailed explanation of how the POD curves were generated. A detailed explanation is already given on Page A-58 in Section A.8.4.3. However, additional details are given below that may augment the explanation already given. Based on the inspection sensitivity data from the peening vendors and the ETSS data in the cited references, the mean, upper bound, and lower bound POD curves were generated as follows: • Upper and lower POD curves were developed representing a two standard deviation offset from the mean POD curve. These POD curves were fit using a log-logistic form, which is a standard distribution for modeling POD of ET examinations [Reference Section I3.1.1 of EPRI 1013706 NDE GL Rev 7 (freely downloadable from EPRI website)] • The upper bound (favorable) curve was chosen such that there is a 50% POD for cracks 0.5 mm deep and a 75% POD for cracks 0.7 mm deep. • The lower bound (unfavorable) curve was chosen such that there is a 50% POD for cracks 1.0 mm deep and a 75% POD for cracks 1.2 mm deep. • A maximum POD of 95% was applied to both curves described above to account for human/equipment error or other factors. • For any given flaw depth, the lower and upper curves described above are consulted to derive a mean ((upper + lower) / 2) and standard deviation ((upper – lower) / 4). These values are then used to generate a POD sample. For RPVHPNs, the random number used to generate this sample is varied from penetration to penetration, not from flaw to flaw, such that two flaws of equivalent depths on the same penetration would possess the same average detectability, but two flaws of equivalent depths on different penetrations might possess different average detectability. The process to develop the POD curve involved some judgment in how to apply the available data. It is emphasized that the conclusions of the MRP-335R1 probabilistic calculations are completely insensitive to the ET POD curve that was developed as the main cases assume no ET is performed at all (POD = 0). ET is not needed to demonstrate the effectiveness of the peening mitigation.

#	NRC RAI	MRP-335R1 Report Section #	Question	EPRI MRP Response
59	5-12	Section 5	Three conclusion statements are made on page 5-4. Please explain how the three conclusions are arrived at in light of the fact that the POD curves are assumed. The NRC staff is concerned about the use of assumed POD curves to reduce the range of depths of cracks that are considered unlikely to be undetected. Please clarify that the dimensions provided in these three conclusion statements are for depths and not lengths.	The POD curves are not arbitrarily selected; they are based on the best available information, and were conservatively assumed in cases of limited information. Comparing these POD curves against expected peening depths assesses the possibility, on a conservative basis, that deep flaws are missed in the pre-peening examination and subsequently grow during operation, which is the scenario that determines the post-peening risk. The detailed calculations allow the possibility, on a conservative basis, that deep flaws are missed in the pre-peening examination and subsequently grow during operation. It is confirmed that the dimensions are for depths, not lengths.

ATTACHMENT 2
SUPPLEMENTAL TECHNICAL BASIS FOR PEENING OF ALLOY 600 RPVHPNs

Background

In 2012, MRP developed the MRP-335R1 [1] topical report to support peening mitigation of Alloy 600/82/182 PWR pressure boundary components. This topical report was formally submitted for NRC review in February 2013. The peening technical basis document, MRP-267R1 [2], supporting the topical report was also submitted to NRC at that time. MRP-335R1 addressed inspection requirements for peening mitigation of Alloy 82/182 piping butt welds in primary system piping and Alloy 600 reactor pressure vessel head penetration nozzles (RPVHPNs). The topical report did not address peening mitigation of reactor vessel bottom mounted nozzles (BMNs) on the basis that volumetric examinations of BMNs is not required.

At the time that MRP-335 was produced, a single peening process offered by one vendor was under active consideration to mitigate RPVHPNs. The detailed MRP-335R1 inspection requirements for mitigation of RPVHPNs were determined in consideration of the capabilities of that single process. Now, in 2014, there are three vendors that are offering in-service peening mitigation services for RPVHPNs, including both water jet- and laser-based peening technologies. In accordance with long-standing practice within the ASME Code, it is important that the ASME Section XI requirements not be unnecessarily biased toward one particular process or technology. Thus, MRP has developed modest changes to the inspection requirements of MRP-335R1 in light of the capability of each of the candidate peening processes to obtain a specific compressive residual stress depth at the treated surface.

Purpose

The purpose of this document is to discuss the applicability of the existing MRP-335R1 [1] technical basis to the range of peening processes and vendors that are now available for mitigation of Alloy 600 RPVHPNs. In addition, a series of supplemental probabilistic cases are presented to demonstrate the effectiveness of the compressive residual stress depths understood to be obtained by the candidate peening processes. Finally, a set of inspection requirements more stringent than those defined in MRP-335R1 is proposed and assessed.

Discussion

Existing MRP-335R1 Technical Basis

The MRP-335R1 technical basis included a requirement for a 3-mm peening compressive residual stress depth on the nozzle outer surfaces, and a 0.5-mm peening compressive residual stress requirement for the nozzle ID surfaces. These requirements were based on the depths obtainable using the peening processes under consideration at that time. The 3-mm depth on the nozzle OD was intended to ensure that flaws located on the nozzle OD below the weld that were deeper than the compressive stress layer would be detected during the pre-peening UT examination performed from the nozzle ID. Nevertheless, the probabilistic calculations presented in Appendix B of MRP-335R1 demonstrated at that time through a sensitivity case (Model Sensitivity Case 19 for the bounding case of a "hot head") the acceptability of a nominal compressive residual stress depth of 1.0 mm on the nozzle outer surfaces.

As described in detail in Appendix B of MRP-335R1, the probabilistic model evaluates the possibility of pre-existing PWSCC flaws not being detected during the pre-peening volumetric examination. Conservatively small probabilities of flaw detection are assumed, and up to six flaws are modeled to initiate on each penetration (on the nozzle ID, nozzle OD below weld, and on the weld wetted surface, for both the uphill and downhill positions). The probabilistic model was used to assess the effects on nuclear safety through the nozzle ejection frequency, as well as the effects on the nozzle leakage frequency.

It is emphasized that the main probabilistic cases of MRP-335R1 did not credit any pre-peening surface examinations on any of the RPVHPN surfaces. The topical report defines requirements for follow-up volumetric examinations and visual examinations for evidence of leakage to be performed subsequent to peening and before entering a long-term schedule of periodic volumetric examinations. Through explicit modeling of the assumed follow-up examinations, the probabilistic calculations of MRP-335R1 demonstrated that the follow-up examinations effectively address the possibility that pre-existing flaws not detected prior to peening are present and grow subsequent to peening. Hence, pre-peening surface examinations are not necessary when appropriate follow-up examination requirements are implemented.

Supplemental Probabilistic Cases

The probabilistic calculations of MRP-335R1 assumed a nominal compressive stress depth of 0.5 mm on the nozzle ID surfaces. However, for at least one of the peening processes under consideration for application to the ID of CRDM/CEDM nozzles, it is understood that the 0.5

mm compressive stress depth can be obtained along less than the full zone to be peened (based on the N-729 inspection volume A-B-C-D per its Figure 2). For the remainder of the zone to be peened, it is understood that the nominal compressive stress depth that is obtained is 0.25 mm. Thus, the series of supplemental probabilistic cases presented in Appendix 1 were applied to investigate the acceptability of a minimum nominal compressive stress depth of 0.25 mm on the nozzle ID.

As discussed in Appendix 1, a reduction in the compressive residual stress depth on the nozzle ID from 0.5 to 0.25 mm had a relatively small effect on the probabilistic results for both nozzle ejection and leakage frequencies. Furthermore, the nozzle ejection frequency for the 0.25-mm case meets the absolute acceptance criteria of MRP-335R1, and also is close in magnitude to that for the baseline unmitigated case assessed in MRP-335R1 assuming inspection types and frequencies per ASME Code Case N-729-1 for an unmitigated head (i.e., risk-neutral result). In summary, a modest extension of the MRP-335R1 probabilistic modeling confirms the acceptability of the minimum 0.25-mm peening compressive stress depth understood to be obtained by all the candidate peening processes on the nozzle ID surface.

Implications of Plant Experience

Plant experience has demonstrated a low frequency of PWSCC on the nozzle ID, even for the most susceptible temperature and material conditions. PWSCC has been detected on the ID of CRDM/CEDM nozzles for only 3 of the 23 heads in the U.S. with reported PWSCC. Only about 15 of the approximate 182 CRDM/CEDM nozzles with detected PWSCC in the U.S. were reported to have PWSCC that originated on the nozzle ID. The unlikelihood of PWSCC originating on the nozzle ID surface provides further support to the requirement for a minimum 0.25-mm compressive stress depth on the nozzle ID, plus the lack of a requirement for a pre-peening surface examination on the nozzle ID surfaces.

Proposed Inspection Requirements for Revision of ASME Code Case N-729-4 [3]

The set of inspection requirements defined in Table 1 are proposed for peening mitigation of Alloy 600 RPVHPNs. These requirements, which are more stringent than the inspection requirements defined in MRP-335R1, were shown in Appendix 1 to result in a net risk reduction in terms of nozzle ejection frequency compared to the MRP-335R1 baseline peening cases (with a 3-mm compressive stress depth on the nozzle outer surfaces and 0.5-mm compressive stress depth on the nozzle ID surfaces), as well as the baseline cases of MRP-335R1 without peening.

The inspection requirements proposed in Table 1 are presented in the same format as ASME Code Case N-729-4 [3] to make clear how the proposed requirements may be implemented.

As discussed in MRP-335R1, the proposed inspection requirements do not include a pre-peening surface examination of the weld wetted surface and nozzle OD. Because of the geometry, surface condition, and original construction criteria typical of the wetted surface of the J-groove welds, it is challenging and time-consuming to perform such surface examinations (using either ET or PT), without an accompanying substantial risk of false calls. Resolving false calls often involves substantial additional worker radiation dose. Operating experience also shows that ET examination has missed detecting PWSCC at these locations. Appendix 2 summarizes the technical basis of MRP-335R1 for not requiring a pre-peening examination to detect PWSCC indications that initiated on the wetted surface of the J-groove weld. The inspection requirements of Table 1 also do not include a pre-peening surface examination of the nozzle ID surfaces. This examination can also be time-consuming and is often not part of the standard NDE package applied to RPVHPNs. The probabilistic results of MRP-335R1 and Appendix 1 demonstrate the acceptability of this approach considering the follow-up examinations that are required.

The probabilistic calculations of Appendix 1 show that the inspection requirements defined in MRP-335R1 for Alloy 600 RPVHPNs are acceptable in the case no pre-peening surface examinations, with a nominal peening compressive stress depth of 1.0 mm on the outer nozzle surfaces and 0.25 mm on the nozzle ID surfaces. Nevertheless, the proposed inspection requirements of Table 1 include substantial conservatisms beyond the requirements defined in MRP-335R1:

- For heads that operate at reactor cold-leg temperature (i.e., EDY < 8 at time of peening):
  - The nominal volumetric ISI examination interval in Table 1 is 10 years, rather than the 20 years presented in MRP-335R1. (A single follow-up volumetric examination is maintained in Table 1 for the case of heads that operate at reactor cold-leg temperature.)
  - Table 1 includes a VT-2 visual examination under the insulation through multiple access points in outages that a full direct visual examination (VE, defined in N-729-1) is not performed. The benefit of this examination is not credited in the probabilistic calculations.

- For currently operating heads that operate at higher temperatures (i.e., EDY ≥ 8 at time of peening):
  - Table 1 includes two follow-up volumetric examinations performed subsequent to peening on the same schedule as would be required for an unmitigated head. MRP–335R1 included a single follow-up volumetric examination.

In addition, it is noted that, like MRP-335R1, Table 1 maintains a VE frequency of every refueling outage after peening for the "hot head" case (i.e., EDY ≥ 8 at time of peening), the same as for the unmitigated case.

Conclusions

The conclusions of this supplemental technical basis document are as follows:

- The existing MRP-335R1 topical report, including the probabilistic calculations presented in Appendix B of MRP-335R1, demonstrates the acceptability of the compressive residual stress depth of 1.0 mm understood to be obtained by all the candidate peening processes on the nozzle outer surfaces. Furthermore, the main probabilistic cases of MRP-335R1 did not credit any pre-peening surface examinations. Follow-up volumetric examinations of the nozzle base metal and periodic visual examinations for evidence of leakage are shown in MRP-335R1 to be effective in addressing the possibility that pre-existing PWSCC flaws are not detected in the pre-peening volumetric examination.

- The modest extension of the MRP-335R1 probabilistic modeling presented in this document confirms the acceptability of the minimum 0.25-mm peening compressive stress depth understood to be obtained by all the candidate peening processes on the nozzle ID surface. The probabilistic results, which explicitly consider the possibility that pre-existing flaws on the various surfaces susceptible to PWSCC are not detected in the pre-peening volumetric examination, assessed the effects on nuclear safety through the nozzle ejection frequency, as well as the effects on the nozzle leakage frequency.

- The modest changes in inspection requirements proposed in Table 1versus those in MRP-335R1 are shown to result in a net risk reduction in terms of nozzle ejection frequency compared to the MRP-335R1 baseline peening cases (with a 3-mm compressive stress depth on the nozzle outer surfaces and 0.5-mm compressive stress depth on the nozzle ID surfaces), as well as the baseline cases of MRP-335R1 without peening.

References

1. *Materials Reliability Program: Topical Report for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision 1)*, EPRI, Palo Alto, CA: 2013. 3002000073. [freely downloadable at www.epri.com]

2. *Materials Reliability Program: Technical Basis for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-267, Revision 1)*, EPRI, Palo Alto, CA: 2012. 1025839. [freely downloadable at www.epri.com]

3. ASME Code Case N-729-4, "Alternative Examination Requirements for PWR Reactor Vessel Upper Heads With Nozzles Having Pressure-Retaining Partial-Penetration Welds," Section XI, Division 1, American Society of Mechanical Engineers, New York, Approval Date: June 22, 2012.

4. *Materials Reliability Program Probabilistic Fracture Mechanics Analysis of PWR Reactor Pressure Vessel Top Head Nozzle Cracking (MRP-105)*, EPRI, Palo Alto, CA: 2004. 1007834. [NRC ADAMS Accession No. ML041680489]

Appendix 1: Probabilistic Cases Supplemental to Appendix B of MRP-335R1

Methodology

To explicitly demonstrate the support of the existing technical basis for the proposed set of inspection requirements and peening compressive stress depths, supplemental probabilistic cases were evaluated. These cases, which are a modification of "hot head" Model Sensitivity Case 19 from Appendix B of MRP-335R1 [1], were evaluated using the same probabilistic framework applied in MRP-335R1. Model Sensitivity Case 19 evaluated the effect of a 1.0-mm compressive depth on the outer nozzle surfaces relative to the baseline peening case in MRP-335R1 of an assumed 3-mm depth on the outer nozzle surfaces. The supplemental cases in this appendix evaluated the effect of a 0.25-mm peening compressive depth on the nozzle ID surfaces, in comparison to the 0.5-mm depth assumed in the base cases of MRP-335R1. Corresponding supplemental cases were evaluated for the "hot head' (600°F) and "cold head" conditions, with assumed inspection schedules specific to each category. Currently, in the U.S., there are 19 cold heads with Alloy 600 nozzles that operate at reactor cold-leg temperature that are potential candidates for peening mitigation, and four hot heads with Alloy 600 nozzles that operate substantially above reactor cold-leg temperature that are potential candidates for peening mitigation.

The effect of the peening compressive depth on the nozzle ID surface was investigated for multiple initial flaw depth assumptions considering that the possibility of an initiated flaw being missed in the pre-peening volumetric examination could depend on the flaw depth assumed at initiation. Five supplemental cases (S1 through S5) were used to assess the effect of the peening compressive stress depth assumption for the nozzle ID for various initial flaw depth assumptions. The final two supplemental cases (S6 and S7) evaluated the effect of the specific inspection requirements proposed in Table 1, in comparison to the base case assumptions of Appendix B of MRP-335R1. Namely, two follow-up volumetric examinations instead of one were assumed for the "hot head" (600°F) case, and a volumetric ISI interval of 10 years rather than 20 years was assumed for the "cold head" case. The S6 and S7 cases considered two different initial flaw depth assumptions for a 0.25-mm compressive peening depth on the nozzle ID surface. Consistent with the approach taken in the baseline cases of MRP-335R1, the supplemental cases do not take credit for performance of a surface examination prior to the application of peening.

Supplemental Probabilistic Results

Figure 1 and Figure 2 present the supplemental case results in terms of the nozzle average ejection frequency (AEF) per year after peening for the "hot head" and "cold head" cases, respectively. The changes relative to the results in MRP-335R1 are small, considering the 5E-5 per year acceptance criterion applied in the MRP-335R1 technical basis. Among the supplemental sensitivity cases investigated, the greatest AEF increase relative to Model Sensitivity Case 19 is about 8% for the hot head cases and 40% for the cold head cases. The highest AEF value for the cold head cases is about an order of magnitude lower than that for the hot head cases. All the nozzle ejection results evaluating the effect of PWSCC on nuclear safety are well below the acceptance criterion applied in the MRP-335R1 technical basis of 5E-5 per year.

The changes to the inspection requirements assumed for Cases S6 and S7 resulted in lower AEF values than the MRP-335R1 baseline peening cases (with a 3-mm compressive stress depth on the nozzle outer surfaces), as well as the baseline cases without peening. These results demonstrate that inspection requirements proposed in Table 1 more than offset the small increase in risk that results from reducing the nominal peening compressive stress depth from 3.0 mm on the outer nozzle surfaces and 0.5 mm on the nozzle ID surfaces to corresponding values of 1.0 mm and 0.25 mm.

In order to illustrate how the calculated risk varies with time, Figure 3 presents the incremental frequency of ejection (IEF) per year for four representative "hot head" cases. The incremental results demonstrate, due to the prevention of newly initiated cracks after the time of peening, a general decreasing trend in ejection risk over time. The follow-up examinations are sufficient to mitigate the ejection risk after peening, with the additional follow-up volumetric examination in

Case S7 producing a discernible decrease in IEF versus the other cases with peening. Finally, the results for the unmitigated ("no peening") case illustrate how the periodic examinations required by ASME Code Case N-729-1 maintain a consistent ejection risk over time.

In addition to the nozzle ejection results presented in Figure 1 through Figure 3, the effects of the peening compressive stress depth and inspection requirements on the leakage frequency were also assessed. In the same manner presented in Appendix B of MRP-335R1, the effect on leakage frequency was assessed in terms of the fraction of Monte Carlo realizations in which the simulated head experiences a first nozzle leak following peening. For the supplemental hot head cases, the maximum leakage frequency was only 22% higher than that for Sensitivity Case 19. For the corresponding cold head cases, the maximum leakage frequency was only 6% higher than that for Sensitivity Case 19. The inspection requirements changes in Table 1 (i.e., Cases S6 and S7) resulted in about a 15% decrease in leakage frequency versus the directly comparable cases (i.e., S3 and S5).

Conclusion

The modest extension of the probabilistic modeling presented in this appendix confirms the acceptability of the peening compressive stress depths that are understood to be obtained by all the candidate processes being now being considered for RPVHPNs. The modest changes in inspection requirements proposed versus those in MRP-335R1 more than compensate for the reductions in minimum compressive stress depth.

Appendix 2: Basis for Not Requiring a Pre-Peening Examination to Detect PWSCC Indications that Initiated on the Wetted Surface of the J-Groove Weld

MRP-335R1 [1] presents the technical basis for the basic inspection approach presented in that report, including the basis for not requiring a pre-peening surface examination of the Alloy 82/182 J-groove weld material. For convenience, that technical basis is summarized in this appendix, as follows:

1. Experience has shown that PWSCC flaws located in the weld metal often extend into the base metal, and are thus detectable via UT from the nozzle ID. There have been no cases of weld flaws growing to the annulus and causing leakage after a UT examination has been performed of 100% of the CRDM/CEDM nozzles in a head. The reason for this is partly that the most susceptible heads operating at the highest temperatures have been replaced, but nonetheless there have been no cases of detected leakage after UT has been first applied to all CRDM/CEDM nozzles in a head.

2. There is minimal safety significance of flaws exclusively located in the weld metal. The leak rate produced by a flaw exclusively located in the weld metal is likely to be much smaller than that which could result in significant boric acid corrosion of the low-alloy steel material. In addition, for a weld flaw to lead to the possibility of a safety-significant circumferential flaw in the nozzle tube (i.e., a large circumferential flaw located in the nozzle tube that could lead to nozzle ejection if it were to grow to encompass a large fraction of the wall cross section) would very likely require that leakage be produced that is detectable during visual examinations of the upper head surface.

3. The inspection requirements defined in Table 1 (and in MRP-335R1) maintain the basic visual examination types and frequencies defined by ASME Code Case N-729-1 for unmitigated heads. Per #2, the possibility of pre-existing flaws located in the weld metal is effectively addressed through periodic visual examinations for leakage. This approach is conservative in that the basic visual examination schedule for unmitigated heads is maintained even though the weld surface has been peened.

4. The follow-up volumetric examinations defined in Table 1 (and in MRP-335R1) are opportunities to detect any flaws that grow from the weld metal and into the nozzle base metal subsequent to the time of peening.

5. The detailed probabilistic calculations of MRP-335R1 explicitly model the possibility of a pre-existing weld flaw ultimately leading to nozzle ejection. The modeling work demonstrates an acceptably small effect on nuclear safety. The probabilistic modeling maintains the key conservatism of the original MRP-105 probabilistic technical basis [4] that a weld flaw reaching the nozzle annulus is assumed to immediately produce a 30° through-wall circumferential flaw in the nozzle tube.

In a similar manner to the above discussion, follow-up volumetric examinations and periodic visual examinations for leakage address the possibility that any PWSCC flaws are located on the nozzle ID surface that are too shallow to be detected via the pre-peening volumetric examination. Any flaws located on the nozzle ID surface are very likely to be axial in orientation and lead to detectable leakage prior to the possibility of safety-significant circumferential cracking.

Table 1. Inspection Requirements Developed for Alloy 600 RPVHPNs Mitigated by Peening (Drafted as Revision to Code Case N-729-4 [3])

EXAMINATION CATEGORIES						
CLASS 1 PWR REACTOR VESSEL UPPER HEAD						
Item No.	**Parts Examined**	**Examination Requirements/ Fig. No.**	**Examination Method**	**Acceptance Standard**	**Extent and Frequency of Examination**	**Deferral of Examination to End of Interval**
B4.10	Head with UNS N06600 nozzles and UNS N06082 or UNS W86182 partial-penetration welds	Fig. 1	Visual, VE (1), (2)	-3140	Each refueling outage (3), (4)	Not permissible
B4.11	Head with UNS N06600 nozzles and UNS N06082 or UNS W86182 partial-penetration welds mitigated by peening (10)	Fig. 1	Visual, VE (1), (2), (11)	-3140	Each refueling outage (3), (11)	Not permissible
B4.20	UNS N06600 nozzles and UNS N06082 or UNS W86182 partial-penetration welds in head	Fig. 2 (5)	Volumetric (6) Surface (6)	-3130	All nozzles, every 8 calendar years or before RIY = 2.25, whichever is less (7), (8), (9)	Not permissible
B4.21	UNS N06600 nozzles and UNS N06082 or UNS W86182 partial-penetration welds mitigated by peening (10)	Fig. 2 (5)	Volumetric (6) Surface (6)	-3130	All Nozzles, not to exceed one inspection interval (nominally 10 calendar years) (9), (12), (13)	Not permissible

NOTES: (1) through (9) are identical to those in ASME Code Case N-729-4

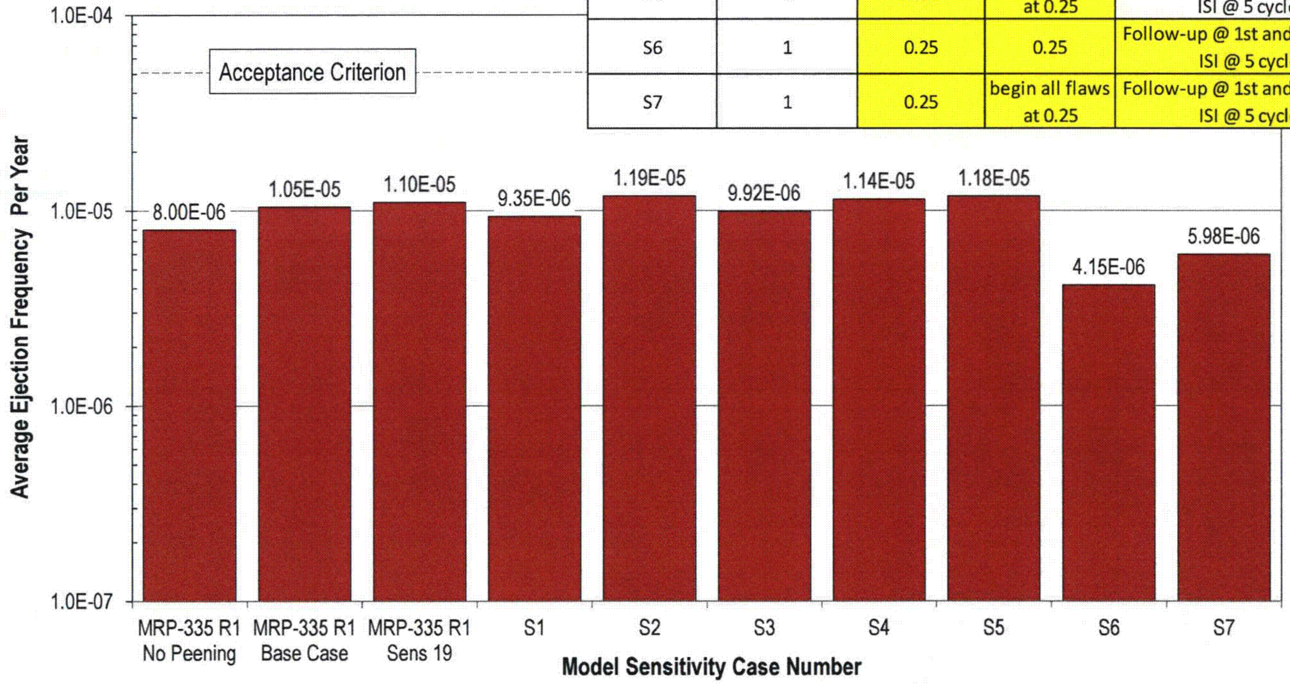
(10) The following requirements shall be met for peening mitigation of the nozzles and welds:
- (a) A documented evaluation shall be completed demonstrating that the stress improvement technique meets the performance criteria in Mandatory Appendix II.
- (b) The surface identified as (A-D) and (C-E-F-G) on Figure 2 shall, as a minimum, be stress improved utilizing a technique that meets the performance criteria of Mandatory Appendix II.
- (c) The nominal peening compressive stress depth shall be at least 0.04 in. (1.0 mm) for the nozzle OD and weld surfaces and at least 0.01 in. (0.25 mm) for the nozzle ID surfaces.

(11) If EDY < 8 at the time of peening and no flaws unacceptable for continued service under -3130 or -3140 have been detected subsequent to the follow-up volumetric examination or examinations per Note (13), the reexamination frequency may be extended to every third refueling outage or 5 calendar years, whichever is less, provided an IWA-2212 VT-2 visual examination of the head is performed under the insulation through multiple access points in outages that the VE is not completed. This IWA-2212 VT-2 visual examination may be performed with the reactor vessel depressurized.

(12) If surface stress improvement techniques qualified in accordance with Mandatory Appendix II are used, the following shall be met:
- (a) Volumetric examinations shall be performed prior to the application of stress improvement techniques of the volume (A-B-C-D) as identified in Figure 2. This examination shall be considered the preservice baseline examination.
- (b) Surface examination may optionally be performed prior to the application of stress improvement techniques of the surface (A-E'-D) as identified in Figure 2.
- (c) All flaws detected during the pre-mitigation inspection shall be corrected by a repair/replacement activity of -3132.2 or -3142.3(b), prior to application of surface mitigation that meets the performance requirements of Appendix II.

(13) Follow-up volumetric examination of the volume (A-B-C-D) as identified in Figure 2 shall be performed in the refueling outages subsequent to the time of peening as follows:
- (a) If EDY < 8 at the time of peening, the follow-up volumetric examination shall be performed in the second or third refueling outage following the application of peening. If flaws attributed to PWSCC were detected prior to peening, the follow-up volumetric examination shall be in the second refueling outage.
- (b) If EDY ≥ 8 at the time of peening, follow-up volumetric examinations shall be performed at two additional refueling outages per the schedule for unmitigated heads (item B4.20).

Case Number	Nominal OD Penetration Depth (mm)	Nominal ID Penetration Depth (mm)	Minimum Initial Flaw Depth (mm)	Post-Peening UT	Post-Peening BMV	All other inputs
MRP-335 R1 Base Case	3	0.5	0.5	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	MRP-335 R1 Hot Head Base Case Inputs
MRP-335 R1 Sensitivity 19	1	0.5	0.5	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S1	1	0.25	0.5	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S2	1	0.5	0.25	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S3	1	0.25	0.25	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S4	1	0.5	begin all flaws at 0.25	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S5	1	0.25	begin all flaws at 0.25	Follow-up @ 2 cycles ISI @ 5 cycles	N-729	
S6	1	0.25	0.25	Follow-up @ 1st and 2nd cycles ISI @ 5 cycles	N-729	
S7	1	0.25	begin all flaws at 0.25	Follow-up @ 1st and 2nd cycles ISI @ 5 cycles	N-729	



All cycles are assumed to be 24 months

Yellow fill indicates difference from Model Sensitivity 19

Figure 1. Average Nozzle Ejection Frequency for Supplemental Hot Head (600°F) Sensitivity Cases per Probabilistic Model of MRP-335R1 Appendix B

Case Number	Nominal OD Penetration Depth (mm)	Nominal ID Penetration Depth (mm)	Minimum Initial Flaw Depth (mm)	Post-Peening UT	Post-Peening BMV	All other inputs
MRP-335 R1 Base Case	3	0.5	0.5	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	MRP-335 R1 Cold Head Base Case Inputs
MRP-335 R1 Sensitivity 19	1	0.5	0.5	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S1	1	0.25	0.5	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S2	1	0.5	0.25	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S3	1	0.25	0.25	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S4	1	0.5	begin all flaws at 0.25	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S5	1	0.25	begin all flaws at 0.25	Follow-up @ 2 cycles ISI @ 10 cycles	N-729	
S6	1	0.25	0.25	Follow-up @ 2 cycles ISI @ 5 cycles	Every 3 cycles	
S7	1	0.25	begin all flaws at 0.25	Follow-up @ 2 cycles ISI @ 5 cycles	Every 3 cycles	

All cycles are assumed to be 24 months

Yellow fill indicates difference from Model Sensitivity 19

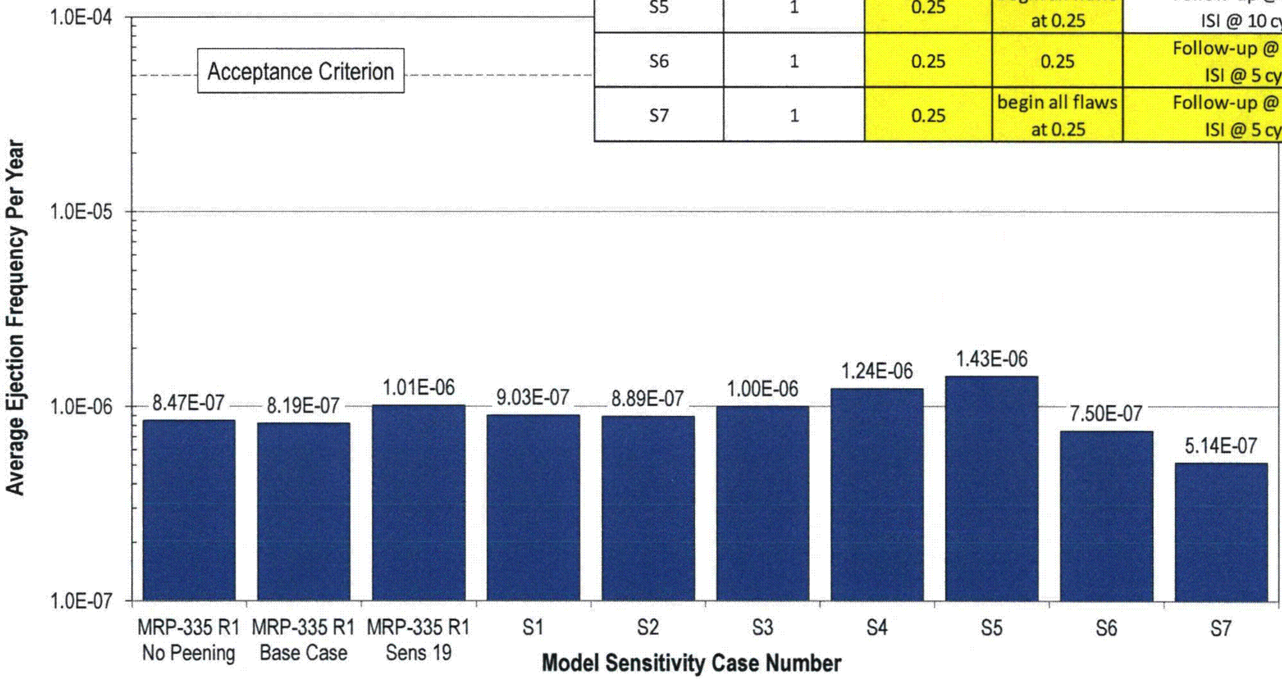


Figure 2. Average Nozzle Ejection Frequency for Supplemental Cold Head (554°F) Sensitivity Cases per Probabilistic Model of MRP-335R1 Appendix B

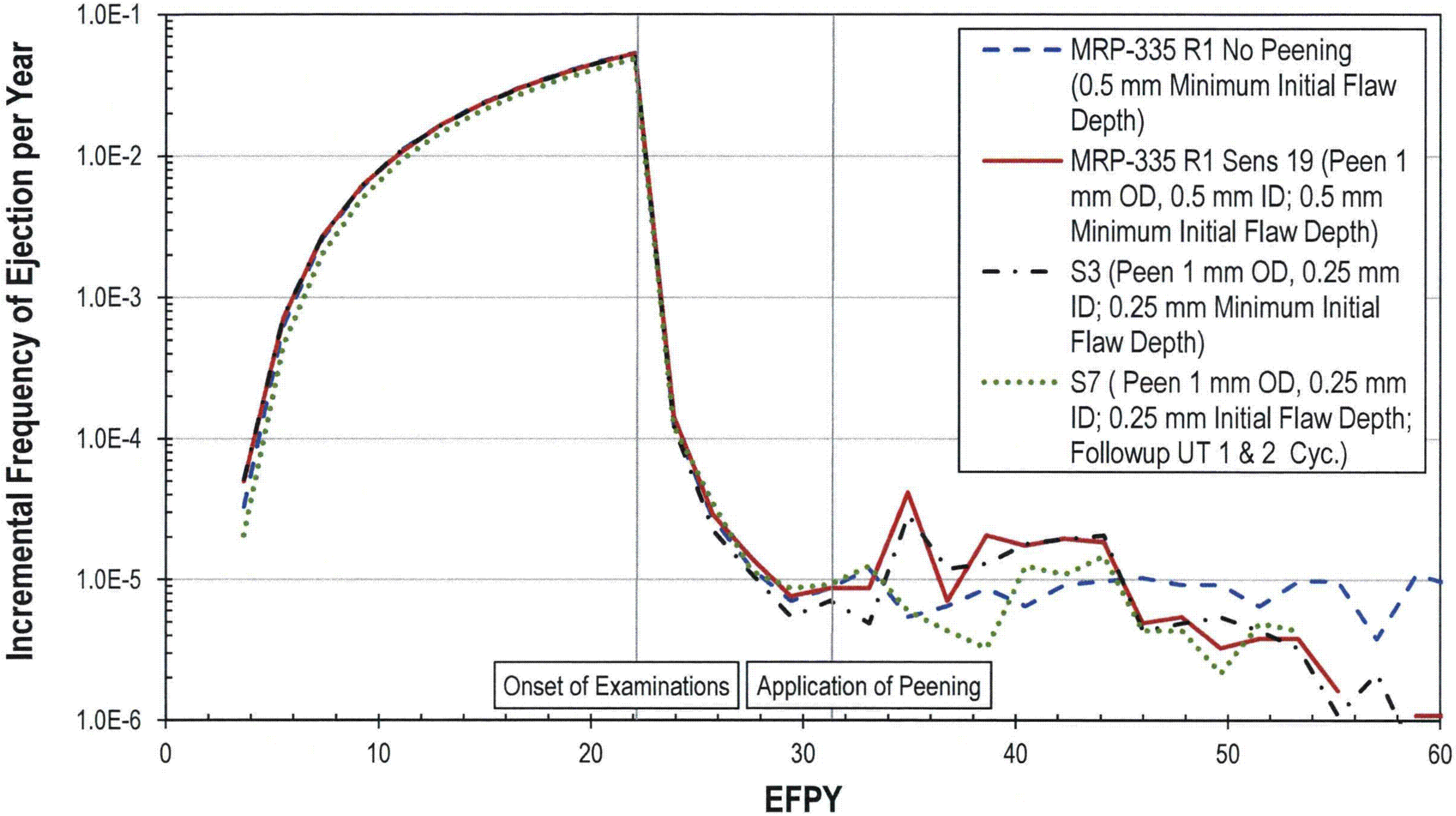


Figure 3. **Incremental Nozzle Ejection Frequency for Selected Supplemental Hot Head (600°F) Sensitivity Cases per Probabilistic Model of MRP-335R1 Appendix B**