**Luminant**

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CP-201301361
TXX-13175

Ref. # 10CFR50.55a(a)(3)(ii)

November 26, 2013

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555

SUBJECT: COMANCHE PEAK NUCLEAR POWER PLANT
DOCKET NO. 50-446
RELIEF REQUEST NO. B-14 FOR THE UNIT 2 REACTOR PRESSURE VESSEL HOT LEG NOZZLE WELD EXAMINATIONS (SECOND ISI INTERVAL START DATE: AUGUST 3, 2004; SECOND ISI INTERVAL END DATE: AUGUST 2, 2014)

REFERENCES:

1. Letter logged TXX-13004 dated January 16, 2013, from Rafael Flores to the NRC submitting Relief Request No. B-2 for the Unit 1 Third 10 Year ISI Interval From 10CFR50.55a Inspection Requirements For Reactor Vessel Hot Leg Nozzle Weld Examinations (Third Interval Start Date: August 13, 2010)(ML13029A592)

2. Letter logged TXX-13023 dated February 7, 2013, from Rafael Flores to the NRC submitting Response to Request for Additional Information for Unit 1 Relief Request B-2 (TAC No. MF0507) (ML13046A054)

3. NRC Letter dated March 15, 2013, from Michael T. Markley to Rafael Flores concerning Comanche Peak Nuclear Power Plant, Unit 1 – Request for Relief No. B-2 from Reactor Vessel Hot-Leg Nozzle Weld Examination Requirements for the Third 10-Year Inservice Inspection Interval (TAC No. MF0507) (ML13056A503)

Dear Sir or Madam:

Pursuant to 10 CFR 50.55a(a)(3)(ii), Luminant Generation Company LLC (Luminant Power) is submitting Relief Request B-14 for Comanche Peak Nuclear Power Plant (CPNPP) Unit 2 for the second ten-year inservice inspection interval. A proposed alternative is requested from the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section XI 1998 Edition through the 2000 Addenda, for an alternative method for examination of the reactor vessel hot leg nozzle welds.

The basis and justification for the relief request is attached. Luminant Power requests approval of this alternative for examination of reactor vessel hot leg nozzle welds scheduled to be performed in the upcoming Unit 2 outage, 2RF14.

A similar relief request was previously submitted to the NRC for Unit 1 via References 1 and 2 and was approved in Reference 3.



A047
NRR

Luminant Power requests approval of this relief request by March 31, 2014, to support the upcoming CPNPP Unit 2 refueling outage.

This communication contains no new commitments regarding CPNPP Unit 2.

Should you have any questions, please contact Mr. Jack Hicks at (254) 897-6725.

Sincerely,

Luminant Generation Company LLC

Rafael Flores

By: ______________________
Thomas P. McCool
Vice President, Station Support

Attachments:
1. CPNPP Unit 2 Relief Request Number - B-14 For the Reactor Vessel Hot Leg Nozzle Weld Examinations (Second 10-Year ISI Interval Start Date: August 3, 2004)
2. CPNPP Unit 2 Reactor Vessel Nozzle Sketch

Enclosure: Electrical Power Research Institute (EPRI) Materials Reliability Program (MRP) MRP 2012-046

c - Marc L. Dapas, Region IV
Balwant K. Singal, NRR
Resident Inspectors, Comanche Peak
Jack Ballard, ANII, Comanche Peak

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1. **ASME Code Component Affected:**

The affected components are the Class 1, R-A, R1.15 (formerly Code Cat. B-F, B5.10) (Code Case N-770-1 Category A-2) Reactor Pressure Vessel (RPV) nozzle to safe-end dissimilar metal (DM) butt welds, as follows:

- TCX-1-4100-1 Loop 1 Hot Leg Nozzle to Safe End DM Weld
- TCX-1-4200-1 Loop 2 Hot Leg Nozzle to Safe End DM Weld
- TCX-1-4300-1 Loop 3 Hot Leg Nozzle to Safe End DM Weld
- TCX-1-4400-1 Loop 4 Hot Leg Nozzle to Safe End DM Weld

A sketch of the outlet nozzle examination technique with dimensions is included as Attachment 2 to this response. Referring to the sketch (reading from left to right):

- Pipe material is cast stainless steel, SA-351-CF8A;
- Weld is stainless steel;
- Safe end is stainless steel, F-316L;
- DM weld is 182; nozzle is stainless steel;
- Nozzle cladding is stainless steel

In addition, actual outlet nozzle safe end dimensions are 34.82 inches OD x 27.88 inches ID with a wall thickness of 2.94 inches.

2. **Applicable Code Edition and Addenda:**

The applicable Code edition and addenda is ASME Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1998 Edition through the 2000 Addenda. In addition, as required by 10 CFR 50.55a, ASME Section XI, 2001 Edition is used for Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems."

3. **Applicable Code Requirement:**

The volumetric examination specified by Examination Category R-A, Item R1.15, "RPV nozzle to safe-end DM butt welds" will be performed using the ultrasonic (UT) examination method as described in IWA-2232 and Appendix 1. Appendix 1, 1-2220 requires that ultrasonic examination procedures, equipment, and personnel be qualified by performance demonstration in accordance with Appendix VIII. Instead of the Appendix VIII qualification requirements, Luminant Power is using NRC-approved Code Case N-695, "Qualification Requirements for Dissimilar Metal Piping Welds."

Code Case N-695 provides an alternative to the Appendix VIII, Supplement 10 requirements for the qualification requirements of DM welds. Paragraph 3.3(c) indicates examination procedures, equipment, and personnel are qualified for depth-sizing when the Root Mean Square (RMS) error of the flaw depth measurements, as compared with the true depths, does not exceed 0.125 inches.

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4. **Reason for Request: Impracticality of Compliance (10CFR50.55a(a)(3)(ii))**

Luminant will be performing volumetric examinations of the RPV nozzle-to-safe end dissimilar metal welds from the inside surface during the upcoming 2RF14 outage (April 2014) and will implement the alternative requirements of ASME Code Case N-695. Code Case N-695 requires that qualified procedures and personnel shall demonstrate a flaw depth-sizing error less than or equal to 0.125 inch RMS. This Relief Request is being submitted due to the impracticality of meeting the required 0.125 inch RMS value required by Code Case N-695. The nuclear power industry has attempted to qualify personnel and procedures for depth-sizing examinations performed from the inside surface of dissimilar metal welds since November 2002. To date, no inspection vendor has met RMS error requirements of Code Case N-695.

The inability of examination procedures to achieve the required RMS error value is primarily due to a combination of factors such as surface condition (e.g., roughness), scan access, base materials, and the dendritic structure in the welds themselves. The combination of these factors has proven too difficult for vendors to achieve an RMS error value that meets the established requirements.

5. **Burden Caused by Compliance:**

The most recent attempt at achieving 0.125 inch RMS error was in early 2008. This attempt, as well as previous attempts, did not achieve the required RMS error value. The qualification attempts have been substantial. The attempts have involved multiple vendors, ultrasonic instruments, personnel, and flaw depth-sizing methodologies, all of which have been incapable of achieving the 0.125 inch RMS error value.

The process of qualification for this type of flaw sizing is well established. The cost and effort involved to perform a successful demonstration is quantifiable when a capable technique is available. However, when a capable technique is not available, the costs and effort required for a successful demonstration cannot be easily quantified.

6. **Proposed Alternative and Basis for Use:**

Luminant Power proposes using an alternative depth-sizing RMS error value greater than the 0.125 inch RMS error value stated in ASME Code Case N-695 for the examination of welds listed above. Luminant Power proposes to use a RMS error of 0.189 inches (based on the results achieved by Luminant Power's examination vendor) instead of the 0.125 inches required for Code Case N-695.

In the event a flaw is detected that requires depth sizing, Luminant Power proposes that the following method for reporting flaw through-wall sizes shall be used:

- For flaw(s) detected and measured as less than 50% through-wall in depth, the depth shall be adjusted by adding the difference between the required RMS error and the demonstrated RMS error to the measured through-wall extent for comparison with applicable ASME Section XI acceptance criteria. The practice of adjusting the measured RMS error value by adding the difference between the required RMS error value and the vendor demonstrated RMS error value is further supported by Electrical Power Research Institute (EPRI) Materials Reliability Program (MRP) document MRP 2012-046 (see

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attached Enclosure to TXX-13175). This document utilizes a statistical approach to provide a technical justification that validates the aforementioned RMS error adjustments.

- For flaw(s) detected and measured as 50% through-wall in depth or greater, the depth shall also be adjusted by adding the difference between the required RMS error and the demonstrated RMS error to the measured through-wall extent for comparison with applicable ASME Section XI acceptance criteria. Additionally, for flaw(s) detected and measured as 50% through-wall in depth or greater and to remain in service without mitigation or repair, Luminant Power shall submit the flaw evaluations including ID profiling information of the weld, pipe and nozzle at and in the region of the flaw, and confirmation whether the flaw(s) are surface breaking, as determined by eddy current, to the NRC for review and approval prior to reactor startup.

There is no Appendix VIII qualification for embedded flaws. Luminant Power's inspection vendor's procedure does address sizing of embedded volumetric (fabrication) flaws, with through-wall sizing determined by measurement of the -6dB (1/2 maximum response) limits of the flaw response, with no correction factor applied.

For an embedded planar flaw, the 0.064 inch-inch correction factor will be added to the bottom tip (nearest to the ID) response. The total through-wall extent and near surface tip or "S" dimension, used for the determination of surface proximity, will also add the adjusted conservative measurement value of 0.064 inches to the computed flaw depth. Eddy current will also be used for the entire ID surface of the inspection area during the detection scans. The eddy current results will be used to help verify the ID surface connectivity of all reported flaws.

If the examination vendor demonstrates an improved depth sizing RMS error prior to the examination, the excess of that improved RMS error over the 0.125 inch RMS error requirement, if any, will be added to the measured value for comparison with applicable acceptance criteria. In the event that an indication is detected that requires depth sizing, a process will be used where the difference between the required RMS error and vendor demonstrated RMS error will be added to the measured through-wall depth. This amended through-wall depth will then be used to determine the acceptability of the indication, as follows:

- For planar indications that are not connected to the inside surface, the amended through-wall depth will be compared with the Section IWB-3500 acceptance criteria.

- For planar indications that are connected to the inside surface, an IWB-3600 evaluation will be performed.

The above statement is not meant to suggest that ID surface connected flaws will not be compared to the acceptance standards of IWB-3500. The intent is that all flaws, either ID connected or embedded, will be compared to the acceptance standards of IWB-3500. Additionally, any flaw determined to be ID connected will also be evaluated per IWB-3600, whether or not an evaluation per IWB-3500 requires an IWB-3600 analytical evaluation. IWB-3600 evaluations will be performed. A flaw evaluation based on IWB-3600 for an inside surface–connected flaw will calculate flaw growth based on the degradation mechanisms of primary stress corrosion cracking and fatigue.

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Luminant Power's inspection vendor will not be attempting any further Appendix VIII qualification demonstrations prior to the 2RF14 refueling outage. Therefore, the demonstrated or measured RMS error of 0.189 inches will be used.

The proposed alternative assures that the DM nozzle-to-safe-end welds will be fully examined by procedures, personnel and equipment qualified by demonstration in all aspects except depth sizing. Therefore, it will assure that there is reasonable assurance of structural integrity and thus, will provide an acceptable level of quality and safety. Pursuant to 10CFR50.55a(g)(5)(iii), relief is requested to use this alternative depth-sizing error due to impracticality.

7. **Duration of Proposed Alternative:**

The proposed relief request is applicable for the CPNPP Unit 2 Second Inservice Inspection Interval, Outage 2RF14, April 2014. The end date for the second 10-year Inservice Inspection Interval for Unit 2 is August 2, 2014.

8. **Precedents:**

McGuire Nuclear Station Unit No. 2 and Comanche Peak Nuclear Power Plant Unit 1 have received approval of a similar relief request

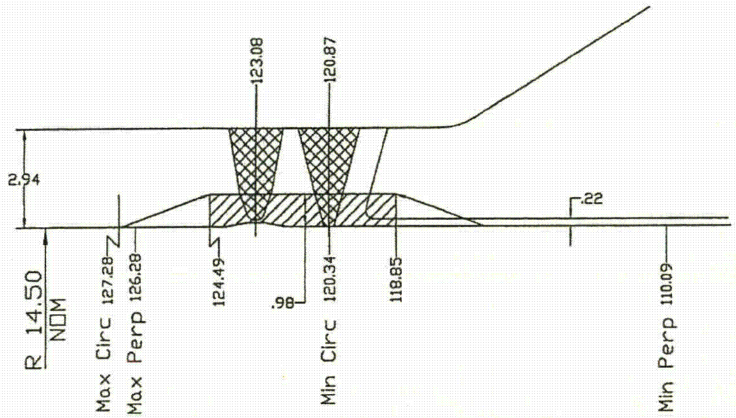
9. **Reference:**

9.1 McGuire submitted Relief Request by letter dated May 8, 2012 (ML12138A008) as supplemented by letter dated August 22, 2012 (ML12250A662).

9.2 NRC approval was granted by letter dated September 24, 2012 (ML12258A363).

9.3 Comanche Peak Nuclear Power Plant Unit 1 submitted Relief Request by letter dated January 16, 2013 (ML13029A592) as supplemented by letter dated February 7, 2013 (ML13046A054).

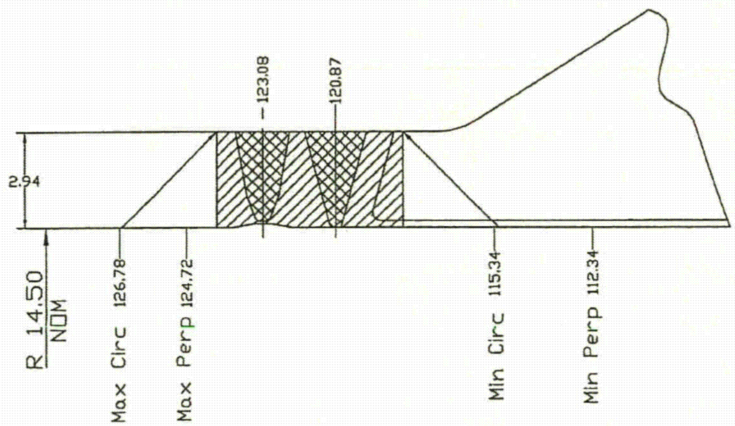
9.4 NRC approval was granted by letter dated March 15, 2013 (ML13056A503).




DETECTION SLED SCANS

INCREMENT DISTANCE = 0.25" (0.99°) for AXIAL SCANS
= 0.08" for CIRC SCANS

DISTANCE FROM VESSEL ℄




SIZING SLED SCANS

INCREMENT DISTANCE = 0.125" (0.49°) for AXIAL SCANS
= 0.08" for CIRC SCANS

| DM WELDS | PIPE WELDS | NOZZLE |
|---|---|---|
| TCX-1-4300-1 | TCX-1-4300-2 | @ 22° |
| TCX-1-4400-1 | TCX-1-4400-2 | @ 158° |
| TCX-1-4100-1 | TCX-1-4100-2 | @ 202° |
| TCX-1-4200-1 | TCX-1-4200-2 | @ 338° |

COMANCHE PEAK 2-TCX

WesDyne International

SHEET TITLE: OUTLET SAFE END EXAMS

2009 EXAMINATION PROGRAM PLAN

ALL DIMENSIONS IN INCHES UNLESS OTHERWISE NOTED

SHEET 6 OF 7

ENCLOSURE TO TXX-13175

ELECTRIC POWER RESEARCH INSTITUTE (EPRI)

MATERIALS RELIABILITY PROGRAM (MRP)

MRP 2012-046

ELECTRIC POWER RESEARCH INSTITUTE

**MRP Materials Reliability Program** MRP 2012-046

(via email)

November 26, 2012

To: MRP TAG, MRP IC, MRP Assessment TAC, and MRP Inspection TAC

Subject: Flaw Depth Sizing Uncertainty Root Mean Square (RMS) Error Treatment for Ultrasonic Piping Examinations from the Inside Surface

Since 2002, the nuclear power industry has attempted to qualify personnel and procedures for depth-sizing examinations performed from the inside surface of dissimilar metal and austenitic stainless steel butt welds in PWR piping. To date, no domestic or international vendor has met the applicable root mean square (RMS) error requirement specified in the ASME Code. Utilities performing these examinations have thus requested relief from the RMS error requirement by employing an adjustment of the measured flaw depth equal to the difference between the RMS error achieved in the qualification process and the RMS error required in ASME Section XI, Appendix VIII. This adjustment has been accepted by the NRC staff on numerous occasions, but recent staff review of qualification data has led to concerns with the adequacy of this adjustment. A more conservative adjustment was proposed early in 2012 by the NRC staff during the review of utility relief requests on this subject.

As a result of the NRC proposal, the MRP initiated an assessment of the procedure that has customarily been used by industry to account for the RMS sizing error, as well as the alternative approach suggested by NRC staff. A simple statistical approach was used to assess the effect of the alternative depth sizing approaches proposed by industry and NRC staff as compared to the ASME Section XI, Appendix VIII, RMS criteria. Additionally, the implications of the depth sizing uncertainty on the use of stress improvement mitigation methods and on the disposition of flaws for continued service were specifically considered.

The results of this MRP assessment were presented to the NRC Staff in a public meeting on March 16, 2012 and subsequently its basis was further evaluated during a meeting in Charlotte on July 27, 2012 to directly assess the supporting data from PDI. Issues and questions raised during those interactions identified several areas of the assessment that warranted further development, explanation, and documentation.

The revised version of the original assessment is provided as the attachment to this letter for use by member utilities in determining the most appropriate treatment of depth sizing uncertainty in upcoming inspection campaigns and is not considered proprietary information.

Please also note that there is a related effort underway for the long term resolution of this issue through a change to the relevant sections of the ASME Code. The specific recommendation and

technical basis document are presently under development for presentation to the appropriate Section XI groups in the first half of 2013.

If you have any questions or concerns, please contact Craig Harrington (charrington@epri.com, 817-897-1433).

Best Regards,

William Sims
William Sims
Entergy
Chairman MRP Assessment TAC

Craig D Harrington

Craig Harrington
EPRI Sr. Project Manager

Attachment 1: Assessment of Effect of the Depth-Sizing Uncertainty for Ultrasonic Examinations from ID Surface of Large-Bore Alloy 82/182 and Austenitic Stainless Steel Butt Welds in PWR Primary System Piping, Revision 1

Cc: Craig Harrington, EPRI



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# Attachment 1 Assessment of Effect of the Depth-Sizing Uncertainty for Ultrasonic Examinations from ID Surface of Large-Bore Alloy 82/182 and Austenitic Stainless Steel Butt Welds in PWR Primary System Piping, Revision 1*

## 1 Introduction

### 1.1 Need for Alternative

Since 2002, the nuclear power industry has attempted to qualify personnel and procedures for depth-sizing examinations performed from the inside surface of dissimilar metal and austenitic stainless steel butt welds in PWR piping. To date, no domestic or international vendor has met the applicable root mean square (RMS) error requirement of ASME Section XI Appendix VIII (Supplements 2 [4], 10 [5], and/or 14 [6]), or the alternative qualification requirements of ASME Code Case N-695 [7] or N-696 [8], as applicable.† Utilities examining from the inner diameter have thus requested relief from the RMS error requirement by employing an adjustment of the measured flaw depth equal to the difference between the RMS error achieved in the qualification process and the RMS error required in Appendix VIII. This adjustment has been accepted by the NRC staff on numerous occasions, but recent staff review of qualification data has led to concerns with the adequacy of this adjustment. A more conservative adjustment has been proposed by the NRC staff during the review of recent utility relief requests on this subject.

### 1.2 Purpose of Assessment

The purpose of this document is to assess the procedure that has customarily been utilized by the industry to account for the RMS error achieved for large-bore Alloy 82/182 and austenitic stainless steel butt welds in PWR piping. The RMS error that is applied in this procedure is the RMS error achieved by the specific inspection vendor that performed the examination for the Appendix VIII supplement applicable to the examined weld. Also considered in this assessment is another alternative approach that was recently suggested by NRC staff. Specifically, the

* This letter report was originally distributed as an attachment to letter MRP 2012-011, March 8, 2012. Revision bars have been added to denote sections added or changed.

† ASME Code Cases N-695 and N-696 have been approved by NRC for use without condition [9].

implications of the depth-sizing uncertainty on the use of stress improvement mitigation methods and on the disposition of flaws for continued service are considered below. A simple statistical approach is taken to assess the effect of the alternative depth-sizing approaches proposed by industry and NRC staff.

### 1.3 Revised Assessment

This assessment was initially issued on March 8, 2012. The initial assessment applied a simple statistical approach to the bounding values reported for the RMS depth-sizing error, assuming that the depth-sizing uncertainty behaves according to a normal distribution. Subsequent to that time, a detailed review of the UT Performance Demonstration qualification dataset maintained by EPRI was performed in support of this assessment. Specifically, data on UT depth-sizing measurement uncertainty (reported flaw depth versus true flaw depth) was examined for ASME Section XI Appendix VIII qualification efforts for Supplement 10 and Supplement 2 piping welds with the UT depth sizing performed from the ID surface. As described in Section 3.1.3 below, the detailed examination of this dataset was performed to investigate (1) the validity of the assumption made below that the measurement uncertainty follows a normal distribution, and (2) the implications of the actual set of measurement errors used by the Performance Demonstration program to calculate and report RMS error on the conclusions of this assessment. Note that changes to this assessment document for Rev. 1 to reflect these additional assessments and make a few minor clarifications are indicated by a double line in the right-hand margin.

## 2 *Background*

### 2.1 Requirements for Large-Bore Butt Welds in PWR Primary System Piping Not Fabricated with Alloy 82/182

ASME Section XI, Table IWB-2500-1, Examination Category B-F and Examination Category B-J, provides inspection requirements for visual, volumetric, and surface inspections of piping butt welds in the primary system that are not made of Alloys 82 and/or 182. Such welds are not considered to be susceptible to primary water stress corrosion cracking (PWSCC). Table IWB-2500-1 generally requires that the large-bore butt welds in the primary system piping not fabricated with Alloy 82/182 be examined using volumetric and surface techniques during each 10-year in-service inspection interval. However, subject to NRC approval, alternative inspection requirements may be applied for such locations on the basis of a risk-informed inspection program for piping implemented by the licensee (per ASME Section XI Appendix R). The volumetric examination requirements of Section XI including those for piping butt welds are

addressed by ultrasonic examinations meeting the requirements of Section XI Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems."

## 2.2 Requirements for Large-Bore Butt Welds in PWR Primary System Piping Fabricated with Alloy 82/182

ASME Code Case N-770-1 [1] provides alternative inspection requirements for visual, volumetric, and surface inspections of piping butt welds in the primary system that are made of Alloys 82 and/or 182, which are considered to be susceptible to PWSCC.* The majority but not all of the dissimilar metal butt weld locations in PWR primary piping systems were fabricated using Alloy 82/182; stainless steel welds were used to join dissimilar base alloys in some cases. This code case has been made mandatory by the US NRC through regulation 10 CFR 50.55a(g)(6)(ii)(F), subject to the conditions detailed in this regulation. The inspection requirements including inspection frequencies for Alloy 82/182 piping and nozzle butt welds were previously defined in Revision 1 of MRP-139 [3]. MRP-139, Revision 1 and an ASME document [2] form the technical basis for the requirements of N-770-1. The volumetric examination requirements of N-770-1 are addressed by ultrasonic examinations meeting the requirements of Section XI Appendix VIII, "Performance Demonstration for Ultrasonic Examination Systems."

Code Case N-770-1 includes specific categories to address inspection methods and frequencies for piping Alloy 82/182 dissimilar metal weld (DMW) locations both unmitigated and mitigated against PWSCC. N-770-1 includes Inspection Items A-1, A-2, and B for unmitigated welds and Inspection Items D and E to address butt welds mitigated with stress improvement with or without welding. Item D covers the case of uncracked butt welds while Item E covers the case of cracked butt welds (i.e., with PWSCC type indications connected to the inside surface). The two currently available stress improvement methods are the Mechanical Stress Improvement Process (MSIP™), which is performed without welding, and Optimized Structural Weld Overlay (OWOL), which also credits reinforcement of the pressure boundary with PWSCC-resistant material.†

The NRC regulation 10 CFR 50.55a(g)(6)(ii)(F)(2) authorizes that "welds that have been mitigated by MSIP™ may be categorized as Inspection Items D or E, as appropriate, provided the [performance] criteria in Appendix I of the code case have been met." Use of Inspection

* An update of N-770-1 (Code Case N-770-2, June 9, 2011) has been approved by ASME, but the version that is currently made mandatory by the NRC regulations will remain in effect until the next NRC final rule is issued in 2013 or 2014.

† Water jet peening, fiber laser peening, and laser shock peening are additional mitigation methods under consideration that result in a layer of compressive residual stress at the wetted surface.

Items D or E for welds treated by OWOL currently requires application-specific review and approval by NRC. Code Case N-754 [25] was recently approved by ASME defining requirements for the design of OWOLs, including the life of the overlay.

For these stress improvement methods, the basic volumetric inspection requirement following mitigation of an uncracked DMW (Item D) is a single examination within 10 years following mitigation,* followed by a program of periodic inspections in which the component is placed into a population to be examined on a sample basis, provided that no indications of cracking are found. The basic volumetric inspection requirement following mitigation of a cracked DMW (Item E) is a single examination during the first or second refueling outage following application of stress improvement, followed by a program of periodic inspections in which the component is placed into a population to be examined on a sample basis, provided that no indications of crack growth or new cracking are found.†

## 2.3 Depth-Sizing Error Requirement for Volumetric Examinations of Piping Butt Welds

The depth-sizing requirement for DMWs (including Alloy 82/182 butt welds) and austenitic stainless steel welds in PWR primary piping is defined in Appendix VIII of ASME Section XI using the RMS error for a performance demonstration:

$$RMS = \left[ \frac{\sum_{i=1}^{n} (m_i - t_i)^2}{n} \right]^{1/2} \qquad [1]$$

where

$RMS$ = root mean square (RMS) error
$m_i$ = measured flaw size
$t_i$ = true flaw size
$n$ = number of flaws measured

The required RMS value is 0.125 inch per Appendix VIII (Supplements 2 [4], 10 [5], and 14 [6]), or the alternative requirements of ASME Code Case N-695 [7] or N-696 [8], as applicable. Since 2002, the nuclear power industry has attempted to qualify personnel and procedures for

* The NRC regulation 10 CFR 50.55a(g)(6)(ii)(F)(9) modifies the timing of the follow-up examination to be "no sooner than the third refueling outage and no later than 10 years following stress improvement application."
† The NRC regulation 10 CFR 50.55a(g)(6)(ii)(F)(8) adds the condition that "welds mitigated by optimized weld overlays in Inspection Items D and E are not permitted to be placed into a population to be examined on a sample basis and must be examined once each inspection interval."

this depth-sizing requirement for ultrasonic examinations performed from the inside surface of dissimilar metal and austenitic stainless steel butt welds in PWR piping. Four domestic and international inspection vendors have demonstrated a capability to depth-size flaws, but to date none of them has achieved an RMS error of 0.125 inch. Repeated efforts have been made over time to reduce the depth-sizing uncertainty for UT exams from the weld ID, including advances in probe design, electronics, and software. These efforts have demonstrated the impracticality of obtaining the RMS error of 0.125 inch given the challenges of weld geometry, rough surfaces, multiple materials, and microstructural anisotropies. The largest demonstrated flaw sizing RMS error of the four vendors for DMWs (i.e., Supplement 10) is 0.224 inch ([13], [33]),* and for austenitic stainless steel piping welds (i.e., Supplement 2) is 0.367 inch [33]. It is noted that the required RMS error of 0.125 inch was originally based on the depth-sizing error that was achievable for ultrasonic examinations of BWR piping welds in the 1980s, and that there is no specific technical requirement satisfied by the 0.125-inch error value.

## 2.4 Proposed Depth-Sizing Procedures in Lieu of RMS Error Requirement of Appendix VIII Supplements 2, 10, and 14 and Code Cases N-695 and N-696

Given the impracticality of achieving the 0.125-inch RMS error value in the subject locations from the weld ID, the industry developed an alternative approach in which a quantity equal to the difference between the actual RMS error and an RMS error of 0.125 inch is added to the measured depth:

$$m_{adj} = m + \left(RMS - 0.125\text{ in.}\right) \quad [2]$$

where

$m$ = measured flaw size
$m_{adj}$ = adjusted flaw size to be applied in flaw assessments
$RMS$ = actual RMS error for applicable Appendix VIII supplement

The intention of this proposed procedure is to bias the measured value upward to account for the increased measurement uncertainty versus an idealized examination satisfying the RMS error requirement. This proposed alternative was submitted to the NRC by some individual licensees in relief requests (e.g., [10], [11], and [12] are for one such relief request). In the past, utility relief requests proposing this alternative approach have been accepted by the NRC pursuant to 10 CFR 50.55a(a)(3)(i) and 10 CFR 50.55a(g)(6)(i) (e.g., [13]). However, recently the NRC

* Of the four vendors, the largest demonstrated flaw sizing RMS error for Supplements 10 and 2 combined (i.e., Supplement 14) is 0.245 inch [33]. This value is similar to, and less than 10% greater than, that for Supplement 10 alone (0.224 inch).

staff has suggested another alternative approach to the depth-sizing issue in which a quantity equal to twice the actual RMS error is added to the measured depth [14]:

$$m_{adj} = m + 2 \times RMS \quad [3]$$

Specifically, this alternative is suggested for qualification specimen diameters from 27 through 29 inches and wall thickness between 2.5 through 2.9 inches for Supplements 2 and 10.

Using a simple statistical approach, the practical effects of these two proposed alternatives (equations [2] and [3]) are assessed below.

# 3 Effect of Alternatives to RMS Depth-Sizing Error Requirement of Section XI Appendix VIII

Indications of flaws that are detected in DMWs and other butt welds in primary system piping must be dispositioned by repair, replacement, mitigation, or acceptance/evaluation for continued service. The replacement and often the repair option remove the indication from the subject component. However, the mitigation and acceptance/evaluation options require the licensee to consider the depth of the flaw indication determined by NDE. The effect on the MSIP™ and OWOL mitigation methods is assessed in Sections 3.1 and 3.2, respectively. The discussion in Sections 3.1 and 3.2 is specific to depth sizing of flaws connected to the inside surface of dissimilar metal butt welds (addressed by Supplement 10) because the MSIP™ and OWOL methods are used to mitigate PWSCC of Alloy 82/182 piping butt welds. The effect on acceptance/evaluation of indications of flaws detected in piping butt welds, especially unmitigated locations, for continued service is assessed in Section 3.3. In Section 3.3, the discussion is broadened to address the effect of depth-sizing error in the context of dissimilar metal butt welds (addressed by Supplement 10) and wrought austenitic stainless steel butt welds (addressed by Supplement 2) in PWR piping.

## 3.1 Implications for Mechanical Stress Improvement Process (MSIP™) to Mitigate Large-Bore Alloy 82/182 Dissimilar Metal Butt Welds in PWR Piping

The MSIP™ method ([15] through [24]) was originally introduced in the nuclear power industry as a mitigation method for BWR piping subject to cracking mechanisms such as IGSCC. The MSIP™ method mitigates SCC by introducing a permanent compressive residual stress field on the inside surface of the DMW by way of mechanical squeezing. The process redistributes the "as-welded" tensile residual stresses, resulting in compressive axial and hoop residual stresses on

the ID surface extending to about the inner 50% of the wall thickness ([17], [18], and [20] through [24]).

As a prerequisite for crediting MSIP™ mitigation, there is a standard requirement that an examination be performed showing that there are no crack indications on the ID surface deeper than 30% of the wall thickness or having a total circumferential extent greater than 10% of the circumference ([3], [15], [16], [17], and [19]). The requirement that any flaws have a depth no greater than 30% of the wall thickness ensures that such flaws are effectively mitigated by the process, considering factors such as the uncertainty in the flaw depth, the uncertainty in the depth of the compressive residual stress zone, and the effect of operating load stresses. Use of MSIP™ to repair a flaw deeper than 30% of the wall thickness would require an application-specific calculation that addresses these specific factors and shows that the pre-existing flaw will be effectively repaired.

The practical effect of the two alternatives for adjustment of the measured depth is illustrated in Figure 1. This figure shows the cumulative distribution function (CDF),* i.e., uncertainty distribution, for the true flaw depth under three different assumptions:

(1) a hypothetical UT depth sizing resulting in a measured flaw depth of 30% of the wall thickness for an examination with an RMS error of 0.125 inch (labeled as "Code" in Figure 1),

(2) a UT depth sizing for a process having the maximum RMS error of 0.224 inch, with a measured depth of 0.651 inch (26.04% of wall), resulting in an adjusted depth of 0.651 + 0.099 = 0.750 inch, or 30% of the wall thickness, per the industry-proposed alternative (Equation [2]) (labeled as "Industry Alternative" in Figure 1), and

(3) a UT depth sizing for a process having the maximum RMS error of 0.224 inch, with a measured depth of 0.302 inch (12.08% of wall), resulting in an adjusted depth of 0.302 + 2×0.224 = 0.750 inch, or 30% of the wall thickness, per the recent NRC alternative (Equation [3]) (labeled as "NRC Alternative" in Figure 1).

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* The cumulative distribution function of Figure 1 describes the probability that a flaw reported to have a depth from the ID of 30% of the wall thickness (after any adjustment under the industry or NRC alternative) has in actuality a depth less than or equal to the value shown on the x-axis.

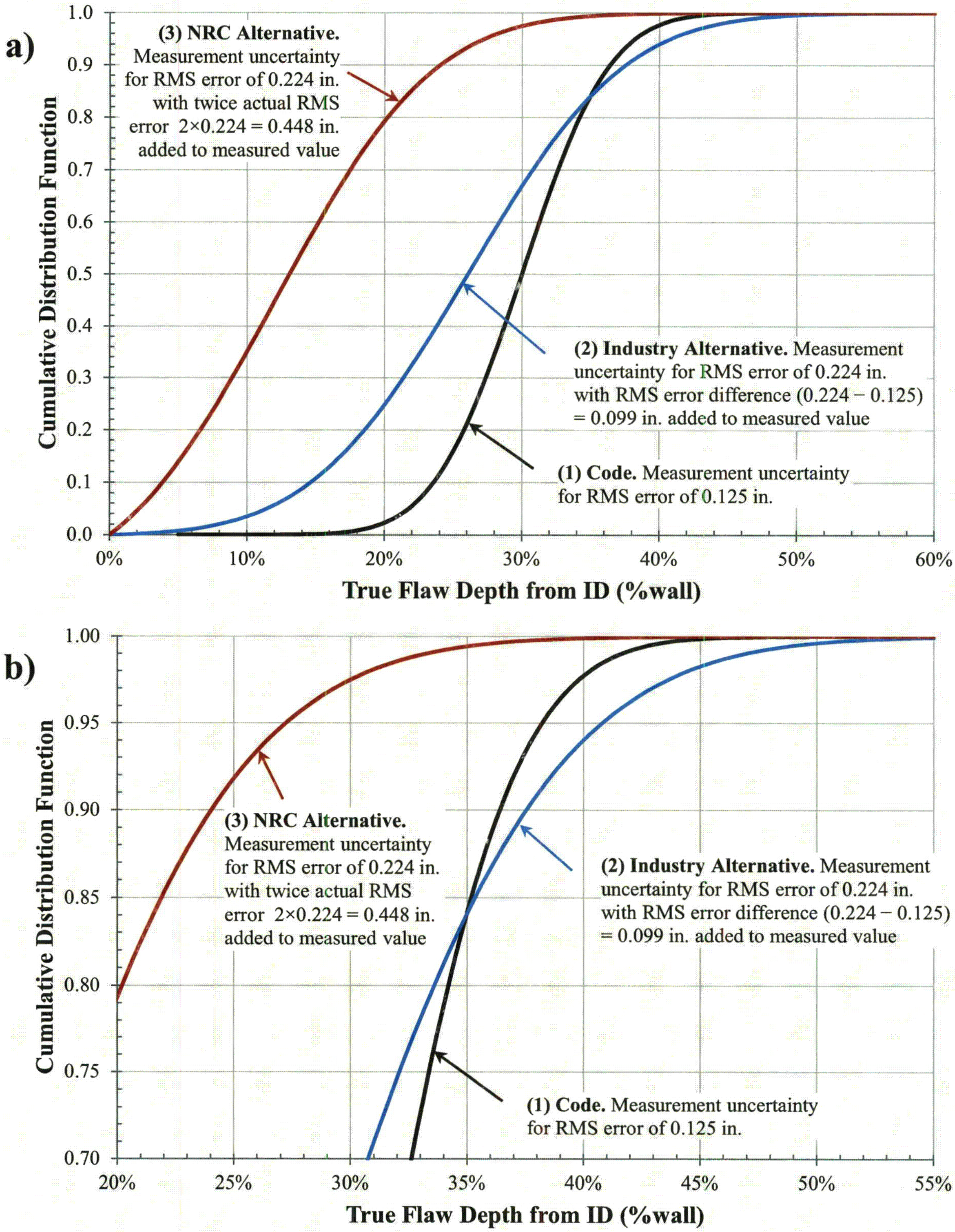


**Figure 1.** Supplement 10 Dissimilar Metal Butt Welds — Uncertainty for Flaw Depth Reported to Be 30%tw for 2.5-inch Wall Thickness: (a) Full Range of CDF, (b) Plot for CDF > 0.7

The upper portion (a) of Figure 1 illustrates the complete distribution function in each case, while the lower portion (b) of Figure 1 compares the upper tails of the distributions in greater detail. In Figure 1, the wall thickness is assumed to be 2.5 inches because this is the lower bound thickness in the range from 2.5 to 2.9 inches cited above [14], thus maximizing the relative depth error as a percentage of wall thickness. In addition, the uncertainty in flaw depth is assumed to be normally distributed in each case, as is commonly assumed to describe measurement error. (As discussed below in Section 3.1.3, the validity and effect of this assumption was assessed through detailed examination of the relevant UT qualification data.) Finally, each distribution function shown in Figure 1 was truncated at a depth of 0% of the wall thickness, so the probability of the actual flaw depth being less than or equal to 0% is zero.* This is a standard statistical approach that is applied when the assumed distribution extends beyond the range of physically meaningful values. The truncation was performed as follows:

$$CDF_{trunc}(\text{flaw depth}) = \frac{CDF(\text{flaw depth}) - CDF(0)}{1 - CDF(0)} \qquad [4]$$

Thus, in each of the three cases, the reported flaw depth would be at the 30% limit of acceptability for mitigation by MSIP™. A comparison of the second (2) or third (3) curve in Figure 1 with the first (1) curve illustrates how the adjustment in the reported depth tends to balance the effect of increased RMS error. For example, the adjustment of adding 0.099 inch to the measured depth effectively shifts the second (2) curve to the left by 4% of the assumed 2.5-inch wall thickness. This shifting brings the upper tail of the second (2) curve into approximate alignment with the upper tail of the first (1) curve, with the two curves indicating the same cumulative probability level for an actual flaw depth of 35% of the assumed wall thickness.

### 3.1.1 Assessment of Industry-Proposed Alternative

A comparison of the curve for the industry-proposed alternative (2) with the hypothetical curve meeting the 0.125-inch RMS error requirement (1) shows that the industry-proposed alternative is a reasonable approach in which most of the uncertainty distribution for the actual examination is conservatively bounded by the distribution for the idealized case meeting the RMS error requirement. The upper tail of the distribution for the industry-proposed alternative extends only modestly beyond the upper tail for the idealized case, and there is an 84% probability that the

* The truncation step in Figure 1 had a negligible effect on the first (1) and second (2) curves. The effect of the truncation on the third (3) curve was to reduce the cumulative probability at a depth of 0% from about 0.09 to zero. This had a negligible effect on the upper tail of the third (3) curve.

industry-proposed approach produces a conservative result versus the idealized case meeting the Appendix VIII depth-sizing RMS error requirement:[*,†]

$$\begin{aligned}
&P\left[\left(t_{RMS}-m_{adj}\right)<\left(t_{0.125}-m\right)\right]\\
&=P\left[\left[\left(m+z\sigma_{RMS}\right)-\left(m+\sigma_{RMS}-\sigma_{0.125}\right)\right]<\left[\left(m+z\sigma_{0.125}\right)-m\right]\right]\\
&=P\left[z\left(\sigma_{RMS}-\sigma_{0.125}\right)<\left(\sigma_{RMS}-\sigma_{0.125}\right)\right]\\
&=P\left[z<1\right]\\
&=0.84
\end{aligned} \qquad [5]$$

where

| | | |
|---|---|---|
| $m$ | = | measured flaw size |
| $m_{adj}$ | = | adjusted flaw size to be applied in flaw assessments |
| $t_{RMS}$ | = | true flaw size distribution per ultrasonic examination with actual RMS error |
| $t_{0.125}$ | = | true flaw size distribution per hypothetical ultrasonic examination with RMS error of 0.125 in. |
| $z$ | = | normal standard deviate |
| $\sigma_{RMS}$ | = | true flaw size standard deviation per ultrasonic examination with actual RMS error |
| $\sigma_{0.125}$ | = | true flaw size standard deviation per hypothetical ultrasonic examination with RMS error of 0.125 in. = 0.125 in. |

In the context of an MSIP™ application to an Alloy 82/182 DMW with crack indications, it is concluded that the alternative proposed by industry is an appropriate method to account for the impracticality of achieving the RMS error of 0.125 inch. Moreover, it is recognized that in the unlikely event that a flaw with an adjusted depth of 30% of wall were to have a true depth such that it was not effectively mitigated by MSIP™, then it is highly likely that potential would be identified by the follow-up ultrasonic examination required by N-770-1 during the first or second refueling outage following the MSIP™ application. That result would trigger flaw evaluation per IWB-3640 [30], as well as additional examinations during subsequent refueling outages or repair/replacement of the indication. Finally, it is also noted that, as shown in MRP-140 [32], leak-before-break behavior is predominant given circumferential cracking of large-bore PWR piping because of its relatively high diameter-to-thickness ratio. Thus, in the unlikely event of extensive growth of the indication or indications sized prior to MSIP™ application, then there is high confidence the resulting leakage would be detected and acted upon while still maintaining a large margin against unstable flaw propagation.

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[*] In this calculation, the same $z$-value is applied for the actual and idealized cases since the comparison is between an actual examination and its idealized case, and not between two distinct, independent examinations.

[†] As shown, the calculated probability of 0.84 is independent of the actual values for the RMS error for the actual and idealized examinations. For an actual RMS error different than 0.224 inch, the calculated probability would still be 0.84 under the alternative proposed by industry.

### 3.1.2 Assessment of Recent Alternative Suggested by NRC Staff

A comparison in Figure 1 of the curve for the recent alternative suggested by NRC staff (3) with the hypothetical curve meeting the 0.125-inch RMS error requirement (1) shows that the NRC alternative is clearly uncharacteristic of the distribution for the idealized case. For essentially all CDF values, the NRC alternative represents a large and overly conservative bias versus the idealized case meeting the RMS error requirement. Similar to the above case for the industry-proposed alternative, the probability that the recent NRC alternative produces a conservative result versus the idealized case is assessed as follows:

$$\begin{aligned} &P\left[\left(t_{RMS}-m_{adj}\right)<\left(t_{0.125}-m\right)\right] \\ &=P\left[\left[\left(m+z\sigma_{RMS}\right)-\left(m+2\sigma_{RMS}\right)\right]<\left[\left(m+z\sigma_{0.125}\right)-m\right]\right] \\ &=P\left[z\left(\sigma_{RMS}-\sigma_{0.125}\right)<2\sigma_{RMS}\right] \\ &=P\left[z<\frac{2\sigma_{RMS}}{\sigma_{RMS}-\sigma_{0.125}}\right] \end{aligned} \qquad [6]$$

For the case of the maximum actual RMS error for Supplement 10 of 0.224 inch, there is a 99.99970% probability that the recently suggested NRC approach produces a conservative result versus the idealized case meeting the RMS error requirement:

$$\begin{aligned} &P\left[z<\frac{2\sigma_{RMS}}{\sigma_{RMS}-\sigma_{0.125}}\right] \\ &=P\left[z<\frac{2(0.224)}{0.224-0.125}\right] \\ &=P\left[z<\frac{0.448}{0.099}\right] \\ &=P\left[z<4.525\right] \\ &=0.9999970 \\ &=1-3.0\times10^{-6} \end{aligned} \qquad [7]$$

In the context of an MSIP™ application to a DMW with crack indications, it is concluded that the alternative recently suggested by NRC staff is unnecessarily conservative and inappropriate as a method to account for the impracticality of achieving the RMS error of 0.125 inch. The overly conservative nature of the NRC alternative would unnecessarily preclude the crediting of MSIP™ mitigation for indications that have a measured (pre-adjustment) depth as small as 12% of the wall thickness (for a wall thickness of 2.5 inch). This 12% figure compares to 26% for the

maximum allowable measured (pre-adjustment) depth for crediting of MSIP™ mitigation under the industry alternative discussed above. This conclusion regarding the NRC alternative [14] extends more generally to the situations for OWOL mitigation and disposition of flaws for continued service given their similarities to the situation for MSIP™ application as is apparent from the discussions below.

### 3.1.3 Examination of Actual UT Depth-Sizing Qualification Data

Subsequent to release of Rev. 0 of this assessment, a detailed review of the UT Performance Demonstration qualification dataset maintained by EPRI was performed in support of this assessment. Specifically, data on UT depth-sizing measurement uncertainty (reported flaw depth versus true flaw depth) was examined for ASME Section XI Appendix VIII qualification efforts for Supplement 10 and Supplement 2 piping welds with the UT depth sizing performed from the ID surface. Depth-sizing measurement uncertainty data were considered for attempts to qualify vendor procedures and personnel for which the results met the alternative depth-sizing error requirement based on RMSP (RMS error calculated as a percentage of the wall thickness). The absolute RMS error values for the attempts to qualify vendor procedures meeting the alternative RMSP requirement are the vendor RMSE values reported to licensees by the Performance Demonstration Program.

The qualification data were examined to investigate the implications of the actual set of measurement errors on the statistical assessment described above in Section 3.1.1. Several different subsets of the qualification data were considered for this purpose:

- Separate datasets covering Supplement 10 welds (456 data points total) and Supplement 2 welds (169 data points total)
- Datasets for flaws with circumferential and axial orientations versus datasets for circumferential flaws only
- Datasets for all inspection vendors pooled together, and datasets for each of the four individual inspection vendors that met the alternative depth-sizing error (RMSP) requirement
- Datasets for qualification of personnel and procedures versus datasets for procedure qualifications only

The detailed examination of the UT depth-sizing qualification data produced the following key results:*

- The various datasets of measurement error were generally reasonably described by normal distributions, with correlation coefficients between 0.92 and 0.99 for the set of measurement errors versus the corresponding values predicted by the fitted cumulative normal distribution (i.e., standard QQ-plot approach). However, rigorous statistical normality checks such as the standard chi-squared test were generally not satisfied for the various datasets examined. Such behavior differing from ideal normal behavior should be expected for the empirical data given the range of test blocks, NDE equipment, and personnel. The greatest deviation from normality tended to be observed at the tails of the observed distributions of depth-sizing error for a small number of greatest measurement errors in each set.

- A standard statistical median ranking of each dataset was performed in order to produce empirical cumulative distributions. This approach facilitated direct assessment of the implications of each dataset without the need to assume any particular type of fitting distribution. Each of these empirical distributions was adjusted per the industry alternative in which the difference between the applicable RMS error and 0.125 inch is added to each reported depth value. These adjusted empirical distributions showed a similar level of conservatism (i.e., potential likelihood and degree of undersizing the true flaw depth) as compared to the simplified statistical assessment illustrated above in Figure 1 assuming unbiased normal distributions:

  - The empirical results based on the actual qualification data generally showed an increased probability that the industry alternative produces a conservative result versus the idealized case meeting an RMS error of 0.125 inch. This probability level was observed to be about 95% for the overall Supplement 10 or Supplement 2 dataset versus 84% for the assessment in Figure 1 (and 82% for the assessment in Figure 2) assuming normal distributions, indicating increased confidence in a conservative result versus the idealized case meeting an RMS error of 0.125 inch.

  - Excepting cases where the flaw is sufficiently deep that it would with high confidence be reported to be too deep (i.e., true depth greater than 50% wall) to meet the MSIP™ repair limit, only a small increase in the maximum undersizing error was observed

* In recognition of the data security requirements for Performance Demonstration Program qualification data, manipulations of these data cannot be illustrated in this document.

(i.e., at the extreme tail of the distributions) for the approach using empirical distributions versus the approach assuming a normally distributed error distribution.

- The potential for undersizing was observed to be somewhat greater for relatively deep flaws (i.e., true depth greater than 50% wall). This behavior reflects the increased potential of depth-sizing error for flaws having a tip relatively far from the ID surface, where the UT probe is located. However, such deep flaws would reliably be reported not to meet the MSIP™ depth repair limit.

- As mentioned above, the potential for significant undersizing was found to be relatively modest for the cases that are most relevant to MSIP™ being used as a repair method, i.e., for flaws reported to be up to 30% deep. Thus, a comparison of reported flaws depths adjusted using the proposed industry alternative versus the corresponding true flaw depths showed high confidence that a flaw with an actual depth approaching 50% of the wall thickness would not be reported to be at or under the 30% depth repair limit.

Based on these results, the conclusion in Section 3.1.1 that the industry approach is an acceptable alternative to the Appendix VIII RMSE requirement is reinforced. Examination of the detailed measurement uncertainty data from the qualification efforts buttresses the conclusion obtained from the simplified statistical assessment presented above. This conclusion extends more generally to the situations for OWOL mitigation and disposition of flaws for continued service given their similarities to the situation for MSIP™ application as is apparent from the discussions below.

## 3.2 Implications for Optimized Structural Weld Overlay (OWOL) to Mitigate Large-Bore Alloy 82/182 Dissimilar Metal Butt Welds in PWR Piping

As introduced in Section 2 above, OWOL mitigation is another method that is available to mitigate PWSCC of Alloy 82/182 DMWs in PWR primary system piping. Per NRC regulation, application-specific review and approval is required by NRC for the treated welds to be categorized as mitigated welds with regard to the inspection requirements of N-770-1. The technical basis for OWOL mitigation, along with that for full structural weld overlay (FSWOL), is documented in MRP-169, Revision 1-A [26], which was approved in 2010 by NRC [27] after an NRC-sponsored technical assessment including detailed modeling of the weld residual stresses associated with the OWOL process [28]. The OWOL mitigation credits the outer 25% of the wall thickness beneath the weld reinforcement in its structural design, and is effective through the combination of improved stress in the inner portion of the susceptible material and introduction of PWSCC-resistant overlay material.

In 2011, Code Case N-754 [25] was approved by ASME defining requirements for the design of OWOLs, including the life of the overlay. N-754 includes requirements for the use of OWOL as a "repair OWOL" in which the process is applied over material with flaws with a depth from the inside surface no greater than 50% of the pre-OWOL wall thickness.* N-754 specifies that a crack growth calculation be performed to determine the life of the overlay based on the time for the detected flaws to grow to a depth of 75% of the original pre-OWOL wall thickness. This crack growth calculation considers the residual stresses that exist prior to application of the OWOL, and crack growth by both PWSCC and fatigue must be evaluated. The analyzed life of the overlay is applied in Code Case N-770-2† to limit the interval between volumetric examinations to the analyzed life, but no more than 10 years.

Thus, the implications of uncertainty in the pre-OWOL flaw indication depth with regard to the effectiveness of OWOL mitigation are similar to the effect of uncertainty in the initial flaw depth for evaluations of PWSCC flaws for continued service as discussed below in Section 3.3. As discussed below in Section 3.3, the standard ASME approach to crack growth calculations is to apply best-estimate type inputs except for the structural factors that are used to assess structural integrity for the end point of the crack growth calculation. As shown above, the depth-sizing adjustment proposed by the industry biases the best-estimate initial flaw depth so that there is an 84% probability that the industry-proposed approach produces a conservative result versus a hypothetical depth sizing meeting the requirement for an RMS error of 0.125 inch, and the uncertainty distribution for the true flaw depth per the industry-proposed alternative is reasonably characteristic of the uncertainty distribution for this hypothetical case.

The flaw depth of 75% of the pre-OWOL wall thickness defines the end point of the crack growth calculation of overlay life, meaning that at the end of overlay life the predicted flaw depth remains outside of the outer 25% of the original wall credited in the OWOL structural design. Furthermore, there is a requirement in N-754 that the OWOL design exhibit minimum structural factors (albeit reduced from the full standard ASME structural margins) under the assumption of circumferential cracking extending around the entire circumference of the item and 100% through the susceptible material.

Given these conservatisms inherent in the OWOL design and the standard ASME approach of using the best-estimate initial flaw size as input to crack growth calculations, it is concluded that

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* Under the industry alternative, the 50% through-wall flaw depth limit for repair OWOL corresponds to a measured (pre-adjustment) depth of about 46% for large-bore Alloy 82/182 piping butt weld locations. Under the NRC alternative, the corresponding limit for the measured (pre-adjustment) depth is as small as 32% of the wall thickness.

† ASME Code Case N-770-2 was approved by ASME on June 9, 2011, but N-770-1 is the version currently made mandatory by the NRC regulations.

the alternative approach proposed by the industry is appropriate to address the impracticality of meeting the required depth-sizing RMS error of 0.125 inch. This conclusion is reinforced by the detailed examination of UT qualification data described in Section 3.1.3. Moreover, it is recognized that both N-770-1 and N-770-2 require a follow-up ultrasonic examination of the treated item during the first or second refueling outage following the OWOL application. If crack growth is detected during this follow-up examination, then additional actions are required such as applying flaw acceptance standards and performing repeat volumetric examinations during multiple refueling outages. Thus, this follow-up examination requirement is another significant source of conservatism with regard to repair OWOL.

## 3.3 Implications for Disposition of Flaws Detected in Large-Bore Dissimilar Metal and Wrought Austenitic Stainless Steel Butt Welds in PWR Piping

The majority but not all of the dissimilar metal butt weld locations in PWR primary piping systems were fabricated using Alloy 82/182, with stainless steel welds used to join dissimilar base alloys in some cases. Unlike stainless steel weld material, Alloy 82/182 welds are susceptible to PWSCC. Thus, the flaw disposition procedures of Section XI require that planar surface-connected flaws that are in contact with the reactor coolant and are detected in Alloy 82/182 weld material be evaluated considering growth due to fatigue and PWSCC. For such flaws detected in stainless steel weld material, growth due to fatigue only must be considered. Hence, flaw disposition is assessed separately below for dissimilar metal (Supplement 10) piping welds, including Alloy 82/182 welds, and for wrought austenitic (Supplement 2) piping welds, which were fabricated using stainless steel weld material.

### 3.3.1 Disposition of Flaws Detected in Large-Bore Dissimilar Metal Butt Welds in PWR Piping (Supplement 10)

The required procedure for evaluation and acceptance of planar surface-connected flaws in contact with the reactor coolant environment in large-bore Alloy 82/182 dissimilar metal butt welds is defined by ASME IWB-3640 [30]. In this procedure the flaw size at the end of the assumed evaluation period is calculated based on deterministic equations of SCC and fatigue crack growth. The acceptable flaw size at the end of the assumed evaluation period is determined through a flaw stability calculation in which structural factors greater than one are applied to operating loads, and the end-of-evaluation-period flaw depth is limited to 75% of the wall thickness. In this deterministic approach, best-estimate type inputs including for the initial flaw size based on NDE are used except for the use of structural factors on the operating loads.

The conservative nature of the flaw disposition procedure is due to the use of the structural factors and the 75% limiting flaw depth.

In the particular case of the PWSCC crack growth rate equation recommended in C-8511 of Section XI for evaluation of flaws in Alloy 82/182 butt welds, this deterministic crack growth rate equation was developed in MRP-115 [31] to bound the log-mean behavior of 75% of the test welds included in the worldwide set of laboratory data considered. The 75$^{th}$ percentile was chosen in MRP-115 in recognition that welds showing a higher crack growth rate than average (normalized for temperature, loading, and environment) are also more likely to initiate flaws.

As shown above, the depth-sizing adjustment proposed by the industry biases the best-estimate initial flaw depth so that there is an 84% probability that the industry-proposed approach produces a conservative result versus a hypothetical depth sizing meeting the requirement for an RMS error of 0.125 inch. Given that best-estimate type inputs except for the structural factors are used in the ASME procedure, it is concluded that the industry-proposed alternative approach is appropriate for dissimilar metal piping welds including those fabricated using Alloy 82/182 to address the impracticality of meeting the required depth-sizing RMS error of 0.125 inch. This conclusion is reinforced by the detailed examination of UT qualification data described in Section 3.1.3.

Moreover, it is recognized that in the unlikely event that the actual end-of-evaluation-period flaw size were to exceed the size calculated in the flaw evaluation, then the result with high probability would be a stable flaw deeper than 75% of the wall thickness or a stable through-wall flaw detected via evidence of leakage. This conclusion is supported by MRP-140 [32], which demonstrates that leak-before-break behavior is predominant given circumferential cracking of large-bore PWR piping because of its relatively high diameter-to-thickness ratio.*

### 3.3.2 Disposition of Flaws Detected in Large-Bore Wrought Austenitic Stainless Steel Butt Welds in PWR Piping (Supplement 2)

The above discussion also generally applies to the case of disposition of flaws detected in large-bore austenitic stainless steel butt welds in PWR piping. In this case, PWSCC crack growth does not apply and ASME IWB-3514 [29] can be used to accept relatively shallow planar flaws that are in contact with the reactor coolant. However, ID surface-connected planar flaws that are deeper than permitted by IWB-3514.1 that are left in service must be evaluated using IWB-3640.

* MRP-140 presents calculation results for PWSCC crack growth of through-wall circumferential flaws. The limiting case within the set of large-bore Alloy 82/182 piping butt welds is for a reactor vessel outlet nozzle. For this case, a period of 11.9 years is calculated for growth from a circumferential length corresponding to the technical specification leak rate limit of 1 gpm to the critical flaw length.

Again, the conservatism in the procedure is due to the use of the structural factors and the 75% limiting flaw depth. Other inputs to the procedure including the initial flaw size based on NDE are generally best-estimate type inputs.

Similar to Figure 1, Figure 2 shows the depth-sizing uncertainty distributions based on the maximum demonstrated flaw sizing error for Supplement 2 (0.367 inch [33]) for the same three cases considered in Figure 1. In Figure 2, the point of intersection between the curves representing the industry alternative (2) and the idealized case (1) is at a cumulative probability level of about 84%. This is the same cumulative probability value as for the intersection point in Figure 1 for these two cases because this point of intersection is independent of the actual RMS error value as shown in equation [5].*

Thus, as in the case of Supplement 10, the industry alternative in the case of Supplement 2 results in an uncertainty distribution for flaw depth that with a probability of about 84% bounds the idealized case meeting the Appendix VIII depth-sizing error requirement. Comparing Figure 1 and Figure 2, the upper tail for the largest achieved RMS error for Supplement 2 extends further toward greater depths than that for Supplement 10. This is judged to be acceptable recognizing that the Supplement 2 welds are not susceptible to PWSCC, and that flaw growth by fatigue is generally small in comparison to that by PWSCC in the Alloy 600/82/182 materials that are susceptible to PWSCC (see, e.g., [34] and [35]). Hence, it is concluded that the alternative approach proposed by the industry is also appropriate for wrought austenitic Supplement 2 piping welds to address the impracticality of meeting the required depth-sizing RMS error of 0.125 inch. This conclusion is reinforced by the detailed examination of UT qualification data described in Section 3.1.3.

Figure 2 also facilitates a comparison of the effect of the NRC alternative (3) versus the idealized case (1) given the largest demonstrated RMS error for Supplement 2. For nearly all CDF values, the NRC alternative represents a large and overly conservative bias versus the idealized case meeting the RMS error requirement. As calculated using equation [6], for the case of the maximum actual RMS error for Supplement 2 of 0.367 inch, there is a 99.88% probability that the recently suggested NRC approach produces a conservative result versus the idealized case meeting the RMS error requirement:†

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* As for Figure 1, the distributions in Figure 2 were truncated for depths below 0% of wall thickness. This resulted in a modest shifting of the second (2) curve in Figure 2, reducing the cumulative probability at a depth of 0% from about 0.08 to zero. This shifting of the second (2) curve lowered the actual intersection point with the first (1) curve slightly down to a probability of 82%. The truncation for the third (3) curve in Figure 2 reduced the cumulative probability at a depth of 0% from about 0.48 to zero.

† The truncation step in Figure 2 caused a slight shifting of the upper tail of the third (3) curve, lowering the actual intersection point of the third (3) and first (1) curves in Figure 2 to a probability of about 99.7% rather than 99.88%.

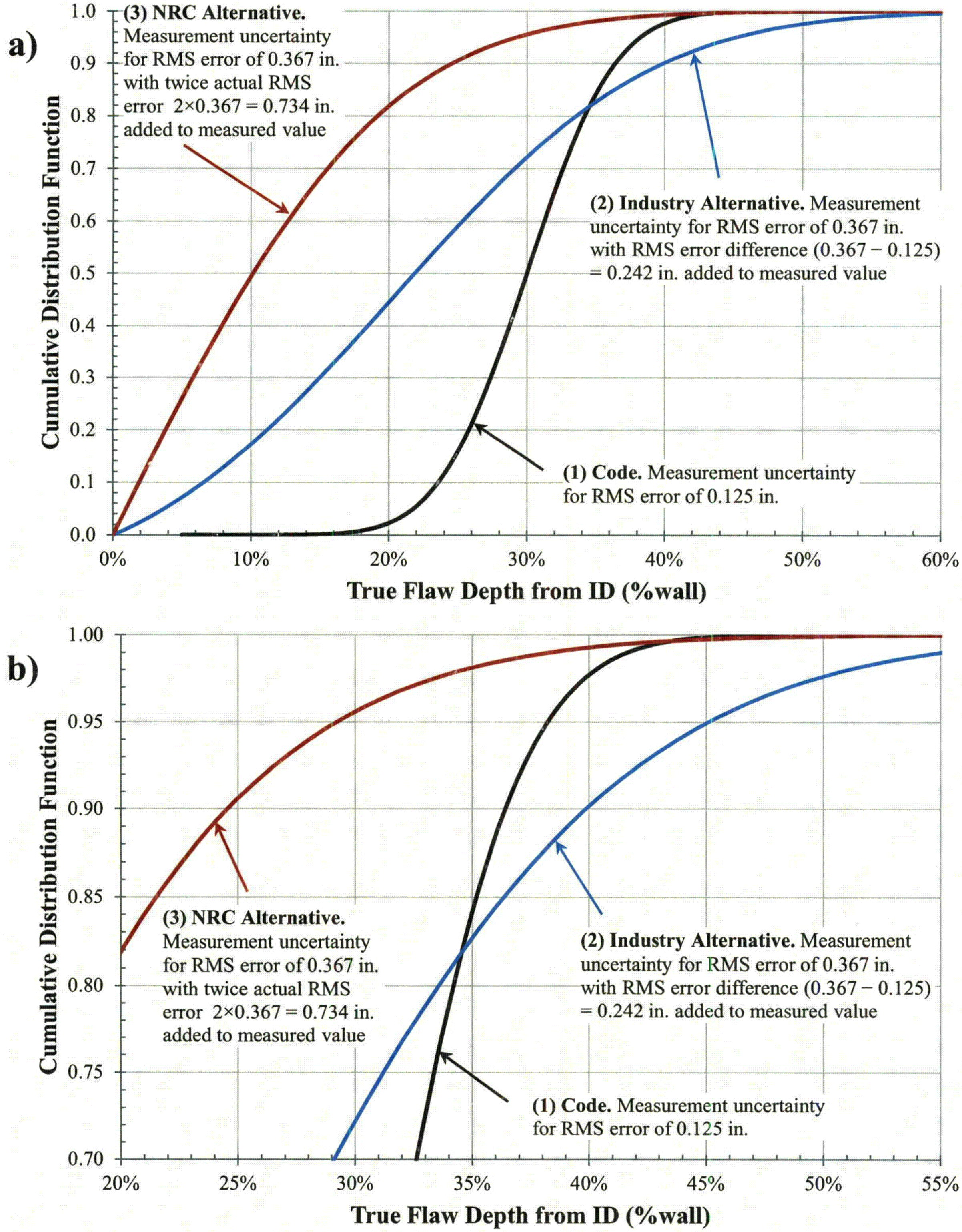


Figure 2. Supplement 2 Wrought Austenitic Stainless Steel Butt Welds — Uncertainty for Flaw Depth Reported to Be 30%tw for 2.5-inch Wall Thickness: (a) Full Range of CDF, (b) Plot for CDF > 0.7

$$\begin{aligned}
&P\left[z<\frac{2\sigma_{RMS}}{\sigma_{RMS}-\sigma_{0.125}}\right] \\
&=P\left[z<\frac{2(0.367)}{0.367-0.125}\right] \\
&=P\left[z<\frac{0.734}{0.242}\right] \\
&=P[z<3.033] \\
&=0.9988
\end{aligned} \quad [8]$$

In the context of disposition of flaws in both Supplement 2 and 10 piping welds, it is concluded that the alternative recently suggested by NRC staff is unnecessarily conservative and inappropriate as a method to account for the impracticality of achieving the RMS error of 0.125 inch. It is noted that under the NRC alternative, the adjustment to the measured flaw depth may be as large as about 29% of the wall thickness, compared to as large as about 10% of the wall thickness under the industry alternative.

## 4 Conclusion

Compliance with the 0.125-inch depth-sizing RMS error required by ASME Code Section XI Appendix VIII (Supplements 2, 10, and 14), or the alternative requirements of ASME Code Case N-695 or N-696, as applicable, is impractical for ultrasonic examinations from the ID surface. The alternative proposed by the industry to add the difference between the required RMS error value of 0.125 inch and the actual RMS error value for the selected inspection vendor, in conjunction with the use of appropriate acceptance standards, continues to provide reasonable assurance of structural integrity of the subject welds. This conclusion is supported by the statistical considerations presented in this assessment, and reinforced by a detailed examination of the UT Performance Demonstration Program qualification data for UT depth-sizing from the weld ID. In summary, the alternative which has been customarily used is an appropriate means of addressing the impracticality of the RMS error requirement for large-bore Alloy 82/182 and austenitic stainless steel butt welds in PWR piping.

The alternative recently suggested by NRC staff of adding twice the applicable RMS error to the measured depth is unnecessarily conservative as clearly seen by comparison of the depth size uncertainty distribution for this alternative with that for the idealized case meeting the Appendix VIII depth-sizing error requirement. While the NRC approach would grossly mischaracterize flaw depths in an effort to address the actual RMS error achieved, the industry proposal

conservatively treats the large majority of indications without unnecessarily distorting the measured flaw depth.

## 5 References

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