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May 8, 2012

10 CFR 50.55a

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

SUBJECT: Duke Energy Carolinas, LLC (Duke Energy)
McGuire Nuclear Station Unit 2
Docket Number 50-370
Relief Request 12-MN-003

By letter dated January 3, 2012, Duke Energy submitted Relief Request (RR) 12-MN-001 for the use of an alternative to the examination requirements of American Society of Mechanical Engineers Code, Section XI. On February 27, 2012, the Nuclear Regulatory Commission (NRC) staff electronically informed Duke Energy of the need to supplement this RR prior to acceptance for technical review. On March 16, 2012, the NRC met with the industry to discuss the root mean square error concern associated with this type of relief. By letter dated March 22, 2012, Duke Energy withdrew this RR. On April 17, 2012, Duke Energy held a conference call with the NRC to obtain further clarification.

Pursuant to 10 CFR 50.55a(g)(5)(iii), Duke Energy hereby submits replacement RR 12-MN-003 requesting approval for use of an alternative depth-sizing qualification for volumetric examinations of the reactor vessel hot leg and cold leg nozzle-to-pipe dissimilar metal welds performed from the inside surface during the McGuire Unit 2 fall 2012 refueling outage.

The basis for the proposed RR for McGuire Unit 2 is provided in Enclosure 1 to this letter. Duke Energy requests approval of this RR by August 15, 2012 to support the inspection of these welds.

If you have any questions or require additional information, please contact P. T. Vu at (980) 875-4302.

Sincerely,

Regis T. Repko

Regis T. Repko

Enclosure

A047
NRR

xc:

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Enclosure 1

Relief Request for
Alternative Depth Sizing Criteria

Duke Energy
McGuire Unit 2

Proposed Relief Request 12-MN-003
Per 10 CFR 50.55a(g)(5)(iii)

1.0 Background

Pursuant to 10 CFR 50.55a(g)(5)(iii), Duke Energy Carolinas, LLC (Duke Energy) is submitting a request for relief from certain requirements of the ASME Code, Section XI, at McGuire Nuclear Station Unit 2 (MNS 2) due to impracticality. Duke Energy also proposes an alternative which supports the examination of Reactor Vessel (RV) hot leg nozzle-to-pipe and cold leg nozzle-to-pipe dissimilar metal welds performed from the inside surface during the next MNS 2 scheduled refueling outage.

2.0 ASME Code Components Affected

Category and System Details:

Code Class:	Class 1
System Welds:	Reactor Coolant System (NC)
Examination Category:	Category R-A for the dissimilar metal welds
Code Item Number:	R1.11 for RV dissimilar metal nozzle-to-pipe welds

MNS 2	Description	Size	Nozzle to Pipe SS-CS DM Weld No.	Drawing
NC Pipe	Hot Leg RV Nozzle - A Loop	Nominal 29.0" ID with 2.33" min wall	2RPV-W15-SE / 2NC2F1-1	Figure 1
NC Pipe	Hot Leg RV Nozzle - B Loop	Nominal 29.0" ID with 2.33" min wall	2RPV-W16-SE / 2NC2F2-1	Figure 1
NC Pipe	Hot Leg RV Nozzle - C Loop	Nominal 29.0" ID with 2.33" min wall	2RPV-W17-SE / 2NC2F3-1	Figure 1
NC Pipe	Hot Leg RV Nozzle - D Loop	Nominal 29.0" ID with 2.33" min wall	2RPV-W18-SE / 2NC2F4-1	Figure 1
NC Pipe	Cold Leg RV Nozzle - A Loop	Nominal 27.5" ID with 2.21" min wall	2RPV-W11-SE / 2NC2F1-8	Figure 2
NC Pipe	Cold Leg RV Nozzle - B Loop	Nominal 27.5" ID with 2.21" min wall	2RPV-W12-SE / 2NC2F2-8	Figure 2
NC Pipe	Cold Leg RV Nozzle - C Loop	Nominal 27.5" ID with 2.21" min wall	2RPV-W13-SE / 2NC2F3-8	Figure 2
NC Pipe	Cold Leg RV Nozzle - D Loop	Nominal 27.5" ID with 2.21" min wall	2RPV-W14-SE / 2NC2F4-8	Figure 2

Component Materials:

1. Nozzles: ASME SA-508 Class 2
2. First Butter Layer: Filler Material Type 309S
3. Remaining Butter Layers: Filler Material Type 308L
4. ID & OD Nozzle Buttering Weld Inlays: Alloy 82/182
5. Buttering-to-Pipe Weld: Filler Material Type 308
6. Pipe: Type ASME SA-351 Grade CF8A

3.0 Applicable Code Edition and Addenda

MNS 2 is currently in the third 10-year Inservice Inspection (ISI) interval that began on March 1, 2004 and is scheduled to end on July 15, 2014. The ASME Boiler and Pressure Vessel Code (ASME Code) of record is the 1998 Edition of Section XI through the 2000 Addenda. Section XI Code Case N-695 (Qualification Requirements for Dissimilar Metal Piping Welds) is referenced in the ISI program. This Code Case is listed in Regulatory Guide 1.147, Rev. 16, Table 1- "Acceptable Section XI Code Cases".

4.0 Applicable Code Requirement

The RV nozzle butt welds are part of the MNS 2, Risk-Informed Inservice Inspection (RI-ISI) program. The MNS 2 RI-ISI program has been developed in accordance with Westinghouse Owners Group (WOG) Application of Risk-Informed Method to Piping Inservice Inspection, Topical Report WCAP-14572, Revision 1-NP-A and WCAP-14572, Revision 1-NP-A, Supplement 2, Revision 1-NP-A. The MNS 2 RI-ISI program has been implemented in accordance with Relief Requests 01-005 and 01-008. The RV nozzle butt welds on the hot and cold legs are dissimilar metal welds and are required to be volumetrically examined.

The volumetric examinations are to be conducted in accordance with ASME Section XI, Appendix VIII, Supplement 10, 1998 Edition through 2000 Addenda. Duke Energy is using NRC-approved Code Case N-695 which provides an alternative to Appendix VIII, Supplement 10 requirements for the qualification requirements of dissimilar metal piping welds.

The specific Code Case N-695 requirement for which relief is requested pertains to the depth sizing qualification requirements for performance demonstration of ultrasonic examination systems for dissimilar metal piping welds.

> Code Case N-695
>
> 3.3 Depth-Sizing Test:
>
> "(c) Examination procedures, equipment, and personnel are qualified for depth-sizing when the RMS error of the flaw depth measurements, as compared to the true flaw depths, do not exceed 0.125 in. (3 mm)."

5.0 Impracticality of Compliance

To date, although qualified for detection and length sizing on these welds, the examination vendors have not met the established root mean square error (RMSE) requirement for depth sizing (0.125 inch) when examining from the inside diameter (ID).

Duke Energy's examination vendor has an RMSE of 0.189 inch instead of the required 0.125 inch. EPRI Policy/Procedure 03-01 describes the criteria for issuing documentation of depth sizing errors that exceed the 0.125 inch RMS Appendix VIII requirement.

6.0 Proposed Alternative and Basis for Use

Duke Energy proposes to use an alternative through-wall depth sizing criteria for dissimilar metal welds that are examined from the ID. Examinations of these components will be performed during the next scheduled refueling outage at MNS 2 scheduled for September, 2012.

Duke Energy proposes to use a contracted examination vendor that has demonstrated the ability to depth size flaw indications with an RMSE of 0.189 inch instead of the 0.125 inch required for Code Case N-695. In the event an indication is detected that requires depth sizing, the difference between the required RMSE and the proposed demonstrated RMSE will be added to the measured through-wall extent for comparison with applicable acceptance criteria. If the examination vendor demonstrates an improved depth sizing RMSE prior to the examination, the excess of that improved RMSE over the 0.125 inch RMSE requirement, if any, will be added to the measured value for comparison with applicable acceptance criteria.

If reportable flaws are detected and they are determined to be connected to the piping ID surface during the inservice examination of the RV inlet and outlet dissimilar welds that are covered by this relief, Duke Energy will supply the flaw evaluations performed along with the measured flaw size as determined by ultrasonic testing (UT) for review. Duke Energy will perform the required evaluations to determine if the flaw(s) are inner diameter surface breaking. In the case of the examinations planned for September 2012, the examination vendor deploys eddy current in order to make these determinations. If a flaw is detected and depth sizing is required, the inner profile of the weld, pipe, and nozzle in the region at and surrounding the flaw, and an estimate of the percentage of potential surface areas with UT probe lift-off will be provided. The flaw degradation mechanism will be determined with aid from the initial and additional nondestructive examination (NDE) data collected.

Duke Energy does not intend to use the NRC-proposed RMSE adjustment which is twice the RMSE to be added to the depth of the measured flaw. Duke Energy believes that the proposed adjustment is overly conservative. Duke Energy understands that an industry assessment regarding this issue is forthcoming and has reviewed the statistical results which support the basis for the requested RMSE adjustment proposed in this relief request. Attachment 1 to this relief request provides the industry assessment.

The obtained procedure RMS sizing error provided in this relief request is a more appropriate value to use for an evaluation of a through-wall flaw measurement. The analyst, while not qualified in accordance with Supplement 10, has demonstrated a capability of sizing to the same secondary acceptance criteria that is used to judge the procedure's performance. Additionally, the data obtained to provide a through-wall depth measurement of reported flaws in the field is encoded and stored digitally. The data can be sent easily to various analysts for concurrent flaw through-wall measurement evaluation. Subsequently, the reported size of a flaw is not determined by a single analyst; the data is reviewed by several analysts and potentially outside consultants prior to supplying a final through-wall measurement determination used in the flaw analysis.

Individual depth sizing error performance is not considered relevant because it is not provided to the utility or the vendor by the administrator of the qualification program. The qualification program provides the RMSE for the procedure and a list of candidates who have met or exceeded the procedures' RMSE performance value. MNS 2 is using the same vendor as Braidwood 1 and 2.

Duke Energy inspects the welds from the ID instead of the OD because of significant dose savings and the physical constraints associated with the sand box configuration.

Pursuant to 10 CFR 50.55a(g)(5)(iii), this relief request is being submitted due to the impracticality of meeting the 0.125 inch RMS value required by Code Case N-695. The subject welds will be examined by procedures, personnel and equipment qualified by demonstration in all aspects except depth sizing. For depth sizing, the proposed addition of the difference between the qualified and demonstrated sizing errors to any flaw that is required to be sized provides an acceptable level of quality and safety.

7.0 Duration of Proposed Alternative

The proposed alternative to the ASME Code is applicable for the remainder of the third 10-year ISI interval at MNS 2.

8.0 Precedents

A similar alternative request has been approved for use at Joseph M. Farley Nuclear Plant, Unit 1 in NRC letter dated April 4, 2012 (ADAMS Accession No. ML12094A281) and at Braidwood Station, Units 1 and 2 in NRC letter dated April 19, 2012 (ADAMS Accession No. ML12108A123).

9.0 References

(1) 1998 Edition through 2000 Addenda, ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components."

(2) 1998 Edition through 2000 Addenda, ASME Code, Section XI, Appendix VIII, Supplement 10.

(3) Code Case N-695, Qualification Requirements for Dissimilar Metal Piping Welds, Section XI, Division 1.

(4) EPRI Policy/Procedure Directive 03-01: Criteria for Issuing Documentation of Depth Sizing Errors That Exceed the 0.125-inch RMS Appendix VIII Criteria.

(5) EPRI Letter dated August 28, 2009 addressed to Mr. Dave Zimmerman, "Summary of WESDYNE International, LLC Supplements 2 & 10 Depth Sizing Results Obtained from the Inside Surface."

10.0 Figures

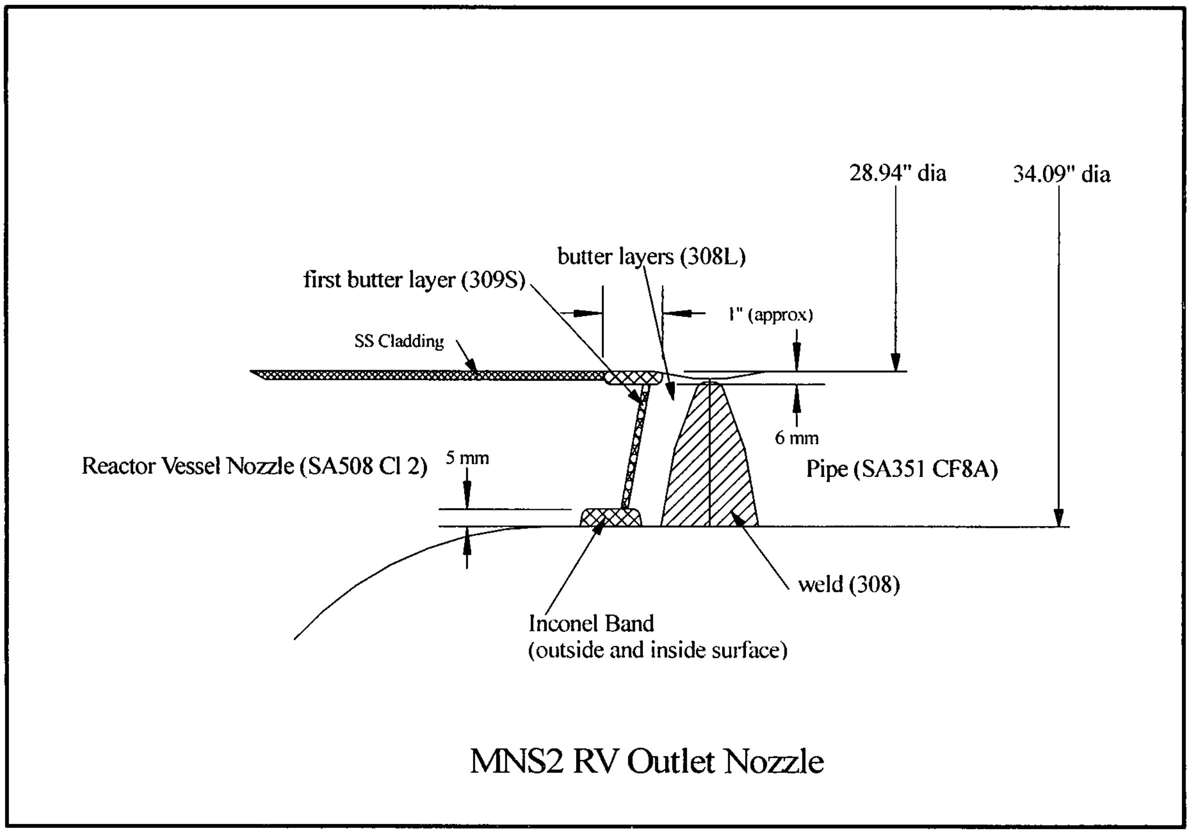

Figure 1

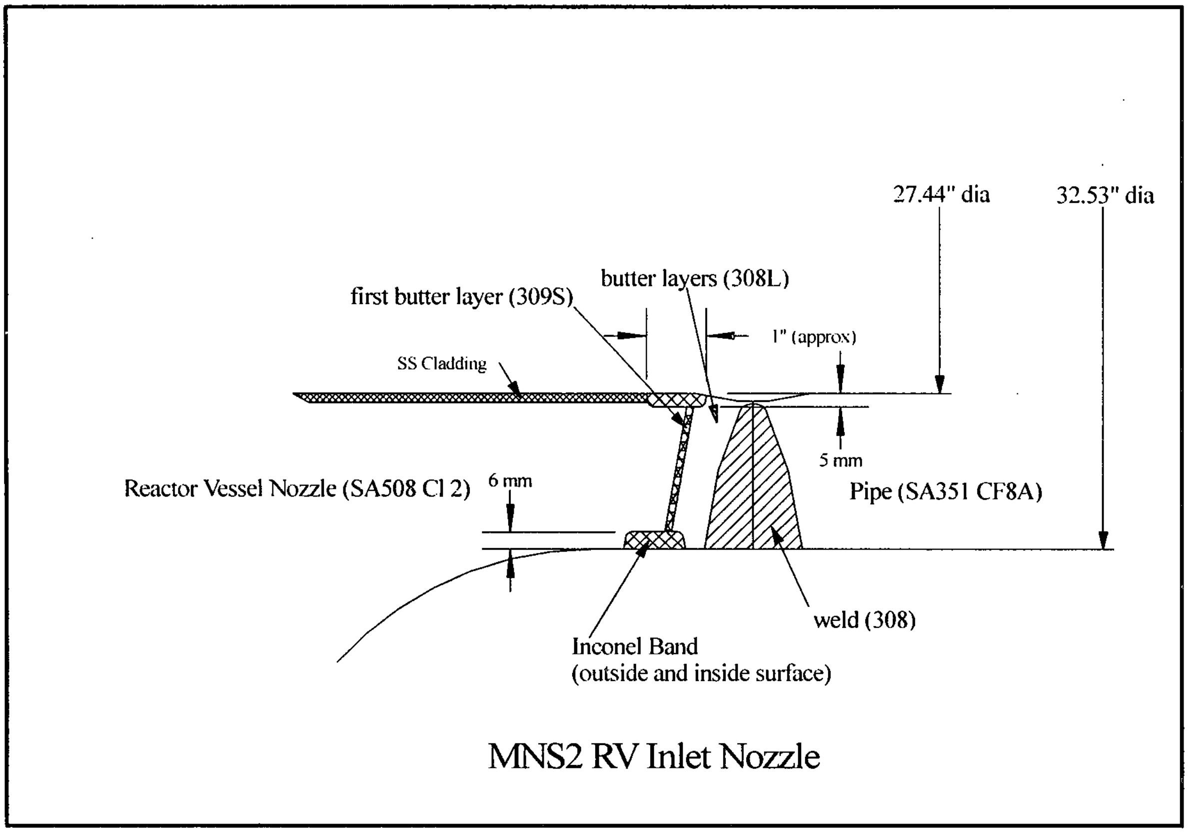
27.44" dia
32.53" dia
butter layers (308L)
first butter layer (309S)
1" (approx)
SS Cladding
5 mm
Reactor Vessel Nozzle (SA508 Cl 2)
6 mm
Pipe (SA351 CF8A)
weld (308)
Inconel Band
(outside and inside surface)
MNS2 RV Inlet Nozzle

Figure 2

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, MRP 2012-011, March 8, 2012

ELECTRIC POWER RESEARCH INSTITUTE

MRP Materials Reliability Program MRP 2012-011
(via email)

March 8, 2012

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

Subject: Inside Surface Flaw Depth Sizing Uncertainty Root Mean Square (RMS) Error Treatment

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 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 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 has been proposed by the NRC staff during the review of recent utility relief requests on this subject.

The attachment to this letter presents an assessment of the procedure that has customarily been used by industry to account for the RMS error achieved during qualification for large-bore Alloy 82/182 and austenitic stainless steel butt welds in PWR piping. Also considered in this assessment is an alternative approach that was recently suggested by NRC staff. A simple statistical approach is taken 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 are specifically considered.

This letter report is being provided 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.

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

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

Cc: Craig Harrington, EPRI

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

1 Introduction

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.

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 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.

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

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."

* 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.

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 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.‡

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* 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.

† 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."

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:

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

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 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. Of the four vendors, the largest demonstrated flaw sizing RMS error for DMWs (i.e., Supplement 10) is 0.224 inch ([13], [33]).* Of the four vendors, the largest demonstrated flaw sizing RMS error 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.

* 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).

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, 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:

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

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 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.

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),

* 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.

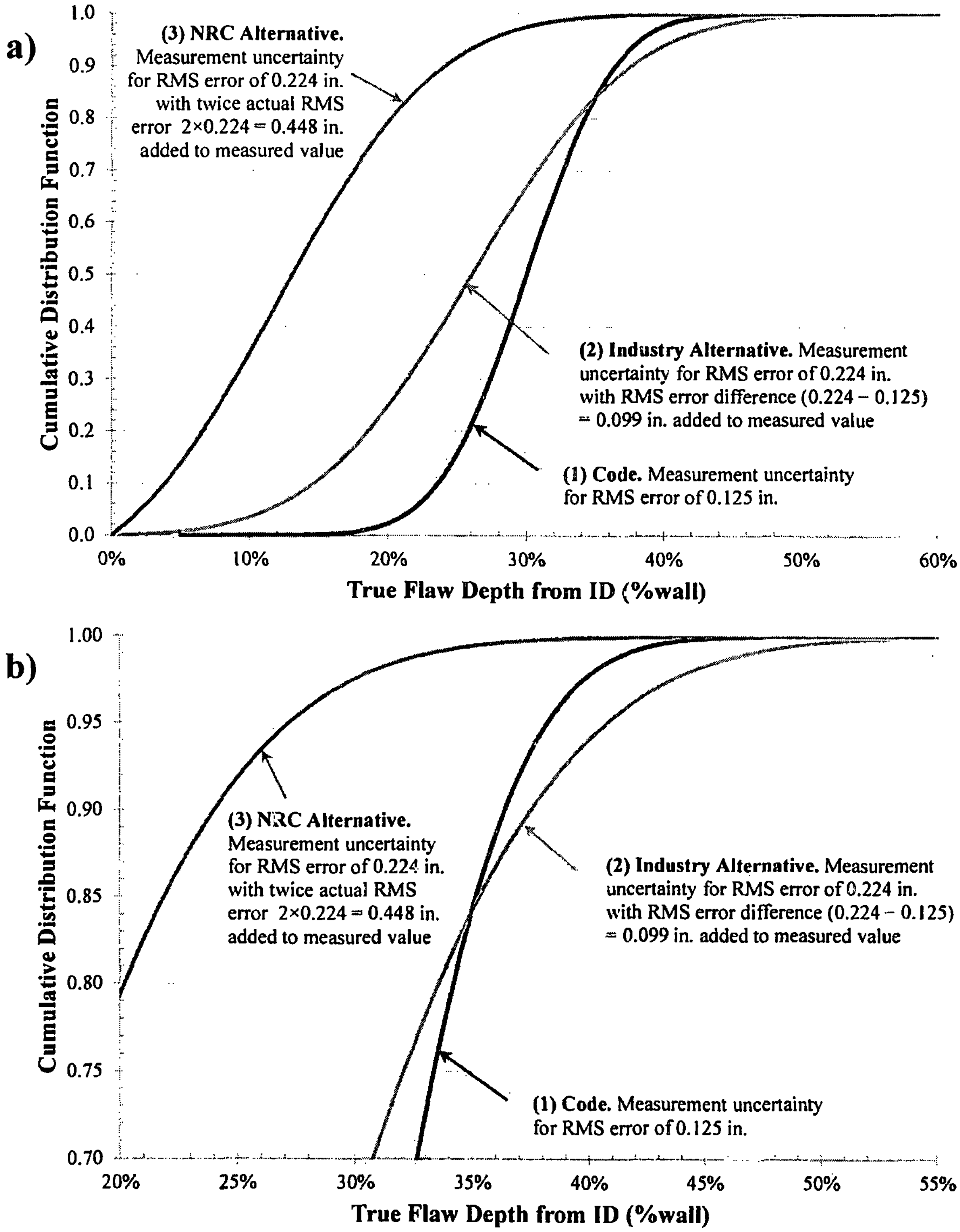

Figure 1. **Supplement 10 Dissimilar Metal Butt Welds — Uncertainty for Flaw Depth Reported to Be 30%tw for 2.5-inch Wall Thickness: (a) Full Range of CDF, (b) Plot for CDF > 0.7**

(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).

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. 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:

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

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

* 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.

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 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
σ_{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

* 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.

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.

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:

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

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:

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

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.

3.2 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

* 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.

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 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. 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.

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* 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.

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 75th 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.

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. 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].†

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* 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.

† 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.

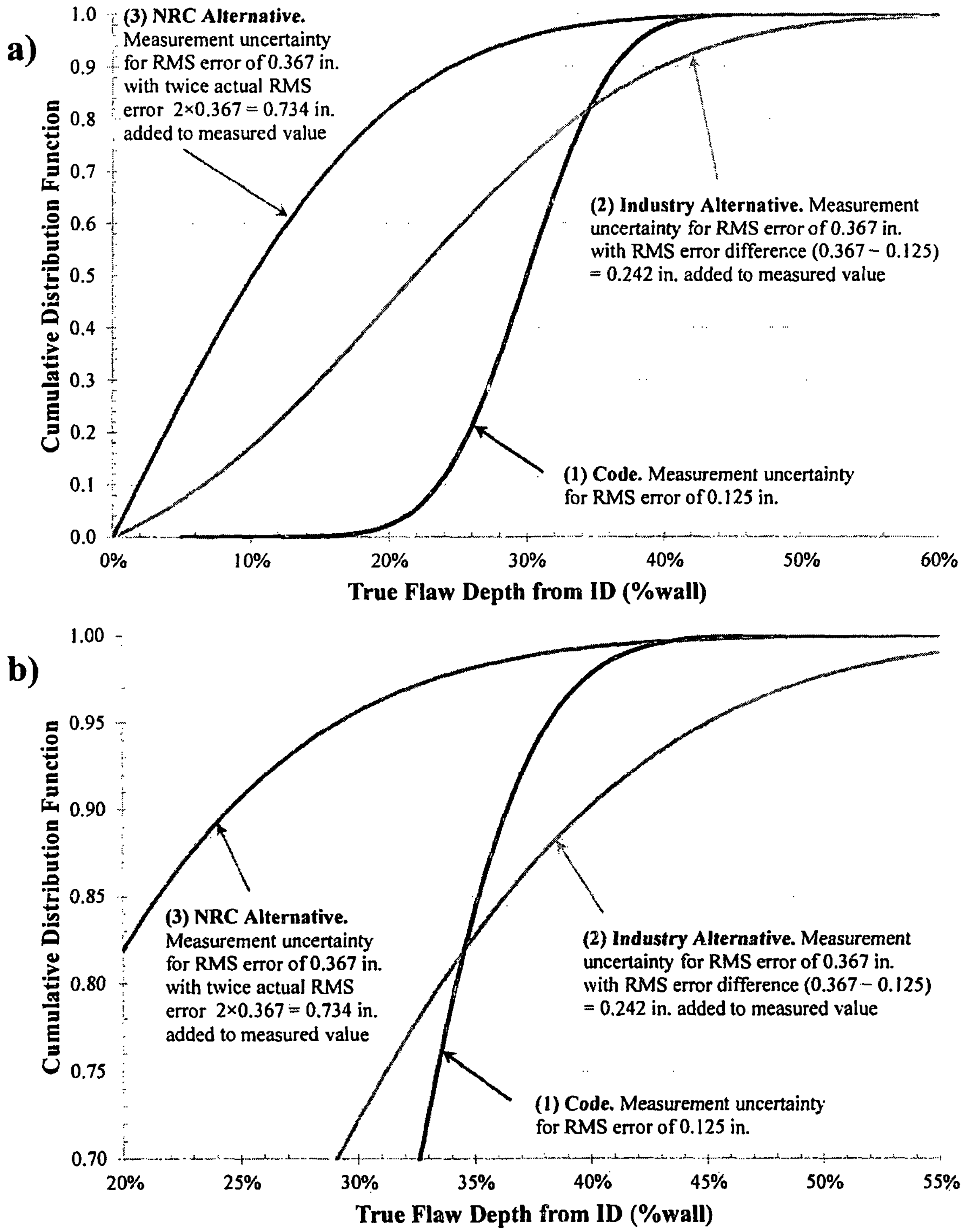

Figure 2. Supplement 2 Wrought Austenitic Stainless Steel Butt Welds — Uncertainty for Flaw Depth Reported to Be 30%tw for 2.5-inch Wall Thickness: (a) Full Range of CDF, (b) Plot for CDF > 0.7

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.

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:*

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

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 the 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.

* 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%.

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, up to the maximum demonstrated RMS value of 0.224 inch, in conjunction with the use of appropriate acceptance standards, continues to provide reasonable assurance of structural integrity of the subject welds. 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.

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