June 27, 2008

MEMORANDUM TO: John A. Grobe, Associate Director
for Engineering and Safety Systems
Office of Nuclear Reactor Regulation

FROM: Michele G. Evans, Director **/RA/**
Division of Component Integrity
Office of Nuclear Reactor Regulation

SUBJECT: RETIRED PRESSURIZER NOZZLE ALLOY 82/182 WELD INSPECTIONS IN FEBRUARY AND MARCH 2008

The purpose of this memorandum is to (1) summarize the events associated with potential primary water stress corrosion cracking (PWSCC) of dissimilar metal butt welds related to the inspections of the nozzle welds in a retired pressurizer, (2) discuss the regulatory concerns that arose from the initial inspection of the retired pressurizer nozzle welds, (3) discuss the decision made on March 7, 2008, to request that industry develop additional information to address those concerns, (4) discuss the follow up activities as a result of this decision, and (5) provide citations for the major documents related to this summary.

INTRODUCTION

PWSCC in dissimilar metal butt welds was first observed in 2000 because of a leaking axially oriented crack at the V.C. Summer plant. Leaks due to PWSCC have occurred in three plants, V.C. Summer in 2000, Tsuruga in Japan in 2003 and Davis Besse in 2008. These leaks have all been due to axial cracks. Indications of cracking both circumferential and axial have been found in numerous plants since 2000. Prior to 2005, inspection of dissimilar metal butt welds was performed under the ASME Code Section XI requirements. In late 2005, the industry implemented an initiative for inspection of dissimilar metal butt welds to be performed on a much more frequent basis than the inspections required by Code. This initiative was developed by the industry Materials Reliability Program and the non-proprietary version is documented in MRP-139, “Primary System Piping Butt Weld Inspection and Evaluation Guideline” [Agencywide Documents Access and Management System (ADAMS) Accession No. ML052150196]. The staff has evaluated the MRP-139 inspection program for managing PWSCC in butt welds and the staff has been monitoring industry’s implementation of this program through NRC regional inspections.

BACKGROUND

On October 13, 2006, the Wolf Creek Nuclear Operating Corporation performed pre-weld overlay inspections using ultrasonic testing (UT) techniques on the surge, spray, relief, and safety nozzle-to-safe end dissimilar metal and safe end-to-pipe stainless steel butt welds. The inspection identified five circumferential indications in the surge, relief, and safety nozzle-to-safe

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end dissimilar metal (DM) butt welds that the licensee attributed to PWSCC [ML063380456] and that were significantly larger and more extensive than previously seen in the industry.

During public meetings with the industry on November 30, 2006 [ML063560371] and December 20, 2006 [ML070330381], the NRC staff presented the results of a fracture mechanics based scoping study that assessed the safety significance of the UT indications found at Wolf Creek. As a result of these analyses [ML071560398], the staff concluded that there may be little or no time margin between the onset of leakage and rupture in pressurizer nozzle DM butt welds containing flaws similar to those found at Wolf Creek.

Over the course of many staff discussions, the staff considered a number of options to assess what regulatory action to take to address this issue. The staff concluded that licensees needed to complete inspections or mitigations of the pressurizer nozzle Alloy 82/182 welds by the end of 2007 and implement interim enhanced leakage monitoring. This decision was based on the judgment that completing the actions by the end of 2007 would provide an appropriate balance of restoring safety margins within a time frame that would avoid compromising weld and inspection quality without placing undue reliance on the compensatory measure of enhanced leakage monitoring. A discussion of the risk-informed process used to recommend this decision is documented at ML070990071. The process used was based on the NRR Office Instruction LIC-504, “Integrated Risk-Informed Decision Making Process for Emergent Issues,” Revision 2, dated February 12, 2007.

In March 2007, the NRC issued Confirmatory Action Letters (CALs) to 40 nuclear power plant licensees with pressurized water reactors (PWR), confirming commitments from those licensees to resolve concerns regarding potential flaws in specific reactor coolant system (RCS) DM butt welds by the end of 2007. The justification to issue CALs is documented in a memorandum dated March 7, 2007, from Michele Evans to John Grobe at ML070660614. (The accession numbers for the enclosures to this memorandum are not cited in the memorandum. The citations for the relevant enclosures to the March 7, 2007 memorandum are Enclosure 2: ML063320131, Enclosure 3: ML063560371, Enclosure 4: ML070330381, and Enclosure 6: ML070160592.) One example of the CALs issued was the CAL sent to Seabrook Station dated March 12, 2007 at ML070610585. The remaining 29 PWR plants had either completed the requisite actions or do not have welds susceptible to these flaws.

Nine of the plants receiving CALs did not have outages scheduled in 2007. These plants committed to accelerate outages into 2007 if the industry was not able to demonstrate an adequate level of safety to the NRC. The nine plants were Braidwood 2, Comanche Peak 2, Diablo Canyon 2, Palo Verde 2, Seabrook, South Texas Project 1, V. C. Summer, Vogtle 1, and Waterford 3.

By letter dated February 14, 2007, the Nuclear Energy Institute indicated that the Electric Power Research Institute (EPRI) Materials Reliability Program (MRP) would be undertaking a task to refine the crack growth analyses pertaining to the Wolf Creek pressurizer DM weld ultrasonic indications. These additional advanced finite element analyses (FEA) were performed to address the NRC staff’s concerns regarding the potential for rupture without prior evidence of leakage from circumferentially oriented PWSCC in pressurizer nozzle welds. The goal of these studies was to demonstrate that PWSCC in pressurizer DM butt welds would progress through-wall and exhibit detectable leakage prior to causing a possible rupture event. These studies reduced unnecessary conservatisms and removed some of the uncertainties in previous analyses.

Industry completed these analyses and documented the results in MRP-216, Revision 1, "Advanced FEA Evaluation of Growth of Postulated Circumferential PWSCC Flaws in Pressurizer Nozzle Dissimilar Metal Welds: Evaluations Specific to Nine Subject Plants" [ML072410235]. These results were provided to the NRC staff by letter dated August 13, 2007.

The NRC staff completed independent analyses to enable the staff to perform an in-depth review and critique of the industry's analyses and to extend the industry's analyses in some key respects. The NRC staff documented its safety assessment on the industry's analyses in an enclosure to a memorandum from Michele Evans to Catherine Haney on September 7, 2007 [ML072430836]. The conclusion of the NRC staff's safety assessment was that there is reasonable assurance that the nine plants addressed by the evaluation could operate safely until their next scheduled refueling outages in the spring of 2008. This conclusion was based on the results of advanced finite element analyses of the fabrication, loading, and postulated flaw growth in the pressurizer nozzle welds. It was concluded that PWSCC in pressurizer DM butt welds of the nine plants analyzed would progress through-wall and exhibit detectable leakage prior to causing a possible rupture event.

INITIAL NOZZLE WELD INSPECTION OF A RETIRED PRESSURIZER

In mid-February 2008, the NRC staff received the results of initial inspections of the nozzles of a retired pressurizer. These initial inspections were provided in MRP 2008-012 [ML080701017]. This pressurizer was removed from service to eliminate the possibility of extended plant outages resulting from cracking associated with the heater sleeves. The pressurizer was donated to NRC for research purposes and the inspections were performed by EPRI to assist in determining the research value of the nozzle welds. These inspections found indications by dye penetrant (PT) and manual-phased array ultrasonic examination (UT). Circumferential and axial indications were found in five of six nozzles. The nozzle welds of most interest were the three safety nozzles. The inspection concluded that these nozzles had 360°, circumferentially-oriented indications with non-uniform depths around the circumference. The deepest indications found were sized at 89% through-wall on the 'A' safety nozzle. The deepest indication found in the 'B' and 'C' safety nozzles were 75% and 69% through-wall, respectively.

Based on this information NRC staff determined that the inspection results needed to be evaluated against the advanced FEA work the staff completed in September 2007 since the advanced FEA formed the basis for the continued operation of plants with pressurizer welds that had not yet been inspected, as mandated by industry guidelines. To help perform such an evaluation, the NRC staff requested that EPRI estimate the flaw profile for safety nozzle 'A' and provide some of the raw UT signals recorded during the inspection. EPRI provided this information to the NRC staff by letter MRP 2008-014, dated March 4, 2008 [ML080670004]. EPRI estimated that the 'A' safety nozzle weld contained a continuous deep indication 360° around the circumference. This reported flaw profile was more severe than any of the predicted flaws in the above-referenced advanced finite element analyses that led to leakage that would be detected with sufficient time for plant shutdown prior to rupture. The flaw profile caused NRC staff to question whether the advanced finite element analyses would still support the spring 2008 pressurizer inspection schedules.

In making a regulatory decision to address the retired pressurizer nozzle weld inspection results, the NRC staff considered three options. Option 1, the base case, would result in no change to existing regulatory and industry programs; i.e., the affected plants would operate until their scheduled spring 2008 outage and inspect or mitigate the affected welds at that time. Option 2 would allow continued operation of the plants for a short time period while NRC staff gathered additional information. Option 3 would require all affected plants to shutdown immediately and not restart until the basis for operation until the spring outages was reestablished or until inspection or mitigation activities were completed. The NRC staff based its regulatory decision on an assessment of the pros and cons of these options using the principles of risk-informed decision making.

On March 7, 2008, the NRC staff concluded that Option 2 was the appropriate decision; the staff judged that it had an appropriate basis to take a short period of time (within a week) to gather information to make a more informed. The initial inspection results were somewhat uncertain given the type of inspection that was performed. More refined inspection was judged to be prudent to reduce some of this initial uncertainty. The NRC staff determined that the questions raised by the March 4, 2008, EPRI letter were safety significant questions and the staff put industry on notice that it was considering regulatory action. A discussion of the risk-informed decision making process used to recommend Option 2 is documented in a memorandum from Michele Evans to Eric Leeds dated June 6, 2008 [ML081580560]. The process used was based on the NRR Office Instruction LIC-504.

DESCRIPTION OF SUBSEQUENT ACTIONS TO MARCH 7, 2008 DECISION

Industry representatives took actions to rapidly put in place a comprehensive inspection effort that consisted of more advanced UT examinations, specifically American Society of Mechanical Engineers (ASME) Code, Section XI, Appendix VIII qualified automated phased array and radiographic testing (RT) examinations, followed a few days later by eddy current testing (ET) examinations. These inspections commenced on March 8, 2008 at the Studsvik-RACE facility in Memphis, the location of the nozzles from the retired pressurizer.

On March 9, 2008 an NRC inspector from Region I and a contracted expert in non-destructive examination, from Pacific Northwest National Laboratory, arrived at the Studsvik-RACE facility in Memphis. A summary of their activities is provided in Enclosure 1 to this memorandum. These NRC representatives immediately began auditing the weld inspection activities by the industry. Their audit included review of the UT inspection procedure, adherence to the UT procedure by the industry inspectors, the validity of the qualification of the inspection procedure by the Performance Demonstrative Initiative (PDI) to ASME requirements, and evaluation of the UT inspection data. The inspectors concluded that the UT procedure was a qualified procedure with one exception noted and addressed below. The NRC representatives verified that the industry inspectors followed the requirements of the UT procedure.

With respect to the qualification of the procedure, the NRC representatives observed that the wedges used to transmit sound beams from the probe transmitters to the weld were not in accordance with the specifications for the UT procedure used to inspect the safety nozzle welds. The wedges were sized for a weld diameter larger than the diameter of the safety nozzle welds and this sizing was outside the limitations specified for the procedure. The industry inspectors noted that the data quality with the oversized wedges was good and continued to scan the welds with this equipment, gathering UT data for evaluation. Subsequently, industry shipped a controlled mockup of the safety nozzle welds to the Studsvik-RACE facility. This mockup contains cracks or crack like reflectors with known sizes that are held as confidential. The mockup was fabricated to use in the qualification of UT procedures, equipment, and personnel.

An inspection of the mockup was performed with the oversized wedge-probe and it was concluded from the results of the inspection of the mockup that the use of the automated phased array UT procedure with the oversized wedge-probe satisfied the criteria specified in the

ASME Code. Based on information provided by industry, the NRC representative concluded that the UT procedure was a qualified procedure in accordance with ASME requirements. Based on the documentation provided by industry and their observations of the industry inspection, the NRC representatives also concluded that the automated phased array UT procedure was properly implemented.

DESCRIPTION OF AUTOMATED PHASED ARRAY INSPECTION AND RESULTS

As recommended in EPRI letter MRP 2008-012, EPRI concluded that a PDI qualified automated phased array UT technique would provide a more accurate profile of any potential degradation in the welds than a PDI qualified manual phased array UT technique. The NRC staff agreed with this conclusion. Phased array ultrasonic inspection is a good technique for detecting critical flaws especially in welds with limited access and difficult microstructures. As with conventional manual ultrasonics, with manual phased array ultrasonics the inspector is physically scanning the weld while looking at the equipment screen and doing data evaluation in real time. Though screen shots of areas of interest can be recorded, all data analysis is done in real time. In comparison with automated (encoded) phased array ultrasonic examination, the weld is scanned and a full set of position encoded ultrasonic data is recorded. This means that the equipment is recording everything that the inspector performing the manual scan was seeing, but each ultrasonic waveform is recorded along with the position information. This is a critical difference between the two methods in that the inspector can go back and carefully process and review the data and create a set of images that enable clearer interpretations of the data. These images include "B", "C" and "D" scans where the "B" scan shows a projected side view of the weld, the "C" scan is shows a projected top view of the weld, and the "D" scan shows a projected end view of the weld. In all three views, the software can project a more three dimensional like profile of the weld on top of the ultrasonic data so that using these views, the inspector can easily visualize and analyze the data (locate and size flaws in the material). Thus, the ability of the automated (encoded) phased array ultrasonic inspection to characterize an indication is superior to that of the manual phased array ultrasonic inspection to provide accurate representations of the flaws in the inspection volume.

The automated phased array UT examinations began on the evening of Saturday, March 8, 2008, and continued into the following week. Each of the St. Lucie pressurizer safety nozzle dissimilar metal welds was inspected. The priority was placed on the ‘A’ safety nozzle weld. The NRC NDE expert contractor and various NRC staff reviewed the UT examination results. The NRC NDE expert contractor was given access at the inspection site to work with the raw recorded data from the inspections. NRC staff had access to draft summary reports and data scans from the inspections. Additional results were communicated during daily teleconferences with EPRI staff at the inspection site and NRC staff and contract staff at the site. The draft summary reports, procedures, personnel certifications, and data scans assessed by NRC representatives in Memphis are listed in Enclosure 1. These reports were left at the facility in Memphis.

On March 13, 2008, the NRC staff held a public meeting with the licensees of the plants with spring outages that had not completed inspections of their pressurizer nozzle welds. The meeting was held to provide an opportunity for stakeholders to understand the results of inspections of the retired pressurizer nozzle welds and the staff concerns regarding whether the advanced finite element analyses would still support the spring 2008 pressurizer inspection schedules. The staff made a presentation to provide an understanding of the background on the issue and the NRC staff questions regarding the initial inspection results. Industry representatives presented a summary of the results of the inspections performed since March 8, 2008, and their conclusions from these inspections. The staff concluded the meeting by indicating that based on the information presented by industry, data independently reviewed on site by NRC representatives, and draft reports received earlier on March 13, 2008, NRC staff would reach its conclusions by the end of the day March 14, 2008. A summary of this meeting is at ML080800024.

On March 13, 2008, EPRI provided to the NRC the draft automated phased array UT examination results summary. This document stated, in part, that the retired pressurizer safety nozzle welds ‘A’, ‘B’ and ‘C’ had multiple embedded fabrication flaws. This document concluded that these fabrication flaws were attributed to slag, porosity, and/or lack of fusion. Also, these indications were found to be clustered as well as individual fabrication flaws. Finally the document concluded that the inspection identified no surface connected flaws. In support of this document on March 13, 2008, EPRI provided a series of UT scans of the inspection data for independent NRC staff and contractor interpretation on site in Memphis.

On March 13, 2008, EPRI also provided to the NRC a draft correlation of the automated phased array UT examination results to the manual phased array UT scans provided in EPRI letter MRP 2008-014. The objective of the correlation was to evaluate the manual phased array UT depth sizing measurements using the manual phased array UT data to determine if any of the reported flaws are connected to inside surface. However, as a direct correlation of the data was not available due to variations between the two techniques, EPRI evaluated the automated data at the same 1-inch intervals around the pipe as used to produce the weld flaw profile shown in the EPRI letter MRP 2008-014. In order to focus data acquisition for the comparison, EPRI identified the similar depth reflector around the same 1-inch intervals for their analysis. According to EPRI’s draft report, for 17 of the 19 points identified in the EPRI letter MRP 2008-014, the correlation shows that the tip signal, the signal from the manual phased array UT used to create the EPRI letter 2008-014 flaw profile through-wall depth, was identified by the automated phased array UT to not be surface connected in the D-scans. For 2 of the 19 points the report notes that the authors were unable to confirm a relevant signal in the area described by the manual phased array UT scan. As manual phased array UT does not have a tracked and precise method of determining location on the weld surface, this conclusion was found by the NRC staff to be reasonable. The draft summary reports that were provided by EPRI and reviewed by NRC staff are contained in an ADAMS package at ML080880002.

NRC staff completed its review of the automated phased array UT results and the correlation of the automated phased array UT examination to the manual phased array UT scans. The NRC staff found that there was sufficient data available to provide reasonable assurance that there were no structurally significant service induced flaws within the retired pressurizer safety nozzle welds ‘A’, ‘B’ and ‘C’. The NRC found that (1) the assumption made in the development of the manual flaw profile that the stacked indications identified in EPRI Letter 2008-012 were connected to the surface and (2) the determination that the flaw profile provided in EPRI letter MRP 2008-014 was potentially due to service induced cracking, while conservative based on the data available, were not supported by the evaluation of the automated phased array UT data.

CONCLUSIONS

The safety question relative to the 9 plants allowed to operate beyond December 31, 2007 due to the results of the advanced FEA was based on the flaw profile provided in EPRI Letter MRP 2008-014 and whether flaws identified in the retired pressurizer were due to service induced cracking. The AFE analyses used detailed plant specific attributes to develop potential service induced flaw propagation profiles for each of the 9 plants. The flaw profile in the EPRI report, MRP 2008-014, which was generated by data from the manual phased array inspection technique, illustrated an indication 360° around the circumference and deep at most locations. This information raised NRC staff questions regarding the continued applicability of the advanced finite element analyses. The NRC finds that the flaw profile provided in MRP 2008-014 and characterized as potential service induced cracking was not supported by the evaluation of the automated phased array UT data. Therefore, the NRC staff concluded that the advanced finite element analyses support the continued operation of the 9 plants beyond December 31, 2007 to their respective spring outages. The NRC staff documented its decision in a memorandum dated March 14, 2008 from Michele G. Evans to Catherine Haney [ML080740419]. Letters were sent to each of the affected utilities informing them of the NRC staff's decision. These letters are contained in an ADAMS package at ML080880002.

The final version of the summary reports that were provided by EPRI is contained in an ADAMS package at ML081050226. These reports were reviewed and determined to be essentially identical to the draft reports reviewed previously.

Enclosure:
Summary of Activities of NRC Representatives at the Memphis Studvik-Race Facility

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SUMMARY OF ACTIVITIES OF NRC REPRESENTATIVES AT THE MEMPHIS STUDVIK-RACE FACILITY

INTRODUCTION

Two NRC representatives, a Region I Inservice Inspection (ISI) inspector and an NRC contracted expert in non-destructive examination (NDE) from Pacific Northwest National Laboratory (PNNL), traveled to Memphis, TN. In this summary, these individuals are collectively referred to as NRC representatives.

The purpose of this trip was to observe and evaluate the nondestructive examinations (NDE) by industry representatives on three safety nozzle dissimilar metal butt welds (DMBWs) from a retired pressurizer (PZR) from a nuclear power plant. This pressurizer was removed from service, in approximately 2004, to avoid the possibility of extended plant outages due to degradation of the welds in the pressurizer nozzles and attached piping connections.

The NRC representatives observed the setup of inspection fixtures and data collection equipment, observed the calibration of the data collection equipment, observed the data collection and evaluation of actual data, and observed the correlation of the data from ultrasonic examination testing (UT), radiographic testing (RT), eddy-current testing (EC), and penetrant testing (PT) to provide a more complete and accurate NDE picture of the nozzle welds and the suspect indications from the previously reported (MRP 2008-012) limited, manual inspection. Also, the NRC representatives reviewed personnel qualifications, NDE procedures, and the documentation of the procedure demonstration qualification summaries for the UT procedures and processes. Additionally, the NRC representatives provided independent expert analysis of this data to determine whether evidence of significant service-induced degradation, specifically, primary water stress corrosion cracking (PWSCC), could be observed in the retired pressurizer nozzle DMBWs.

The primary business of the Studsvik-RACE Processing Facility is to receive contaminated components from operating nuclear plants and prepare these components for disposal by disassembly and/or cutting and compacting. Studsvik representatives responsible for the work at the facility were present and health physics and support personnel were engaged in the retired pressurizer nozzle weld inspection work. The support and cooperation extended to the NRC representatives by Studsvik-RACE was outstanding.

Personnel from the Electric Power Research Institute (EPRI) were on-site to coordinate the scheduling and use of the various NDE methods being used on the nozzles and to act as technical experts on the NDE processes on behalf of industry. These personnel were from the EPRI NDE Center in Charlotte, NC, and were the primary EPRI contacts. EPRI contracted NDE support from LMT, Inc. for ultrasonic testing (UT) with phased array and conventional techniques and WesDyne for eddy current testing (ET) on the inside surface of the nozzles. Radiographic testing (RT) was also performed by a subcontracted, local radiographic testing company under the supervision of EPRI. The safety nozzles, designated Nozzles A, B and C, remained integrally welded to a portion of the pressurizer (PZR) head; this head section was located in a contamination zone within the facility.

After completing radiation worker training and a facility orientation tour of the work areas, the NRC inspector discussed the planned EPRI inspection scheduled and plans.

He requested copies of all NDE procedures being used, copies of the personnel qualifications for all data collectors and evaluators, as well as process qualification documentation for the UT process being used. The NRC's NDE expert arrived at Studsvik-RACE on the morning of March 10, 2008. It was reported that the UT data on two of the three safety nozzle DMWs had been acquired the previous day and a portion of the data was being initially evaluated by LMT, Inc., while UT data acquisition continued on the remaining nozzle. It was also reported that RT on one of the nozzles had been performed on the back shift and that the resulting film would be available when the RT inspectors arrived for further work on Monday evening, March 10.

The NRC's NDE expert observed a portion of the data acquisition with the UT vendor using a manual-encoded (semi-automated) phased array method, but primarily was engaged with the UT analysts to review the data collected on the DMBWs. In addition, he reviewed the radiographic film on each of the nozzle welds and reviewed/discussed the ID surface ET results. The NRC inspector was primarily engaged with reviewing the qualifications of the equipment, procedures and personnel in accordance with the Performance Demonstration Initiative (PDI). PDI has served as the U.S. nuclear industry's agent to develop and implement a program to qualify UT inspections in accordance with the requirements of the American Society of Mechanical Engineers (ASME) Code, Section XI, Appendix VIII.

<u>REVIEW AREAS</u>

<u>Ultrasonic Testing</u>

LMT, Inc. performed phased array UT from the outside diameter (OD) surface of the nozzle DMBWs. These examinations were aimed at detecting circumferential flaws that may be present in the weld, buttering, and adjacent base metal, and were performed from both the ferritic steel (nozzle) and austenitic steel (pipe) side of the welds. It should be noted that these examinations are not truly automated; the scanner is manipulated manually, however, X and Y spatial coordinates are acquired via wheel encoders, thus, the data is comparable to that produced by an automated system, although this method should correctly be termed a "manual-encoded" or "semi-automated" technique.

The UT contractor used a ZETEC-designed scanning system that is attached to the pipe by a series of interlocking links. As previously stated, this scanning device is equipped with wheel encoders so while the scanner is manually moved around the pipe circumference, UT data along each sound path is electronically stamped with OD spatial information and recorded. By coupling the angles of insonification with OD surface positions (as related to the weld dimensions) off-line analyses may be performed using a series of images (B-, C- and D-scans) of UT data responses from the volume of material examined. In the case of the subject DMBWs, a C-scan is a top view, a B-scan is a cross-sectional view along the axis of the pipe, and a D-scan is a cross-sectional view in the circumferential direction.

The ability to develop and analyze these volumetric images off-line is an extremely important and powerful evaluation technique, especially in the case of DMBWs, where multiple responses caused by metallurgical or geometric weld features may cause misinterpretation of UT data. This is the primary difference between ordinary manual UT, where all data is evaluated in real time by the examiner as the UT probe is being manipulated, and spatially-encoded, recorded UT signals. This generally holds true for automated, semi-automated or manual-encoded using both conventional and phased array UT methods.

While observing the manual-encoded phased array tests, the NRC inspector noted that the wedge being used on the UT probe had a contact radius of curvature designed for a 12-14 inch OD pipe, whereas the pressurizer safety nozzles' OD dimensions were approximately 6-inches. This mismatch between the wedge and component OD surface has the potential to cause UT coupling problems, and the NRC inspector determined that the qualified procedure being used had not accounted for this issue, i.e., the essential parameters of the procedure did not extend to the radius of the wedge used. EPRI stated that this was the only wedge available on such short notice, and the UT vendor was attempting to compensate for the mismatch by careful manipulation of the probe. The manual scanning system requires the examiner to place his/her hand on the probe while circumferential line scans are being made, which is an advantage over automated devices. After discussing this issue, EPRI personnel determined that a qualification expansion test, using the larger radius wedge on 6-inch flawed specimens (from the industry's Performance Demonstration Initiative), would be required to satisfy procedure requirements, since a wedge for a 6-inch OD pipe was not immediately available.

EPRI had several secure test specimens containing flaws unknown to the examiners. These specimens were shipped to the Studsvik facility and EPRI personnel administered blind testing of the UT vendor using the 12-inch diameter wedge on the 6-inch OD specimens. This is similar to what occurs when as-built conditions at a plant dictate a site specific procedure scope expansion. It was determined that all flaws in the secure test specimens were detected with the larger 12-inch diameter wedge, with no increased false call rate having occurred. This means that the 12-diameter wedge passed the detection qualification requirements for UT examination of the 6-inch OD pipe. Therefore, the PDI procedure could be amended to include this specific wedge and pipe size combination.

Subsequently, the NRC inspector received and reviewed the following documents:

(1) Ivey Cooper Services, LLC: Procedure QOP 9-RT-1, Appendix 1, Radiographic Inspection ASME/API, Revision 2, 3/27/06

(2) Ivey Cooper Services, LLC: Procedure 9-RT-1 For Radiographic Inspection And Acceptance Standards For Welds, Base Materials And Components, Revision 2, 3/27/08

(3) Zetec Procedure, Zetec OmniScan PA 03Revision D.doc, 1/25/07; Procedure For Encoded, Manually Driven, Phased Array Ultrasonic Examination of Dissimilar Metal Piping Welds

(4) Westinghouse Procedure WDI-ET-003, Revision 12, 1/16/88; IntraSpect Eddy Current Imaging Procedure for Inspection of Reactor Vessel Head Penetrations

(5) Westinghouse Procedure WDI-UT-010, Revision 15, 1/16/08; IntraSpect Ultrasonic Procedure for Inspection of Reactor Vessel Head Penetrations, Time of Flight, Longitudinal & Shear Wave

(6) UT and ET Personnel Certifications for Eric Overly and Timothy Majoros

(7) Data Sheet: Radiographic Inspection Report, EPRI, Studsvik, 3/10/08

(8) Data Sheet: Radiographic Inspection Report, EPRI, Studsvik, 3/11/08

(9) WesDyne Indication Summary (Draft): FPL-1 Removed Pressurizer Eddy Current Testing Performed at Studsvik, Memphis, TN; March 12, 2008

(10) LMT, Inc. letter to Mr. Carl Latiolais, Program Manager, Summary of Preliminary Phased-Array UT Results of the PSL-1 Pressurizer Safety nozzles, March 10, 2008

(11) RT personnel certifications for Grady Pickett, Matthew Heap and Jason Glasco

The NRC inspector did not identify any concerns from the review of these documents.

The NRC's NDE expert reviewed all manual-encoded phased array UT data sets acquired on the pressurizer safety nozzles, with particular emphasis on Nozzle A, which had been reported to the NRC staff to potentially contain a 360° deep inside diameter connected flaw as measured by the initial manual real-time phased array method. The review was performed by observing merged volumetric images (B-, C-, and D-scans), and manipulating the analysis software to enhance areas of the images to facilitate data interpretation. The data review by the NRC's UT expert was assisted by and coordinated with a senior data analyst from LMT.

The data on Nozzle A show several responses from embedded flaws, most probably related to welding fabrication anomalies such as slag or porosity. These are randomly distributed around the circumference of the weld, and in some cases, are clustered, which appear "vertically stacked" in limited areas of the cross-sectional images. Ligaments of undisturbed weld material are observed above and beneath these embedded flaws in the angle beam data. Additionally, during a limited review of data generated by a focused conventional 0-degree longitudinal wave transducer, several of these fabrication flaws were observed (with the exception of the lower parts of the vertically stacked indications), which generally corroborates these to be volumetric embedded flaws (as opposed to planar in nature). When carefully imaged and a cross-sectional weld schematic template is applied, many of these flaws lie on or near the fusion zone of the weld. No upper or lower tip diffracted signals from these indications were typically seen which is also consistent with volumetric embedded flaws.

A large response is also observed over the circumference of the weld that is believed to be generated from refraction (or re-direction) of steep angles (approximately 30-35 degrees) of the UT sound beam. This refracted signal is due to slight changes in sound velocity between the wrought base materials and the weld/butter which causes the sound near the ID of the weld to be re-directed nearly perpendicular to the inside surface, resulting in a strong reflection over the entire circumference. The amplitude and duration of this re-directed response is dependent on the grain structure of the weld/butter, and therefore, is of intermittent strength. However, this response is not evident in higher angles (45-55 degrees), where one would expect to observe the presence of corner-trapped signals indicative of ID-connected flaws, if they were present. Because this signal appears to be generated from the ID surface of the weld, it is understandable that it could easily be misinterpreted as an ID-connected flaw using manual real-time UT techniques.

Data for Nozzles B and C are similar to Nozzle A with fabrication (embedded) flaws being clearly observed, however, signals from these welds are less populated with this type of response. The re-directed response from the weld/butter-to-base metal interface is also evident, but has less amplitude and this signal appears more intermittently.

Based on the manual-encoded phased array UT data, it is concluded that no clear evidence of significant cracking could be detected in any of the manual-encoded (semi-automated) data images.

Radiographic Testing

RT was performed on back shifts; therefore, the actual testing was not observed. However, film was reviewed to determine if any indications could be imaged by this method. Nozzle A was the first DMBW to be examined and the NRC's NDE expert reviewed the resulting film on Monday evening. The RT exposures were somewhat difficult to make, as the nozzle is only 6-inches in OD and approximately 1.5-inches in thickness, so a double wall exposure technique was used. For this small diameter of component, this means that only approximately 2-3 inches of weld can be properly imaged with the correct density for viewing. This makes film interpretation challenging and requires masking of the light source when viewing the film.

The RT film on Nozzle A exhibited several small fabrication flaws, which were interpreted as slag and porosity. These were on the order of 3/16-inch or less in size, which would have been acceptable to ASME Section III. NRC's NDE expert concurred with the RT vendor's interpretation of these indications; no large linear indications could be seen in these double-wall images. Later in the week single-wall exposures were made on Nozzle A which confirmed the interpretations of the double-wall technique, except that three linear indications were also reported by the vendor. RT, as performed on these nozzles, is not capable of determining whether any of these reported indications are surface connected. NRC's NDE expert reviewed this film and could not discern these linear flaws in the single-wall images.

It is therefore concluded that the radiographic examinations confirmed the presence of ASME Section III acceptable fabrication flaws; no crack-like indications could be observed in the RT film.

Eddy Current Testing

ET data was acquired using the same procedure as that used by the vendor for examining control rod drive mechanism housings. Axial scan lines were made and recorded to produce images similar to C-scans, except showing surface breaking responses which are located in the weld/buttering and adjacent base materials. The ET system was calibrated using a 0.040-inch deep electrical discharge machining (EDM) notch and the ET probe was operated at 100 and 400 kHz.

The preliminary data on Nozzle A showed 4 small circumferentially-oriented linear indications (all less than 0.5-inches in length), located at intermittent circumferential weld positions which appear to originate in the weld near the weld-to-austenitic base material interface (on the opposite side of the weld to the buttering). All of these short linear flaws were less than or equal to the 0.040-inch EDM notch in signal amplitude, indicating a probable loss of material less than the depth of the notch standard. No conclusions can be drawn from the ET data regarding whether these linear indications are shallow surface-breaking cracks, or remnants of linear fabrication flaws such as lack of fusion or another anomaly formed during fabrication.

Nozzles B and C showed only intermittent "spot" indications with ET.

CONCLUSIONS

Based upon independent evaluation of the examinations conducted by and data collected by EPRI's contractors, the NRC representatives on-site concluded that:

(1) the automated phased array ultrasonic examinations performed on all three safety nozzle DMBWs show embedded fabrication flaws to exist in the welds and no significant crack-like signals were observed; this finding was corroborated by the RT examinations, although the ability to detect PWSCC using radiography has not been reliably demonstrated,

(2) the report of significant cracking by the manual real-time phased array data, initially performed on the nozzles and reported in MRP 2008-012, was a characterization of the condition of the nozzles based upon a limited UT testing methodology that later was not supported by the evaluation of the automated phased array UT data, and

(3) the UT responses caused by welding fabrication flaws and metallurgical interfaces influenced the examiner to over-conservatively misinterpret these signals as evidence of a large crack.