White Paper on Improving the Effectiveness and Reliability of Nondestructive Examination

1.0 INTRODUCTION

The NRC imposed the performance demonstration requirements of ASME Code, Section XI, Appendix VIII, when an updated Codes and Standards rule, Title 10 of the Code of Federal Regulations, Part 50.55a (10 CFR 50.55a), was issued in 1999. These performance demonstration requirements for ultrasonic testing (UT) qualifications are implemented by the U.S. nuclear industry's Performance Demonstration Initiative (PDI), administered by the Electric Power Research Institute (EPRI). PDI utilizes blind testing on representative mockups to qualify procedures, equipment and personnel, a costly and extensive process that does not readily lend itself to revisions and changes.

Industry events in recent years associated with Appendix VIII-qualified techniques have called into question a number of aspects of UT that may impact their effectiveness and reliability, as implemented in the field.

This white paper summarizes a number of events that have occurred and relates those events to considerations for potential improvements in UT qualifications and field examinations. It is intended that this white paper serve as a starting point for discussions between Industry and the NRC staff on improving the effectiveness and reliability of ASME Code, Section XI, ultrasonic testing applications.

2.0 SUMMARIES OF NDE-RELATED EVENTS

2.1 North Anna, Unit 1

Flaws were detected in an inlet hot leg steam generator nozzle dissimilar metal weld (DMW) as a result of outside diameter (OD) surface machining in preparation for a full structural weld overlay (Anderson et al., 2012). The flaws had initially gone undetected by the licensee's manual, non-encoded UT technique and were identified later in the outage as a result of through-wall leakage. Further, UT examination revealed five, large axially-oriented primary water stress corrosion cracks (PWSCC) in varied locations around the weld circumference.

The hot leg safe end-to-nozzle weld configuration has an approximately 11-degree OD taper from the thinner austenitic piping side up to the thicker carbon steel nozzle. This is a replacement steam generator, and the OD taper of this particular design is not included as a blind performance demonstration mock-up in the industry's PDI specimen set. The licensee implemented a site-specific qualification that utilized open mockups to address their configuration.

As described in Anderson et al. (2012), the NRC has a number of concerns as a result of the failure to detect several PWSCC flaws at North Anna.

The UT probes used for this site-specific examination do not appear to have been tested after receipt, as the probe's effective angle is listed as being 40-degrees as impinged on the inner diameter (ID) surface, while NRC's modeling shows that the effective impingement angle for the probe configuration is actually about 30-degrees. Laboratory testing since the incident has confirmed this 30-degree angle.

NRC's probe modeling further indicated that the manual, real-time examinations conducted were insufficient to properly discriminate and characterize inside diameter (ID) surface-connected flaws from other welding or metallurgical features in the inner one-third of the weld volume on these DMWs. The probes were sufficient to detect specular responses from deep crack tips but extremely limited for detection of ID connected flaws due to loss of UT energy in the lower one-third of the material and the non-ideal impingement angle. This finding was corroborated by site observations that show a low signal-to-noise ratio for the flaws in the mock-up in the presence of spurious indications that interfere with detection and classification of the implanted thermal fatigue cracks used to simulate PWSCC.

Section XI, Appendix VIII, supports procedure, personnel, and equipment (UT system) qualifications and requires blind performance demonstration. There are no requirements in the ASME Code addressing open demonstrations. The mock-ups, tandem probes, and scanning techniques used in the site-specific qualification were not subjected to a blind performance demonstration. In addition, PDI does not have a qualification procedure for the open demonstration process. Round-robin exercises that have been conducted and reported demonstrate that blind and open demonstrations have different sets of challenges.

Section XI, Appendix VIII, contains a minimum set of essential variables and requires requalification of the UT system involved if these variables are modified. At North Anna, essential variables were changed under the site-specific qualification process.

A "team scanning" approach was also used. In a team scanning approach, the PDI qualified individual observes both the UT instrument screen and the individual performing actual scanning to determine if there are signals of interest. This is performed in real-time. There are no requirements in the ASME Code that address team scanning.

2.2 Duane Arnold Energy Center, Unit 1

During a refueling outage in February 2007, circumferentially-oriented ultrasonic indications emanating from the ID were detected in two recirculation riser safe end-to-nozzle dissimilar metal welds (PNNL, 2007). The indications were characterized as being IGSCC with significant through-wall depths on the order of 50-70 percent. Encoded UT had been conducted in 1999, and 2005, however these inspections did not identify the cracks detected in 2007. Review of the earlier data indicates that the cracks were detectable in the 1999 and 2005 data, but that

complications associated with weld crown geometry in 1999 and UT coupling issues in both 1999 and 2005 caused the indications to be overlooked. Experts from EPRI also reviewed the data and confirmed that the indications were present in the 1999 and 2005 data. The procedures used in 1999 were pre-Appendix VIII procedures, which may have been a contributing factor to the missed detections.

The examinations performed in 2005 employed an automated scanner and were Appendix VIII qualified. The weld crowns had been removed prior to the 2005 examinations. However, in general, the data gathered was of poor quality in that it had very low signal-to-noise ratio and inconsistent responses throughout the circumferential scans. The vendor applied 40, 45, and 60-degree refracted longitudinal (RL) sound beams, but used a gel-type couplant which can cause problems for automated devices. The couplant “gummed up” the transducer wedge which affected coupling between the probe and the inspection surface. In addition, the vendor chose to collect data in both the forward and reverse raster motions, which can save scanning time, but can also result in signal loss due to different mechanical pressures pressing the probe to the component surface, and wiping of couplant from the surface that usually occur during forward and reverse scanning. Also, it is difficult to optimize the scanning device with proper spring tension to ensure gimbaled wedge contact for both forward and reverse raster strokes. Finally, the software that the vendor used was not user friendly for imaging and viewing of data. Limitations in the software inhibited thorough investigation of geometrical and flaw responses, and pixilation of the images did not provide adequate resolution for depth-sizing, and, in some cases, for determining accurate spatial positions of responses. This can make distinguishing cracks from geometrical reflectors very challenging. With the crack having been identified in 2007, flawed areas can be identified in the 2005 data. The re-evaluated 45-degree RL data set showed that a flaw indication had intermittent response along its length and appeared to be roughly 10-11 inches in total length. The licensee noted that UT coupling issues were associated with the 2005 inspection. Also, it is not known whether the procedure used in the 2005 inspection was qualified for collecting data in the forward and reverse directions and whether the software was replaced or updated to make it more user friendly. Although, not certain, it also appears that the 2005 data was not independently reviewed, since some of the issues noted could have been identified and addressed as a result of an independent review. These issues were briefly discussed here because they are additional indications that greater attention to detail is needed with respect to NDE and examinations.

The 2007 examinations were manually driven, encoded phased array data collected in accordance with Procedure Zetec OmniScanPA 03, Revision D, dated January 25, 2007. This examination is a type of manual/automated hybrid in that a scanning device with encoding was used to gather spatial information, while the attached phased array probe is moved around the pipe manually. The arrays were designed to enable electronic raster scans for the sound beams, which allowed the inspector to only make single line passes adjacent to the weld. Phased array data was acquired from both the nozzle and safe end sides of these welds. The nozzle side data included 30, 45 and 60-degree RL, and the safe end was examined with 45, 60, and 70-degree RL, and 45 and 60-degree shear waves. The 2007 data was observed to have good signal-to-noise ratios and high resolution images.

Analysis showed that the crack-like indications existed in 1999 and were of similar through-wall size as in 2007. Some of the flaw responses exhibited fairly deep tip-diffracted signals, although the subject responses were being limited by the presence of weld crowns. The appearance of tip-diffracted signals could have indicated possible deeper through-wall extent, given that BWRs have had a history of intergranular stress corrosion cracking (IGSCC).

2.3 Retired Pressurizer Nozzle from St. Lucie, Unit 1

Laboratory examinations were performed on six pressurizer nozzle DMWs that had been removed-from-service in January 2008. The examinations were performed using manual non-encoded phased-array UT, supplemented by additional examinations including liquid penetrant (PT). Both PT and UT inspections found indications. 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 reported to be 75% and 69% through-wall, respectively. Under the procedures normally used in the field, these types of indications would be recorded and evaluated as one continuous linear planar flaw. Similar linear planar indications were detected in the other nozzles. (EPRI, 2008)

A March 4, 2008 letter from EPRI (King, 2008) recommended that in order to obtain a more accurate three-dimensional representation of the indication, or indications, an automated ultrasonic system should be employed to take continuous measurements of the entire circumference of the weld. Additional qualified inspectors were sent to the facility, including experts from the EPRI NDE Center, to conduct encoded phased array inspections and to better assess the provenance of the reflectors. The examination methods included ultrasonic, liquid penetrant, and eddy current examination. PT of the inside surface of “A” safety nozzle identified five short linear indications. Four short linear indications were found by ET on the inside surface of this nozzle. Three ET indications overlapped PT indications and the fourth ET indication was close to a PT indication. However, none of the indications from the PT or ET approached the extent of the UT indications.

Based on these examinations, it was concluded that the pressurizer nozzles have multiple embedded fabrication flaws attributed to slag, porosity, and/or lack of fusion but no specific indication of stress corrosion cracking (King, 2008a). Some of these flaws are “stacked” or vertically connected, and start very near the inside surface. Upon completion of the NDE, the portion of the “A” safety nozzle containing the DMW was removed and sent to a laboratory for destructive examination to verify the NDE results. High magnification examinations by SEM/EDS and optical metallography indicated the cracks observed by PT and ET most likely occurred during original manufacture due to hot cracking. There was no evidence that the cracks initiated or propagated in-service due to primary water stress corrosion cracking, fatigue, or other mechanism. The destructive evaluation confirmed the UT indications and determined

that the flaws found within the retired pressurizer “A” safety nozzle are fabrication defects with no evidence of PWSCC. The flaws were also confirmed to be non-safety significant and did not challenge the structural integrity of the component. (Weakland, 2008)

2.4 Calvert Cliffs Nuclear Power Plant, Unit 1

In 2006 the licensee for Calvert Cliffs, Unit 1, mitigated a pressurizer relief nozzle DMW containing an approximately 8-percent through-wall axial flaw using a process known as the mechanical stress improvement process (MSIP) (Spina, 2006). MSIP has been widely used in BWRs to produce compressive residual stress in the inner region of welds and mitigate welds against IGSCC. PWR licensees have used MSIP on some welds to mitigate against PWSCC. The compressive residual stress produced by MSIP inhibits the initiation of PWSCC and the growth of existing PWSCC, provided any existing PWSCC is shallower than about a third of the weld thickness.

A vendor conducted an examination of this DMW in early 2010. The intent of the examination was to scan the entire weld, and to detect and size the previously reported flaw. The inspection vendor examined the DMW using manual non-encoded phased-array UT and had difficulty detecting the axial flaw, because its profile had been diminished by the squeezing process. However, reflectors were observed that had not been recorded in examinations prior to 2010 and a concern arose regarding the effectiveness of the mitigation by MSIP. EPRI’s NDE Center was called in to perform a review and to help with the evaluation. Another inspection vendor was mobilized to collect spatially encoded conventional UT data. Ultimately, two subsequent sets of data were collected using a time-encoded (non-spatially encoded) phased-array technique and spatially encoded conventional UT. Both data sets were sent to PNNL for review. While PNNL was able to review the time-encoded data, the results of this review were inconclusive. PNNL was not able to review the spatially encoded data, because the analysis software for this data was not available to PNNL. However, at the completion of the re-examination, the inspection vendors, EPRI, and NRC staff on site at Calvert Cliffs concluded from their review of the encoded data that there was no evidence of any ID-connected circumferential flaws in the component and that the signals originally reported earlier in the outage were caused by embedded fabrication flaws and geometric reflectors from the ID (Cinson and Anderson, 2010).

2.5 Point Beach Nuclear Plant, Units 1 & 2

On March 3, 2011, NRC inspectors identified through direct observation that an NDE examiner failed to perform required circumferential UT examinations on two elbow-to-pipe Containment Spray welds as required by procedure NDE-173, “PDI Generic Procedure for the Ultrasonic Examination of Austenitic Piping Welds” (Kunowski, 2011). The required UT examinations of the two welds should have included additional circumferential scans. The latest revision of the weld procedure required that when the weld crown was ground flush to allow scanning on the weld, as had occurred for these two welds, additional scans were to be performed with the sound beam directed essentially parallel to the weld axis in two opposing

directions to permit enhanced interrogation of the weld. Subsequent to NRC identification of the oversight, the licensee performed the required examinations as a part of its corrective actions with no relevant indications identified.

If left uncorrected, the failure to perform the weld examinations would have the potential to become a safety concern. The NRC inspectors also noted that procedure NDE-173 was issued as an "Informational Use" type procedure that allowed licensee staff to rely on memory to perform the procedural steps.

2.6 Ginna – Part I

The following information was provided by the licensee in a letter dated March 16, 2012 (Mogren, 2012a). The welds in this summary are the two replacement steam generator welds, which have highly similar as built configurations. These are ASME Code Category B F, pressure-retaining DMWs in vessel nozzles. The licensee sought relief from impractical examination coverage requirements for the fourth interval ISI. An assessment of field profile conditions on the steam generator inlet and outlet weld configurations revealed that as much as ¼ inch (6.25 mm) of material (including butter, DMW, safe-end, and narrow-groove weld) would have to be removed to meet the PDI procedure requirements for a flush surface. The site engineering department concluded that there was insufficient margin for any metal reduction on the subject welds.

The Code coverage obtained in the July 29, 2011, RAI response (Mogren, 2012b) was 40.5 and 42 percent for the two steam generator nozzle-to-safe end welds. The site confirmed during the 2009 refueling outage that these existing DMWs had some original fit-up and off-set joint issues. In the discussion on page 14 of 20 of the RAI response, it states that reductions in claimed coverage were taken because of the surface condition of the components and inability to maintain contact during the examination.

During outage planning in 2008 and 2009, the site compared conventional manual UT to phased-array techniques and based on the limited fleet and site experience with phased array methods as well as the fact that the PAUT probes would have had similar scan limitations as the conventional probes, the site decided to employ conventional UT examinations. The decision was made prior to the fabrication of a site-specific mockup. A site-specific demonstration process was followed using a site-specific mockup because the PDI DMW program inventory does not include Ginna's particular steam generator weld replacement configuration and Ginna's configuration did not match with any of the nine existing steam generator DMW site-specific mockups in the industry. Thus, a PDI-demonstrated procedure for conventional UT was not followed; rather, it was modified through a site-specific demonstration process.

2.7 Ginna – Part II

The same March 16, 2012 letter summarized above describes the licensee's response to an NRC request for additional information on a manual UT examination performed on a cast

austenitic stainless steel (CASS) elbow-to-CASS pump weld. Through the RAI process, the NRC identified an inconsistency in the licensee's submittal. The licensee inappropriately used PDI techniques to examine a weld between a CASS elbow and CASS pump, as at the time of the inspections, the licensee believed that the weld was a SS elbow to CSS pump. When the site was preparing their RAI response, the site discovered that the examination had been performed incorrectly in 2008. The site personnel provided the outage ISI examination scope list to the selected ISI/NDE vendor. This list included the requested essential component information such as Work Order #, Summary #, Component Identification #, Description, Line name, Diameter, Thickness, Material, etc. During the process of populating the ISI list with information, the site NDE person provided the vendor information that identified this weld as a wrought stainless-steel elbow-to-CASS pump configuration instead of CASS-to-CASS. This human performance error caused the vendor to perform the required ISI UT examination with a stainless-to-CASS ultrasonic PDI procedure and a stainless calibration block.

The vendor communicated to the site that they had reviewed the historical ISI examination record, which had the correct CASS calibration block. However, partly due to the human error previously described, the vendor did not use the applicable calibration block or the correct NDE procedure that is applicable to CASS-to-CASS. Also, during the post-examination reviews of this weld by the vendor and site personnel, the error was not caught.

2.8 Arkansas Nuclear One, Unit 2 (ANO-2)

By letter dated November 30, 2011 (Pyle, 2011), and with subsequent information letters in 2012, the licensee submitted an alternative to volumetric examination coverage requirements for multiple DMWs at ANO-2. The alternative applied only to limited coverage on circumferential scans for detection of axially-oriented cracking for two reactor coolant pump (RCP)-to-primary loop piping welds. Full coverage was obtained on the axial scans (to detect circumferentially-oriented flaws).

Weld 09-008 is a full penetration DMW on the RCP discharge nozzle joining the carbon steel, ID clad primary piping to a CASS safe end. The safe end is welded directly to the RCP pump housing. The licensee had estimated volumetric coverage as being approximately 73.8%, which includes the inner one-third of the ID-clad carbon steel piping, but no coverage on the CASS safe end. That is, scan coverage was only credited for the non-CASS volume, as the Appendix VIII, Supplement 9 requirements for CASS are still in the course of preparation

NRC modeled the licensee's proposed examination to evaluate the alternative with respect to coverage and ultrasonic technique capabilities (PNNL, 2012). Modeling of the sound beams is based on actual phased-array design parameters and component geometrical information provided by the licensee. The licensee's and NRC's estimated extents of volumetric coverage are in general agreement. The modeling results show that a large center portion of the weld could not be adequately examined, due primarily to OD surface features. The phased array was operated with focal laws defined to produce steered beams from 0 to 80 degrees, at one-degree increments, each focused at approximately 4.8 inches (122 mm) of metal path after exiting the probe. This focal length is beyond the inside surface for steered beams less than

around 20 degrees; greater than −6 dB sound field densities are generated at the inside surface only for beams at approximately 20–25 degrees. In a similar manner, steered beams above about 65–70 degrees could not produce useful beam profiles for detecting flaws near the ID because they were focused at too short a metal path length. It should be noted that one of the features of the phased array technique is the ability to adjust the focal laws for the varying beam angles.

According to the industry's PDI generic DMW ultrasonic procedure (PDI-UT-10), the optimum ID impingement angle for detecting PWSCC on the subject welds is in the range of 55–60 degrees and the transmitted refracted angle should be in the range of 42–45 degrees.

Considering the optimum range of impingement angles for flaw detection in the subject welds and the "best-case" theoretical sound field intensities modeled by NRC, it was estimated that insufficient acoustic energy at the optimal transmitted refracted angles (42–45 degrees) would be generated by the phased-array probe and focal laws used for detecting axially-oriented PWSCC. This would be especially true for shallow cracks, on the order of 20–30% through-wall and smaller. As noted above, the model predicts that only beams at approximately 20-25 degrees appear to provide adequate (≥ −6 dB) sound fields to facilitate detection of ID corner trap reflections. The results of this analysis call into question how well these lower transmitted angles, and resultant impingement angles, would perform on ID surface-breaking flaws.

2.9 Nine Mile Point, Unit 1

On March 25, 2011, Nine Mile Point Nuclear Station, LLC (NMPNS) submitted a relief request to use an alternative to the requirements of 10 CFR 50.55a(g) for the repair of control rod drive (CRD) housing penetrations (Pacher 2011) (Swift, 2012). The alternative repair strategy was a variation of the CRD housing penetration welded repair geometry specified in Boiling Water Reactor Vessel and Internals Project (BWRVIP) report BWRVIP-58-A, entitled "BWR Vessel and Internals Project, CRD Internal Access Weld Repair."

In its submittal, the licensee references the original work done to develop the UT examinations described in BWRVIP-58-A. This original work does not apply to the NMP1 configuration which had smooth, machined surfaces rather than as-welded surfaces.

To support the technical bases developed for repairs performed in accordance with BWRVIP-58, mockups were built to represent the BWRVIP-58 repair configuration. The mockups were designed and fabricated to simulate repair conditions containing fabrication type flaws that simulate typical lack of fusion, horizontal dis-bond and cracking. The mockups were composed of flat-bottomed holes, axial and circumferentially oriented fatigue cracks, and lack of fusion flaws. The mockups had an "as-welded" surface finish. Two issues associated with UT limitations arose with the use of the BWRVIP-58 mockups and are discussed as follows.

The ultrasonic examination technique chosen used conventional ultrasonic examination and required the use of several search unit beam angles and scanning directions. The transducers

selected were those used successfully in the repair of PWR reactor vessel closure head penetrations, as follows:

- 0° search unit, used for weld profiling and detection
- 45° refracted longitudinal (RL) search unit, scanned axially "up" and "down," used for detection of flaws parallel to the weld,
- 70° RL search unit, scanned axially "up" and "down," used for detection of flaws parallel to the weld, and
- 45° RL search units, clockwise and counterclockwise, used for detection of flaws perpendicular to the weld.

The mockups were ultrasonically examined. In one of the mockups, five of the six circumferential flaws were detected. The flaw that was missed was the circumferential reflector with the smallest through-wall dimension. A phased array probe was used to determine if a specific angle could be used to detect this flaw. The phased array technique showed that a 35-degree longitudinal wave was required to detect this reflector. Thus, the vendor determined that the flaw was likely missed because the conventional probes did not produce a longitudinal wave at this optimum angle.

Two of the three axial flaws present in the two blocks were missed. The vendor indicated that it would be possible that the flaws were missed due to the highly attenuative weld material; however, they did not think that that was the case. Rather, the vendor believed that the axial flaws were missed primarily because of the as-welded surface. The detection of the axial flaws required scanning on the weld ID surface. The vendor indicated that an as-welded surface creates problems for ultrasonic inspection, since it tends to scatter the sound entering the component as well as partially decouple the probe through the introduction of excessive water gaps under the wedge. Detection of small flaws with the probe coupled to this surface is difficult and the most probable cause for missed detections. Thus, the vendor concluded that surface roughness prevented detections in the weld regions.

The issues discussed above pertain to original work done to develop the UT examinations described in BWRVIP-58-A. However, this original work does not apply to the NMP1 configuration which had smooth, machined surfaces rather than as-welded surfaces. This information is of value to relate historic information on limitations associated with the use of conventional UT using a few, fixed angles and with inspections of as-welded surfaces.

2.10 Diablo Canyon, Unit 2

In the 2013 refueling outage at Diablo Canyon Unit 2, laminar indications associated with the overlaid Alloy 82/182 dissimilar metal welds and similar metal welds associated with pressurizer nozzles (safety nozzles A, B, and C and spray nozzle) were detected using qualified phased array UT. The laminar indications in the weld overlay installed on safety nozzles A and B and the spray nozzle exceeded one of the acceptance standards for laminar flaws in Section XI, Appendix Q, Paragraph Q-4100, which was a condition of NRC approval of the relief request to install the weld overlays (Hiltz, 2008). While the laminar indications satisfy Table IWB-3514-3 acceptance criteria in Q-4100(c)(1), the reduction in the required examination coverage due to

laminar flaws exceeded the 10% limit in Q-4100(c)(2). Using qualified conventional UT, the licensee did not detect these indications after weld overlay installation in 2008 nor during the follow-on ISI examinations in October 2009.

The following comes from Polickoski, (2013). The licensee performed a flaw evaluation in accordance with the requirements of the ASME Code, Section XI, IWB-3600, assuming planar flaws. The laminar indications satisfy the acceptance standards of both Table IWB-3514-3 and IWB-3640 of Section XI of the ASME Code. The laminar flaws are not open to the OD pipe surface, and therefore, will not grow due to environmental effects. The licensee performed an ASME Code stress analysis to demonstrate that the interface length between the weld overlay and the nozzle/pipe base metal is sufficient in light of the laminar indications.

The NRC staff determined that the licensee's proposed alternative provides reasonable assurance of quality and safety in regards to the structural integrity and leak tightness of the subject welds for one cycle of operation. However, for future operational cycles, the NRC staff stated that the licensee will need to demonstrate the effectiveness of the ultrasonic examination techniques used to examine structural weld overlays. In addition, the licensee will need to perform a finite element analysis, modeling the voids in the weld overlay where the laminar flaws exist, to support the conclusion that the laminar flaws will not challenge the structural integrity of the subject overlaid DMWs for the remaining service life of the subject overlaid welds.

While the manual phased array ultrasonic technique used by the licensee in the 2013 inspections is apparently more effective than the conventional technique, both ultrasonic techniques were similarly qualified to identify defects to support ASME Code, Section XI, Appendix VIII, Supplement 11 examinations. The differences in the inspection results from 2008 to 2013 gives rise to questions regarding the adequacy of the techniques to identify potential fabrication defects to the sensitivity required by the acceptance criteria of the licensee's proposed alternative.

3.0 DISCUSSION

Shortcomings have been identified in the implementation of qualified UT at a number of plants in recent years. The shortcomings are in the areas of techniques and procedures, training and qualification of personnel, poor data quality, and inadequate probe design. The following paragraphs provide an overview of these shortcomings based on consideration of the NDE occurrences discussed in Section 2.0.

3.1 Spatially Encoded UT Data

Many examinations are performed in real-time, i.e., non-encoded. With non-encoded examinations an inspector has to make a determination whether a particular transient signal on the screen is a crack, a geometrical reflector, or spurious noise. Often these determinations are made under the constraints of access issues, outage delays, occupational exposure concerns, and other environmental or safety issues that can affect human performance.

With encoded data, careful independent review of all inspection data, and in particular, questionable indications, can be conducted more thoroughly off-line. If an inspector identifies a questionable indication and the data is not encoded, the approaches available for additional evaluation are (1) for another inspector to manually rescan the inspection volume, or (2) to re-acquire encoded data with a qualified procedure. Both of these approaches incur additional occupational exposure.

Independent review has long been recognized as one of the most important steps that can be taken to effectively increase the reliability of skill-dependent processes, such as NDE. There have been many situations involving NDE at nuclear power plants, including steam generator tube exams, where shutdowns, repairs, or replacements were avoided as a result of being able to rely on recorded data to favorably disposition questionable indications, or to detect flaws in the presence of many indications in the data. Encoded data is frequently used to assess whether a flaw is surface-connected or sufficient ligament of material is present to classify the flaw as embedded. The capability to use detailed and enhanced imaging techniques of encoded data makes this possible.

Phased array technology enables electronic raster scanning and multiple propagation angles to be performed simultaneously, which allows simple line scans along the direction of the weld to be made (as opposed to mechanical serpentine raster) and significantly reduces examination time on the component. In addition, a manually driven, encoded scanning device can provide instant feedback to the inspector if a condition such as surface roughness, or degraded couplant, is experienced. The examination can be started or stopped anywhere along the scan length, and re-scanned, because encoders keep track of the circumferential position of the probe, and data can be easily re-acquired for any area of interest.

A number of the events discussed in Section 2.0, strongly suggest that use of encoded phased array technology, coupled with independent data review, could have prevented the event or problem from occurring or facilitated more efficient assessment of the problems.

3.2 Training and Qualification of Personnel

The EPRI NDE Implementation Focus Group (NIFG) has recognized that training requirements need to be improved and is currently developing recommendations. It has been recognized from round-robin exercises, laboratory testing, and field experience that UT inspectors lose proficiency over time. In the nuclear industry, testing has demonstrated that frequent practice on specimens is required to maintain skill level. Inspectors in the field examine unflawed welds much more frequently than flawed welds and, therefore, they do not get to routinely exercise their skills with detecting stress corrosion cracking or other in-service degradation such as fatigue.

The current non-standard employer based personnel qualification and certification (PQ&C) process is based on ASNT CP-189. CP-189 can be used by any industry. It was designed for

general use with the employer ultimately responsible to address specific needs. Since there is no other source for NDE PQ&C criteria in the United States, the ASME references CP-189. Each employer (manufacturer, vendor, or utility) has its own PQ&C self-certification program, including non-standard training, experience, written, and practical examinations. Upon acceptance of these qualifications, which by its non-standard nature varies, each employer issues a non-portable certification.

The following are issues that the ASME Nondestructive Examination (ANDE) program has identified with PQ&C (Turnbow, 2011):

(a) The number of hours that are required for training is a minimum applicable to all industries. There are no nuclear specific requirements, and there is no standard for training development, evaluation for effective results and performance, and no accreditation.

(b) The experience requirements are time-based. Qualification criteria or attributes are not provided or required, and no industry evaluation for effective results and performance is required.

(c) CP-189 requires a written examination. The examination requires a minimum number of questions, however there is no standard for quality, and standard psychometric practices are not usually employed.

(d) The practical test has a limited number of sample sets, and typically does not address many conditions that are expected to be encountered in the field for nuclear power plant applications.

(e) There is no way to evaluate the effectiveness and quality of either written or practical examinations.

This list of issues strongly suggests the need for improvements in the area of personnel qualification and certification.

In June 2009, the EPRI NDE Integration Committee recommended that an NDE/QC central certification program be developed under ASME. The ASME's Board of Directors approved a business plan on March 16, 2010, for the ANDE program which is currently developing a new certification program. When completed, the results of the ANDE program with respect to the issues identified with the current program, including training, will need to be evaluated for the next steps.

A paper by Lareau (2010) discusses a recurring problem with resolving ultrasonic indications encountered during the inspection of dissimilar metal welds. The paper stated that, "Use of either the ASME Code, Section XI, Appendix VIII methods or the French RCCM Code are likely to produce false positive indications that need to be resolved by additional, confirmatory testing. The primary issue for existing plants is the confusion of being able to

separate internal, embedded fabrication flaws from stress corrosion cracking originating on the inner, wetted surface." The author attributed the issue to current qualification practice.

EPRI (2008a) summarizes the past performance of experienced candidates who have been certified to different written practices and programs and indicates their capabilities as measured by undertaking hands-on practical qualification testing. The report recognizes that unstructured training and job experience may or may not include the key factors that are essential for learning; for example, measurement and feedback of performance results as it is difficult to measure performance and feedback on the job since actual flaws may be rarely encountered. The report also states that evidence obtained in the course of the study substantiated the concern that certified personnel may not have adequate training and the experience to perform reliable inspections for particular applications in a variety of industries. The study concludes that pass rates for experienced certified personnel is very rarely above 50 percent on the first attempt for a demonstration test that simulates field examinations, even when the test mockups with flaws were removed-from-service so that there can be no question about their applicability to field inspections.

EPRI (2006) discusses the concerns regarding pass rates, and the numerous attempts necessary to successfully pass the UT performance required by the nuclear industry since May 2000. The study focused on IGSCC pass rates and concludes that the overall pass rates for initial and re-qualification fluctuated between 50 percent and 60 percent from year to year. The report states that hands-on training can significantly improve the performance of examiners.

A recent compilation of pass rates versus attempts for Appendix VIII manual (non-encoded) qualifications was prepared by EPRI as part of the NRC-PDI-EPRI bi-annual public meeting (Latiolais, 2012). For ferritic similar-metal piping welds the first attempt failure rates show that almost half of the individuals (13 out of 28) failed on their first attempt at detection and length sizing using either conventional or phased array methods. For manual qualification for detection on austenitic similar-metal piping welds, twice as many failed on their first attempt using conventional probes (21 failed out of 33 attempts) as opposed to phased array (6 failed out of 19 attempts). For through-wall sizing, 1/3 of the individuals (4 out of 12) attempting a manual similar-metal piping weld qualification failed on the first attempt. For a phased array method, the through-wall sizing results were much better (6 of 7 passed). Manual qualification of weld overlay repairs has a noticeably higher pass rate. These rates, derived from Latiolais (2012), are shown in Table 3.1 below.

Data provided by EPRI shows that inspectors with extensive experience who have received an IGSCC qualification do no better at re-qualification than inspectors attempting qualification for the first time. These data on qualification and requalification strongly suggest that improvements in training, skills maintenance, practice and/or continued education are needed.

Human factors have been a contributing factor to the unsatisfactory results of NDE in a number of the events discussed in section 2 of this paper. A conference paper by Stephens (2000) discusses the heavy burden placed on human information processing by some NDE

Table 3.1 Pass Rates (numbers of individuals) on First Attempt for Manual, Non-encoded UT Qualification Examinations

Weld Configuration	Qualification	Technique	Pass	Fail
Ferritic Similar Metal Supplement 3	Detection and Length Sizing	Conventional	15	13
		Phased Array	11	8
Dissimilar Metal Piping Welds Supplement 10	Detection Only	Conventional	1	1
	Detection and Length Sizing	Phased Array	4	3
Austenitic Similar Metal Piping Welds Supplement 2	Detection and Length Sizing	Conventional	12	21
		Phased Array	13	6
Weld Overlay Supplement 11	Fabrication and Crack Detection	Conventional	6	1
		Phased Array	9	1
IGSCC Requalification Austenitic Piping (Supplement 2)	Detection Only	Conventional	14	12
		Conventional with Guided Practice and Instruction	8	3
		Phased Array	0	1
Similar Metal Piping Welds Supplements 2 and 12	Through-Wall Sizing	Conventional	8	4
		Phased Array	6	1
	Notes: Only first attempt data shown. Latiolais 2012 provides data on second and third attempts.			

examinations and techniques such as the ultrasonic examination for detection and through-wall sizing of IGSCC. The paper discusses the role that perception plays in functions such as detection, location, discrimination, comparison, and categorization. The paper argues that a focus on essential NDE application parameters and other aspects of the human factors will lead to needed improvements.

A conference paper by C. Mueller (2012) discusses an investigation of the influence of certain human factors on manual ultrasonic inspection performance. The time available for inspection, evaluation, and writing protocols were varied in the study. Psychological factors were additionally assessed in the course of the experiment. The results show a high influence of human factors on the inspection results. The effect of individually perceived time pressure and mental workload were found to have a significant negative impact on the performance. Good preparation before the inspection (e.g. thorough briefing and training on test pieces) and

the communication between the organization (e.g. the supervision of the utilities, inspection companies, and expert organizations) and the inspectors were considered as highly important psychological factors.

3.3 UT Modeling – Coverage and UT Capabilities

UT modeling can be performed to determine the minimum specific beam angles that are necessary to perform a reliable UT examination and also, can approximate the sound field density. Some recent issues related to poor examination results have been attributed to the use of probes inadequate for the specific examination. Analyses have shown instances of probes used that were not able to insonify the entire examination volume because either the angle(s) or focal laws used were inadequate. Missed indications in some instances have occurred because of access limitations. The orientation of the crack in conjunction with the transmitting angles of the probes can result in the sound energy not being reflected back to the search unit. Also, the microstructure of a material will affect the way that sound is reflected, refracted, and attenuated. Modeling provides information to design UT probes that optimize coverage and signal to noise ratio for specific applications.

A number of the events discussed in Section 2.0 suggest that the issues that arose may have been avoided with the use of UT modeling. It may be appropriate for industry and NRC to work cooperatively to develop a handbook on good modeling practices. Such information would be useful for improving probe designs and would provide a degree of uniformity in probe design within the industry.

3.4 Site-specific Qualification

Section XI, Appendix VIII, requires blind performance demonstration and is a framework that has been developed to support procedure, personnel, and equipment (UT system) qualifications through rigorous and statistically based testing protocols. Site-specific qualification is a practice that has been used to extend existing PDI qualifications for similar welds to weld geometries outside those addressed by PDI qualification mockups. EPRI, who administers the PDI program, has been assisting NIFG in revising the site-specific mockup process to incorporate lessons learned from the application of the process at North Anna. The NRC is working with NIFG with respect to concerns raised by the NRC, including the concern that there are no requirements in the ASME Code, Section XI, for the site-specific qualification. Accordingly, a potential resolution path already exists with respect to addressing the issues associated with past performance regarding the application of site-specific processes and developing a robust process moving forward. Thus, there does not appear to be a role for the expert group at this time. However, should resolution not be achieved, the expert group may be asked to investigate this issue.

3.5 Team Scanning

An approach for acquiring non-encoded data called “team scanning” is being used. PDI does not have a qualification procedure for this process. In a team scanning approach, the PDI qualified individual watches the monitor to determine if there are signals of interest. The individual manipulating the probe works under the visual and verbal supervision of an Appendix VIII examiner. In team scanning non-PDI qualified individuals can be used to perform scanning. The certification of individuals performing the scanning is not clear.

EPRI, who administers the PDI program, has been assisting NIFG in assessing the use of team scanning. The NRC is working with NIFG with respect to concerns raised by the NRC, including the concerns that a qualification process for team scanning has not been developed, and there are no requirements in the ASME Code, Section XI, addressing team scanning. Accordingly, a potential resolution path already exists with respect to addressing the issues associated with team scanning. Thus, there does not appear to be a role for the expert group at this time. However, should resolution not be achieved, the expert group may be asked to investigate this issue.

3.6 Probability of Detection (POD)

One input into the Extremely Low Probability of Rupture (xLPR) project evaluates the effects of inspection to be modeled. To create inspection models, the PDI was judged to be the best source for detection and sizing performance for DMWs. DMW performance qualification data from PDI were used to develop POD curves for xLPR. These POD curves are contained in MRP-262 (Ammirato, 2009).

PDI is focused on qualifying ultrasonic examiners. MRP-262 states, “It is impractical and unnecessary to incorporate all plant conditions, such as component surface condition in the qualification mock-ups.” PDI simulates plant conditions in some of the test samples in that the samples are not perfectly clean and, as such, contain plate stock fabrication anomalies. In general, however, PDI samples do not consider all field conditions such as adjacent welds, geometrical tapers, surface roughness, or fabrication flaws in field welds.

A lack of data for the region in which each POD curves change most rapidly (0 to 10% TW) is observed in the curves. Also, the DMW-PDI curves are surprisingly flat over the 10 to 100% range. One would expect the signals from large flaws to result in PODs closer to 1, and correspondingly, the signals from smaller flaws to be weaker. The flatness of these POD curves is not an artifact of the logistic regression model; the raw POD data points trace out a flat curve.

It is known that as-built weld conditions can dramatically impact ultrasonic coverage, and detection and discrimination of responses from service-induced flaws and other origins in as-built welds may be complicated. A number of events discussed in Section 2.0 call into question whether it is appropriate to assume that the PDI PODs are representative of what is achievable in the field and what should be done to determine appropriate PODs.

3.7 Matrix of Technical Issues Versus Plant Occurrence

Table 3.2 provides a matrix showing technical issues discussed in Sections 3.1 to 3.7 potentially involved in the plant occurrences discussed in Section 2.0.

Table 3.2 Matrix of Technical Issues versus Plant Occurrence

Plant/Issue	Spatially Encoded Data	Qualification and Training	Modeling	Site-Specific Qualification	Team Scanning	POD
North Anna-1	X	X	X	X	X	X
Duane Arnold-1	X	X				
Retired St. Lucie-1 Pressurizer	X	X	X			X
Calvert Cliffs-1	X	X				
Point Beach-1&2		X				
Ginna	X	X	X	X		
ANO-2	X		X			X
Nine Mile Point-1	X		X			X
Diablo Canyon	X					X

<u>3.0 CONCLUSIONS</u>

Reviews of recent events involving UT of nuclear power plant piping components have revealed a range of shortcomings with the implementation of Appendix VIII requirements, as well as with training, qualification and certification of NDE personnel. The shortcomings identified relate to a range of aspects of qualified UT systems.

A cooperative NRC/Industry follow-on effort may provide a useful vehicle to address the concerns identified in this paper.

4.0 REFERENCES

Ammirato F. 2009. *Development of Probability of Detection Curves for Ultrasonic Inspection of Dissimilar Metal Welds to Support Leak-Before-Break Assessment*. EPRI Report 1019088 (MRP-262), Electric Power Research Institute, Palo Alto, California.

Anderson MT, AA Diaz, and SR Doctor. 2012. PNNL-21546. *Evaluation of Manual Ultrasonic Examinations Applied to Detect Flaws in Primary System Dissimilar Metal Welds at North Anna Power Station*. June 2012. Pacific Northwest National Laboratory, Richland, Washington. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML12200A216.

Cinson A, MT Anderson. 2010. SIA PA Data Summary on Calvert Cliff's PZR Nozzle DMW. March 12, 2010. Pacific Northwest National Laboratory, Richland, Washington. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML13098A250.

EPRI. 2006. Improve PDI Pass Rates Progress Report. EPRI Report 1013546. November 2006. Electric Power Research Institute, Palo Alto, California.

EPRI. 2008. *St. Lucie Pressurizer Nozzle DM Weld Examination Project, Internal Office Report*. MRP 2008-012, Electric Power Research Institute, Palo Alto, California. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML080701017.

EPRI. 2008a. Nondestructive Evaluation: A Review of NDE Performance Demonstrations – NDE Round Robin Report. EPRI Report 1016969. June 2008. Electric Power Research Institute, Palo Alto, California.

Hiltz T. 2008. Diable Canyon Power Plant, Unit No. 2- Approval of Relief Request REP-1 U2, Revision 1, for the Application of Weld Overlay on Dissimilar Metal Welds of Pressurizer Nozzles. February 6, 2008. U.S. Nuclear Regulatory Commission, Washington, DC. ADAMS Accession No. ML080110001.

King C. 2008. MRP 2008-14. Reference: MRP 2008-012, "Examination Results on Nozzles from removed St Lucie Pressurizer with attachment St. Lucie Pressurizer Nozzle DM Weld Examination Project Internal Office Report." March 4, 2008. Electric Power Research Institute, Palo Alto, CA. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML080701020.

King C. 2008a. MRP 2008-027. Non Destructive Examination Summary of Pressurizer Safety Nozzles Removed from Service at Port St Lucie Unit 1. March 19, 2008. Electric Power Research Institute, Palo Alto, CA. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML080850647.

Kunowski MA. 2011. Letter to L Meyer. Point Beach Nuclear Plant Units 1 and 2, NRC Integrated Inspection Report 05000266/2011002; 05000301/2011002. April 29, 2011. U.S. Nuclear Regulatory Commission, Lisle, IL. ADAMS Accession No. ML111190331.

Lareau J. 2010. Inspection of Dissimilar Metal Welds to Resolve False Positive Indications. Eighth International Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurised Components. September 29, 2010. Berlin, Germany

Latiolais C. 2012. Compilation of Pass Rates vs. Attempts for App VIII Qualifications for Piping, DM Welds and Weld Overlay and RPV. December 7, 2012. Electric Power Research Institute, Charlotte, NC. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML13095A002.

Mogren T. 2012a. Letter to NRC Document Control Desk. "Ginna Nuclear Power Plant Docket No. 50-244, Additional Information Re: Fourth Interval Inservice Inspection Program Relief Requests Nos. ISI-02 and ISI-03." March 16, 2012, CENG, Ontario, New York. ADAMS Accession No. ML12081A119.

Mogren T. 2012b. Letter to NRC Document Control Desk. "Ginna Nuclear Power Plant Docket No. 50-244, Response to Request for Additional Information Re: Fourth Interval Inservice Inspection Program Relief Requests Nos. ISI-02 and ISI-03." July 29, 2011, CENG, Ontario, New York. ADAMS Accession No. ML11215A012.

Mueller C, M Bertovic, M Pavlovic, D Kanzler, U Ewert, J Pitkanen, and U Ronneteg. 2012. Holistically Evaluating the Reliability of NDE Systems – Paradigm Shift. 18th World Conference on Nondestructive Testing. April 2012. Durban, South Africa.

Pacher JE. 2011. Letter to NRC Document Control Desk. Nine Mile Point Nuclear Station Unit No. 1; Docket No. 50-220, Request to Utilize an Alternative to the Requirements of 10 CFR 50.55a(g) for the Repair of Control Rod Drive Housing Penetrations for the Remainder of the License Renewal Period of Extended Operation. March 25, 2011. CENG, Lycoming, NY. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML110950307.

PNNL. 2007. Technical Evaluation Report Review of Ultrasonic Data for Flaws Detected at Duane Arnold Energy Center, Unit 1 JCN-J3218, Task 6, TAC MD4630. June 18, 2007. Pacific Northwest National Laboratory, Richland, Washington. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML071760259.

PNNL. 2012. Technical Letter Report, Evaluation of Licensee's Alternative to 10 CFR 50.55a(g)(6)(ii) for Limitations to Volumetric Examinations of Dissimilar Metal Welds, Entergy Operations, Inc., Arkansas Nuclear One, Unit 2 – Docket Number 50-368. December 11, 2012. Pacific Northwest National Laboratory, Richland, Washington. . U.S. Nuclear Regulatory Commission, ADAMS Accession No.ML13113A218.

Polickoski, JT. 2013. Memorandum to File. Summary of March 8, 2013, Conference Call Between Pacific Gas and Electric Company and the Nuclear Regulatory Commission Regarding Verbal Authorization of Relief Request REP-1 U2, Revision 2 (TAC No. MF0880). April 11, 2013. U.S. Nuclear Regulatory Commission, Washington, DC. ADAMS Accession No. ML13081A074.

Pyle SL. 2011. Letter to NRC Document Control Desk. Use of Alternate ASME Code Case N-770-1 Baseline Examination Request for Alternative ANO2-ISI-007, Arkansas Nuclear One, Unit 2 ,Docket No. 50-368 License No. NPF-6. November 30, 2011. Entergy Operations, Inc., Russellville, AR. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML113340158.

Spina JA. 2006. Letter to NRC Document Control Desk. "Calvert Cliffs Nuclear Power Plant Unit No. 1; Docket No. 50-317, ASME Code Section XI Flaw Evaluation of Dissimilar Metal Weld Flaws Identified by Ultrasonic Testing." May 31, 2006, Constellation Energy Generation

Group, Calvert Cliffs Nuclear Power Plant, LLC, Lusby, Maryland. ADAMS Accession No. ML061580443.

Stephens H. 2000. NDE Reliability Human Factors – Basic Considerations. Presented at the 15th World Conference on NDE. May 31, 2000. Rome, Italy. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML13114A196

Swift PM. 2012. Letter to Document Control Desk. Request to Utilize an Alternative to the Requirements of 10 CFR 50.55a(g) for the Repair of Control Rod Drive Housing Penetrations - Response to NRC Request for Additional Information (TAC No. ME5789). October 31, 2012. CENG, Lycoming, NY. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML12312A255.

Turnbow, M. 2011. "ASME/NDE (ANDE) Personnel Qualification and Certification Initiative." Presented at the 2011 U.S. NRC Regulatory Information Conference (2011 RIC), Session T10, Emergent Topics in Consensus Standards, North Bethesda, MD, March, 2011.

Weakland D. 2008. Letter to the MRP Technical Advisory Group. MRP 2008-053. St. Lucie Unit 1, Retired Pressurizer Safety "A" Nozzle DM Weld Destructive Examination Report. August 12, 2008. Electric Power Research Institute, Palo Alto, CA. U.S. Nuclear Regulatory Commission, ADAMS Accession No. ML082480225.