ADDENDUM
to
MEMORANDUM OF UNDERSTANDING
between
U.S. NUCLEAR REGULATORY COMMISSION
and
ELECTRIC POWER RESEARCH INSTITUTE
on
COOPERATIVE NUCLEAR SAFETY RESEARCH

Nondestructive Examination (NDE)

I. Introduction

This Addendum to the Memorandum of Understanding (the Addendum) is entered into by and between the Office of Nuclear Regulatory Research (RES) of the U.S. Nuclear Regulatory Commission (NRC) and the Electric Power Research Institute (EPRI), effective as of the date of signature of the last of the parties to execute this Addendum (the effective date). The NRC and EPRI are parties to the Memorandum of Understanding on Cooperative Nuclear Safety Research, dated September 30, 2016 (the MOU, found at ADAMS Accession Number ML16223A497). The MOU allows and encourages cooperation in nuclear safety and security research that provides benefits for both NRC and EPRI. These benefits include technical expertise and information exchange, whenever such cooperation and sharing can be accomplished in a mutually beneficial manner.

This MOU Addendum is authorized pursuant to Section 31 of the Atomic Energy Act of 1954 as amended, and/or Section 205 of the Energy Reorganization Act. The roles, responsibilities, terms, and conditions of this Addendum should not be interpreted in a manner inconsistent with, and shall not supersede, applicable Federal laws and regulations.

II. Background

An Addendum to the MOU addressing nondestructive examination (NDE Addendum) including methods, procedures, equipment, and personnel was added to the MOU on March 22, 2011 (ADAMS Accession Number ML103080165). Specific areas of collaboration identified in Attachments 1 through 5 to the NDE Addendum were: 1.) Visual testing; 2.) Cast austenitic stainless steel; 3.) Ultrasonic testing in lieu of radiographic testing for repairs, replacements, and modification; 4.) Documentation of the basis for ASME Section XI, Appendix VIII; and 5.) Root mean square error - inner diameter pipe examinations depth sizing. On November 2, 2011, a sixth Attachment addressing high-density polyethylene (HDPE) piping was added to the NDE Addendum (ADAMS Accession Number ML 112570034). On April 14, 2014, a revision to the NDE Addendum was executed extending the expiration date to April 30, 2018 and adding a seventh Attachment addressing nondestructive examination modeling (ADAMS Accession Number ML14112A187). Both organizations agree that the research conducted under the April 14, 2014 Addendum revision has been very useful, and as such, plan to continue to collaborate on NDE-related topics. This NDE Addendum hereby supersedes the April 14, 2014 NDE

Addendum given Attachment 8 is hereby added addressing human performance influences on NDE reliability.

As reactor facilities continue to age, it becomes more important that adequate inspections are conducted to ensure that components are capable of performing their function, and safety is sufficiently maintained. Inservice inspection (ISI) is one of the primary tools in the management of age-related degradation in nuclear power plants and has become increasingly critical as the units continue to age. Inservice inspections are performed to verify that no known or unknown damage mechanisms are compromising reactor safety, operational safety, and personnel safety. Operating plant materials and components have experienced varying levels of degradation, and new mechanisms have become apparent approximately every seven years over the past few decades. Degradation problems may result in significant operational and potential safety problems requiring substantial resources. Dependable inservice inspection programs are one tool that can be used to deal with materials degradation in the management of resources.

The NRC and EPRI conduct research investigating the reliability and effectiveness of various NDE methods. While the research efforts of the NRC and EPRI may be conducted for different purposes, the underlying data and the results obtained have common value to both the NRC and EPRI. Accordingly, to conserve resources and to avoid unnecessary duplication of effort, the NRC and EPRI agree to cooperate in selected NDE-related research efforts and to share information related to such research. The information will be shared on a basis that is consistent with the procedures outlined in the MOU, dated September 30, 2016, and this NDE Addendum, and under conditions acceptable to existing agreements made with the owners or sponsors of data not owned by NRC or EPRI. The NRC will maintain its independence consistent with its regulatory function. The NRC or EPRI will be individually responsible (with the proper coordination) for certain activities, and none of the activities will be co-funded.

III. Objectives

This NDE Addendum addresses cooperative research on all aspects of nondestructive examination including methods, procedures, equipment, and personnel. The overall objectives of this effort are to identify and evaluate the effectiveness of NDE methods in detecting and characterizing flaws, to evaluate the reliability of NDE methods for selected examinations, and to evaluate aspects of inspector qualifications.

Specific areas of collaboration are identified in the Attachments to this NDE Addendum. However, it is likely that emerging degradation issues at existing plants or issues regarding new plant designs related to the areas of NDE and ISI will be of interest to both organizations and therefore candidates for future inclusion under this Addendum. Accordingly, additional Attachments may be added to the NDE Addendum without having to revise the NDE Addendum provided: i) the provisions of the NDE Addendum are not modified; ii) new Attachments are subjected to the same organizational approval process as the original NDE Addendum; and iii) new Attachments are signed by the designated officials.

As noted in the background section, the April 14, 2014 NDE Addendum included seven Attachments. This revision to the NDE Addendum supersedes the NDE Addendum dated April 14, 2014 in its entirety. Further, this NDE Addendum revises the expiration date, changes the

NRC project manager, and adds an eighth Attachment addressing human performance influences on NDE reliability.

IV. Period of Performance:

The period of performance will be from the effective date through September 30, 2021, to be extended in writing if mutually agreeable to EPRI and RES.

V. Project Direction and Coordination:

Overall project direction and coordination will be conducted through project managers who will be the single point of contact representing NRC and EPRI. Technical meetings to coordinate this effort and to assess progress will be arranged through the respective project managers for each organization. The project managers are:

EPRI	NRC
Greg Selby, Senior Technical Executive, NDE	Carol A. Nove, Senior Materials Engineer
Electric Power Research Institute	Component Integrity Branch
P.O. Box 127097	Division of Engineering
1300 Harris Blvd	Office of Nuclear Regulatory Research
Charlotte, NC 28221	U.S. Nuclear Regulatory Commission
	M/S T10-A36
	Washington, DC 20555-0001

The NRC or EPRI will be individually responsible (with the proper coordination) for certain activities. To ensure that the overall effort is successfully completed, NRC and EPRI should coordinate proposed contract actions prior to either party entering into an agreement with others. To avoid confusion and maintain consistent project direction, the project managers should discuss matters related to project direction prior to the performance of the activities by the contractor. The respective project managers will coordinate the technical information exchanges to be held between EPRI and the NRC.

VI. Costs

NRC and EPRI are responsible for their respective costs. NRC funding for work to be conducted through FY 2021 is subject to the availability of appropriated funds. None of the work shall be co-funded. This NDE Addendum does not create any binding obligation or enforceable right of action of any kind on the part of either party. This NDE Addendum does not obligate any funds.

VII. Disputes

If a dispute arises out of or relating to this NDE Addendum, or any breach thereof, the parties will first attempt to settle the dispute through direct negotiation between the respective project managers. If such dispute cannot be settled by the respective project managers, the dispute shall be submitted to the Director of the Office of Nuclear Regulatory Research, US NRC, and the Vice President and Chief Nuclear Officer, EPRI.

AGREEMENT

/RA/

Michael F. Weber
Director of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission

2/17/17

Date

/RA/

Neil M. Wilmshurst
Vice President & Chief Nuclear Officer
Electric Power Research Institute

2/14/17

Date

12/8/2016

Attachment 1

SCOPE OF WORK
Visual Testing

Background:

U.S. nuclear industry representatives have proposed using visual testing (VT) methods in lieu of certain American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (Code) Section XI volumetric and/or surface examination requirements. Certain reactor pressure vessel components are examined using VT because the geometry precludes the use of ultrasonic testing (UT). Other components are examined using remote VT to reduce occupational exposure.

Literature searches revealed that few comprehensive studies of the probability of various video systems used for remote VT to detect cracks had been published. To evaluate the reliability and effectiveness of VT, the Nuclear Regulatory Commission (NRC) conducted a parametric study at Pacific Northwest National Laboratory (PNNL) that examined the important variables influencing the effectiveness of remote VT. Six parameters—the important variables that influence the effectiveness of remote VT and the ability of remote systems to detect cracks—were assessed, i.e., crack size, lighting conditions, scanning speed, camera resolution, surface specularity, and surface conditions. A limited laboratory test was also conducted using a commercial visual testing camera system to experimentally determine the ability of the camera system to detect cracks of various widths under ideal conditions. The results of the studies were published in NUREG/CR-6860, "An Assessment of Visual Testing," and NUREG/CR-6943, "A Study of Remote Visual Methods to Detect Cracking in Reactor Components."

As discussed in the reports, the results of the studies indicated that crack opening displacement is the parameter that most dramatically impacts the reliability of inspections. The studies stated that a significant fraction of the cracks that have been reported in nuclear power plant components are at the lower end of the capabilities of the VT equipment currently being used. The authors suggested that inspection conditions need to be nearly ideal to detect these cracks, and that further study was required to resolve the questions raised through the preliminary research.

Task 1, Round Robin Protocol Formulation:

NRC and the Electric Power Research Institute (EPRI) met to develop a round-robin visual testing exercise design parameters/testing protocol, and to formulate a plan for the exercise including scope, test variables, and oversight. NRC fabricated specimens with fatigue cracks and blanks and shipped them to EPRI for the round-robin exercise.

Status: Complete

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Task 1, Round Robin Exercises:

NRC and EPRI were jointly responsible for conducting round-robin exercises at the EPRI NDE Center to determine the detection and sizing capabilities of current industry VT equipment, procedures, and personnel for a variety of crack sizes and specimen configurations. Both parties were responsible for identifying commercial remote VT vendors, camera manufacturers, and experienced industry personnel to participate. The round-robin exercises were broken up into three phases:

Phase I: Mini-round robin and parametric studies to define parameters impacting remote visual inspections

Phase II: Round robin testing by multiple vendors with field procedures used by each vendor

Phase III: Round robin testing of procedure improvements with multiple vendors.

Status: Complete

Task 1, VT Camera Test:

NRC conducted a test of a VT camera by a VT camera manufacturer to assess new technology.

Status: Complete

Task 2:

Assess the capabilities and limitations of remote visual examinations to detect cracking in nuclear power plant components. NRC and EPRI will each separately review the results of the round-robin exercise to attempt to quantify the effectiveness of current practice. Each organization will provide an analysis detailing the measured performance in detection and sizing.

Status: Data analysis was completed in FY16.

Task 3:

NRC and EPRI will each be responsible for developing their own final technical reports detailing the fabrication of the specimens, conduct of the tests, results of the inspections, and independent data analysis. Each organization will review and comment on the final technical report of the other organization prior to publication of the reports.

Status: In-process. PNNL's draft NUREG/CR was delivered to the NRC in November 2016.

12/8/2016

Attachment 2

SCOPE OF WORK
Cast Austenitic Stainless Steel

Background:

Cast austenitic stainless steel (CASS) material was used extensively in the primary pressure boundary of pressurized water reactors. The ASME Code requires periodic inservice inspection of welds in the primary pressure boundary. The coarse-grained and anisotropic microstructure of CASS material makes it difficult to inspect. The large grain sizes of these materials strongly affect the propagation of ultrasound by causing severe attenuation, change in velocity, and scattering of ultrasonic energy. Thus, the signal patterns originating from flaws can be difficult to distinguish from scatter. In addition, the result of redirection of the sound beam may mean that some portions of the material are not examined. This is problematic for component configurations where examination from the CASS side is required to assess weld conditions on the far-side.

Thermal embrittlement of CASS components in nuclear plants due to time and temperature is well known and has been widely studied. Électricité de France (EdF) representatives have discussed occurrences of thermal embrittlement of CASS materials. Industry organizations have discussed the development of a technical basis for a probabilistic model with the objective of determining the influence of thermal aging embrittlement on the reliability and integrity of CASS components and to quantify the benefits of inspections, mitigations, and other options for managing risk.

NRC and EPRI have been collecting CASS piping specimens (or materials for fabricating new specimens) for investigation with an emphasis on obtaining material representative of U.S. power plants currently in operation. Vendors have discussed the potential use of CASS in new reactor designs. These specimens will be used in the performance of Tasks 1 and 6, below.

Task 1:

NRC will be responsible for conducting laboratory examinations of large-bore and small-bore CASS piping specimens using low-frequency phased-array ultrasonic probes. The focus of the study will be to determine the smallest through-wall flaw that can be reliably detected. Sound field mapping of various CASS microstructures as a function of incident angle, inspection frequency, focal depth, and modality will be conducted. In-situ microstructural characterization methods will be investigated measuring acoustic backscatter as a function of angle. Sizing and detection capability will be analyzed.

Status: Small bore studies are complete. Large bore studies are in process.

Deliverables:

- NUREG/CR-7122, “An Evaluation of Ultrasonic Phased Array Testing for Case Austenitic Stainless Steel Pressurizer Surge Line Piping Welds” (ADAMS Accession Numbers ML12087A061 and ML12087A063)

- PNNL Technical Letter Report PNNL-23393, "Phased Array Ultrasonic Sound Field Mapping in Cast Austenitic Stainless Steel (ADAMS Accession Number ML14155A134)

Task 2:

EPRI was responsible, to the extent possible for the material specification records that are available, for collecting data regarding the locations of CASS piping in operating plants. The data was to include information relative to heats of materials. Weld specific analyses were conducted to determine the locations most susceptible to thermal fatigue. The purpose of this study was to determine which welds need to be examined, i.e., locations that are safety-significant and susceptible. Conversely, the information from the study could be used to determine which locations can be removed from an inspection program or inspected at a reduced frequency.

Status: Complete

Deliverables:

- EPRI 1019128, "Flaw Tolerance Evaluation of Thermally Aged Cast Austenitic Stainless Steel Piping"
- EPRI 1024966, "Nondestructive Evaluation: Probabilistic Reliability Model for Thermally Aged Cast Austenitic Stainless Steel Piping"
- EPRI 3002000672, "Materials Reliability Program: Technical Basis for ASME Section XI Code Case on Flaw Tolerance of Cast Austenitic Stainless Steel (CASS) Piping (MRP-362)"

Task 3:

The NRC conducted a study at PNNL to assess eddy current testing (ET) for detection of surface-breaking cracks in CASS piping from the inside surface of the pipe. The results were published in NUREG/CR-6929, "Assessment of Eddy Current Testing for the Detection of Cracks in Cast Stainless Steel Reactor Piping Components." EPRI studied the effectiveness and reliability of ET for the examination of CASS components. EPRI provided the results of its ET study to NRC so that the results of the two investigations could be compared relative to an assessment of ET for examining CASS components.

Status: Complete

Deliverable:

- EPRI 1022928, "Nondestructive Evaluation: Inside Surface Examination Techniques for Cast Stainless Steel Progress in 2011"

Task 4:

EPRI collected data regarding locations of CASS in existing plants, including data such as heats of material and evaluated existing field conditions that may impact examinations performed from the inside or outside diameter surfaces of CASS piping welds. Weld crowns, counter-bores, or other geometrical restrictions may be found in susceptible examination locations. This data was needed to ensure that specimens used for evaluating UT systems are representative of field conditions. Also, since calibration blocks may exist at plants that could be useful for this exercise, EPRI gathered information on calibration block configurations.

Status: Complete.

Deliverable: The deliverable for this task was the development of a set of representative mockups to be used in the round robin study described in Task 6.

Task 5:

NRC will pursue completing the probability of failure approach initiated by Structural Integrity Associates (SIA). For this task to proceed, EPRI will have to obtain agreement from SIA and industry oversight groups. If agreement is obtained, the NRC will hold periodic meetings with EPRI to coordinate approach and review interim/final results.

Status: Task eliminated due to limited funding resources

Task 6:

EPRI will conduct a CASS round robin study (RRS) to assess the capabilities of currently available nondestructive examination (NDE) techniques and identify any areas in need of improvement. The objectives of the CASS-RRS are: (1) Identify and quantitatively assess volumetric examination techniques for the detection, sizing, and characterization of flaws in test specimens; (2) Evaluate present NDE techniques applied by experienced ISI practitioners for capability and effectiveness; (3) Quantify the performance of the current NDE technology and personnel in terms of probability of detection and false call probability; and (4) identify any shortcomings in the current CASS mockup manufacturing techniques.

NDE vendors and laboratories will be encouraged to participate in the CASS-RRS. PNNL will participate on behalf of NRC. The results of the round robin study, coupled with the results of prior tasks including the probabilistic study, will be used in consideration of a meaningful configuration for ASME Section XI, Appendix VIII, Supplement 9; this Supplement, currently identified as “in course of preparation”, will define performance demonstration requirements for UT of CASS components from the outside surface.

PNNL will deploy the low-frequency phased array ultrasonic test (PA-UT) techniques developed at the laboratory to collect data on all mockups in the RRS. PNNL will then analyze the data and report results to EPRI in the format required of all of the vendors and laboratories. PNNL will contribute to the analysis and evaluation of all of the vendors/participant CASS RRS data and flaw population assessment by:

- Reviewing candidate indication report forms and data sheets (not actual data)
- Reviewing limited data collected for the purpose of evaluating a technique’s performance
- Verifying results input into the CASS RRS summary sheet
- Performing analysis of results supplied by candidates

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- Assessing flaw population for statistical significance

NRC and EPRI will each be responsible for developing their own final reports detailing the conduct of the testing, results of the examinations, and independent data analysis. Each organization will be provided an opportunity to review and comment on the final technical report of the other organization prior to publications of the reports.

Status: In-process. EPRI estimates that the RRS will be complete in early CY17. PNNL's assessment/report will not be available until late in FY17, at a minimum.

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Attachment 3

SCOPE OF WORK
UT/RT for Repairs, Replacements, and Modifications

NOTE: The cooperative efforts in this Attachment have been completed to the extent possible with available funding. The results are supporting ASME Code Case N-831, "Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe," Section XI, Division 1 being balloted at Section XI Standards Committee in 2016.

The following background, description, and scope of work remain for historical purposes.

Background:

Several years ago, two ASME Code Cases were developed that would allow the use of ultrasonic testing in lieu of radiographic testing: Code Case N-659-2, "Use of Ultrasonic Examination in Lieu of Radiography and for Weld Examination, Section III, Division 1, and Code Case N-713, "Ultrasonic Examination in Lieu of Radiography." In response, the NRC conducted a technical gap analysis at PNNL (PNNL-19086, "Replacement of Radiography with Ultrasonics for the Nondestructive Inspection of Welds - Evaluation of Technical Gaps - An Interim Report." ADAMS Accession Number ML101031254) to assess the availability of publications detailing research in the areas of RT, digital radiography (DRT), and UT used in place of RT (applicable to nuclear applications). While the literature survey found over 600 journal and conference papers and technical reports, and over 100 related documents, it was determined that most of the research was narrowly focused, i.e., specific to an industry need, or to specific material(s). Accordingly, the NRC developed a research program to address some of the knowledge gaps.

In response to industry needs, EPRI conducted a project to evaluate DRT through a series of equipment demonstrations with selected detector panels, phosphor plates, and radiation sources. In addition, EPRI is assessing the possibility of modifying the Code to allow the acceptance of fabrication flaws that are projected to pose no structural challenge during the life of the plant. Thus, it is important that the capabilities of film RT and DRT be established relative to distinguishing orientations and flaw sizes for nuclear applications.

The NRC program will assess industry research being conducted to: use UT in lieu of RT, and replace traditional film radiography with DRT. PNNL has a 450 kV X-ray machine that will be used in the assessment. The evaluation will also determine the capabilities of the methods based on examination effectiveness and reliability to detect and characterize flaws common to Section III repair and replacement activities and Section XI preservice inspection and inservice inspection activities.

Task 1:

EPRI will be responsible for identifying suitable dates and a venue for a UT/RT workshop. The purpose of the workshop is to: assemble experts from around the world to determine the state-of-the art relative to RT/DRT and use of UT in lieu of RT, determine what research, if any, is currently being conducted with application to nuclear power plants, and determine what technical gaps exist where research is needed to support the use of UT in lieu of RT and implementation of DRT.

EPRI and NRC will be responsible for managing and conducting the workshop. The NRC will be responsible for developing a report on the workshop including copies of the presentations and recommendations.

Status: While the workshop was planned, due to lack of response, the workshop was cancelled.

Task 2:

EPRI will be responsible for evaluating DRT equipment through a series of demonstrations with selected detector panels, phosphor plates, and radiation sources. NRC will be responsible for assessing the human factors that affect NDE reliability.

Status: DRT equipment evaluations are complete. Human factors studies being conducted under Attachment 8 of the NDE Addendum.

Deliverables:

- EPRI 1016656, "Nondestructive Evaluation: Evaluation of Filmless Radiography, 2008 Update"
- EPRI 1019121, "Nondestructive Evaluation: Evaluation of Filmless Radiography, 2009 Update"
- EPRI 1021154, "Nondestructive Evaluation: Evaluation of Filmless Radiography, 2010 Update"

Task 3:

No studies were found in the literature examining the equivalence of film RT and DRT for nuclear applications. In addition, procedures have not been established to optimize DRT for typical nuclear power plant component configurations. EPRI and NRC will assess DRT inspection variables such as dose, exposure, time, handling (e.g., dust, humidity, temperature), and resolution (in consideration of any information identified from workshop). EPRI and NRC will assess the impact of replacing film RT with DRT in nuclear applications currently in use in the nuclear industry.

Status: Due to limited funding, this task was not addressed.

Task 4:

NRC will research the capabilities of film RT and DRT to detect different flaw types (e.g., fabrication, service-induced), orientations, and sizes, with attention to false calls and sizing accuracy.

Status: Due to limited funding, this task was not addressed.

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Task 5:

The ASME developed Code Cases to allow the use of UT in lieu of RT. The literature survey identified several relevant studies comparing UT and RT that showed that UT appears to have equivalent or better detection performance in ferritic steel welds. However, the studies also showed that grouping of porosity could be interpreted as a crack, or two small voids may be interpreted as upper and lower tip signals. Thus, anomalous indications may be a consideration in replacing RT with UT. The NRC assessed factors such as probability of detection, reliability, and sizing accuracy, when replacing RT with UT and proposed additional guidance and/or changes/improvements to standards currently in use in the nuclear industry. The NRC provided an assessment of the interchangeability of UT and RT relative to flaw detection, orientation, sizing, false calls, and type identification in accordance with Section III and Section XI acceptance requirements.

Status: Complete

Deliverable:

- NUREG/CR-7204 “Applying Ultrasonic Testing in Lieu of Radiography for Volumetric Examination of Carbon Steel Piping” (ADAMS Accession Number ML15253A674)

Attachment 4

SCOPE OF WORK
Documentation of Basis for Appendix VIII

NOTE: While the cooperative efforts under this Attachment have been completed, this item will remain in the MOU and potentially be re-visited in the future as Section XI, Appendix VIII is revised. NUREG/CR-7165 "The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination Systems," (ADAMS Accession Number ML13144A107) published in May 2013, documents closure of this work.

The following background, description, and scope of work remain for historical purposes.

Background:

Experiments conducted by the Pressure Vessel Research Council between 1971 and 1978 provided the first data to indicate that ultrasonic procedures were not as reliable as "expert" opinion suggested. Later experiments under Programme for the Inspection of Steel Components (PISC) programs proved that minimum ASME procedures were not reliable. In 1977, the NRC initiated a program to address nondestructive examination (NDE) reliability issues. The program produced a technical basis for Research Information Letter (RIL) 113, "Reliability of In-service Inspection of Primary Piping Systems," dated January 29, 1981, recommending the need for nondestructive examination (NDE) performance demonstrations. Large leaking cracks in pipes were discovered after inspections had been performed. Finally, research sponsored by NRC at PNNL in the 1980s indicated that "reliable" ultrasonic inspection could not be written into procedures and that inspection procedures were not capable of describing precisely how to differentiate between geometric or metallurgic indications and cracks.

Representatives of the industry, ASME Code and NRC met and agreed that major improvements in the quality of inservice inspection were needed, and that qualification of NDE systems might be the answer. It was determined that the ASME Section XI Code committees should develop qualification requirements. The efforts of the ASME Code committees resulted in Appendix VIII on ultrasonic testing system performance demonstrations, which was approved by the ASME Boiler and Pressure Vessel Standards Committee in early 1989 and approved by the Board on Nuclear Codes and Standards in mid-1989. The Appendix was published as part of the 1989 Addenda to the ASME Code Section XI. The rules of Appendix VIII marked a revolutionary change in the conduct of inservice ultrasonic examination requirements for piping and reactor pressure vessels; rather than prescriptive requirements, the concept of performance demonstration was developed. The industry initiated the Performance Demonstration Initiative (PDI), which is administered by the Electric Power Research Institute, to ensure that inspectors were qualified per the requirements of Appendix VIII.

As indicated by the dates above, a great deal of time has passed since the requirements in ASME Section XI, Appendix VIII, were developed. As technology improves, there has been a desire to use new the technology for inservice inspection. During the consideration of appropriate procedure and equipment qualifications, questions have been raised regarding the technical bases behind current requirements. In addition, many of the individuals that conducted the research showing the need for performance demonstration, or that were responsible for the development of Appendix VIII, have retired or are about to retire. A technical basis document is needed to ensure that the basis for the development of Appendix VIII is not lost, and to provide ASME Code users with an understanding of the technical rationale for the requirements. The NRC tasked PNNL with developing such a technical basis document.

Task 1:

PNNL staff involved with research leading to the need for Appendix VIII and instrumental in the development of the Appendix VIII requirements contributed to a technical basis document. The NRC provided a copy of the draft technical basis document to EPRI. EPRI personnel that administer Appendix VIII reviewed the draft and provided comments, additional technical basis, and references where appropriate. EPRI's review included solicitation of input from retired individuals who had prominent roles in the development of Appendix VIII.

Status: Complete

Task 2:

The NRC published the final technical basis document as a publicly available report.

Status: Complete

Deliverable:

- NUREG/CR-7165 "The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination Systems" (ADAMS Accession Number ML13144A107)

12/8/2016

Attachment 5

SCOPE OF WORK
RMSE – ID Pipe Examinations Depth Sizing

NOTE: This Attachment is complete. The work comprises the technical basis for Code Case N-695-1: Qualification Requirements for Dissimilar Metal Piping Welds and N-696-1: Qualification Requirements for Mandatory Appendix VIII Piping Examinations Conducted from the Inside Surface. These Code Cases were generated to provide an alternate RMSE qualification value of 0.250 in. (6 mm) for piping greater than or equal to 2.1 in. (54 mm) in thickness for inspections performed from the inside surface.

The following background, description, and scope of work remain for historical purposes.

Background:

During periodic discussions between NRC staff and representatives from the EPRI and the Performance Demonstrative Initiative (PDI), PDI representatives noted that vendor personnel have not been able to pass the root mean square error (RMSE) depth sizing requirement for dissimilar metal weld (DMW) examinations from the inner diameter (ID) of piping. Factors that can affect ID qualifications are pipe wall thickness, surface waviness, surface geometry, through-wall flaw depth, and transducer size. Industry representatives have discussed the difficulties in meeting the requirement and provided developed alternatives for a revised RMSE screening criterion.

The NRC transmitted a letter to the chair of the PDI on November 8, 2010, requesting that the DMW pipe performance demonstration database be queried to assess the results of qualifications. Specifically, information regarding demonstrations performed from the inside pipe surface would be used to assess results relative to the RMSE requirement.

The results of the data search are needed to develop a technical basis report that would support a revision to the current RMSE requirement (as supported by the data).

Task 1:

EPRI provided NRC and PNNL with access to the similar and dissimilar metal weld samples used for ID Supplement 2 and 10 qualifications, as well as any statistical information or actual test results required for the purpose of determining the practical issues associated with these qualifications and any related statistical information. EPRI provided individual(s) to query the database, and EPRI and PNNL personnel jointly assessed the data. EPRI provided information on its assessment of the data relative to ability to meet the ID 0.125 inch RMSE criterion. PNNL and NRC staff were provided an opportunity to review the information and provide comments to EPRI.

Status: Complete

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Task 2:

EPRI developed a technical basis supporting a change in the current 0.125 inch RMSE requirement. The resulting EPRI white paper described industry issues with regard to difficulties in meeting 0.125 inch RMSE criteria, and provided an adequate technical basis to support the proposed alternative(s) to the current requirement. The NRC provided technical expertise to review the white paper prior to finalization. The EPRI white paper was used by ASME Section XI to provide the technical basis for requested changes to Section XI, Appendix VIII. Further, it provided the necessary information for the NRC staff to consider any requested changes to regulations.

Status: Complete

9/7/2016

Attachment 6

SCOPE OF WORK
High Density Polyethylene (HDPE) Piping

Background:

Recent incidents at several nuclear stations, including Braidwood Generating Station, Oyster Creek Generating Station, Oconee Nuclear Station, and Vermont Yankee Nuclear Power Station, involving radioactive contamination of groundwater wells and soil have caused NRC licensees and the NRC to take actions to address the source of the radioactive material (e.g., buried piping leaks) and to communicate the impact of such incidents to the public and other external stakeholders. Although the NRC actions in each incident have been adequate to prevent off-site releases in excess of Federal limits, the incidents raise questions about (1) the completeness of NRC actions to date, and (2) whether those actions need to be augmented.

Degradation in buried piping has occurred in safety-related and non-safety-related piping at nuclear power plants. The piping degradation referred to above has not affected the operability of safety systems, and the type and amount of radioactive material or chemicals released to the environment have been a small fraction of the regulatory limits. However, there has been at least one situation where bio-fouling led to severely restricted flow. In addition, the leakages and subsequent contamination has resulted in heightened public scrutiny.

Recent excavations at several nuclear power plants (NPPs) have found instances of significant wall thinning in carbon steel piping systems. The primary cause of degradation is that the metal surface of these systems was exposed to the elements when the coating was damaged during installation or degraded over time through wear and tear.

Nuclear industry representatives have been working with representatives from the gas transmission, mining, and plastic pipe manufacturers to develop ASME Code requirements for the use of high density polyethylene (HDPE) piping at NPPs. Specifically, the representatives have been working on development of ASME Code, Section III, Mandatory Appendix XXVI, Rules for Construction of Class 3 Buried Polyethylene Pressure Piping. Appendix XXVI was published in the ASME Code, 2015 Edition, and is currently within the scope of NRC Rulemaking to incorporate by reference the ASME Code, 2015 Edition. ASME Code, Section XI is also developing the criteria and guidance for inservice inspection of HDPE pipe.

Several industry organizations are investigating NDE methods that can be applied to HDPE materials; ultrasonic techniques primarily, but there is at least one organization investigating the use of microwave technology for determining the structural integrity of joints. The ability of these techniques to detect and characterize flaws with air gaps caused by contamination has been demonstrated but not for voids and cold fusion (kissing bonds).

A robust program is required to better understand the issues that have been raised and potential problems of for using HDPE in nuclear applications. It is believed that the range of conditions can be assessed by testing the smallest diameter pipe (and thinnest wall thickness) and largest diameter (and thickness wall) projected to be used. An intermediate diameter may be required if warranted by early test results. With regard to Task 4, fracture mechanics experts will have to be engaged so that the critical flaw size is determined to guide the selection of flaw sizes and flaw types to include in the studies for the other tasks, i.e., understand how precise NDE has to be. Given the time that may be required to develop the critical flaw sizes, it may be necessary to make some assumptions regarding the smallest flaw sizes to be included in the studies so as to not delay important NDE work.

Task 1:

Various nuclear industry organizations are currently investigating the effectiveness and reliability of ultrasonic, RT and microwave technologies, for example, to detect flaws in HDPE joints. The NRC is conducting a study to determine the effectiveness and reliability of visual and volumetric examination methods to detect and characterize surface breaking flaws and embedded flaws that are located at various through-wall depths and in various shapes. It is anticipated that the NRC's and EPRI's focus will be on phased array and time of flight diffraction (TOFD). EPRI conducted a preliminary study to assess the capabilities of microwave technologies. The NRC will be assessing industry results relative to microwave technologies (e.g., EPRI, Evisive). Under this agreement, EPRI will focus on the effectiveness and reliability of UT, RT, NMR and microwave technologies to detect flaws in HDPE joints. EPRI will develop and provide to NRC a technical paper providing its assessment of their investigation. NRC will develop a final technical report describing the findings of the research regarding the effectiveness and reliability of ultrasonic and microwave technologies for the examination of HDPE.

Status: Complete

Deliverables:

- NUREG/CR-7136, "Assessment of NDE Methods on Inspection of HDPE Butt Fusion Piping Joints for Lack of Fusion," May 2012 (ML Accession Number ML12153A005)
- EPRI 1011628, Technical Support for Proposed Polyethylene Pipe Code Case. EPRI, Palo Alto, CA, 2005.

Task 2:

NRC and EPRI will determine an appropriate matrix of samples to assess the effectiveness associated with detection and characterization of flaws for visual and volumetric examination methods. Industry organizations are procuring HDPE specimens to conduct various investigations, and some of these specimens may be available for inclusion in this task. NRC and EPRI will develop a joint plan to obtain or procure samples in accordance with the matrix and conduct detection/characterization research.

Status: Due to different funding cycles and priorities, NRC and EPRI have pursued this task independently. However, results have been shared between the two organizations. For example, in April 2016, NRC Staff attended a performance demonstration at EPRI of NDE for HDPE joints. In addition, EPRI is conducting a round robin exercise for inspection of HDPE joints and the results of this round robin will eventually be shared with NRC. Lastly, PNNL has published the results of their recent work on NDE of HDPE at PVP 2016, and will be publishing a publicly available PNNL Technical Letter Report summarizing their work by March 2017.

9/7/2016
Task 3:

The industry is working through the ASME to develop a technical basis regarding flaw sizes and acceptance criteria. NRC and EPRI will independently assess the acceptance criteria developed for the different NDE methods. The industry is also working through the ASME to determine the critical flaw sizes for different wall-thicknesses/diameters and the effects on critical flaw size with regard to effects from aging, temperature, and pressure.

It is important to know the tolerable flaw size for HDPE pipe in service in order to set NDE acceptance criteria. As a result, it is important to study the flaw tolerance of HDPE pipe. The primary mode of service failures in HDPE piping is a mechanism known as slow crack growth (SCG). SCG rates are affected by temperature, stress, and flaw and component geometry. The design service temperatures for safety-related nuclear applications are up to 140 F for a design life of at least 50 years with allowances for shorter-term (0.3-year) temperature "spikes" of up to 176 F. The combination of service conditions (temperatures, pressures, and allowable flaw size) associated with Class 3 safety-related applications are outside of the historical design requirements for HDPE and pose new challenges especially for HDPE joints including both butt fusion and electrofusion joints. Very limited SCG data exist that characterize the effect of extrinsic stress risers such as scratches and defects introduced during fusion.

The purpose of this task is to validate the long-term service life allowable temperatures and stresses for HDPE piping and joints in the presence of an allowable flaw. This task will cover both butt fusion joints and electrofusion joints. The results of the research will inform the public, regulators and standards organizations pertaining to the design of, and NDE requirements for, safety-related Class 3 buried piping systems using HDPE.

Task 3 is composed of several subtasks:

Subtask 3.1: Parent material allowable flaw testing

Status: NRC and EPRI testing on parent material is complete

Deliverables:

- NRC: PENT and hydrostatic testing data
- EPRI: PENT tests of butt fusion joints and hydrostatic pressure test data of surface scratches are complete.
- EPRI 3002003089, “Pennsylvania Edge Notched Tensile Resistance of High Density Polyethylene Butt Fusion Joints”
- EPRI 3002005333, “Sustained Pressure Test Results for Surface Scratches in PW4710, Cell Classification 445574C High Density Polyethylene Pipe Material”.

Subtask 3.2: Butt fusion joint SCG testing and allowable flaws

Status: NRC’s first phase of testing is complete. Additional testing is planned including whole pipe tensile tests and PENT tests on 4” and 12” pipe material, service life predictions, and allowable flaw size predictions for butt fusion joints. EPRI’s first phase of testing is complete (EPRI 3002003089). The EPRI second phase of testing has started which will include parametric coupon tests with varying sizes of surface and subsurface flaws. EPRI's third phase of testing is planned including confirmatory whole pipe tests using flaw sizes determined from the phase 2 coupon tests.

Deliverables:

- NRC: PENT, WPTT and modified PENT testing data on butt fusion joints to be compared with EPRI data
- EPRI: modified PENT test data of parent pipe material and butt fusion joints, test data from parametric coupon tests, and data from confirmatory tests of whole pipes with candidate flaws in the butt fusion joints

Subtask 3.3: Butt fusion joint quality assurance testing

Status: NRC has completed several high-speed tensile test (HSTT), waisted tensile test (WTT), and guided side-bend tests. Charpy testing is underway for joint parameter approach on butt fusion joints. EPRI has evaluated the effectiveness and adequacy of mechanical testing methods for use in evaluating the integrity of HDPE butt-fusion joints, and conducting limited studies comparing the high speed tensile impact test to the guided side band and waisted tensile test methods.

Deliverables:

- NRC: HSTT, WTT, and Charpy test data for various fusion conditions to validate the joining parameter approach for butt fusion joints
- EPRI 3002005434, "Advanced Nuclear Technology: Literature Review of Mechanical Testing Methods to Evaluate the Integrity of HDPE Butt-Fusion Joints." Results of limited studies on the comparison of the high speed tensile impact test to the guided side band and waisted tensile test methods.

Subtask 3.4: Electrofusion joint SCG testing and allowable flaws

Status: The NRC work is on hold due to low budgeting priority related to the postponing of HDPE deployment by industry, and EPRI has no work planned for this subtask.

Deliverables:

- The results of NRC's literature review on failure modes and failure data for electrofusion joints, SCG or other appropriate long-term service failure testing data on but fusion joints is to be compared with EPRI data, service life predictions, and allowable flaw size predictions for electrofusion joints
- EPRI: none

Subtask 3.5: Electrofusion joint quality assurance testing

Status: The NRC work is on hold due to low budgeting priority related to the postponing of HDPE deployment by industry, and EPRI has no work planned for this subtask.

Deliverables:

- NRC: HSTT, WTT, Charpy, or other relevant test data for various fusion conditions to validate the joining parameter approach for electrofusion joints
- EPRI: none

Subtask 3.6: 'Non Ideal' butt fusion and electrofusion joint testing

Status: The NRC work is on hold due to low budgeting priority related to the postponing of HDPE deployment by industry, and EPRI has no work planned for this subtask.

Deliverables:

- NRC: recommendations on maximum tolerable adverse conditions allowable to maintain joint integrity for its service life
- EPRI: none

Task 4:

ASME Code, Section III, Appendix 26 and Section XI Code (under development) allow the use of volumetric and visual methods; however, the acceptance criteria is limited (cut out any joints that have flaws). If flaws are to be allowed to remain, the industry needs to develop acceptance criteria for the chosen volumetric method(s). The NRC will investigate these criteria in its assessment of the interchangeability of NDE methods, and include the results of the assessment in the final technical report.

Status: Due to limited funding, this task has been tabled.

9/7/2016

Attachment 7

SCOPE OF WORK
Ultrasonic Modeling and Simulation

Background:

With advancements in computer technology and software, NDE simulation programs developed to predict inspection results have become commercially available. Parametric studies can be performed with these simulation tools to optimize examination procedure variables. In addition, some of these NDE simulation packages enable the development of interactive training materials which can be efficiently utilized to build computer-based courses to maintain proficiency for existing technicians as well as to help introduce new personnel into the industry, narrowing the NDE workforce gap.

The NRC and EPRI are establishing NDE modeling and simulation as a strong strategic area to assist in enhancing inspection reliability. The tasks outlined in this document provide the initial framework for collaboration between these two organizations by starting with simple study cases and progressing to more complex applications for ultrasonic methods. Collaborations on modeling of other NDE methods may follow.

The EPRI NDE center has developed an internal team to evaluate various ultrasonic modeling and simulation software packages to assist in enhancing inspection reliability and as a training tool. PNNL has been evaluating CIVA and Ultravision 3D, and NRC/RES and PNNL have developed a team to evaluate and better understand the operating characteristics of these software packages. NRC has recently begun using CIVA for the purpose of verifying the adequacy of inspections (particularly for operating events and relief requests). EPRI has been assessing the capabilities of several ultrasonic modeling and simulation software packages.

PNNL, through a NRC- Institute for Radiological Protection and Nuclear Safety (IRSN) cooperative research MOU, provided mathematical scattering and attenuation models to Commissariat à l'énergie atomique (CEA). The models facilitated a development of the basis for the current Voronoi diagram approach to simulating CASS that appears in the latest version of CIVA. In addition, PNNL played a significant role in the development of ZETEC's UltraVision 3D phased array modeling software by performing several rounds of beta testing, and submitting technical input to the developers. These activities resulted in on-going close technical relationships with developers of both of these ultrasonic modeling platforms. PNNL will leverage this relationship to engage the software developers in order to expedite any necessary corrections discovered as a result of this NRC-EPRI cooperative project. EPRI and NRC will mutually determine how the results of each task will be reported such that it can be referenced (e.g. white paper, letter report, technical report).

Task 1, Assessment of Simulation of Transmitted Sound Fields:

NRC and EPRI will cooperatively develop a framework for experimental trials and simulation runs and corresponding metrics to assess issues such as how well the modeling platforms simulate transmitted sound fields, including factors such as handling beam dispersion and attenuation/noise. A set of configurations will be used to assess the various parameters and effects. NRC and EPRI will conduct independent analyses and then compare the results. Each organization will make their findings available to the other organization for review and comment.

EPRI will model the following configurations: simple geometries (notches in blocks), similar metal weld piping applications, and dissimilar metal weld piping applications and provide modeling information/results to NRC. NRC will conduct confirmatory modeling of a sampling of these configurations. Each organization will exchange their modeling results with the other.

PNNL will use state-of-the-art phased array probes to acquire data on samples and will provide data to EPRI.

Status: In process

Deliverables, to date:

- EPRI "NDE Modeling and Simulation Protocol (DRAFT)" dated October 29, 2015.
- EPRI 3002004439, "Program on Technology Innovation: Benchmarking of Ultrasonic Simulation Software"
- PNNL-SA-115482, PowerPoint Presentation entitled "Verification and Validation of Computational Models for Ultrasound Non-Destructive Evaluation Sensitivity Study" presented during NDE MOU WebEx meeting on 1/20/16

Task 2, Ability of Models to Address All Waveforms:

NRC and EPRI will collaborate to develop the metrics to assess issues such as each model's ability to account for all of the waveforms that might be present (depending on how the transmitted energies are produced). For example, mode-converted signals are frequently observed when using transmit/receive longitudinal waves. NRC and EPRI will determine a set of configurations to model to assess the various parameters and effects. NRC and EPRI will conduct independent analyses. Once the trials and simulations runs have been completed, each organization will make their findings available to the other organization for review and comment.

Status: In process

Deliverables to date:

- PNNL draft template for recording parameters needed in modeling software entitled "Documentation of Empirical Ultrasonic Data Parameters for Use in Modeling Software" 1/13/2016
- PNNL-SA-117549, PowerPoint Presentation entitled "Validation Metrics for Computational Models in UT" presented during NDE MOU WebEx meeting on 3/30/2016

Task 3, Flaw Description, Addressing Specular and Diffracted Patterns:

NRC and EPRI will cooperatively develop the metrics to assess issues such as back-scattered energies from internal reflectors. Geometrical and flaw responses need to be modeled and compared to actual data to determine the accuracy of the models. NRC and EPRI will determine how best to describe a flaw (in a 3D volume), and how to address specular as well as diffracted patterns of reflection. EPRI and NRC will start the assessment by independently modeling simple reflectors like notches and side-drilled holes. More complex morphologies that better simulate cracks would then be assessed. NRC and EPRI will compare the results of the analyses after the trials and simulation runs have been completed. Each organization will make their findings available to the other organization for review and comment.

9/7/2016
Status: In process

Deliverables to date:

- EPRI presentation entitled "An Ultrasonic Experimental and Simulated Comparison" presented during a NDE MOU WebEx meeting on 5/25/2016

Task 4, Modeling Best Practices:

It is important that industry and NRC be able to use models in a way that is mutually recognized as being technically valid and proper, without exhaustive case-by-case review. NRC and EPRI will collaborate in developing procedures or other descriptions for how to use ultrasonic modeling to reach conclusions about various aspects of ultrasonic examination in nuclear power plants. These aspects should include, but may not be limited to, the following:

- Modeling of flaw response to expand existing practical qualifications, either as a stand-alone method or in conjunction with physical trials. Such expansions might include adding probes, modifying focal laws, expanding the qualified thickness or diameter range, or including more complex component configurations.
- Prediction or review of examination coverage.
- Using models to increase understanding of prior examination results, or to facilitate comparison of prior results to current results.

This task will be accomplished by NRC and EPRI collaborating in drafting best practices, and developing experimental test cases to verify the draft best practices. If new data acquisition is necessary to support the test cases, responsibilities will be negotiated at the time. NRC and EPRI will independently apply the draft best practices to test the cases, compare results, and modify the draft best practices, as appropriate. These best practices will be documented, and the two organizations will jointly agree upon mechanisms for application such as ASME Code or a Regulatory Guide.

Status: TBD

9/7/2016

Attachment 8

SCOPE OF WORK
Human Performance Influences on NDE Reliability

Background:

Several operational experiences (OE) have involved failures of the NDE process due to human error, when the NDE technology and procedures were considered to be adequate for the job. Failures have occurred in both manual and mechanized examinations. The failures have been marked by one or more of the following features:

- Not following the procedure faithfully.
- Procedure technically adequate, but would have been more effective if it had been written more clearly.
- Failing to notice defect indication that was present in the data and should have been recorded.
- Failure mode unknown; manual examination missed defects, while a follow-up examination using the same procedure and equipment detected the defects.

Industry and regulatory research has primarily been focused on NDE equipment and procedures, and on rigorous qualification processes for techniques and personnel. The above experiences indicate that robust techniques and qualifications are necessary, but sometimes may not be sufficient, to accomplish reliable NDE.

The investigation of human performance described in this Attachment is intended to identify human factors issues associated with NDE. Human performance issues exist in all methods of NDE. This Attachment will focus on manual conventional and phased array ultrasonic examination. However, the results of this work may be more widely applicable to other NDE methods as well. This effort is intended to inform industry and the NRC about practices that may improve NDE reliability in the field. Some examples of the possible improvements are: improved UT technology; technology that is not directly involved with the UT but which may improve oversight or the ability for secondary review of data; improved structuring of written procedures; improved training and pre-job briefs; improved sense of an NDE reliability culture.

Task 1, Systematically evaluate the human performance issues facing examiners:

NRC will perform a review of human performance research to date in nuclear NDE, and in other relevant fields and author a technical letter report that will be shared with EPRI. NRC and EPRI will work independently to collect OE; however, the NRC and EPRI will then cooperate to collate the potentially relevant OE and agree on which OE should inform a gap analysis. Each organization will produce separate gap analysis reports.

Status: In process

Task 2, Identify the key differences between human performance in qualification versus in the field:

Human performance subject matter experts (SMEs) from the NRC and EPRI (if applicable) will observe, in detail, UT as it is performed in practice and qualification environments, and as it is performed in the field. The observations should include manual conventional UT and manual phased array UT. Thus, the SMEs must obtain entry to one or more nuclear power plants during their outage UT activities as well as to EPRI for qualification activities. This task may also involve activities such as interviews, surveys, and focus groups conducted by both NRC and EPRI staff. These observations and activities will be compared in order to identify key differences. Independent reports on the comparative task analysis will be developed.

Status: In-process

Task 3, Prioritize the human performance issues for examinations in the field:

NRC and EPRI will co-lead workshop(s) held with SMEs to categorize and prioritize the human performance issues for manual conventional UT and manual phased array UT. Prioritization should be based upon both the degree of improvement that may be achievable, and the difficulty of achieving it. Some potential improvements may be impractical because of factors such as “As Low As Reasonably Achievable,” the size of the available workforce, or the time constraints of nuclear plant outages. The NRC and EPRI will collaborate to develop a list of prioritized issues.

Status: TBD

Task 4, Outline the potential applicability of the research results to other NDE methods:

Much of the learning from this work may be applicable to other NDE methods. For example, the same principles that create a more effective written UT procedure probably would improve written procedures for encoded UT and for other methods. This task, performed cooperatively between NRC and EPRI, should develop a brief summary of potential applicability of the research results to other NDE methods.

Status: TBD