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Performance Demonstration Test Blocks to Meet the Requirements of the ASME Code

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ABSTRACT

Recent adoption of performance demonstration requirements in the ASME Code, Section XI - Appendix VIII - 1989 Addenda, will require the fabrication of a comprehensive set of test blocks to meet the qualification needs of U.S. nuclear utilities. With more than 100 operating units from four different NSSS vendors, fabrication of suitable test specimens which meet these requirements is a considerable challenge. U.S. nuclear utilities are proceeding with a cooperative program to implement a performance demonstration program which best serves the needs of the industry as well as satisfying the requirements of the code. This effort is currently being directed by the "Utility Performance Demonstration Initiative (PDI) Steering Committee for Implementation of Appendix VIII NDE Performance Demonstration Requirements". A major activity of this committee is the definition of the test sample requirements. The sample fabrication program will address samples for both BWR and PWR reactor pressure vessels, austenitic and ferritic piping, and bolting greater than 2 inches in diameter. This paper describes the samples which will be fabricated and their technical requirements.

1 BACKGROUND

Appendix VIII, contained in the 1989 Addenda to the 1989 Edition of Section XI of the ASME Boiler and Pressure vessel Code (1), specifies requirements and acceptance standards for performance demonstration of ultrasonic examination procedures and personnel. The Appendix currently addresses the reactor pressure vessel (RPV), wrought austenitic piping, ferritic piping and bolting greater than two inches in diameter. The RPV requirements specifically address; the clad-to-base metal interface, plate-to-plate welds, the nozzle inner radius and nozzle-to-shell welds. Performance demonstration requirements for dissimilar metal welds, weld overlay repairs, and cast stainless steel are in course of preparation. Adoption of these Code requirements will require an extensive array of performance demonstration test specimens and a comprehensive demonstration test program.

A group of U.S. utilities have joined together to address the needs and requirements of a performance demonstration program. This group is formally organized under the title of Utility Performance Demonstration

Initiative (PDI) and currently represents more than 90% of operating units in the U.S. The PDI Steering Committee, under the Chairmanship of T. N. Epps, Southern Nuclear Operating Company, is collecting the necessary funds and will oversee the operation of the program. The Steering Committee has selected the Electric Power Research Institute to execute the program under the direction of the Committee. The Technical Working Group of the Steering Committee has the responsibility for developing the Guidelines for operation of the demonstration program as well as the technical requirements for demonstration test specimens. Dr. Mark Richter, Baltimore Gas and Electric is Chairman of the Technical Working Group. Membership on the Technical Working Group includes: utilities, inservice inspection vendors, and consultants. The two primary products of the Technical Working Group are the Utility Industry Guidelines for Performance Demonstration and the General Design Specifications for Performance Demonstration Specimens.

2 DESIGN SPECIFICATIONS

The General Design Specification for RPV Demonstration Specimens is currently nearing completion. This document describes requirements for: material, flaws, fabrication, examinations, quality assurance, and documentation. This document will serve as the primary reference for design and procurement of test specimens. Appendix VIII of Section XI specifies the general requirements for demonstration test specimens. However, the Appendix is not sufficiently specific regarding methods of manufacture, tolerances, and flaw characteristics. The Specifications, therefore, expand on the requirements of Appendix VIII, to provide the most suitable test specimens consistent with reasonable technical and economic considerations.

It is expected that the demonstration test specimens will be fabricated mainly using material obtained from scrapped or cancelled nuclear pressure vessels. Available materials are from units of relatively recent vintage and are expected to be of reasonably high quality. Examinations to an acceptance criteria of 10% ASME DAC will be performed before the material is released for specimen fabrication.

The existing submerged arc cladding will be used as is in most cases. SMAW clad will be deposited over regions of implanted flaws. The roughness and flatness of this cladding will be to workmanship standards which will be provided. The workmanship standards will be established based on available information of conditions in operating RPVs as well as the accepted limits of inspectability for under clad cracks.

Flaw specifications are based on the requirements of Appendix VIII, with additional specifications for flaw characteristics. Flaw characteristics specifications include; roughness, flaw tip sharpness and flaw type. The types of flaws which are considered include; smooth planar cracks, rough cracks, volumetric flaws and EDM notches. Both smooth and rough cracks will have sharp crack tips. The specified crack tip radius is 0.0008 inch (0.02 mm) or less. The surface roughness of rough cracks are required to be in excess of 0.02 inch (0.5mm)Ra. Smooth cracks will have a surface roughness of less than 0.0012 (0.03 mm)Ra. Volumetric flaws will simulate slag conditions. EDM notches will have an opening of no more than 0.01 inch (0.4 mm) as required by Appendix VIII.

With the exception of smooth planar cracks, the flaws will be distributed throughout the inspection volume. Smooth planar cracks will be limited to within one inch of the internal and external surfaces. The use of EDM notches will be held to a minimum.

Flaw skew is limited by Appendix VIII to 10 degrees. With the exception of EDM notches the code does not specify flaw tilt. The issue of flaw tilt is still under consideration by the Technical Working Group. For plate to plate examinations, the vertical orientation is considered to be conservative for examination techniques used in the US. For nozzle to shell welds and other single side access conditions, this may not be true.

Fabrication processes will not be defined in the specification. However, the process which is used must meet several requirements. These requirements include the following:

1. The coupon containing the flaw must be subjected to rigorous physical measurements or NDE examinations which exceed the capability of inservice inspection techniques, before it is implanted.

2. The implantation process shall not alter the flaw size and character.

3. The process shall have been demonstrated to be capable of producing high quality implants without the introduction of satellite reflectors or interfaces.

4. Evidence of the implantation shall not be visible on the surface of the component.

5. The process shall not distort the curvature of the component.

Four NDE examinations are specified in the design criteria. These include a material receival examination, flaw verification, weld acceptance examination and "finger print examination". The fabrication vendor may also apply in-process examinations to assure the acceptability of the fabrication. Receipt examinations will be performed to a 10% DAC sensitivity before the material is released to the fabrication vendor. A detailed examination of the flaw using the most sensitive techniques available will be performed on each flaw before it is implanted. The weld acceptance and finger print examinations may be combined depending on the capability of the fabrication vendor. The finger print examination will be performed using automated scanning equipment and zero threshold recording techniques. The finger print examination will be the primary documentation of the sample's suitability for performance demonstration.

A quality assurance program, suitable for the intended purposes of the test specimens, will be implemented. The essential features of the program include: material identification, flaw size documentation, flaw location documentation and verification of each fabrication process.

3 PERFORMANCE DEMONSTRATION SAMPLES

3.1 Reactor pressure vessel

The proposed sample matrix is divided into BWR, PWR, and practice specimens. The specimen sets described here are a best estimate of the most appropriate samples and flaws for implementing the performance demonstration requirements of Appendix VIII. Surveys are currently in progress to assure that the fabricated samples cover the installed configurations, to the greatest extent possible. The key features of this sample set are as follows:

1. To the extent possible the samples will be portable to accommodate vendor facilities, and weigh less than 20 tons.

2. The plate samples used for the clad/base metal interface and vessel welds will use well-characterized flaw implantation processes; notches will be used only in limited circumstances where technically justified. The nozzles will contain both implanted flaws and notches, to demonstrate the capabilities of the procedures and personnel.

3. The number of specimens and flaws were selected to accommodate demonstrating essential variables and retesting while maintaining sample truth security.

4. The sample sets provide a basis for demonstrating manual as well as automated examinations. Manual examinations are often performed on PWR and BWR heads and BWR nozzles. It is expected that the BWR sample set will be used for demonstration of manual procedures.

3.2 PWR sample set

The PWR sample set includes three 5-feet x 8-feet x 11.25-inch thick curved plates, an inlet nozzle, an outlet nozzle and one or more smaller nozzle mockups. The curved plates would contain approximately 40 clad/base metal and 40 imbedded flaws. Where possible existing and surplus material will be used for the fabrication of these components. Thorough NDE examination of the material will be required to assure its suitability for the sample making process. The flaws will be installed by implantation of highly characterized flaws.

3.2.1 PWR nozzles

The controlling requirements for PWR nozzles are the Appendix VIII requirements for maximum nozzle thickness (bore to weld centerline) for nozzle-to-shell weld qualifications and the minimum diameter requirements for nozzle inner radius demonstrations. The maximum thickness requirement will be addressed by installing a suitable nozzle in a shell course section and implanting suitable flaws. Preliminary survey results indicate that designs should consider a maximum nozzle thickness of at least 15 inches and plate thicknesses of 12.5 inches. A revision, currently being considered by the Code, allows a 10% tolerance on the maximum plate thickness to be examined. The design currently under consideration includes a 42 inch diameter outlet nozzle installed in a 11.25 inch thick plate. The 11.25 inch thickness will be sufficient for demonstration of techniques designed for thicknesses up to 12.5 inches. Larger plate thicknesses will require supplementary demonstrations. A sketch of this mockup is shown in Figure 1. A minimum of 16 flaws will be included in the nozzle to shell weld. Bore to flaw distances of 9 to 19 inches can be installed in this mockup. The planned nozzle to shell weld mockup will weigh approximately 18 tons. The in-service inspection vendors which have replied to our inquires have indicated crane capacities of 20 tons or more or access to suitable portable cranes.

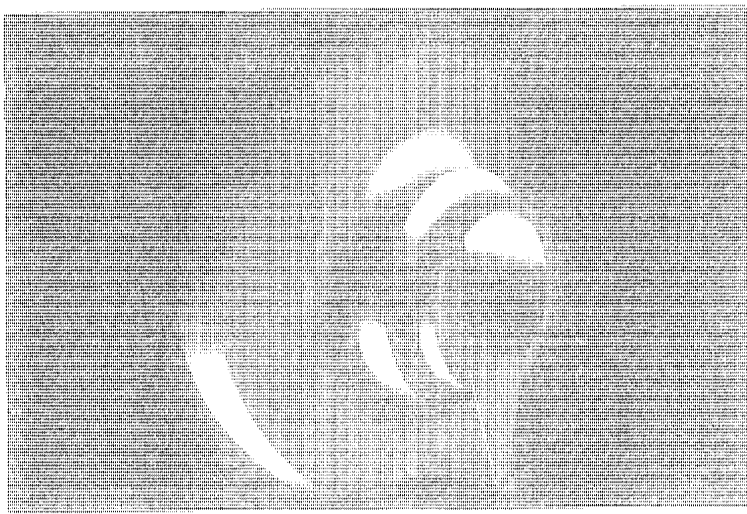

Fig. 1. PWR Outlet Nozzle Performance Demonstration Test Specimen, Weight 18 tons.

The second nozzle will be an inlet nozzle of minimum diameter. The exact size for the inlet nozzle has not yet been determined. This nozzle need not be installed in a plate section as its primary objective is for nozzle inner corner radius demonstrations performed from the inside surface. This sample could be made from a thick wall pipe or a nozzle drop out. The nozzle inner surface profile would be machined into the sample. If we find that a 28 inch diameter nozzle will be sufficient, an available nozzle forging would be used. A conceptual sketch of such a mockup is shown in Figure 2. A minimum of 12 defects would be placed in the bore and inner radius region of the mockup. At least 50% of the flaws would be weld induced cracks or implanted fatigue cracks, the remainder would be EDM notches. This mockup is expected to weigh approximately 8 tons.

Four older Westinghouse PWR reactors contain four inch diameter safety injection nozzles. Babcock and Wilcox units contain 12 inch core flood nozzles. The safety injection nozzles are normally examined from the bore and the core flood from the inside plate surface. A mockup is currently under consideration which would accommodate both of these examinations.

3.2.2 PWR plates

Three 5-feet x 8-feet PWR plate samples will be fabricated. These samples will be fabricated from 11.25 inch thick plates. Current plans call for implantation of as many as 30 flaws in each plate. The samples will contain clad/base metal, imbedded and outside surface flaws. To the greatest extent possible the plates will appear identical to assist in maintaining the sample security. A 12 inch wide strip of manually ground, Shielded Metal Arc Welding (SMAW) manual clad will be deposited over the implanted flaws. These blocks are intended primarily for automated examinations but will also be suitable for manual examinations. In the event that a vendor or utility wishes to use additional clad/base metal flaws, to address PLEX or PTS issues, the BWR plates could be made available to augment the PWR test set. A conceptual sketch of the these plates is shown in Figure 3.

These blocks will weigh approximately 8 tons each and will be supplied with lifting lugs suitable for mounting in vendor facilities.

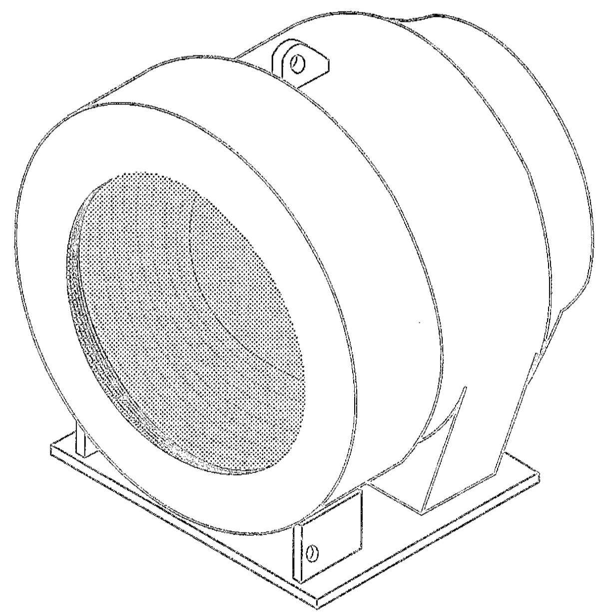

Fig. 2. PWR Inlet Nozzle Performance Demonstration Test Specimen for Inner Radius examinations, Weight 8 tons.

3.3 BWR sample set

The BWR sample set will contain five curved plates and 6 to 8 nozzle mockups. The nozzle mockups are designed for demonstrations of nozzle-to-shell welds and the nozzle inner radius examinations.

3.3.1 BWR nozzles

Two nozzle mockups are planned to address the nozzle-to-shell weld. One will be a 12 inch inlet nozzle the other a 24 inch steam nozzle. These mockups will contain flaws parallel and perpendicular to the weld center line and will distributed throughout the required inspection volume.

BWR nozzle inner radius exams are performed from the outside surface. Appendix VIII requires that, outside surface, nozzle inner radius demonstrations, be performed on samples where the ratio of nozzle thickness to plate thickness is within 30% of the nozzles to be examined. Ratios of .3 to 1.8 exist in operating BWR units. Current plans call for at least six nozzles ranging in size from 2 to 28 inches in diameter. The majority of nozzles in older BWR units are clad, newer ones are not. Since demonstrations on clad nozzles are suitable for examinations on unclad nozzles, we expect that the majority of the nozzles will be clad. A sketch of one of the mockups, which contains two inlet nozzles and a jet pump instrumentation nozzle, is shown in Figure 4. One of the inlet nozzles will not be clad the other two will be clad. This mockup is expected to weigh approximately 12 tons.

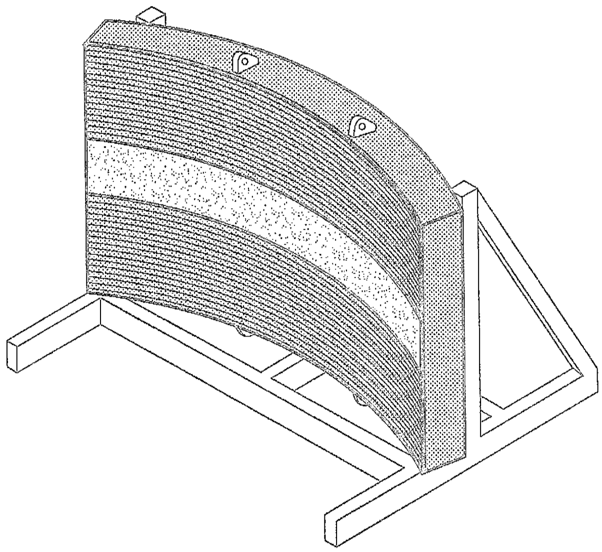

Fig. 3. PWR Plate-to-Plate Weld, 5 X 8 feet, 11.25 inch Thick, Weight 8 tons. Flaws are Implanted in Shaded Area Which is Clad With Manually Ground SMAW Clad.

3.3.2 BWR plates

The five curved BWR plates will be fabricated from existing material located at the NDE Center. The material was obtained from cancelled BWR plants. These samples contain circumferential and vertical weld seams. The flaws will be installed by implantation of accurately characterized coupons containing realistic flaws. The use of notches will be minimized. These curved plates will contain approximately 40 clad/base metal flaws and 40 imbedded flaws. The clad/base metal flaws may be used to augment the PWR sample set if necessary. The five plates will visually appear to be identical and may be rotated by 180 degrees to provide flexibility and to assist in maintaining sample security.

3.4 Reactor pressure vessel practice samples

The Performance Demonstration Steering Committee has established that, practice samples will be provided as a part of the program. The practice samples are provided to assist ultrasonic examiners in assuring that their techniques and procedures are adequate to address the requirements of Appendix VIII. EPRI is providing their current inventory of pressure vessel samples for this purpose. The EPRI samples simulate shell-to-shell welds and under-clad cracking with various clad surface conditions. A total of 10 full size pressure vessel practice specimens are planned to be fabricated by the PDI program. The PDI fabricated specimens will simulate the nozzle-to-shell weld and nozzle inner-radius examinations for BWR and PWR reactors. The majority of these samples are planned to be available in 1992.

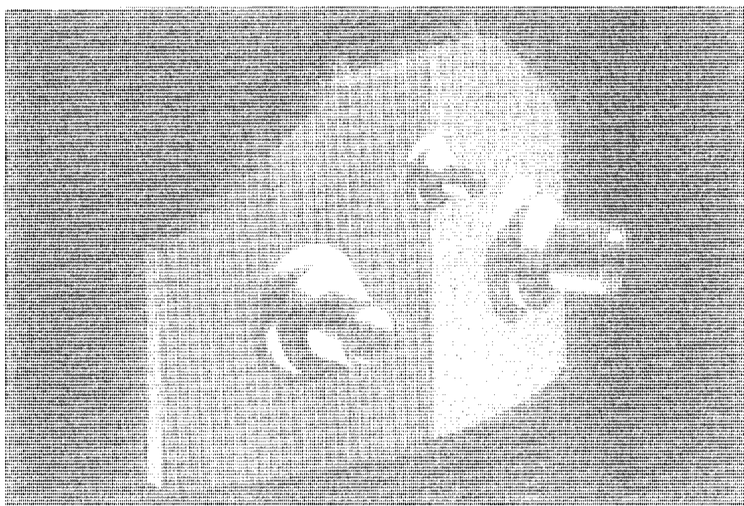

Fig. 4. BWR Nozzle Performance Demonstration Test Specimen, Weight 12 tons. Specimen Contains Two 12 inch Inlet Nozzles and One 4 inch Jet Pump Instrumentation Nozzle.

3.5 Piping

The current edition of Appendix VIII addresses only wrought austenitic and ferritic piping. Dissimilar metal welds, overlays and cast stainless steel piping are listed as "in course of preparation". Qualification demonstrations for the detection and sizing of intergranular stress corrosion cracking (IGSCC) have been carried out at the EPRI NDE Center since 1982. This program has been carried out under an agreement between the BWR Owners Group (BWROG), the US Nuclear Regulatory Commission (NRC) and EPRI. The requirements of Appendix VIII extend performance demonstration requirements to all piping which is required to be ultrasonically examined. The required program must address the minimum and maximum diameters and thicknesses of piping which will be examined, in both BWR and PWR systems. It is expected that there will be a dramatic increase in the number of personnel who will need to be qualified. Additionally these qualifications will be need to be accomplished in a short period of time, after adoption of Appendix VIII requirements by the US NRC.

The PDI Steering Committee is considering establishing up to four regional centers to address the large number of piping and bolting qualifications which are expected. It is expected that the EPRI NDE Center will serve as the initial site for the piping and bolting performance demonstrations with the program expanding to the other centers after the initial start up phase of the program. The details for these centers are currently under consideration by the PDI Steering Committee.

The piping program is currently divided into four separate areas. These include: wrought austenitic, ferritic, wrought austenitic main coolant loop piping, and clad ferritic main coolant loop piping. PWR Main coolant loop piping is being considered as a separate category due both to size of the components and the fact that some portions of the system are examined from the inside surface. The primary qualifications will be for austenitic piping with the others considered as supplements to this primary qualification demonstration.

3.5.1 Wrought austenitic piping

The field removed samples currently in the BWROG IGSCC detection program will serve as the foundation for the wrought austenitic piping sample set. The sample set will be augmented with smaller and larger pipe sizes to fill out the requirements for the range of piping sizes used in both PWR and BWR piping systems. Where possible field removed samples will be used. However, few if any field removed samples are available outside the range of the existing inventory. The additional samples will be fabricated with; laboratory induced IGSCC, thermal fatigue cracking and fatigue cracks. The range of pipe sizes to be included is the subject of an ongoing survey of utility needs. It is expected that the range will include diameters of 4 to greater than 30 inches and thicknesses from less than 0.2 inch. to more than 3.0 inches. It is anticipated that it will require more than 100 samples to adequately stock four regional centers. Approximately one third of these are available within the current BWROG program.

3.5.2 Ferritic piping

A candidate may qualify for ferritic piping, after successfully qualifying on austenitic piping, by correctly examining three additional ferritic pipe samples. The requirements for ferritic pipe samples will be approximately 1/4 to 1/3 of that required for austenitic pipe samples, ie 25 to 30 samples. These samples will be fabricated with fatigue and thermal fatigue cracks.

3.5.3 PWR main coolant loop piping

Although Appendix VIII does not separately address this class of piping, it is considered separately here due to the large range of thicknesses which are involved. Clad ferritic piping and components up to 4.75 inches in thickness are included in some operating reactor piping systems. The first one or two welds adjacent to the RPV nozzles are often examined during the RPV examination, using a central mast manipulator. Separate specimens will be provided for qualifications, performed from the inside surface, during the RPV qualification demonstrations. There will be a sufficient number of samples available for detection and sizing qualification demonstrations directed specifically for this range of piping.

3.6 Bolting

The requirements for bolting demonstrations are contained in Supplement 8 of Appendix VIII. These requirements are limited to bolting 2 inches in diameter and greater. Reactor head studs and reactor coolant pump studs are the principle components in this category. The sample requirements for studs and bolts are currently under investigation. However, we do expect that a range of studs and bolts will be available at each of the regional centers.

4 STATUS

The conceptual design phase of the reactor pressure vessel program has been completed. We expect that detail design and specification activities will be completed during the spring of 1991 and that fabrication of the first practice samples will be initiated by the summer of 1991. Definition of the piping and bolting programs are expected to be completed by May of 1991. With sample production starting in the fall of the year. It is expected that the complete set of practice samples will be available by the end of 1992. Schedules for implementation of the demonstration programs, are currently under consideration.

REFERENCES

ASME Boiler and Pressure Vessel Code, Section XI "Rules for Inservice Inspection of Nuclear Power Plant Components". American Society of Mechanical Engineering. 1989 Edition, 1989 Addenda.