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The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination Systems

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The Technical Basis Supporting ASME Code, Section XI, Appendix VIII: Performance Demonstration for Ultrasonic Examination

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ABSTRACT

Ultrasonic inspection requirements specified in the American Society of Mechanical Engineers (ASME) Code, Section XI (ASME 2004) were written in a very prescriptive fashion until an accumulation of field experience in examinations that failed to detect defects in piping and pressure vessels, coupled with evidence from round-robin tests conducted by the Pressure Vessel Research Council, the Programme for the Inspection of Steel Components, and Pacific Northwest National Laboratory, demonstrated that improvements in ultrasonic inspection reliability were needed.

At an October 1984 meeting held between the U.S. Nuclear Regulatory Commission (NRC) and industry in Rockville, Maryland, a draft qualification document was proposed and discussed as the basis for an NRC Regulatory Guide. This meeting resulted in the formation of an ASME Code Ad Hoc Task Group of industry experts charged with developing new Code rules that would improve the reliability of ultrasonic inspection. This Ad Hoc Task Group developed the initial rules that were later documented in Appendix VIII. 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 Ad Hoc Task Group developed the concept of ultrasonic system qualification through performance demonstration.

This report addresses the technical bases that support the requirements of the performance demonstration specified in the 2007 Edition, 2008 and 2009 Addenda of ASME Boiler and Pressure Vessel Code, Section XI, Appendix VIII. The intent of this report is to provide the reader with an understanding of the technical rationale for the requirements stated in Section XI, Appendix VIII.

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FOREWORD

Research involving parametric studies and round-robin exercises conducted during the1970s and early 1980s revealed that ultrasonic procedures were less reliable than generally perceived. The failure of inservice inspections to detect leaking cracks also raised concerns regarding the effectiveness of ultrasonic testing being conducted at nuclear power plants and showed that improvements in inspection requirements were needed. In response, the NRC began conducting research at the Pacific Northwest National Laboratory (PNNL) to assess nondestructive examination (NDE) reliability. This research showed that prescriptive requirements could not be written to sufficiently accommodate the diversity of power plant materials, field conditions, and flaw degradation processes typically encountered. These conditions need to be considered in order to provide highly reliable NDE performance. Based on positive results in other industries (e.g., medical, welding, and aerospace), it was decided that a performance-based testing approach would be the most effective means for achieving the needed improvements in NDE reliability.

In November 1984, the NRC held a workshop with representatives from the industry. It was generally agreed by the participants that major improvements in the quality of inservice inspection were needed. Industry participants recommended that qualification requirements be developed and incorporated into Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. The ASME subsequently developed Section XI, Appendix VIII, “Performance Demonstration for Ultrasonic Examination Systems.” Appendix VIII was first published with the 1989 Addenda. Appendix VIII is a performance-based testing approach for the demonstration of ultrasonic examination systems (i.e., procedures, equipment, and personnel) used to detect and size service degradation-type flaws. Procedures and techniques qualified in accordance with the Appendix are acceptable for use; however, it should be recognized that Appendix VIII provides only a basic framework of requirements necessary to allow such an approach. Protocols and detailed guidance for specific application have, as yet, not been listed in Appendix VIII.

Appendix VIII was developed over 20 years ago. Extensive revisions and additions to the requirements have resulted from their application and lessons learned during implementation. The purpose of this NUREG report is to provide to the extent possible the rationale for the current requirements in Appendix VIII. It is anticipated that further changes to Appendix VIII will be necessary as new technologies are introduced, advances in current techniques are implemented, or as new lessons are learned. This report will be useful in understanding the basis for the current requirements and to inform decision-making, as revisions to the requirements are considered in the future.

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EXECUTIVE SUMMARY

The performance demonstration requirements specified in the ASME Code, Section XI, Appendix VIII were developed because the U.S. nuclear industry and regulatory authorities were concerned about the reliability of ultrasonic inservice inspection being conducted at nuclear power plants. The problems that led to the development of performance demonstrations are summarized below.

- Ultrasonic inspection reliability experiments conducted by the Pressure Vessel Research Council (PVRC) 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 U.S. Nuclear Regulatory Commission (NRC) initiated a program under Dr. Joseph Muscara to address nondestructive examination reliability issues. The program produced a technical basis for Research Information Letter (RIL) 113, “Reliability of Inservice Inspection of Primary Piping Systems,” dated January 29, 1981, recommending the need for nondestructive examination (NDE) performance demonstrations.
- Inspections failed to detect large leaking cracks in piping during field inspections; for example, the leaks that were discovered in the recirculation system piping at Nine Mile Point Nuclear Power Plant.
- Research sponsored by NRC at the Pacific Northwest National Laboratory (PNNL) 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.

In response to the incidents listed above, the NRC developed a working draft of a proposed qualification document in October 1984. The document was discussed extensively during a meeting of the NRC NDE Research Review Group and other interested NRC staff in Bethesda, Maryland. In early November 1984, a second workshop was held with industry in Rockville, Maryland. This workshop attracted more than 60 U.S. and foreign attendees representing a broad cross section of the nuclear industry, ASME Code, and regulatory interests. Representatives of the industry, ASME Code, and NRC agreed that major improvements in the quality of inservice inspection were needed and that qualification of NDE systems might be the answer. However, the industry and Code representatives recommended that in lieu of the NRC issuing a Regulatory Guide based on the qualification document, the ASME Code Section XI committees should review the document and develop qualification requirements on a priority basis. It was recommended that this action be undertaken by the ASME Code Section XI Subgroup on Nondestructive Examination. 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. This Appendix was published as part of the 1989 Addenda to the ASME Code, Section XI.

This report reviews the requirements of the 2007 Edition of ASME Code, Section XI, Appendix VIII, including the 2008 and 2009 Addenda, which was the most recent version of the ASME Code that had been approved by the NRC and provides the rationale for requirements as well as technical references that the reader may use to gain a more in-depth knowledge of each technical topic. Information regarding the application of these requirements by U.S. utilities has also been included on a limited basis because as Appendix VIII was implemented there have been lessons learned resulting in changes and improvements in Appendix VIII requirements.

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ACRONYMS AND ABBREVIATIONS

ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
BWR	boiling water reactor
CFR	Code of Federal Regulations
CRC	corrosion-resistant clad
EC	eddy current
ENIQ	European Network for Inspection Qualification
EPRI	Electric Power Research Institute
FCP	false call probability
I.D.	inside diameter
IEB	Inspection and Enforcement Bulletin
IGSCC	intergranular stress corrosion cracking
ISI	in-service inspection
IVC	Inspection Validation Centre
MOST	(Korean) Ministry of Science and Technology
NDE	nondestructive examination
NDT	nondestructive testing
NRC	U.S. Nuclear Regulatory Commission
O.D.	outside diameter
PA	phased array
PDI	Performance Demonstration Initiative
PISC	Programme for the Inspection of Steel Components
PNNL	Pacific Northwest National Laboratory
POD	probability of detection
PVRC	Pressure Vessel Research Council
PWR	pressurized water reactor
RI-ISI	risk-informed in-service inspection
RMS	root mean square
ROC	relative operator characteristic
SCC	stress corrosion cracking
SGNDE	Subgroup on Nondestructive Examination
TOFD	time-of-flight diffraction
UK	United Kingdom
UT	ultrasonic testing

1 INTRODUCTION

Most of the nuclear power-based electricity generation capacity in the United States was constructed from the mid-1960s through the early 1980s. The requirements for the nondestructive inspections of these reactors were developed while the reactors were being constructed. Preservice and inservice inspection requirements were developed, and the initial edition of Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code was issued in 1970 (Hedden 2000). The ultrasonic inspection techniques specified in this edition were adapted from manufacturing practices and were based on previous experience with fatigue cracking. The ultrasonic examination rules were prescriptive and had not been evaluated on nuclear reactor service-induced degradation mechanisms. The reliability of the nondestructive examinations (NDE) that were specified by Section XI was not quantified via testing; instead, the initial premise of Section XI was that reliable ultrasonic testing (UT) could be ensured through detailed rules. Consequently, early editions of Section XI had very detailed, prescriptive requirements for

- calibration procedures, calibration block designs, or calibration checks
- examination angles
- scanning
- recording and reporting criteria
- flaw sizing criteria.

The discovery of a large defect during a preservice examination of the reactor pressure vessel in the early 1970s at the E. I. Hatch plant (Jackson et al. 2001) began to raise questions about the reliability and adequacy of inspections performed to the requirements of Section XI. The reliability studies conducted by the Pressure Vessel Research Council (PVRC) between 1971 and 1978 (Chockie 1980) yielded the first data to indicate that ultrasonic procedures were not as reliable as “expert” opinion had suggested. Negative field experience with inspections carried out using Section XI requirements also eroded the confidence in these requirements.

Events that demonstrated the insufficient reliability of Section XI examinations included the following:

- The discovery in 1975 of leaks caused by intergranular stress corrosion cracking in boiling water reactor (BWR) piping prompted the U.S. Nuclear Regulatory Commission (NRC) to shut down all BWRs for inspection (NRC 1975).
- Thermal cracking was found in BWR feedwater nozzles up to 1978; NRC required effective inspection via NUREG-0619 (NRC 1980).

More recent events, which are detailed in NUREG-1823 (Grimmel 2005), include

- dissimilar metal weld cracking in BWR units
- primary water stress corrosion cracking of the reactor coolant system piping at the V. C. Summer and Ringhals nuclear power plants

- cracking in the control rod drive housing of vessel head penetrations of many pressurized water reactor (PWR) units.

As this report was being prepared, there were several events that should also be highlighted that illustrate that the further improvements are still needed:

- the discovery of misinterpreted inspection data at the Duane Arnold plant (Anderson 2007)
- the failure of ISI to detect stress corrosion cracking (SCC) in a dissimilar metal weld at North Anna with five cracks being discovered when preparing the weld for overlay (Anderson et al. 2012).

Round-robin experiments conducted by PNNL under NRC sponsorship concluded that prescriptive ultrasonic inspections of piping using Section XI had the following deficiencies (Heasler and Doctor 1996):

- Ultrasonic examination of austenitic (on both near side and far side) and cast austenitic materials had a low probability of flaw detection.
- Flaw depth sizing was not accurate using the prescriptive techniques based on probe motion and amplitude threshold levels.
- Flaw detection was unreliable for amplitude-based UT because many flaws had responses substantially different from machined reflectors employed for calibration.

As part of the round-robin exercises conducted by PNNL in the early 1980s, teams were provided training on an "improved" inspection procedure developed by PNNL through extensive laboratory testing. These improvements included using more effective transducers, training on flaw UT response signatures, and evaluating all signals that exceeded the background noise. Subsequent blind testing showed that the improved procedure and training had little effect on improving ultrasonic inspection performance.

A major international program was also being conducted before and during the aforementioned round-robin studies. The Plate Inspection Steering Committee (PISC I) conducted a round-robin exercise using plates provided by PVRC on thick-section reactor pressure vessel steels from 1976–1979 (PISC I 1979). This work showed substantial differences in performance for different flaw types and for different procedures. These activities were followed up by a Programme for the Inspection of Steel Components (PISC II) that expanded upon PISC I to include special in-vessel sizing studies, parametric studies, and an expansion of ultrasonic testing procedures; this work was conducted from 1980 to 1985 (Nichols and Crutzen 1988). PISC III expanded the studies to include piping weldments, dissimilar metal welds, steam generator tubing, and human factors, and was performed from 1986 through 1996 (European Commission 1994). The PISC studies were consistent with all of the other studies cited because NDE is very skill-dependent and performance varied extensively based on many factors including the personnel, equipment, procedures, and environment.

Faced with field experiences of prescriptive Section XI techniques failing to detect defects, and data from round-robin experiments indicating poor UT reliability, the nuclear industry, led by the NRC, was willing to consider new approaches to improving inspection requirements.

Sponsored by the NRC, PNNL developed and presented a draft performance demonstration document to the nuclear industry in a public meeting held at Rockville, Maryland, in November 1984. As a result of discussions during that meeting, an ASME Code Ad Hoc Task Group was established in late 1984 to develop performance demonstration requirements that would become part of the ASME Code Section XI. Further details of the effort by PNNL to pursue the development of performance demonstration can be found in NUREG/CR-4882 (Spanner et al. 1990).

The present report documents, to the best of the authors' collective memory, the technical bases and rationale for the performance demonstration requirements listed in the 2007 Edition, 2008 and 2009 Addenda of ASME Code, Section XI, Appendix VIII.

Section 2 provides the background for performance demonstration development and explains how performance demonstration was adopted by the ASME Code. The requirements of ASME Code, Section XI, Appendix VIII are juxtaposed with the rationale underlying each requirement in Section 3. Technical resources for more in-depth knowledge of the technical topic are also included. The reliability of ultrasonic inspections qualified to the requirements of Appendix VIII is discussed in Section 4. Full references cited in this report are listed in Section 5.

2 BACKGROUND

In this section, efforts in the early to mid-1980s to develop requirements for inservice inspection qualification are summarized.

2.1 Evolution of Inservice Inspection Qualification in the United States

This section of the document is taken in most part from the Executive Summary of NUREG/CR-4882 (Spanner et al. 1990).

Prior to approval of Appendices VII and VIII to ASME Code Section XI, the NDE qualification requirements within the nuclear industry were as follows:

- personnel – The applicable qualification criteria for NDT personnel were defined in an American Society for Nondestructive Testing (ASNT) recommended practice, SNT-TC-1A (ASNT 2006). Since NUREG/CR-4882 was published in 1990, the editions of SNT-TC-1A that the NUREG/CR references are the 1975, 1980, and 1984 editions, as supplemented by the ASME Code (Section III or XI, as applicable). Personnel were required to be certified by their employers, and SNT-TC-1A implied (but did not require) application-specific training. The employer certification involved organized training to become familiar with the principles and practices of a specific test method. Written examinations (covering both general principles and specific applications) and a practical hands-on examination were also required for Level I and II personnel. Written examinations covering the Basic, Method, and Specific areas of knowledge were required for Level III personnel.
- equipment – Ultrasonic instruments and search units were only required to meet the ASME Code Section V and XI requirements for vertical display response and attenuator linearity and instrument calibration capability. Other critical electronic performance characteristics were not addressed in the ASME Code. Thus, if the UT equipment was linear and calibrated, it was qualified.
- procedures – Ultrasonic examination procedures were required to be based on the applicable edition of ASME Code Sections V and XI but could be (and often were) quite general with respect to several important variables. Also, such procedures rarely provided useful guidance on how to interpret the UT inspection data collected during preservice inspection (PSI) and inservice inspections (ISI).

As noted above, the controlling document for personnel requirements was SNT-TC-1A, a publication issued by the ASNT. The American Society for Nondestructive Testing *Recommended Practice SNT-TC-1A* provided guidelines, ***not*** requirements, and its major limitations were 1) the absence of requirements for periodic training to maintain and upgrade technical skills, 2) insufficient baseline competence criteria and no specific training requirements for Level III personnel, and 3) standards for qualification and certification of NDE personnel left to the discretion of each employer. Hence, significant variations in the minimum technical competence for NDE personnel existed throughout U.S. industry.

In mid-1984, the “Coordination Plan for NRC/EPRI/BWROG Training and Qualification Activities of NDE Personnel” was formally adopted by the NRC. This plan replaced the interim program established in response to Inspection and Enforcement Bulletin 83-02 (NRC 1983). The program in effect at the Electric Power Research Institute (EPRI) NDE Center has undergone improvements since it was initially established in the 1982–1983 era; however, it originally addressed primarily only the problem of intergranular stress corrosion cracking (IGSCC) and applied only to personnel because equipment and procedures were not uniquely addressed during the qualification process.

In October 1984, a working draft of a proposed qualification document was discussed extensively during a meeting of the NRC NDE Research Review Group and other interested NRC staff in Bethesda, Maryland. The working draft only addressed UT and it was discussed that after these requirements were put in place, further work would be conducted to expand this process to the other skill-dependent NDE methods as needed to achieve reliable performance levels. In early November 1984, a second workshop was held with industry in Rockville, Maryland. This workshop attracted more than 60 U.S. and foreign attendees representing a broad cross section of the nuclear industry, ASME Code, and regulatory interests. The industry, Code, and NRC representatives in attendance agreed that major improvements in the quality of ISI were needed and that qualification of NDE systems might be the answer. However, the industry and Code representatives recommended that in lieu of the NRC issuing a regulatory guide based on the qualification document, the ASME Code Section XI committees should review the document and develop qualification requirements on a priority basis. It was recommended that this action be undertaken by the ASME Code Section XI Subgroup on Nondestructive Examination (SGNDE). It was expected that this subgroup would utilize the qualification document as the basis for strengthening the existing Section XI requirements for qualifying the NDE personnel and procedures for performing ISI in nuclear power plants.

Following the November 1984 meeting with industry, ASME Code Section XI established the ASME Code Ad Hoc Task Group to address this problem. Three separate subtask groups were organized in early 1985 to develop proposed ASME Code rules for 1) performance demonstrations, 2) personnel training and qualification, and 3) ASME implementation. During the following 15-month period, this Ad Hoc Task Group met 7 times and its subtask groups each met 10 times. This active effort provided a measure of the industry’s interest in this problem, as well as its willingness to participate.

The output of the Ad Hoc Task Group was a proposed Mandatory Appendix VII to ASME Code Section XI. This document was formally approved for submission to the SGNDE in February 1986. The SGNDE initially vacillated between proposed Code Cases and mandatory appendices as the mechanism for Code action. The SGNDE ultimately selected the mandatory appendix approach and chose to separate the requirements into Appendices VII and VIII. Appendix VII on personnel qualification was accepted by the ASME Code committees in 1988 and was published in the 1988 Addenda to Section XI. Appendix VIII on UT system performance demonstrations was approved by the ASME Boiler and Pressure Vessel Committee in early 1989 and was approved by the Board on Nuclear Codes and Standards in mid-1989. This appendix was published as part of the 1989 Addenda to ASME Code Section XI. Although these proposed requirements encountered resistance at various levels of the

ASME hierarchy, the resistance seemed to be primarily based on concerns with the mechanics rather than the substance of the proposed documents.

The significance of Appendices VII and VIII was to improve many aspects that influenced the reliability of NDE being performed during UT/ISI. It was thought that if personnel had gone through appropriate training, with extensive hands-on UT experience in both the field and under laboratory conditions, then performance demonstration testing should confirm whether the candidate had acquired all of the knowledge and skills needed. As a result, it was argued that a performance demonstration test would not need to develop a probability of detection (POD) curve for each candidate, but that a simpler "screening" test would suffice to verify that candidates had acquired the necessary skills and knowledge. This screening approach is an underlying assumption for both Appendix VII and VIII, and needs to be remembered as part of the basis for why the requirements have evolved as they have. This report only addresses the technical bases for Appendix VIII, but it is important to note the role that Appendix VII plays in the process to achieve acceptable levels of ISI performance. Changes to Appendices VII and/or VIII could undermine the assumptions that were originally used for development; therefore, it is extremely important to understand the basis for the requirements in both appendices. <u>It is also very important to acknowledge that Appendix VIII remains as a screening approach, not as a method to assess the systematic training and experience needed for personnel to acquire fundamental levels of skills and knowledge in order to successfully perform NDE</u>. Fundamental NDE personnel qualification requirements reside elsewhere.

The Ad Hoc Task Group and the SGNDE failed to address issues of implementation; thus, duties and responsibilities of the implementation agency/organization are not defined. The implementer in the United States has to date been the Performance Demonstration Administrator (PDA), which is the EPRI NDE Center. There are currently no requirements in the ASME Code for the PDA.

The U.S. nuclear utilities united and funded the Performance Demonstration Initiative (PDI), which included the development of a program to implement performance demonstration requirements that are defined in the ASME Code, Section XI, Appendix VIII. PDI was funded as a utility-requested program through EPRI. The EPRI NDE Center provided technical assistance and administered the performance demonstration program under the directions of PDI. Later, PDI was absorbed into the EPRI Advisory Structure. PDI has been the principle point of contact with the NRC; however, this industry initiative implements the requirements of Appendix VIII, which remain under ASME Code jurisdiction.

Development of the PDI program was initiated in 1991. The Steering Committee along with technical and material assistance from EPRI developed the operating guidelines for the program. The current implementation is contained in the publically available "Guideline for The Implementation of Appendix VIII and 10 CFR 50.55a, Summary" (EPRI 2005).

The major reason to bring up the PDA is that as implementation progressed, there have been a significant number of updates and changes that were identified and adopted by ASME Code, Section XI, Appendix VIII.

It should also be noted that “The Coordination Plan for NRC/EPRI/BWROG Training and Qualification Activities for NDE Personnel” was terminated in January 1997, when those activities became part of the PDI program implementing Appendix VIII.

2.2 Summary of the Technical Bases for the ASME Code Performance Demonstration Tests

The effectiveness of examination systems are demonstrated through procedure, personnel, and equipment demonstrations. Each is important to the systematic effectiveness of examinations.

2.2.1 Procedure Qualification Demonstrations

Procedure qualification requires that each intended flaw or flawed grading unit, which is within the scope of the procedure, is detected and/or sized according to specific criteria of the candidate procedure. The required minimum number of flaws is specified by each Supplement of Appendix VIII. In practice it includes a much larger population, depending on the number of independent test sets that will be used for personnel qualification. This may include all of the available flaws that challenge the scope of the procedure, and in some cases this may result in numbers approaching 100 flaws. Each flaw must be correctly identified or sized. The PDA must verify that the procedure specifically describes the detection and sizing criteria for each step of the examination.

2.2.2 Personnel Qualification

The objective of the personnel examination is to assure that examination personnel are capable of performing to the specified requirements of the qualified procedure and to reach the desired conclusions regarding detection and sizing.

As stated in Heasler et al. (1986), the performance demonstration requirements described and specified in ASME Code, Section XI, Appendix VIII are based upon the assumption that an inspector’s capability to detect cracks can be described by two metrics:

- probability of detection and correct interpretation (usually stated as POD), which is the probability that a crack in a particular length of weld material will be detected and correctly interpreted as a crack by the inspector.
- false call probability (FCP), which is the probability that a crack will be falsely detected/interpreted in a crack-free length of weld material.

Therefore, the basic objective of a demonstration test is to determine which inspectors perform with an acceptable POD and FCP (i.e., perform at or above a specified POD threshold and below the FCP threshold). Unfortunately, because any demonstration test of finite size has uncertainty in the estimate of an inspector’s true (POD, FCP) performance, some inspectors with generally unacceptable performance are bound to be passed and some of those with acceptable performance are failed.

The Ad Hoc Task Group formed by Section XI recognized that there were two technically valid methods by which to separate *Acceptable* performance from *Unacceptable* performance. One method would be to employ a test that would use simple binomial statistics. This testing method had the advantage of defining a test set so that all inspectors who successfully completed the test would have a set POD and FCP with defined confidence bounds. The disadvantage of such a test was that the number of samples required for reasonable confidence bounds (i.e., 90%) is very high; thus, the test set and testing would be very expensive (Singh 2000).

As an alternative, the Ad Hoc Task Group developed the performance demonstration tests based upon the defining POD and FCP thresholds using power curves. The power curve distributions are described by the following equations:

$$\mathrm{Pwr(FCP)} = \sum_{k=0}^{C_0} \binom{N}{K} \mathrm{FCP}^k \ (1-\mathrm{FCP})^{N-k} \tag{1}$$

and

$$\mathrm{Pwr(POD)} = \sum_{k=C_1}^{M} \binom{M}{K} \mathrm{POD}^k \ (1-\mathrm{POD})^{M-k} \tag{2}$$

where N = total number of blank weld units inspected
M = total number of cracked weld units inspected
C_0 = threshold for FCP test
C_1 = threshold for POD test.

An inspector having proficiency given by (FCP, POD) will therefore pass the total demonstration test with the probability of Pwr(FCP) × Pwr(POD). Figure 2-1 shows the power curves that represent the probabilities of passing a 0/5 false call probability test, a 1/5 false call probability test, 5/5 probability of detection test, and a 4/5 probability of detection test.

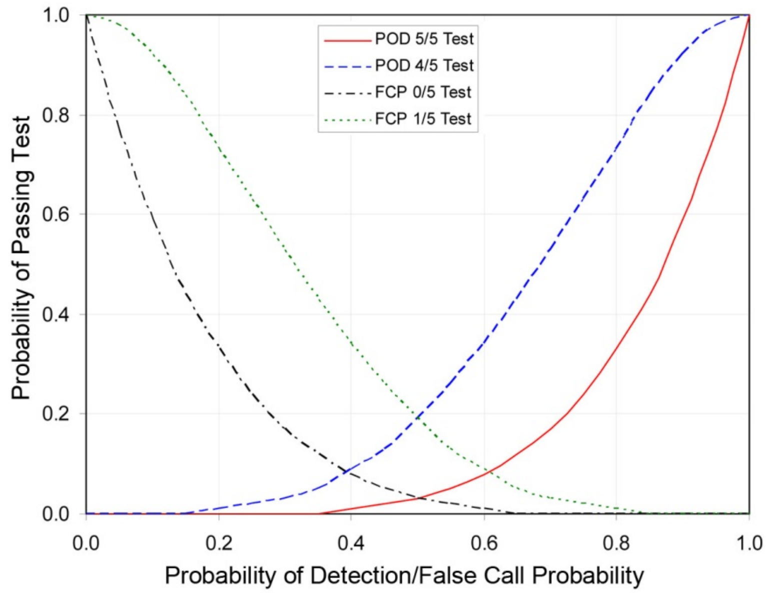


Figure 2-1 Power Curves for Test Using 5 Samples

The shape of the power curves for the smallest test (five weld units) is quite informative. Notice that both POD tests displayed in Figure 2-1 (the 4/5 and 5/5 tests) could misclassify a large number of inspectors. For example, an inspector with a POD proficiency of 50% would have an 18% chance of passing a 4-out-of-5 test, quite a large chance for someone with such poor capabilities. The 5-out-of-5 test would screen out many of the poor performers (the inspector with a 50% POD has a 3% chance of passing) at the risk of needlessly eliminating some good performers. An inspector with 95% POD proficiency will pass the 5-out-of-5 test only 77% of the time (as opposed to 98% of the time for a 4/5 test).

These misclassification errors are reduced in the larger tests. And, as we would expect, the most dramatic reduction occurs when we go from the 5-sample tests to the 10-sample tests. If the 8-out-of-10 POD test is used, the chance of an inspector with 50% POD proficiency passing the test drops to 5%. A 9-out-of-10 test might also be considered, which allows an inspector with 60% POD proficiency only a 5% chance of passing. In addition, neither of these tests is unduly penalizing for the good inspectors; an inspector with a 95% POD has a 99% chance of passing the 8-out-of-10 test and a 91% chance of passing the 9-out-of-10 test. Figure 2-2 shows the power curves for 10 samples or grading units for POD tests.

Comparing Figures 2-1 and 2-2 shows that misclassification errors in testing are reduced for tests that use larger sample sets. For a more complete explanation of performance demonstration tests, the reader is directed to NUREG/CR-4464 (Heasler et al. 1986).

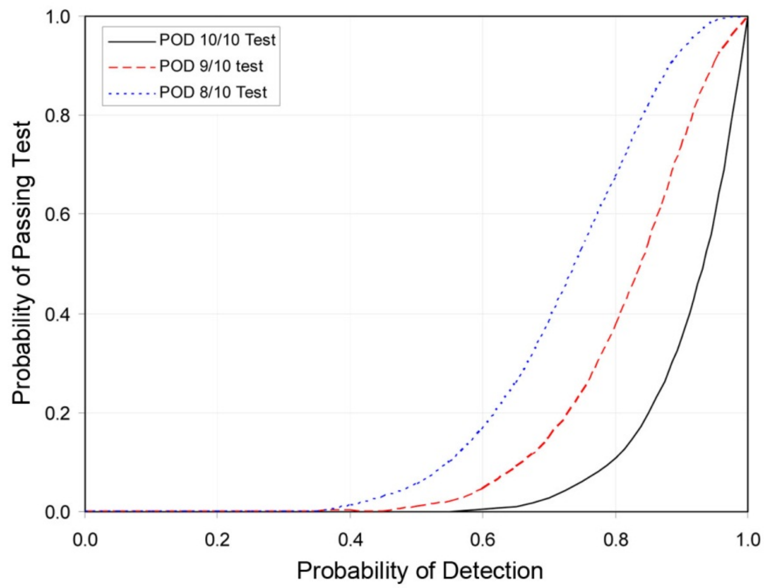


Figure 2-2 Power Curves for POD Tests Using 10 Samples

Using the information that is contained in NUREG/CR-4464, the Ad Hoc Task Group decided to construct a series of tests that used power curves. This decision was based in part upon costs of providing test samples (especially vessel samples) if testing were to use binomial statistics, and the actual time that candidate inspectors would need to complete such a test.

The power curves described above apply to one individual and one test set in isolation. In practice, the process includes a very large blind procedure qualification test (30 or more flaws), where no failures are allowed, coupled with a number of separate personnel tests using the same procedures and the same or similar equipment. Heasler et al. (2000) have shown that analysis of this two-step, procedure and personnel qualification describe a population that performs at a higher level than expected based on a single personnel test. Since developing well-defined POD curves for examiners is not practical, a single screening type performance demonstration test will not quantify performance accurately and will have high uncertainty when trying to extrapolate to the full population. In contract, the robustness of a rigorous procedure and equipment demonstration coupled with collapsing performance demonstration test data across a number of personnel tests will provide a more accurate estimate of the population performance and will be higher than that extrapolated from a single screening performance demonstration test.

The performance level of the population of qualified examiners may be inferred from the qualification test results from the large number of individually qualified examiners. POD evaluations have been performed by Becker (2001), Heasler et al. (2000), and Gosselin et al. (2007).

2.2.3 Equipment Qualification

At the time Appendix VIII was originally developed, most UT was conducted with manual, non-encoded methods, but has evolved over time to include computer-based UT systems and, more recently, phased-array systems. This evolutionary process has driven changes to Appendix VIII requirements, particularly for equipment. In reality, the ASME Code struggles to keep up with all of the advances in technology and there are a number of issues with phased-array systems such as modules for focal laws which are not addressed by the Code.

Qualified equipment is defined as an essential variable during the procedure qualification. Thus, the procedure must specify the manufacturer and model number of the equipment being qualified so that any changes in operability can be assessed. In recent years, many UT systems are computer-based and software must be addressed. The qualification includes not only the physical hardware, it also includes the software used for data collection and data analysis. The owner is required to maintain control of the software through their quality control system. The PDA documents the revision of the software and hardware used during the original qualification.

In practice, revisions to the system hardware and software have been re-qualified by demonstration on a smaller set of flaws or by analysis of the software revisions. The procedure owner is required to record and maintain a record of software revisions. The original procedure and documented software revision are maintained by the PDA for comparison. Equipment from the same manufacturer and with the same model number can be substituted without re-qualification. To address other types of hardware changes, the ASME Code approved Code Case N-780, which details alternative requirements for upgrade, substitution, or reconfiguration of examination equipment when using Appendix VIII-qualified ultrasonic examination systems. This Code Case has not as yet been approved by the NRC, which is awaiting industry implementation of the Code Case in order to make a regulatory assessment.

3 RATIONALE FOR SECTION XI, MANDATORY APPENDIX VIII REQUIREMENTS

The technical basis underlying the requirements of the ASME Code, Section XI, Appendix VIII, 2007 Edition, including the 2008 and 2009 Addenda, is provided in this section. The Appendix VIII Articles are provided in Section 3.1, followed by the Supplements in Section 3.2. In a dual-column layout, each requirement is reproduced verbatim in the left-hand column. The right-hand column presents the rationale for the requirement. Technical references for more in-depth knowledge of each topic also are provided in the right-hand column (see Section 3.1.3.1) where they are available. In the tables, grey highlighting has been used to make it easier for the reader to correlate the associated information in the two columns.

3.1 Articles

3.1.1 ARTICLE VIII-1000 – SCOPE

3.1.1.1 VIII-1100 General

ARTICLE VIII-1000 – SCOPE (VIII-1100 General)

	Rationale for Requirement and Relation to Referenceable Documentation
(a) This Appendix provides requirements for performance demonstration for ultrasonic examination procedures, equipment, and personnel used to detect and size flaws. (b) Each organization (e.g., Owner or vendor) shall have a written program that insures compliance with this Appendix. Each organization that performs ultrasonic examinations shall qualify its procedures, equipment, and personnel in accordance with this Appendix. The organization may contract implementation of the program. (c) Performance demonstration requirements apply to personnel who detect, record, or interpret indications or size flaws in welds or components. (d) The performance demonstration requirements specified in this Appendix do not apply to personnel whose involvement is limited to mounting a scanner device, marking pipe, or other situations where knowledge of ultrasonics is not important. (e) Any procedure qualified in accordance with this Appendix is acceptable. (f) Instrument characterization described in Supplement 1 is optional. When Supplement 1 is selected, both the original and substituted equipment shall be characterized.	The requirements of VIII-1100 were specified by the original ASME Code Ad Hoc Task Group that developed Appendix VIII. • The scope of ultrasonic procedures, personnel, and instruments that must follow the requirements of Appendix VIII is defined. • The organizations that must comply with the requirements of Appendix VIII must define by a written program how the requirements of Appendix VIII will be met. This requirement is intended to apply to licensees and vendors who perform ultrasonic examinations for licensees, which explains why the phrase "may contract the implementation of the program" is included. If the licensee or vendor uses PDI, then the written program will reference the PDI program. • The instrument characterization referred to in VIII–1100(f) allows for instances in which equipment such as search units or pulsers/receivers are replaced by components with differing essential variables. The requirement allows substitution of equipment without the necessity to requalify under Appendix VIII. • Components of the same manufacturer, and model or series, are substitutable without further consideration. See Appendix VIII-4100(g).

ARTICLE VIII-1000 – SCOPE (VIII-1100 General)	
	Rationale for Requirement and Relation to Referenceable Documentation
	Technical references supporting this section of Appendix VIII are • NUREG/CR-2264 (Busse et al. 1982) • ASTM Standards E-1065 (1987) and E-1324 (1990). (Table IWA-1600-1 from ASME Code Section XI lists reference edition dates and indicators.)

3.1.2 ARTICLE VIII-2000 – GENERAL EXAMINATION SYSTEM REQUIREMENTS

3.1.2.1 VIII-2100 Procedure Requirements

ARTICLE VIII-2000 – GENERAL EXAMINATION SYSTEM REQUIREMENTS (VIII-2100 Procedure Requirements)	
	Rationale for Requirement and Relation to Referenceable Documentation
(a) The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability (e.g., materials, thickness, diameter, product form). (b) The examination procedure shall specify a single value or a range of values for the variables listed in VIII-2100(d).	This requirement specifies the basic input into ultrasonic procedures that are to be qualified to Appendix VIII. The requirements in VIII–2100 were developed from the basic requirements that existed in Article III–2000 "General Requirements" of the 1989 Edition of Section XI. The significant differences between the requirements of VIII–2100 and Article III–2000 "General Requirements" of the 1989 Edition of Section XI are as follows:
(c) Any calibration method may be used provided it is described and complies with VIII-2100(d)(5).	Appendix VIII–2100(c) requires calibration but does not specify how calibration must be performed. The rationale was that any method of calibration that produced inspection performance results during the procedure qualification meeting the performance demonstration criteria was acceptable. This was, and is, a significant departure from the prescriptive requirements that were the basis for ultrasonic inspection prior to Appendix VIII. For the first time, Section XI did not prescribe calibration sensitivity. Instead, the responsible Level III inspector was allowed to define calibration procedure requirements to ensure proper performance of the equipment,

	Rationale for Requirement and Relation to Referenceable Documentation
	technique, and procedure in order to achieve the required performance, as demonstrated during the procedure demonstration.
(d) The examination procedure shall specify the following essential variables: (1) instrument or system, including manufacturer, and model or series, of pulser, receiver, and amplifier; (2) search units, including manufacturer, and model or series, and the following: (a) nominal frequency or, if Supplement 1 is used, the center frequency and either bandwidth or waveform duration as defined in VIII-4000; (b) mode of propagation and nominal inspection angles; (c) number, size, shape, and configuration of active elements and wedges or shoes; (3) search unit cable, including the following: (a) type; (b) maximum length; (c) maximum number of connectors; (4) detection and sizing techniques, including the following: (a) scan pattern and beam directions; (b) maximum scan speed; (c) minimum and maximum pulse repetition rate; (d) minimum sampling rate (automatic recording systems); (e) extent of scanning and action to be taken for access restrictions; (5) methods of calibration for detection and sizing (e.g., actions required to insure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination); (6) inspection and calibration data to be recorded; (7) method of data recording; (8) recording equipment (e.g., strip chart, analog tape, digitizing) when used; (9) method and criteria for the discrimination of indications (e.g., geometric versus flaw indications and for length and depth sizing of flaws); (10) surface preparation requirements.	Appendix VIII–2100(d) states which inputs into ultrasonic procedures are considered “Essential” but does not provide prescriptive requirements for how to fulfill the requirement for the input. Again, the nonprescriptive nature of VIII–2100 is a significant departure from previous editions of Section XI. As an example, under VIII, there are no specific requirements for calibration block design, only a requirement that the “methods of calibration for detection and sizing (e.g., actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination)” be specified in the procedure. Because only general guidance is provided for essential variables, by default it has become the responsibility of the PDA to confirm documentation of the essential variables either in the procedure or in the qualification documentation (see Records Article VIII-5000). The concept of not prescribing each detail of an ultrasonic procedure places significant responsibility on the individual writing the procedure. The utilities’ QA or ISI coordinator must ensure that the qualified procedure and essential variables demonstrated are the same as those employed in the field. The requirement implies that the NRC must verify that the process works and look for programmatic documentation including records tracking the initial procedure qualification to the field application. The PDA supplies detailed documentation to the extent that a knowledgeable individual can ascertain that the procedure is applied as it was qualified. With the development of new instruments and the advancements of phased-array (PA) and time-of-flight diffraction (TOFD) technology, the Code needs to develop guidance for additional essential variables that were not envisioned at the time this list was developed.

3.1.2.2 VIII-2200 Personnel Requirements

ARTICLE VIII-2000 – GENERAL EXAMINATION SYSTEM REQUIREMENTS (VIII-2100 Procedure Requirements)	
	Rationale for Requirement and Relation to Referenceable Documentation
Personnel shall meet the requirements of Appendix VII and shall be qualified in accordance with VIII-3000.	The ASME Code Ad Hoc Task Group that initially submitted Appendix VIII included this sentence as a means of stating what the training requirements for Appendix VIII were and what specific performance demonstration requirements personnel were required to meet.

3.1.3 ARTICLE VIII-3000 – QUALIFICATION REQUIREMENTS

3.1.3.1 VIII-3100 Qualification Test Requirements

ARTICLE VIII-3000 – QUALIFICATION REQUIREMENTS (VIII-3100 Qualification Test Requirements)	
	Rationale for Requirement and Relation to Referenceable Documentation
VIII-3110 Detection	
(a) Qualification test specimens shall meet the requirements of the appropriate Supplement listed in Table VIII-3110-1.	The NRC/PNNL strategy was to first pursue performance demonstration for the Class 1 components of greatest safety significance. Following implementation of all supplements, the extension of performance demonstration to Class 2, 3, and balance-of-plant components would be discussed. As of the date of this report, all supplements except Supplement 9 have been implemented. Not all ultrasonic examinations are required to be qualified to Appendix VIII. Appendix I Article I–2000 directs the reader to Appendix VIII for the following reactor pressure vessel examinations: (a) Shell and Head Welds Excluding Flange Welds (b) Nozzle-to-Vessel Welds (c) Nozzle Inside Radius Section (d) Clad/Base Metal Interface Region. Ultrasonic examination of reactor vessel-to-flange welds, closure head-to-flange welds, and integral attachment welds must be conducted to the requirements of Section V Article IV,

	Rationale for Requirement and Relation to Referenceable Documentation
	as supplemented by Table I-2000-1. Other reactor components are addressed in I-2200 and I-2300. Procedures qualified to the requirements of Supplements 4 (Qualification Requirements for the Clad/Base Metal Interface of Reactor Vessel) and 6 (Qualification Requirements for the Reactor Vessel Welds Other than Clad/Base Metal Interface) are often used for the examination of vessel-to-flange and head-to-flange welds as well as other vessels that are within the qualified range of the procedure as an alternative to Section V requirements. These must be approved by the NRC via proposed alternatives.
(b) The examination procedure, equipment, and personnel are qualified for detecting flaws upon successful completion of the performance demonstration specified in the appropriate Supplement listed in Table VIII-3110-1.	The rationale for the requirements in the supplements is discussed in the next section for each specific supplement.
(c) For piping welds whose requirements are in course of preparation, the requirements of Appendix III, as supplemented by Table 1-2000-1, shall be met.	As stated above, only the piping examinations that have explicit supplements require qualification to Appendix VIII; all other piping examinations are performed to the requirements of Appendix III as supplemented by Table I-2000-1. Currently, the only piping examinations that do not have explicit supplements are cast stainless steel and austenitic structure inlay or onlay (corrosion-resistant clad) welds. Procedures qualified in accordance with Supplements 2 and 3 are often used for examination of vessels less than 2.0 in. (51 mm) in lieu of Appendix III requirements. These must be approved by the NRC via proposed alternatives.
VIII-3120 Sizing	
(a) Qualification test specimens shall meet the requirements of the appropriate Supplement listed in Table VIII-3110-1.	Same rationale as that listed with VIII–3110 Detection.
(b) The examination procedure, equipment, and personnel are qualified for sizing flaws upon successful completion of the performance demonstration specified in the appropriate Supplement listed in Table VIII-3110-1.When the applicable piping supplement contains no provisions for a performance demonstration using axially oriented flaws, examination personnel, equipment procedures, and the associated essential variables qualified for sizing on circumferentially oriented flaws shall be used.	The rationale for the requirements in the supplements is discussed in the next section for each specific supplement.

	Rationale for Requirement and Relation to Referenceable Documentation
(c) For piping welds whose requirements are in course of preparation, the requirements of Appendix III, as supplemented by Table 1-2000-1, shall be met.	
(d) RMS error shall be calculated as follows: $$\text{RMS} = \left[\frac{\sum_{i=1}^{n}(m_i - t_i)^2}{n}\right]^{1/2}$$ where m_i = measured flaw size; t_i = true flaw size; n = number of flaws measured	Earlier versions of the ASME Code had a series of requirements for performing a regression fit of the data. At that time, an inspector needed to meet a requirement for slope, correlation coefficient, and mean of deviation, and could not undersize by more than 50% the larger flaws (called a critical miscall). This approach was based on industry experience for evaluating the depth sizing performance on IGSCC cracks under Inspection and Enforcement Bulletin (IEB) 83-02 (NRC 1983). PNNL showed that the use of root mean square (RMS) error on actual PDI data provided a criterion for achieving the same objective that was equivalent to the previous more complex set of criteria. Root mean square error is a standard statistical measurement that was adopted into this Appendix. The calculation of RMS error is defined in Beyer (1979).

VIII-3130 Essential Variable Ranges

(a) Any two procedures with the same essential variables [VIII-2100(d)] are considered equivalent. Pulsers, search units, and receivers that vary within the tolerances specified in VIII-4100 are considered equivalent. When the pulsers, search units, and receivers vary beyond the tolerances of VIII-4100, or when the examination procedure allows more than one value or range for an essential variable, the qualification test shall be repeated at the minimum and maximum value for each essential variable with all other variables remaining at nominal values. Changing the essential variable may be accomplished during successive personnel performance demonstrations. Each examiner need not demonstrate qualification over the entire range of every essential variable.	This requirement provided a method for showing equivalency of two procedures. The tolerances referenced in VIII–4000 were based upon NUREG/CR-5871 (Green et al. 1992). The procedure shall demonstrate that it is effective for any combination of essential variables selected when they are specified with a range, and this is achieved by testing the procedure when the minimum and maximum values are selected for each of the essential variables. A blind test performance demonstration for the essential variables at the extremes of the ranges specified in the procedure satisfies this requirement.
(b) When the procedure does not specify a range for essential variables and establishes criteria for selecting values, the criteria shall be demonstrated.	The administrator of the performance demonstration test must challenge the criteria used for selecting essential variable ranges, to ensure that the procedure criteria enable effective performance. Again, the ranges of essential variables based on the procedure criteria must be fully evaluated in this process.

Rationale for Requirement and Relation to Referenceable Documentation

VIII-3140 Requalification

When a change in an examination procedure causes an essential variable to exceed a qualified range, the examination procedure shall be re-qualified for the revised range.

Rationale: This simply states that procedure changes must be demonstrated successfully before they can be used for inspections.

TABLE VIII-3110-1
COMPONENT QUALIFICATION SUPPLEMENTS

Component Type	Applicable Supplement
Piping Welds	
Wrought austenitic	2
Ferritic	3
Cast austenitic	[Note (1)]
Structural weld inlay (corrosion-resistant clad) austenitic	[Note (1)]
Dissimilar metal	10
Overlay	11
Coordinated implementation	12
Vessels	
Clad/base metal interface region	4
Nozzle examinations from the outside surface	5
Reactor vessel welds other than clad/base metal interface	6
Nozzle examinations from the inside surface	7
Bolts and Studs	8

NOTE:
(1) In the course of preparation.

Rationale: This is simply a listing of the supplements in Appendix VIII and the type of component that they address. The ASME Code needs to update Table VIII-3110-1 to include Supplement 14 for the coordinated implementation of Supplements 10, 2, and 3 for piping examinations performed from the inside surface. It should be noted that Note (1) regarding a supplement addressing structural weld inlay (corrosion-resistant clad) for austenitic materials is not up-to-date. No ASME Code Committee is currently working to develop this supplement.(1)

(1) EPRI has conducted relevant work on accessing the inspectability of inlays/onlays on qualified Supplement 10 procedures and presented some of this information at ASME Code meetings although the authors have not reviewed the published report. This report is only available by purchase from EPRI for $14,250 and is titled *Nondestructive Evaluation: Ultrasonic Equivalency Testing of Weld Inlaid and Weld Onlaid Components* (EPRI, Palo Alto, California, 2008; Report No. 1016655.

3.1.4 ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES

3.1.4.1 VIII-4100 Procedure Modifications

ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES (VIII-4100 Procedure Modifications)

	Rationale for Requirement and Relation to Referenceable Documentation
VIII-4110 Examination System Components Components of the same manufacturer, and model or series, are substitutable without further consideration. The qualified procedure may be modified to replace pulsers, receivers, or search units without requalification when the following conditions are met.	Components may be replaced in-kind and do not require requalification. Different or modified components are subject to VIII-4110 requirements. NUREG/CR-5871 (Green et al. 1992) provided the basis for all the equipment tolerances listed in VIII-4110. NUREG/CR-5871 describes work conducted at PNNL on the effect of frequency domain equipment interactions on the reliability of ultrasonic inspection. The specific tolerances specified in VIII-4110(e), (f), (g), and (h) are supported by the conclusions in NUREG/CR-5871.
(a) Instruments with reject, damping, or pulse tuning controls, have discrete settings specified in the procedure.	
(b) Pulsers and receivers shall be evaluated using ASTM E 1324, Guide for Measuring Some Electronic Characteristics of Ultrasonic Instruments, with the following exceptions: (1) The lower (F_L) and upper (F_U) limits for receivers shall be determined between frequencies that are 6 dB below the peak frequency. (2) The receiver center frequency (F_C) shall be determined by: $F_C = \frac{F_L + F_U}{2}$ (3) The receiver band width (BW) shall be determined by: $BW = \frac{F_U - F_L}{F_C} \times 100$	The definitions in this section (F_L, F_u, etc.) are consistent with *The New IEEE Standard Dictionary of Electrical and Electronics Terms* (IEEE 1992).
(c) Search units shall be evaluated using ASTM E 1065, Evaluation of the Characteristics of Ultrasonic Search Units.	

ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES (VIII-4100 Procedure Modifications)

	Rationale for Requirement and Relation to Referenceable Documentation
(d) Examination systems shall be evaluated using Supplement 1.	
(e) Replacements of the instrument or the pulser section of the instrument system shall be within the following tolerances of the original equipment as measured into a 50 ohm, noninductive, noncapacitive, resistive load: (1) pulse amplitude, ±10%; (2) pulse rise time, ±10%; (3) pulse duration, ±10%;	The provisions addressing the replacement of malfunctioning equipment were developed to ensure that essential parameters would be maintained, and also so that re-qualification of the system would not be required when the replacement did not adversely affect the examinations.
(f) Replacements of the instrument or the receiver section of the instrument system shall be within the following tolerances of the original equipment: (1) lower and upper frequency limits at the -6 dB point, ±0.2 MHz; (2) center frequency for instrument receivers with bandwidths less than 30%, ±5%; (3) center frequency for instrument receivers with bandwidths equal to or greater than 30%, ±10%.	
(g) Replacement search units of the same manufacturer's model, size, and nominal frequency may be used without requalification.	
(h) Replacement search units not of the same manufacturer's model, size, and nominal frequency shall be within the following tolerances of the original search units: (1) propagation mode is the same (2) measured angle, ± 3 deg. (3) center frequency for search units with bandwidths less than 30%, ±5% (4) center frequency for search units with bandwidths equal to or greater than 30%, ±10% (5) waveform duration, ±½ cycle or 20%, whichever is greater (measured at -20 dB), or bandwidth, ±10%	
(i) As an alternative to (e) through (g) above, or for substitution of other components of the examination system identified as essential variables, equipment replacement is acceptable if the examination system is within the following tolerances of the original system when evaluated in accordance with Supplement 1: (1) system center frequency for examination systems with bandwidths less than 30%, ±5% (2) system center frequency for examination systems with bandwidths equal to or greater than 30%, ±10%	

ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES (VIII-4100 Procedure Modifications)	
	Rationale for Requirement and Relation to Referenceable Documentation
(3) system bandwidth, ±10%	
VIII-4120 Search Unit Characterization Characterization measurements of the search unit shall be made using either a sinusoidal tone burst technique or shock excitation. When using shock excitation, the characterization pulser and UT instrument pulser shall be the same within the limits of VIII-4110(e).	The requirement is support by the conclusions of NUREG/CR-5871 (Green et al. 1992).

3.1.4.2 VIII-4200 Computerized System Algorithms

ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES (VIII-4200 Computerized System Algorithms)	
	Rationale for Requirement and Relation to Referenceable Documentation
When the performance demonstration uses prerecorded data, algorithms for automated decisions may be altered when the altered algorithms are demonstrated to be equivalent to those qualified. When the performance demonstration results meet the acceptance requirements of VIII-3000, the algorithm shall be considered qualified.	This specific requirement has actually never been used, to the authors' knowledge. Software is an essential variable. Any changes require requalification, and this was an attempt to address how to do this. The ASME Ad Hoc Task Group wanted this included.

3.1.4.3 VIII-4300 Calibration Methods

ARTICLE VIII-4000 – ESSENTIAL VARIABLE TOLERANCES (VIII-4300 Calibration Methods)	
	Rationale for Requirement and Relation to Referenceable Documentation
Alternative calibration methods may be demonstrated equivalent to those described in the qualified procedure without requalification. This demonstration of equivalence shall be conducted for each beam angle and mode of propagation to which it applies, as follows.	The authors are unaware of this being used. The ASME Ad Hoc Task Group felt it was important to include in Appendix VIII. Calibration or reference reflectors are used to establish reference sensitivity from which recorded indications can be compared. It should be noted that the majority of qualified procedures do not establish sensitivity on a set of calibration reflectors. These procedures set sensitivity based on the NDE response noise level on the actual component being examined.

(a) Calibrate the examination system in accordance with the alternative methods.	
(b) Compare the sensitivity of the alternative calibration method to that of the qualified calibration method.	
(c) The alternative calibration method is acceptable when the system sensitivity is no more than 2 dB below that obtained by the qualified method.	

3.1.5 ARTICLE VIII-5000 – RECORD OF QUALIFICATION

3.1.5.1 VIII-5100 General

ARTICLE VIII-5000 – RECORD OF QUALIFICATION (VIII-5100 General)

	Rationale for Requirement and Relation to Referenceable Documentation
The organization's performance demonstration program shall specify the documentation that shall be maintained as qualification records. Documentation shall include identification of personnel, NDE procedures, and equipment and specimens used during qualification, and results of the performance demonstration.	Documentation was required so that programs could be audited and third parties could confirm that the procedures, personnel, and equipment had successfully passed the demonstration as well as serving as a means to verify that UT was being performed according to what was qualified. This documentation must be maintained and made available upon request.

3.2 Mandatory Appendix VIII - Supplements

3.2.1 SUPPLEMENT 1 – EVALUATING ELECTRONIC CHARACTERISTICS OF ULTRASONIC SYSTEMS

This supplement was created to provide a standard means for objectively evaluating the performance characteristics of conventional UT systems. The supplement allows substitution of essential variables, such as search units or critical equipment that might be damaged or lost, without having to repeat the performance demonstration process described in Appendix VIII. At the time this supplement was developed, no national standard existed for evaluating the electronic characteristics of ultrasonic systems. This supplement was based on extensive studies, including those reported in NUREG/CR-2264 (Busse et al. 1982), as well as initial results from round-robin studies being conducted by ASTM Committee E-7.

ASTM has developed E1324-00, “Standard Guide for Measuring Some Electronic Characteristics of Ultrasonic Examination Instruments,” and E1065, “Standard Guide for Evaluating Characteristics of Ultrasonic Search Units.” These ASTM standards were evolving at the time that Appendix VIII was being written and now could simply be referenced with Supplement 1 deleted from Appendix VIII. This supplement adequately addresses only conventional manual UT systems and does not address newer technology such as phased arrays. To the best knowledge of the authors, this supplement has only been used on a very limited basis. It was used to address cable and connector changes at the Duane Arnold Energy Center in 2007 (ADAMS accession number ML070580285) and in 2007 at Quad Cities Unit 1 (ML0716203020). The ASME Code Task Group Appendix VIII developed Code Case N-780 entitled “Alternative Requirements for Upgrade, Substitution, or Reconfiguration of Examination Equipment When Using Appendix VIII Qualified Ultrasonic Examination Systems,” to address the issue of requirements for the upgrade, substitution, or reconfiguration of UT examination equipment. This Code Case has been approved by Section XI but not by the NRC. The task group plans to upgrade the ASME Code Section XI to include this Code Case by replacing Supplement 1 with requirements that apply to all UT systems, including conventional, imaging, and phased arrays.

SUPPLEMENT 1 – EVALUATING ELECTRONIC CHARACTERISTICS OF ULTRASONIC SYSTEMS

	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SYSTEM FREQUENCY CHARACTERISTICS	The requirements in Supplement 1 are consistent with those in ASTM Standards E-1324 and E-1065 referred to above. This supplement was developed for manual UT equipment and has seen very limited use. Some recent work by EPRI (2010) on cable equivalency used this supplement. To expand this approach beyond manual UT, Code Case N-780 was developed; but it has not been implemented, demonstrated, or accepted by NRC.
1.1 The frequency response, also known as the frequency spectrum, shall be determined by measuring of the amplitude of the pulse echo response from a target as a function of frequency. This response shall be used as a basis for establishing the center frequency and bandwidth of the ultrasonic system. CAUTION: The required output signal test point from the ultrasonic instrument may require access to ultrasonic circuitry inside the instrument chassis. The use of high impedance test probes may also be required if the signal of interest is not buffered.	
1.2 Connect the ultrasonic instrument including the search unit and, if applicable, the wedge, as shown in Fig. VIII-S1-1A. The output signal from the ultrasonic instrument that is used in data analysis for flaw detection or flaw sizing (i.e., the output signal after amplification, filtering, and video detection) shall be input to a device that is capable of measuring the frequency spectrum (e.g., a spectrum analyzer or a digitizing circuit with a software package that determines the frequency response of waveforms). If a digitizing circuit is used, the rate of digitizing shall be at least five times the nominal (labeled) frequency of the search unit.	
(a) If the receiver or transmitter provides variable signal filtering or frequency control, the signal controls shall be set as specified in the examination procedure. Check all connections in the test setup to ensure that it is safe to turn on the ultrasonic system.	
(1) Flat or nonfocused search units shall be adjusted so that the distance (Z_o) from the face of the search unit to the target is 2 in. (50 mm) (see Fig. VIII-S1-1B). A smooth glass block with dimensions 2 in. × 2 in. × 1 in. (50 mm × 50 mm × 25 mm) thick is recommended as the target. Using a manipulator, adjust the search unit angle with respect to the block until the return echo is maximized indicating that the sound field is perpendicular to the block. Adjust the receiver section gain controls until the ultrasonic signal amplitude from the block is 80% of full scale without saturating the ultrasonic signal. Plot the frequency spectrum of the ultrasonic signal as shown in Fig. VIII-S1-2A.	A glass block is recommended to deal with issues associated with trying to define the smoothness of a surface. Glass blocks, easily obtained, are smooth to optical standards and thus acceptable as UT reference targets.

	Rationale for Requirement and Relation to Referenceable Documentation
(2) Determination of the frequency response for focused search units shall follow the same procedure for flat search units, except that the distance Z_o shall be adjusted to maximize echo from the glass target.	
1.3 System Frequency Response Results	The definitions in this section (F_L, F_u, etc.) are consistent with *The New IEEE Standard Dictionary of Electrical and Electronics Terms* (IEEE 1992).
(a) Lower Frequency Limit (F_L) — The lower frequency limit (MHz) at a specific frequency control setting is the lowest frequency on the frequency response curve that is 6 dB below the maximum amplitude as shown in Fig. VIII-S1-2A.	
(b) Upper Frequency Limit (F_U) — The upper frequency limit (MHz) at a specific frequency control setting is the highest frequency on the frequency response curve that is 6 dB below the maximum amplitude as shown in Fig. VIII-S1-2A.	
(c) Center Frequency (F_C) — The center frequency (MHz) at a specific frequency control setting shall be calculated as follows: $$F_C = \frac{F_L + F_U}{2}$$	
(d) Bandwidth (BW) — The bandwidth (%) at a specific frequency control setting shall be calculated as follows: $$BW = \frac{F_U - F_L}{F_C} \times 100$$	
(e) The system frequency response results, (a) through (d) above, shall be obtained for the remaining receiver and transmitter control module setting combinations used in the performance demonstration. These values shall be recorded.	

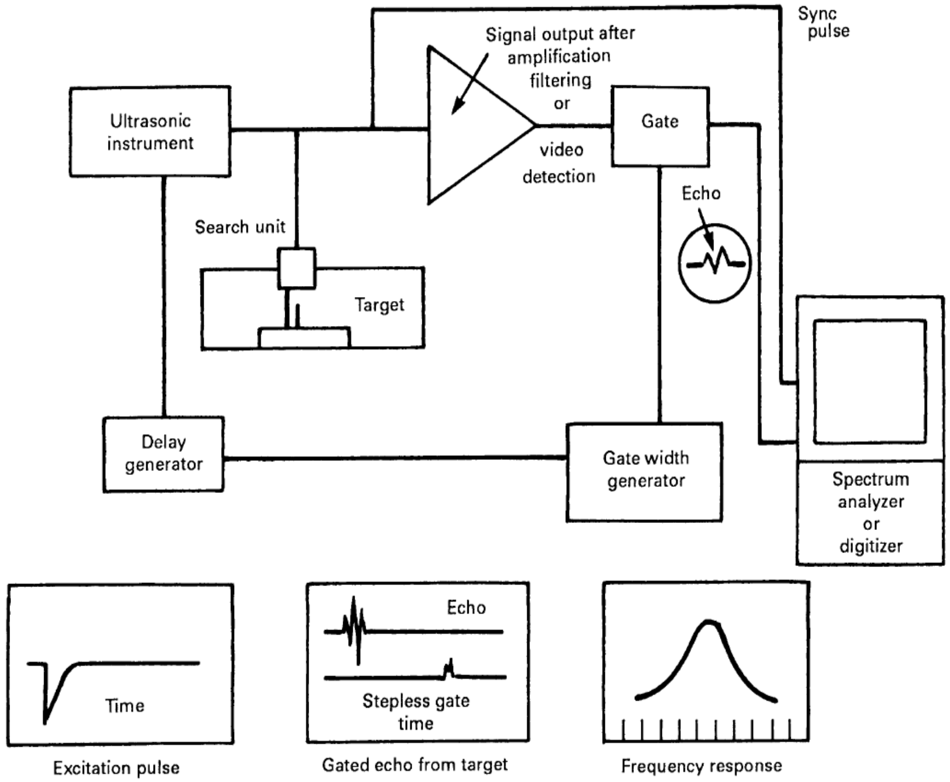


FIG. VIII-S1-1A SYSTEM CONFIGURATION

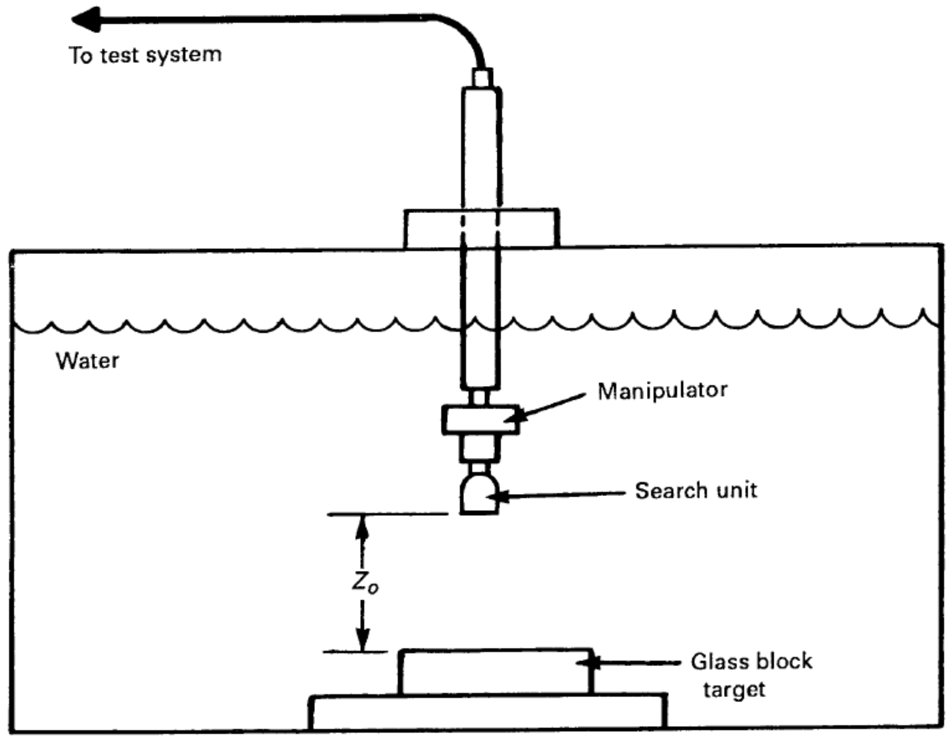


FIG. VIII-S1-1B TEST CONFIGURATION

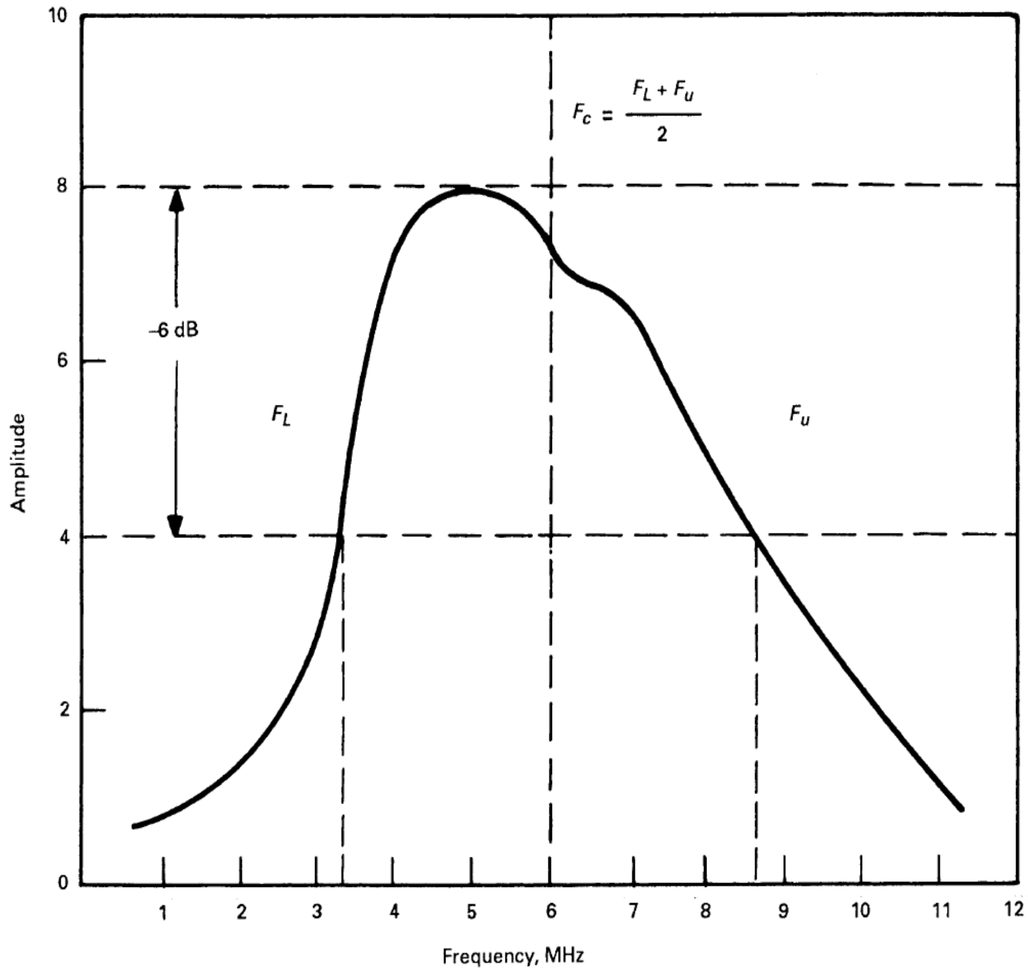


FIG. VIII-S1-2A FREQUENCY RESPONSE CURVE

3.2.2 SUPPLEMENT 2 — QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

This supplement was based on extensive experience as documented in NUREG/CR-4464 (Heasler et al. 1986), NUREG/CR-4882 (Spanner et al. 1990); round-robin tests, such as NUREG/CR-5068 (Heasler and Doctor 1996), NUREG/CR-4908 (Heasler et al. 1990), and NUREG/CR-5410 (Heasler et al. 1993); and the data and experience from the IEB 82-03 (NRC 1982) and 83-02 (NRC 1983) exercises.

The assumption used in developing the detection performance demonstration requirements specified in this supplement (and other supplements in Appendix VIII) was that an inspector's capability to detect flaws can be quantified in the test by estimating two probabilities. The first is the probability of detection and correct interpretation (POD), which is the probability that a crack in a particular length of weld material will be detected by the inspector. The second is the false call probability (FCP), which is the probability that a crack will be falsely detected in a "blank" or crack-free length of weld material.

The Ad Hoc Task Group that initially developed Appendix VIII accepted the experience described in the documents above and developed the Specimen Requirements for both Detection and Sizing Specimens, Conduct of Testing and Acceptance Criteria for the supplements described in the rest of this document.

The Ad Hoc Task group that developed the original requirements for austenitic stainless steel weldments thought that the flaws should be located on both the near side and the far side of austenitic stainless steel test samples. Thus, the supplement applies to flaws located on both the same side of the weld as the inspection probe (near side) and when the flaw is located on the opposite side of the weld as the inspection probe (far side) of austenitic stainless steel weldments. In many cases, the weld crowns are left in place and preclude UT probes from being able to scan on top of the weld. After the initial publication of Appendix VIII, the NRC added additional requirements into 10 CFR 50.55a stating that in order to qualify an austenitic procedure for single-side access, it must demonstrate the capability on a test set containing all flaws on the far side of the weld. To date no procedure has satisfied this criterion. Demonstrations are offered for near-side access and far-side access or the opportunity to demonstrate a best-effort approach on far-side flaws that are known to be detectable.

In lieu of a full single-side endorsement, a best-effort approach was developed. In this approach, three or more examples of far-side flaws, which are known to be detectable, are included in the test set. If a candidate misses no more than one of the far-side flaws and meets all other acceptance criteria, he/she is qualified for the "Best-Effort Approach."

SUPPLEMENT 2 — QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.	This is a general requirement that the specimen set needs to be selected to fully address the scope of the procedure and be representative of the surface conditions during ISI.
1.1 General. This Supplement is applicable to austenitic piping welds examined from either the inside (I.D.) or outside (O.D.) surface. The applicable qualification criteria shall be satisfied separately. This Supplement is not applicable to piping welds containing supplemental corrosion-resistant cladding applied to mitigate IGSCC. The specimen set shall conform to the following requirements.	This supplement was originally set up for inspections from only the O.D. surface but was later updated to also address I.D. inspections.
(a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.	The specimens must reflect realistic field conditions; if the specimens are too small, then signals will be present that will not be seen on full-sized components.
(b) The specimen set shall consist of at least four specimens having different nominal pipe diameters and thicknesses. The set shall include pipe specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 0.5 in. (13 mm) less than the maximum thickness for which the examination procedure is applicable. It shall include the minimum, within NPS 1/2, and maximum pipe diameters for which the examination procedure is applicable. If the procedure is applicable to pipe O.D. of 24 in. (600 mm) or larger, the specimen set must include at least one specimen 24 in. O.D. (600 mm) or larger but need not include the maximum diameter.	Because inspection procedures cover a range of pipe diameters and wall thicknesses, this guidance explains how to bracket the range to ensure that the procedure/equipment and personnel are tested for all conditions covered by the procedure scope. The basis for the requirement that the specimen set should contain “at least four specimens” came from the discussions within the Ad Hoc Task Group that identified four basic conditions for most inspection procedures at that time (circa 1984). The conditions were • less than 12-in. (300-mm) nominal pipe diameter and less than 0.6-in. (15-mm) nominal wall thickness • less than 12-in. (300-mm) nominal pipe diameter and 0.6-in. (15-mm) or greater nominal wall thickness • 12-in. (300-mm) or greater nominal pipe diameter and less than 0.6-in. (15-mm) nominal wall thickness

	Rationale for Requirement and Relation to Referenceable Documentation
	• 12-in. (300-mm) or greater nominal pipe diameter and 0.6-in. (15-mm) or greater nominal wall thickness. Therefore, the requirement evolved into at least four specimens. The intent is to cover the same range of pipe thicknesses and diameters as stated in the scope of the pipe inspection procedure. Four specimens are considered the minimum number of specimens to adequately address the range of austenitic piping conditions located in nuclear power plants.
(c) Taking into consideration the accessible scanning surface, the O.D. or I.D. specimen set shall include applicable examples of the following fabrication conditions:	Surface conditions and geometrical conditions are potential major limitations adversely impacting inspection effectiveness; thus, these conditions must be part of the sample set in order to have assurance that they do not impact the inspection. In U.S. nuclear power plants, many welds, geometries, and materials were not selected or installed based on their impact on inspections. As a result, all of these conditions must be included in the test samples. Since the designed versus as-built conditions are not known or documented, inspection experience and surveys have been needed to collect a knowledge base to guide the selection of representative specimens.
(1) unground weld reinforcement (crowns);	
(2) wide crowns, such that the total crown width is 1 ½ to 2 times the nominal pipe wall thickness;	
(3) geometric conditions that normally require discrimination from flaws (e.g., counterbore, weld root conditions such as excessive I.D. reinforcement for O.D. scans, or O.D. reinforcement for I.D. scans, as applicable);	
(4) typical limited scanning surface conditions (e.g., diametrical shrink, single-side access due to safe ends or fittings, clad surfaces, or counterbore within the scanning area, as applicable).	

SUPPLEMENT 2 — QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
(d) All flaws in the specimen set shall be cracks.	Early parametric studies conducted on inspection parameters (NUREG/CR-1696, Becker et al. 1981) showed that cracks did not have UT responses like machined reflectors. In fact, cracks produce much lower responses. Thus, to ensure that NDE personnel, equipment, and procedures can reliably detect and accurately size service degradation (cracks), they need to be included in the test specimens.
(1) Mechanical fatigue cracks and either IGSCC or thermal fatigue cracks shall be used. At least 75% of the cracks shall be either IGSCC or thermal fatigue cracks.	Based on laboratory studies and round-robin tests listed above, IGSCC tended to have very low UT responses and thermal fatigue cracks under residual compressive stresses tended to have a similar UT response.
(2) At least 50% of the cracks shall be coincident with fabricated conditions described in (c) above.	Fabrication conditions make inspections more challenging. IGSCC grows in the heat-affected zone of a weldment and, thus, is near to the weld root, to metallurgical conditions, and to the transition point for short counter bores. This requires that all of these conditions must be included in the test set.
1.2 Detection Specimens. The specimen set shall include detection specimens that meet the following requirements.	
(a) Specimens shall be divided into grading units. Each grading unit shall include at least 3 in. (75 mm) of weld length. If a grading unit is designed to be unflawed, at least 1 in. (25 mm) of unflawed material shall exist on either side of the grading unit. The segment of weld length used in one grading unit shall not be used in another grading unit. Grading units need not be uniformly spaced around the pipe specimen.	Grading units were selected to simplify the grading process and make it objective. The size of the grading unit was a compromise. The compromise was based on evidence documented in NUREG/CR-4908 (Heasler et al. 1990) that showed that FCP and POD have a complicated relationship with grading unit size. A grading unit of 1 in. (25.4 mm) tends to under-estimate POD and FCP; a large grading unit such as 8 in. (203 mm), while providing a reasonable estimate of POD and FCP, was determined by the Ad Hoc Task Group to result in a set of test specimens that would be very expensive to fabricate. The spacing between grading units helps ensure that there is no cross contamination from one grading unit to another because of their proximity. Grading units are not

SUPPLEMENT 2 — QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
	marked on the test specimen so that an inspector does not know how many are in a particular specimen or where they are located.
(b) Detection sets for personnel qualification shall be selected from Table VIII-S2-1. The number of unflawed grading units shall be at least twice the number of flawed grading units. For initial procedure qualification, detection sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.	Originally the ASME Code required that if an inspector could pass the performance demonstration test, the personnel, equipment, and procedure were acceptable. In some cases, only one person could pass the performance demonstration using a particular set of inspection equipment and procedure. Thus Appendix VIII was modified to include the requirement that initially the procedure and equipment become qualified only after they have successfully passed the equivalent of three personnel qualification sets. This increased the robustness of the equipment and procedure qualification because all the flaws had to be detected by the procedure and equipment. Heasler et al. (2000) showed that a two-stage process achieving improved equipment and procedures should lead to higher personnel pass rates.
(c) Flawed grading units shall meet the following criteria for flaw depth, orientation, and type.	
(1) A minimum of 1/3 of the flaws, rounded to the next higher whole number, shall have depths between 5% and 30% of the nominal pipe wall thickness. At least 1/3 of the flaws, rounded to the next higher whole number, shall have depths greater than 30% of the nominal pipe wall thickness.	Any size of service flaws may exist at the time of inspection, and the demonstration must show that the personnel, equipment, and procedures can reliably detect and accurately size all flaws that might be in the degraded component.
(2) At least one and a maximum of 10% of the flaws, rounded to the next higher whole number, shall be oriented axially. The remainder of the flaws shall be oriented circumferentially.	Service cracks occur both circumferentially and axially. As such, both conditions need to be included in the test samples.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(3) Service-induced flaws shall be included when available. When the procedure is intended to detect IGSCC, at least four field-removed, IGSCC-flawed grading units shall be included in the detection test set.	This paragraph acknowledges that the best flaws to use for performance demonstration testing are service flaws because this is what needs to be found during ISI. Although not explicitly stated, it is expected that if new degradation processes occur in the future, then consideration would be given to adding new flaws simulating the NDE responses from the new degradation process to the test sets. Based on recent industry experience, the emergence of a new degradation process is likely. Currently there are no requirements for how these flaws would be added to the test sets. Since there are a number of ways that this could be accomplished, it would be prudent for Section XI to develop guidance on how this should be done.
1.3 Sizing Specimens. The specimen set shall contain sizing specimens that meet the following requirements.	
(a) The minimum number of flaws shall be ten. For initial procedure qualification, sizing sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables at least one personnel qualification set is required.	The Ad Hoc Task Group that developed the initial sizing specimen requirements chose a minimum number of 10 flaws for sizing. This minimum number is based upon the need for reasonable statistics to assess whether the sizing performance is acceptable or not. This number of flaws is a tradeoff between several factors. As a larger number of flaws are included, the error associated with accurately estimating the true sizing performance is reduced. However, as the number of flaws increases, the costs for the demonstration process also increase (need more specimens, more flaws, longer testing duration). The requirement to include the equivalent of three personnel qualification sets provides a robust procedure and equipment qualification that should lead to a higher pass rate for personnel (Heasler et al. 2000).

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(b) Flaws in length sizing sample sets shall meet the requirements of para 1.2(c)(l), when given in conjunction with a detection test. When the length sizing test is administered independently, the flaw depth requirements do not apply.	This requirement is used to address the specific case in which the detection test was passed but the length sizing demonstration was not passed and now the personnel need to demonstrate only length sizing. It is also intended to address cases where length sizing may employ a different technique. The authors do not believe that a different technique has been used, but it was thought to be a possibility when this was first considered in 1986.
(c) Flaws in the depth sizing sample set shall be distributed as follows: (see table below)	The Ad Hoc Task Group that developed the initial requirements for Appendix VIII understood and assumed that whoever was responsible for implementing the sizing test would develop a sizing test set that distributed the flaws evenly throughout the ranges specified in the requirements. It is necessary to ensure that flaws are somewhat evenly distributed; otherwise, the RMS error criterion is not the best method for evaluating the performance of a candidate. This range of sizes is provided to ensure that all sizes are included in the test set as well as to keep the demonstration process blind so that the inspectors do not know how many flaws in a particular sizing range are in the test set. This was intended to reduce testmanship.

Flaw Depth (% Wall Thickness)	Minimum Percentage of Flaws
5–30%	20%
31–60%	20%
61–100%	20%

The remaining flaws shall be in any of the above categories.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

When scanning from the O.D., the specimen inside surface and identification shall be concealed from the candidate. When scanning from the I.D., flaw location and specimen identification shall be obscured to maintain a “blind test.” All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.	This supplement provides requirements to keep the test samples blind and to ensure that testmanship is not a factor in the demonstration testing.
2.1 Detection Test. Flawed and unflawed grading units shall be randomly mixed.	These requirements help ensure that the test is not biased and that any potential testmanship is minimized.

	Rationale for Requirement and Relation to Referenceable Documentation
2.2 Length and Depth Sizing Test	Guidance on how to administer the performance demonstration tests.
(a) Each reported flaw in the detection test shall be length sized. When only length sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.	Length sizing is performed as part of the detection testing and all detected flaws are length sized with the flaw location unknown to the candidate (blind test).
(b) The depth sizing test may be performed in conjunction with or separate from the detection test. When only depth sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	Depth sizing is performed separately from detection testing because the requirements for flaws of particular sizes are different for the two test sets and different techniques are used. Flaws may be presented in a region which is revealed to the candidate. The candidate must locate and measure the deepest portion of the flaw. The Code did not specify the flaw orientation for depth sizing, but only circumferential flaws should be used because these flaws are more important structurally to component integrity and function.

TABLE VIII-S2-1
PERFORMANCE DEMONSTRATION DETECTION TEST ACCEPTANCE CRITERIA

Detection Test Acceptance Critera		False Call Test Acceptance Criteria	
No. of Flawed Grading Units	Minimum Detection Criteria	No. of Unflawed Grading Units	Maximum Number of False Calls
5	5	10	0
6	6	12	1
7	6	14	1
8	7	16	2
9	7	18	2
10	8	20	3
11	9	22	3
12	9	24	3
13	10	26	4
14	10	28	5
15	11	30	5
16	12	32	6
17	12	34	6
18	13	36	7
19	13	38	7
20	14	40	8

Rationale for Requirement and Relation to Referenceable Documentation

The performance demonstration detection process described in this supplement actually consists of two separate tests—a test that measures detection capability and a test that measures false call probability.

The number of specimens described in the sections for detection and sizing do not permit a binomial criterion to be specified (e.g., a POD of 90% with a 90% confidence level). Instead, the acceptance criteria in the table were created to screen the inspectors to ensure that the inspector population that passed had the desired performance. The tables were based on round-robin data for the previous distribution of performance capability. The design was based on criteria that if the inherent capabilities of personnel, equipment, and procedure were at least 80% POD and a FCP less than 20%, then they would have a high probability of passing the screening test. However, if they had a POD less than 50% and a FCP greater than 20%, then they should have less than a 3% chance of passing the test. A table is used to provide a range of tests so that the inspector taking the test does not know how many flaws are in their test set or how many blank grading units. This has been discussed in Section 1.2 of this report, and more technical details can be found in NUREG/CR-4464 (Heasler et al. 1986).

The Ad Hoc Task Group that developed the initial criteria had to balance factors such as eliminating poor performance while not penalizing good performance. The following considerations were used to develop the criteria:

SUPPLEMENT 2 — QUALIFICATION REQUIREMENTS FOR WROUGHT AUSTENITIC PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
	• NUREG/CR–3869 (Simonen and Woo 1984) concluded that "For the PNL round robin study, the improvement as measured by reduction in leak probability from the "good" team to the "advanced" team is less than that from the "poor" team to the "good" team. This elimination of "poor" teams through training and qualification testing can produce significant benefits to ISI effectiveness." NUREG/CR-3869 defines "poor," "good," and "advanced" teams as follows: – Poor team – This represents a lower bound on performance among teams that participated in the PNNL Piping Inspection Round Robin (PIRR) test. These teams followed ASME minimum Code requirements that were being used at the time of the round-robin tests (e.g., the 1977 Edition including the 1978 Addenda of Section XI). – Good teams – These teams represent the better teams' performance in the PNNL PIRR round robin. – Advanced teams – These teams represent hypothetical performance that was thought to be achievable with improvements to existing technology (technology circa 1985). It assumes a 0.999 flaw detection probability for a through-wall flaw and a POD of approximately 90% for flaws with a depth of 10% through-wall.

	Rationale for Requirement and Relation to Referenceable Documentation
	• The consideration of the NRC/EPRI/BWROG coordination plan (see Section 2.1) in place at the time. • The consideration among members of the Ad Hoc Task Group that a test that was “too” difficult would impair the ability of industry to perform ISI because there would be a lack of inspectors.

3.0 ACCEPTANCE CRITERIA

3.1 Detection Acceptance Criteria

(a) Personnel demonstration shall meet the requirements of Table VIII-S2-1 for both detection and false calls. If the procedure is intended to detect IGSCC, failure to detect more than one of the IGSCC flaws is unacceptable for personnel qualification.	The test set must include varied potential degradation processes that may occur in wrought austenitic piping welds. This leads to the need to define the types and number of each flaw type to be included as well as any constraints on pass/fail criterion. The PDI has developed a process for doing this. The basic piping performance demonstration test includes fatigue flaws. If an IGSCC endorsement is sought, then the test set includes IGSCC flaws and at least four of the flaws would need to be IGSCC. If the best-effort single-side endorsement is also sought, then at least four of the flaws would be on the far side of the weld with at least one of them being IGSCC. For an 8-out-of-10 test for IGSCC and single-side endorsement, a total of two flaws could be missed and only one of them could be IGSCC or a far-side flaw.
(b) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure. Successful personnel demonstrations may be combined to satisfy the requirements for procedure qualification.	Remember that the procedure qualification requires the equivalent of three personnel demonstrations with all the flaws being detected. If the design involves a 10-flaw test set, then all 30 flaws must be detected in blind testing for the procedure to be qualified. Each flaw must be detected according to the criteria of the procedure.

	Rationale for Requirement and Relation to Referenceable Documentation
3.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing if the results of the performance demonstration satisfy the following criteria:	Since candidates are going to be passed or failed based on their test results, it is necessary to know the flaw dimensions and locations with minimum uncertainty. In some cases, the true state of the flaws can be controlled by physical measurements during the implanting processes and/or by extensive NDE measurements to verify location and dimensions.
(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.75 in. (19 mm);	Originally this was a requirement of 1 in. (25.4 mm) on the maximum over- and under-sizing error that the inspector needed to meet. Under ideal conditions, the 1 in. (25.4 mm) criterion is reasonable and that was the only basis for its inclusion. Initial demonstrations indicated that the 1 in. (25.4 mm) criteria was very difficult to meet when faced with low amplitude responses and flaws with overlapping or interfering geometrical responses. The Code was asked to revise the requirement based on the small influence of flaw length on piping integrity and the judgment that 0.75 in. (19 mm) RMS criterion were sufficient to determine adequate length sizing capability. The RMSE criterion of 0.75 in. (19 mm) was based upon an analysis of PDI test data that was presented to the ASME Code but not formally published.

	Rationale for Requirement and Relation to Referenceable Documentation
(b) The RMS error of the flaw depths estimated by ultrasonics, as compared with the true depths, shall not exceed 0.125 in. (3 mm).	The original acceptance criteria were described by the following parameters: • slope of the linear regression line > 0.6 • correlation coefficient had to be > 0.7 • mean of the deviation < 20% • no flaw undersized by 0.2 in. (5.1 mm) or 25% of the pipe wall thickness. The initial IGSCC sizing test had no acceptance criteria. After approximately 30 candidates took the test, the results were analyzed using various statistical tools. The decision was based at least in part that a reasonable number of candidates would be able to pass the criteria. All of the testing was performed on 0.8 in. (20 mm) thick stainless steel piping. After a significant amount of data was collected, a statistician showed that the pass rate would be the same (except for the undersizing criteria) when using the multiple parameters as when using the single RMS error value of 0.125 in. (3 mm). This analysis was presented to the ASME Code groups but it was not formally documented and published. This single parameter is easier to implement and provides an effective measure of the sizing error. The inclusion of a critical miss-call criterion results in consistent over-sizing bias by candidates. The RMS error is a better predictor of field performance. The 0.125 in. (3 mm) requirement is now applied to ferritic piping up to 8 in. (203 mm) in thickness and austenitic piping up to 3 in. (76 mm) in thickness when examining from the outside surface. This requirement is also applied to pipe wall thicknesses of 4 in. (101.6 mm) when examining austenitic material from the inside surface.

3.2.3 SUPPLEMENT 3 — QUALIFICATION REQUIREMENTS FOR FERRITIC PIPING WELDS

SUPPLEMENT 3 — QUALIFICATION REQUIREMENTS FOR FERRITIC PIPING WELDS	
	Rationale for Requirement and Relation to Referenceable Documentation
Qualification of examination procedures, equipment, and personnel for ferritic pipe examination shall be accomplished by satisfying the requirements of Supplement 2, except that the sample material shall be ferritic and 75% of the sample set defects shall be mechanically or thermally induced fatigue cracks. In addition, the set shall include pipe specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 1.0 in. (25 mm) less than the maximum thickness for which the examination procedure is applicable.	Originally, this set of requirements was based on the experience from the round-robin studies (NUREG/CR-5068, Heasler and Doctor 1996), which showed that ferritic steel is much easier to inspect than austenitic stainless steel, as well as statistical theory that states if one is certain that one test is more difficult than another, one may demonstrate the equivalent capability on the easier test with fewer numbers of samples. This section of the supplement assumes that the same inspection procedure will be used for ferritic piping as for austenitic piping. The original criterion stated that if an inspector had successfully passed the performance demonstration for austenitic piping, then the candidate needed to detect 3 out of 3 additional ferritic specimens with no false calls. Now the criterion has changed so that the same requirements for ferritic piping welds are to be met as that for the Supplement 2 austenitic piping welds. However, if the intent is to demonstrate both Supplements 2 and 3, then the requirements are as defined in Supplement 12.

3.2.4 SUPPLEMENT 4 — QUALIFICATION REQUIREMENTS FOR THE CLAD/BASE METAL INTERFACE OF REACTOR VESSEL

SUPPLEMENT 4 — QUALIFICATION REQUIREMENTS FOR THE CLAD/BASE METAL INTERFACE OF REACTOR VESSEL	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This Supplement applies to the inner 15% of the clad ferritic reactor vessel. It may also be applied to the inner 15% of the unclad ferritic reactor vessel in accordance with Table VIII-S6-1, Note 1.	
2.0 SPECIMEN REQUIREMENTS The qualification test specimens shall provide full and unrestricted access to the examination volume to permit scanning in two directions parallel and two directions perpendicular to the weld. The same specimens may be used to demonstrate single-side access conditions.	Flaws in the inner surface volume are the most important flaws to the structural integrity of the reactor pressure vessel and, as a result, they are highlighted with a supplement dealing specifically with this volume.
2.1 Detection Specimens. Detection specimens, which may be full-scale mock-ups, shall conform to the following requirements.	It is preferable to use full-scale mockups to provide materials and conditions representative of those found in operating nuclear power plants. Material from cancelled nuclear power plants was considered one available source. Representative mockups would be required for BWR vessels and other mockups for PWR vessels. Vessel cladding processes changed substantially during the 1960s through 1980s, making representative conditions an important variable that must be verified during ISI to confirm similarity to the mockups used for performance demonstration.
(a) Specimens shall have sufficient volume to minimize spurious reflections. Specimen length and width shall be at least 12 in. (300 mm). There shall be at least 10 sq ft (1 sq. m) of clad surface in the specimen set.	The specimens must be large so that spurious signals from the specimens do not interfere with the demonstration data or analysis.
(b) Specimen Thickness (1) When the examination procedure requires the examination to be performed from the vessel I.D. (clad surface), the specimen minimum thickness shall be 3 in. (75 mm) or the maximum thickness of the vessel (whichever is less).	Specimen thickness is driven by whether the inspection is conducted from the I.D. or the O.D. The I.D. inspections can be performed on thin specimens because areas outside the inner volume are not being inspected and should not contribute any spurious signals.

	Rationale for Requirement and Relation to Referenceable Documentation
(2) When the examination procedure requires the examination to be performed from the vessel O.D. surface, the specimen shall be at least 90% of the maximum thickness to be examined.	The inspections from the O.D. need to replicate the thicknesses of the actual vessels because the thicker a vessel is, the more challenging the inspection becomes. A tolerance of 10% was applied because it would save several million dollars and allow surplus material from cancelled plants to be used. This was first a Code Case and then a Code revision necessary to allow for this thickness tolerance. Only the BWR reactor pressure vessel (RPV) is examined from the outside surface. The 10% tolerance is used in many instances in the Code, including calibration block thickness.
(c) The performance demonstration shall be on the same type cladding as that to be examined, with the following exceptions:	
(1) demonstration on shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes;	SMAW is the most challenging surface finish that can adversely impact an inspection. If an inspection can be performed on SMAW, then it can easily deal with other cladding processes because they produce much smoother surfaces.
(2) demonstration of multiple-wire or strip-clad is considered equivalent but is not transferable to SMAW-type clad.	The technical basis for this requirement and the requirements above comes from NUREG/CR–2878 (Taylor et al. 1983).
(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.	Specimens must be representative of the conditions of the cladding on field components.
(e) The detection test matrix shall include flaws with the following description.	
(1) *Flaw Type.* At least 70% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches. Notches may be used only if the examination is performed from the clad surface. Machined notches shall meet the following requirements:	Cracks are the major concern for service degradation, so that is the focus of the flaws in the test set. However, the experience has been that many fabrication flaws entered service and will be detected. This test includes some fabrication flaws to ensure that the procedure will be able to correctly handle them. The Ad Hoc Task Group that initially developed the supplements was conscious of the technical challenge with placing very small flaws of known dimensions in these components and with the cost of requiring real cracks. Because the flaw dimensions would be used

	Rationale for Requirement and Relation to Referenceable Documentation
	to select flaws for testing, the uncertainty associated with the flaw dimensions needed to be minimized. Therefore, the Ad Hoc Task Group did allow some machined reflectors to be used in these specimens for specific locations. This in part was based on the PISC II studies, which showed that notches with sharp tips (called in PISC II a Type A flaw) had NDE responses similar to the NDE responses from cracks (Crutzen et al. 1989).
(a) Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.5 mm). (b) Notches shall conform to the following: (1) Notch depth shall not exceed 0.25 in. (6 mm) (2) Notches shall be semi-elliptical.	The acceptability of this maximum tip radius/width requirement is not known. In reviewing the PISC II parametric studies, PISC II fabricated a number of artificial flaws having tip radii up to 0.0012 in. (0.03 mm) and they provided tip responses within 1 dB of that for a hydraulically grown fatigue crack with a tip radius less than 0.000004 in. (0.0001 mm). What they did not do was to quantify how the tip response would change as the tip radius becomes larger than 0.0012 in. (0.03 mm). The tip response is key since for inspections from the inside surface for shallow flaws, the specular response is not detected; only the tip response is. Research has not been conducted to resolve this issue, and thus the criteria lack a firm technical basis. However, it needs to be noted that the number of notches is limited to ≤ 30%, can only be used if examination is from the inside surface, and must be less than 0.24 in. (6 mm) in depth and semi-elliptical in shape. These parameters were chosen as it was not possible to reliably implant cracks of these small sizes in full-scale mockups. The method is limited to clad side examination, where there is no direct reflection from the face of the flaw. The use of semi-elliptical shape limits the magnitude of the tip diffraction response. There is also an uncertainty of at least 0.04 in. (1 mm) in the implantation process. The EDM

	Rationale for Requirement and Relation to Referenceable Documentation
	process allows closer control of the flaw size at these smaller sizes without resorting to destructive testing. The basis for acceptance by the Code was that these notches had a lower signal response than similar sized cracks and resulted in a lower detection rate by candidates.
(2) Flaws shall be oriented either parallel or perpendicular to the clad direction ±10 deg. For procedure qualification, at least 40% of the flaws shall be included in each orientation. For personnel tests, at least 20% of the flaws shall be included in each orientation.	Flaws may form perpendicular or parallel to the clad direction, so the procedure and personnel must be shown to be effective in detecting flaws in both orientations.
(3) The flaw sizes shall be uniformly distributed in through-wall depths among the ranges: (a) 0.075 to 0.200 in. (1.9 mm to 5.1 mm) (b) 0.201 to 0.350 in. (5.11 mm to.9 mm) (c) 0.351 to 0.550 in. (8.91 mm to 14 mm) (d) 0.551 to 0.750 in. (14 mm to 19 mm)	The flaws need to span the range of the inner surface volume, so this range of sizes was selected to cover the range by the Ad Hoc Task Group. One size was not thought to be more important than another, so the distribution is uniform.
(4) No flaw shall have an aspect ratio (depth/length) less than 0.1. Flaws smaller than 50% of the allowable flaw size, as defined in IWB-3500, need not be included as detection flaws.	This is guidance on aspect ratio that needs to be used for selecting the appropriate flaws. This revision to the Code was requested as the flaw sizes in Supplement 4, 2.1(e)(3) could result in flaws much less than those included in the IWB-3514 tables. In addition, in 10 CFR 50.55a(b)(xv)(B)(2), the NRC restricted this to not needing to include flaws smaller than 50% of those defined in IWB-3500.
(5) The material thickness used to determine flaw acceptability shall be as follows: (a) The minimum thickness specified in the scope of the procedure, for procedures applied from the inside surface. (b) The thickness of the test specimen, for procedures applied from the outside surface.	Guidance on the thickness of the test samples. 10 CFR 50.55a(b)(xv)(B)(2) further states that for procedures applied from the inside surface, use the minimum thickness specified in the scope of the procedure to calculate a/t. For procedures applied from the outside surface, the actual thickness of the test specimen is to be used to calculate a/t. This prevents the elimination of the smaller flaw depths in thick sections.
(f) The number of flaws in a personnel detection demonstration shall be selected from Table VIII-S4-1.	

(g) For initial procedure qualification, the detection set shall include the equivalent of three personnel qualification sets. To qualify new value of essential variables, at least one personnel qualification set is required.

TABLE VIII-S4-1
PERSONNEL DETECTION TEST ACCEPTANCE CRITERIA

Detection Test Acceptance Criteria	
No. of Flaws	Minimum Detection Criteria
7	7
8	8
9	9
10	10
11	11
12	11
13	12
14	13
15	14
16	14
17	15
18	16
19	17
20	18

Rationale for Requirement and Relation to Referenceable Documentation

The equivalent of three personnel qualification test sets are required to demonstrate that the procedure is robust and capable of detecting the test specimen flaws. If an essential variable is modified for an already-qualified procedure, then only one personnel qualification test set needs to be demonstrated to verify the procedure is still capable of detecting the required flaws.

In contrast to piping, the reactor pressure vessel is a high-risk component and needs to maintain high structural integrity. Thus, the reliability of inspections needs to be higher than that for piping. In this case, the goal is to have a high pass rate for those personnel, equipment, and procedures that have an inherent POD of 95% and a FCP less than 20%. Unacceptable performance was POD values < 70% and FCP > 20%. A table is used to provide the test administrator a combination of tests that can be used and limits testmanship because the inspector will not know the number of flaws that will be in a given test. The FCP is not listed because for vessels it became more challenging to define blank grading units. Instead, the requirement for the number of false calls is based on the area inspected and is defined in 3.1(c).

	Rationale for Requirement and Relation to Referenceable Documentation
(h) The requirements of IWA-3000 shall be used to determine if closely-spaced flaws are to be treated as separate flaws.	This is intended to make the testing consistent with other areas of the Code dealing with flaw evaluation.
(i) Flaw location and specimen identification shall be obscured to maintain a "blind test."	The test must remain blind for the statistical basis to remain valid.
2.2 Sizing Specimens (a) The sizing test matrix shall contain a minimum of ten flaws, at least 70% of which shall be cracks.	The same rationale is used for this as that used for the Supplement 2 paragraph 1.3(a).
(b) Procedure qualifications shall include the equivalent of three personnel qualification sets.	Consistent with Supplement 2 rationale.
(c) Sizing specimens shall conform with the requirements of 2.l(b), 2.l(c), 2.l(d), and 2.l(e).	Sizing must be performed under conditions expected on components in service.
2.3 Supplemental Single-Side Access Test Specimens. Supplemental test specimens required to demonstrate the effectiveness of single-side examination procedures for detecting or sizing of reflectors with non-optimum sound-reflecting properties shall comply with the following. (a) All flaws shall be cracks. (b) Two or more cracks shall be included. (c) The cracks shall exhibit non-optimum sound reflecting properties. (1) The nominal orientation shall be 45 ±10 deg relative to the local surface normal. (2) The reflecting surface shall exhibit the characteristics of a crack that could occur during fabrication or repair. (d) The inner tip of the cracks shall be located no more than 2.5 in. (65 mm) and no less than 0.1 in. (2 mm) from the clad-to-base-metal interface. (e) The flaws shall be oriented parallel or perpendicular to the clad direction.	Under some field conditions, it may not be possible to inspect all volumes with UT from four different directions. This set of requirements details what has to be demonstrated to show that the volume can be inspected effectively with limits on the directions in which the volume can be interrogated with ultrasound. Procedures need to state that if four directions are available, then the inspection will be conducted by using all four of them as required in Mandatory Appendix **I**, Article I-3300(a). If four directions are not available, then the procedure must default to a single side-access inspection that has been demonstrated to successfully meet these requirements. These requirements are meant to be challenging and to demonstrate that flaws can be found under field conditions. These supplemental test blocks are used to demonstrate that flaws of non-optimum orientation can be detected if single-side examination is necessary.

SUPPLEMENT 4 — QUALIFICATION REQUIREMENTS FOR THE CLAD/BASE METAL INTERFACE OF REACTOR VESSEL

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS **3.1 Detection Test**	
(a) Specimen identification and flaw locations shall be obscured so as to maintain a "blind test." Divulgence of particular specimen results or candidate viewing of unmasked specimens is prohibited.	The test must be blind for the statistical design to remain valid.
(b) If a flaw is reported within the greater of 1 in. (25 mm) or 10% of the metal path length to the flaw from its true location *(x, y,* and *z)* it shall be considered detected. All other reported flaws shall be considered false calls.	Because of ultrasonic speed variations and the long distances traversed, increased location error will occur. This requirement addresses this fundamental fact.
3.2 Length and Depth Sizing Test (a) Each reported flaw in the detection test shall be length sized. (b) When only length sizing is being tested, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region. (c) For the depth sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	These are the same general requirements as found in Supplement 2. When candidates are performing detection, length, and depth sizing of the same flaw during the demonstration, the flaw location shall remain unknown. This reduces the cost and examination time without affecting the blind testing results.
3.3 Single-Side Access (a) Qualification of personnel and procedures for single-side access shall be performed as in 3.1 and 3.2, except that access shall be restricted to one direction parallel and one direction perpendicular to the weld.	Defines what is meant by a single-side inspection.
(b) The procedure shall demonstrate that it is capable of detecting or sizing flaws described in 2.3. This need not be a blind demonstration.	The procedure has already been demonstrated to be effective for four-direction inspection, so now the demonstration is to show that the same procedure when having only two directions can detect or size the flaws acceptably.(2)
(c) The procedure shall define specific evaluation criteria for detection, such that an independent evaluator can make an unbiased decision.	This requires that the procedure be very detailed so that an independent evaluator can reach the same interpretation.

(2) EPRI has studied the issue of limited scanning access and published this work, but the authors have not reviewed it, although some of this information was presented by EPRI staff at ASME Code meetings. The EPRI report can be purchased for $23,750, and is titled *Implementation of ASME Section XI, Appendix VIII Performance Demonstration Requirements as Modified by 10 CFR 50.55a: Single Side Examination for Ferritic RPV Welds* (EPRI NDE Center, Charlotte, North Carolina, 2000; Report No. 1001037).

	Rationale for Requirement and Relation to Referenceable Documentation
4.0 ACCEPTANCE CRITERIA	
4.1 Detection Acceptance Criteria	
(a) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure.	As in other supplements, the original procedure qualification required one successful personnel qualification. This soon proved to be unworkable for both automated and manual procedures. It was possible for personnel to pass an 8-out-of-10 test and the procedure would be qualified under the original rules, even though flaws within the scope of the procedure were not detected. This was an unacceptable situation to have flaws that a procedure could not detect so it was changed to require all flaws to be detected during the procedure qualification. The quantity of three personnel test sets was selected and included the requirement that each flaw that will be used in testing candidates be detectable according to the criteria contained in the procedure. If the procedure cannot find a particular flaw, then the procedure and/or the equipment need to be improved or the procedure scope should be limited to exclude what cannot be detected.
(b) Personnel are qualified if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S4-1 and no flaw greater than 0.25 in. (6 mm) depth is missed.	This provision increases the stringency by requiring that no flaw greater than 0.25 in. (6 mm) in depth can be missed. This is based on the PDI database where for many years no one ever missed a flaw deeper than this criterion. Consequently, industry decided that it should be added to allow flaws smaller than this to be missed while nothing deeper than this criterion may be missed.

	Rationale for Requirement and Relation to Referenceable Documentation
(c) For procedure and personnel demonstrations, the number of false calls shall not exceed A/10, rounded to the next whole number, where A is the total scan area of specimens in the test measured in square feet. The total scan area is defined as the area that would be scanned when scanning from all four directions.	This requirement is different than for piping. It was decided that because of the large volume of material being inspected (particularly from the O.D.), placing a small number of grading units would not necessarily be effective in measuring FCP. The Ad Hoc Task Group decided that the FCP should be based on the size of the surface area scanned and that the FCP be ≤ 1/10 of the area scanned. Vessel examinations differ from piping in that surface geometric conditions are generally significantly less of a problem for O.D. examinations. For I.D. examinations, the clad roughness can be an issue if the cladding is in the as-welded condition for a single-wire clad process.
4.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing if the results of the performance demonstration satisfy the following criteria:	
(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared to the true lengths, shall not exceed 0.75 in. (19 mm)	The length sizing requirement originally was −1/4 in. (6.4 mm) to +1 in. (25.4 mm) of the actual length. The −1/4 in. (6.4 mm) was unrealistic and the requirement was updated to RMS error and the basis is the same as that for piping in Supplement 2.
(b) The RMS error of the flaw depths estimated by the ultrasonics, as compared to the true depths, shall not exceed 0.15 in. (4 mm)	The original requirements were as follows: • No flaw is undersized for depth by more than 0.2 in. (5.1 mm). • Slope of the linear regression line is not less than 0.7. • The mean deviation of flaw depth is less than 0.25 in. (6.4 mm). • The correlation coefficient is not less than 0.70.

	Rationale for Requirement and Relation to Referenceable Documentation
	This was changed to an RMS error criterion to simplify the evaluation process. However, the depth sizing error is larger than that for piping. The basis for this is that if the inspection is from the I.D., then the measurement is made through cladding, which introduces a larger error. If the measurement is made from the O.D. of the component, then a very long metal path is involved, which also increases the measurement error. EPRI as the administrator of PDI provided data that showed that inspectors were not able to meet the same criteria as for piping.
4.3 Single-Side Acceptance Criteria (a) Demonstrations performed according to 3.3(a) shall meet the applicable requirements of 3.1 for flaws located within the inner 10% of the vessel thickness. (b) The supplemental procedure demonstration of 3.3 is acceptable when all flaws described in 2.3 are detected in accordance with the evaluation criteria qualified in 3.3(c).	The basis for single-sided inspections is that the procedure has already successfully passed the performance demonstration for unlimited access. This can be considered an expansion of the qualified procedure scope, which is the reason that these demonstration results are being added to those for the unlimited access results or the single-side results from Supplement 6.

3.2.5 SUPPLEMENT 5 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE OUTSIDE SURFACE

This supplement was changed significantly in the July 2005 Addenda so that it now focuses on just the nozzle inside corner regions and inner 15% of the ferritic nozzle-to-shell weld only for when the examination is conducted from the O.D. These two areas use the same inspection procedure so they were integrated in this supplement. Other parts of the nozzle-related inspection volumes are addressed by Supplements 4 and 6. This supplement was developed by the Task Group Appendix VIII, with the basis provided by the EPRI NDE Center.

SUPPLEMENT 5 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE OUTSIDE SURFACE	
	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This Supplement is applicable to examination of ferritic nozzle inside-corner regions and the inner 15% of ferritic nozzle-to-shell welds when scanning for flaws oriented perpendicular to the weld. Demonstration on clad nozzle mockups may be used for examination of unclad nozzles. Demonstrations performed on unclad nozzle mockups shall not be used for examination of clad nozzles. Supplement 4 qualification is required when scanning for flaws oriented parallel to ferritic nozzle-to-shell welds. Supplement 6 qualification is required for the outer 85% of ferritic nozzle-to-shell welds.	Clarifies what volume is being inspected and from which component surface.

Rationale for Requirement and Relation to Referenceable Documentation

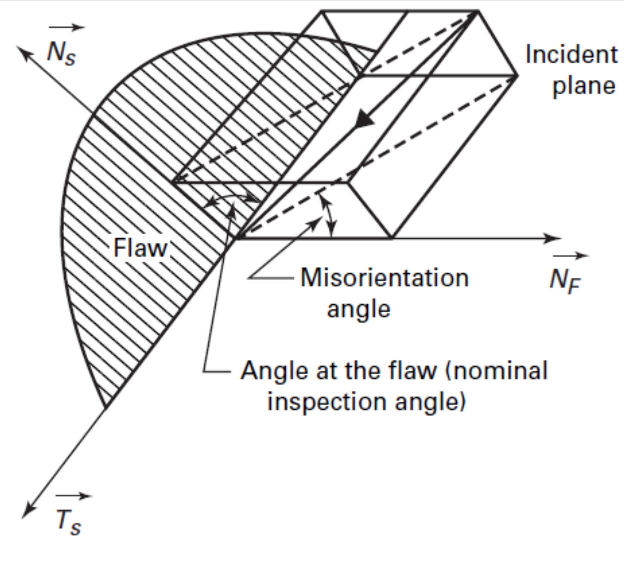


FIG. VIII-S5-1 MISORIENTATION ANGLE

This new concept was introduced based on work conducted at the EPRI NDE Center (EPRI 1997). This work showed that O.D. inspections from the complex geometries between the nozzle O.D. and the I.D. can lead to inspection angles at the flaw locations, which makes detection extremely challenging. Thus, it was proposed and approved that each nozzle to be inspected from the O.D. requires a modeling analysis to determine what the misorientation angle would be at the flaw for the inspection angles proposed in the procedure. The performance demonstration is then conducted with this misorientation angle becoming qualified. When a nozzle in the field is inspected, the inspector must show that all locations will be insonified with the flaw impingement angles always being less than the misorientation angle that was demonstrated.

2.0 MODELING REQUIREMENTS

The examination procedure shall include or provide for the following.

This defines the modeling process for determining the misorientation angles.

2.1 A computational model that calculates misorientation angles, the maximum metal path distance to the required examination volume, and the angle at the flaw (nominal inspection angle). Misorientation angle and the angle at the flaw is shown in Fig. VIII-S5-1. These calculations apply to the central ray of the ultrasonic beam. The modeling process and associated essential variables shall be identified and defined.

2.2 A statement that specifies the examination surface and the associated maximum acceptable misorientation angle and metal path, and the range of angles at the flaw for the examinations.

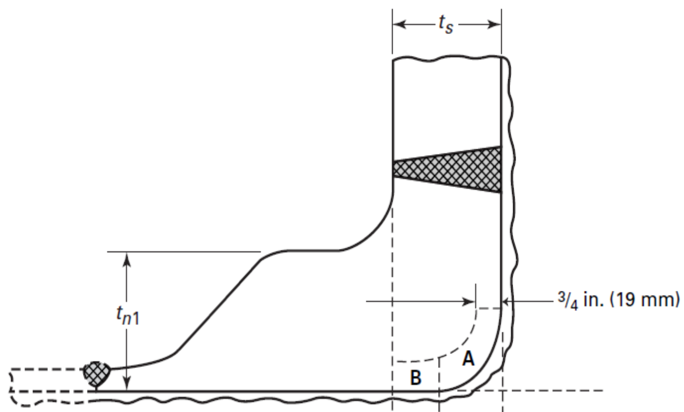
	Rationale for Requirement and Relation to Referenceable Documentation
2.3 Division of the surface of the required examination volume into grids of 1.0 in. (25 mm) or less in the nozzle axis direction and 10 deg or less of azimuth.	This systematically breaks up the inspection surface into small enough areas to ensure that all inspection locations are included in the calculations.
2.4 The misorientation angle, metal path distance, and angle at the flaw in each grid cell location for each search unit or scan shall be documented. Alternatively, when multiple search units with different skew or incident angles are used, the search unit or scan that produces the minimum misorientation angle and the associated metal path and angle at the flaw in each grid cell location shall be documented.	This requires documenting everything to ensure that the worst-case misorientation angles are defined for each nozzle and inspection location.
3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS	
3.1 Specimen Requirements. Demonstration specimens shall meet the following requirements.	This requires that realistic and representative components are used for the demonstration.
(a) Two or more full-size or sections of full-size nozzle mockups shall be used. Specimens shall have sufficient volume to minimize spurious reflections.	Several nozzle mockups need to be included so that the wide range of nozzles that are in service are represented.
(b) Nozzle mockup material and configurations shall be representative of nozzles installed in operating reactor vessels, but may be any thickness, diameter, or radius suitable for demonstration in accordance with 3.2 or 3.5.	
(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions. (1) Demonstration on shielded metal arc welding (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad process. (2) Demonstrations on multiple-wire or strip-clad are considered equivalent but are not transferable to SMAW-type clad.	These are the same cladding requirements that are in Supplement 4.
(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.	Requires representative surface conditions.
(e) The detection test matrix shall include flaws with the following description.	The flaws are in the inner region of the nozzle, so the requirements are consistent with those in Supplement 4.

	Rationale for Requirement and Relation to Referenceable Documentation
(1) *Flaw type.* At least 50% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches. Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.50 mm).	The target flaws for this examination are cracks initiated by thermal cycling and then grown by successive cycling of reactor start up and shut downs and low temperature over-pressurization (LTOP) events. Cracks reported in the events described in NUREG-0619 (NRC 1980) were very rough and open. The techniques to be qualified in this supplement are based on the maximum misorientation of the sound beam with the flaw face. The relatively smooth face of the notches would require a smaller range of misorientations and thus a more stringent qualification. There are a mixture of flaws and notches, and response amplitudes may be compared. However, the primary objective is the demonstration of the range of misorientation angles which are effective. The acceptability of this maximum tip radius/width requirement is not known. In reviewing the PISC II parametric studies (Crutzen et al. 1989), PISC II fabricated a number of artificial flaws having tip radii up to 0.0012 in. (0.03 mm), and these flaws provided tip responses within 1 dB of that for a hydraulically grown fatigue crack with a tip radius less than 0.000004 in. (0.0001 mm). However, PISC II did not quantify how the tip response would change as the tip radius becomes larger than 0.0012 in. (0.03 mm). Thus, without further research, there is no firm technical basis to resolve this issue.
(2) The flaw sizes shall be distributed in through-wall depths among the ranges: (a) 0.075 to 0.200 in. (1.90 mm to 5.08 mm) (b) 0.201 to 0.350 in. (5.09 mm to 8.89 mm) (c) 0.351 to 0.550 in. (8.90 mm to 13.97 mm) (d) 0.551 to 0.750 in. (13.98 mm to 19.05 mm)	
(f) Flaws in the nozzle inside radius section shall be uniformly distributed in examination zones A and B of Fig. VIII-S5-2. At least 50% of the flaws shall be located within ±45 deg of nozzle azimuth angles 90 deg or 270 deg.	Because there are several zones where the flaws may be located, this requirement provides guidance for the flaw locations needed in the mockups.

	Rationale for Requirement and Relation to Referenceable Documentation
(g) All flaws shall be located in the required examination volume and shall be oriented in the radial axial plane as shown in Fig. IWB-2500-7.	
(h) Flaw location and specimen identification shall be obscured to maintain a “blind test.”	

3.2 Procedure Qualification Demonstrations

(a) The qualification shall demonstrate the following: (1) examination surfaces to be used, i.e., vessel plate, outer blend radius, and nozzle boss (2) maximum metal path length (3) maximum misorientation angles (4) range of angles at the flaw	The performance demonstration will include all of the essential variables associated with the complex geometries of nozzles. All of these must be documented so that when inspections are performed in the field, the real geometries will be used. It will need to be shown that all the inspection conditions fall within what has been demonstrated.



The extremities of Zone A are defined by the tangent points of the nozzle bore and the vessel inside diameter.

FIG. VIII-S5-2 FLAW DISTRIBUTION ZONES

	Rationale for Requirement and Relation to Referenceable Documentation
(b) The demonstration shall include at least 10 flaws for detection and sizing, in one or more mockups. At least one but no more than two flaws shall be located in the nozzle-to-vessel weld. At least 50% of the flaws in the demonstration test set must be cracks, and the maximum misorientation shall be demonstrated with cracks. Flaws in nozzles with bore diameters not exceeding 4 in. (100 mm) may be notches. The demonstration test set shall contain a representative distribution (e.g., depths, examination zones, and flaw azimuth locations) of flaws.	Specification of the number of flaws needed for the demonstration and other specifics associated with their location. Because of the difficulty in putting small cracks of known dimension in curved test specimens, the use of up to 50% noncracks were permitted by the NRC.
(c) The initial demonstration shall be a blind test.	This requires that the initial demonstration be conducted in a blind manner. If there is a need to extend the procedure, this may be performed blind or nonblind. However, if it is to be performed nonblind, then the examination procedure must be very detailed to allow an independent evaluator to reach the same interpretation.
3.3 Procedures Using Multiple Search Units	
(a) After a successful initial demonstration, the procedure may be extended by nonblind demonstrations on at least one flaw using scan parameters calculated to provide the desired maximum path length, misorientation angle, or angle at the flaw. Detection shall be demonstrated to specific criteria listed in the examination procedure for any expansion of procedure scope.	This section defines what is meant by an extension of a qualified procedure.
(b) This demonstration shall not be performed successively or increase the misorientation angle or angle at the flaw by more than 9 deg or the maximum metal path by more than 30%.	These requirements limit the extent of the procedure extension. Exceeding these values requires a full blind demonstration.
(c) Qualification of other essential variables requires at least one acceptable personnel qualification test.	For essential variables other than misorientation angles or path length, at least one successful blind personnel qualification test is required. This provides evidence that the procedure is effective in detecting flaws in the extended range.

	Rationale for Requirement and Relation to Referenceable Documentation
3.4 Procedure Qualification Documentation (a) The examination procedure, modeling program and methods, and qualification results shall be documented to the extent necessary to determine that inservice examinations produce equivalent or smaller misorientation angles than the procedure demonstrated.	This section defines what must be documented so that when inspections are conducted in the field, it can be determined if the component falls within what was demonstrated. Because of the complexity of nozzles, computer modeling programs must be used to ensure coverage. The modeling developed by EPRI (1997) has been validated to correctly identify misorientation angles in the large range of nozzle geometries. The modeling results presented by examination vendors are compared to the EPRI model and the differences if any are reconciled and recorded in the qualification documents.
(b) The qualified essential variables associated with the maximum metal path, misorientation angles, and range of angles at the flaw shall be defined by the model documentation. Individual flaw validation is not required except for nonblind expansions of scope.	
3.5 Personnel Qualification	This section defines the personnel qualification. Notice that a Supplement 4 qualification is a prerequisite for the personnel qualification. Because of this prerequisite and the extensive demonstration of the procedure, the actual performance demonstration is only a sampling of the conditions and does not require the full range of essential variables be demonstrated by each personnel qualification.
(a) Personnel shall be qualified in accordance with the requirements of Supplement 4, for the same type of procedure (manual or automated), from the outside surface, using the same type of instruments and data recording and analysis equipment, and the following additional requirements. (1) Successful demonstration shall include at least three additional flaws. (2) Examinations shall be conducted from each of the scan surfaces covered by the procedure. (3) The candidate shall demonstrate a selection of essential variables covered by the procedure, but need not demonstrate the full range.	
(b) The demonstration test set shall contain a representative distribution (e.g., depths, examination zones, and flaw azimuth locations) of flaws. Flaws in the nozzle-to-vessel weld are not required for personnel demonstration.	

	Rationale for Requirement and Relation to Referenceable Documentation
3.6 Acceptance Criteria	
(a) Examination procedures and equipment are qualified for detection if each flaw is detected and identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path. The number of false calls shall not exceed D/10 (D/254) rounded up to the next whole number, with a maximum of 3, where D is the nominal nozzle inside diameter, in. (mm). If only a portion of a nozzle is examined, proportional credit for false calls shall be allowed. Personnel are qualified if each of the flaws presented are detected at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path and identified with no false calls.	The rationale for the false call is similar to that in Supplement 4, but it should be noted that it was decided to relate this to the diameter of the nozzle versus the area that is scanned. The other tolerances are consistent with location error criteria in other Appendix VIII supplements for thick-section steel components.
(b) Examination procedures and equipment are qualified for depth sizing if the results of the sizing demonstration meet the requirements of Supplement 4. Personnel are qualified if the results from the depth sizing test, when added to the results from Supplement 4, met the acceptance criteria of Supplement 4.	Because this is an extension of sizing from Supplement 4 and only a limited number of flaws are used, the pass/fail criterion is based on combining the results from both supplements.
(c) Examination procedures and equipment are qualified for length sizing if the deviation between measured length and true length does not exceed 0.75 in. (19 mm). Length sizing is required only for flaws in the nozzle-to-shell weld. No additional personnel qualifications are required.	This is consistent with other supplements.
4.0 FIELD EXAMINATIONS	
4.1 To demonstrate that the proposed examination variables are within the bounds of the qualified demonstration, the computational model requirements defined in 2.0 shall be applied in conjunction with each field examination. Documentation shall be provided for each nozzle examination application.	This section requires that inspections in the field be shown to be within the parameters demonstrated and modeled.
4.2 Modeling need not be applied for repeated examination of the same or identical nozzles.	
4.3 As an alternative to Supplement 5, if the qualified model indicates that the maximum misorientation angle is 10 deg or less, examination of the nozzle-to-vessel weld may be performed using personnel, procedures, and equipment qualified in accordance with Supplement 4. The examinations shall be conducted from the vessel shell, and the component materials and sizes shall be within the scope of the qualified procedure. The Supplement 4 procedure essential variables shall be demonstrated on a specimen meeting the requirements of 3.1(b) that contains at least one nonblind flaw, oriented perpendicular to the weld, in the inner 15% of the volume. The demonstration shall meet the applicable requirements of 3.6(a) for detection and 3.6(b) and 3.6(c) for sizing. No additional personnel qualifications are required.	This is an alternative offered for those cases in which modeling shows that the maximum misorientation angle is ≤ 10 degrees.

3.2.6 SUPPLEMENT 6 — QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE

This covers the remainder of the vessel wall outside the clad/base metal interface, and vessels without cladding.

SUPPLEMENT 6 — QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This Supplement applies to unclad ferritic components and the outer 85% of clad ferritic components.	
2.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure. The same specimens may be used to demonstrate both detection and sizing qualification.	
2.1 Detection Specimens. Detection specimens, which may be full-scale mock-ups, shall conform to the following requirements.	
(a) Specimens shall have sufficient volume to minimize spurious reflections. Specimen length and width shall be at least 12 in. (300 mm). There shall be at least 10 sq ft (1 sq m) of scan surface in the specimen set.	Adequate test specimens are needed to ensure that there are no problems with spurious signals and that the specimens are adequate for meeting the surface requirements for measuring false call rates.
(b) The specimen set shall contain at least one sample that is at least 90% of the maximum thickness to be examined. The specimen set shall contain one or more flaws in each of the locations and size ranges shown in Table VIII-S6-1.	Requires that the largest thickness be included in the test set because this is one of the very challenging essential variables.
(c) When the examination procedure requires the examination to be performed from the vessel I.D. (clad surface), the cladding on the mockup shall be of the same type as the cladding on the component to be examined, with the following exceptions: (1) demonstration on shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes; (2) demonstration on multiple-wire or strip-clad is considered equivalent but is not transferable to SMAW-type clad.	Consistent with cladding requirements in Supplements 4 and 5.
(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.	Surface conditions affect the inspections, so those on the demonstration specimens must be representative of field conditions.

SUPPLEMENT 6 — QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(e) The detection test matrix shall include flaws with the following description.	
(1) *Flaw Type.* At least 55% of the flaws shall be cracks. The balance shall be cracks or fabrication flaws (e.g., slag, lack of fusion).	Requires that the flaws are cracks or fabrication flaws.
(2) Detection and sizing examinations shall include surface-connected flaws or flaws with unflawed ligaments of more than 0.2 in. (5 mm). Procedure demonstrations shall include examples of both.	Flaws near the component surface must be included in the test set.
(3) Flaws shall be oriented either parallel or perpendicular to the clad direction ±10 deg. For procedure qualification, at least 40% of the flaws shall be included in each orientation. For personnel qualification, at least 20% of the flaws shall be included in each orientation.	Flaw orientation relative to the clad lay direction is important, and a range of flaws covering these orientations is included. The number at each orientation is not specified so that the test can remain blind.
(4) Flaws for the detection test matrix shall be selected from Table VIII-S6-1. The flaws selected shall provide a demonstration of the minimum and maximum metal path ranges to be demonstrated as well as a representative distribution of flaw sizes and locations.	The minimum and maximum metal paths must be included in the demonstration and cover a range of through-wall depth sizes as specified in Table VIII-S6-1.
(5) For initial procedure qualification, the detection set shall include the equivalent of three personnel qualification sets. Qualification of new values of essential variables requires at least one personnel qualification set. Procedure qualification flaws shall be uniformly distributed over the ranges defined in Table VIII-S6-1. The number of flaws in a personnel detection demonstration shall be selected from Table VIII-S4-1.	As in other supplements the original procedure qualification requirement required only one successful personnel qualification. This soon proved to be unworkable for both automated and manual procedures. The initial procedure demonstration must meet the very strict standard of detecting all flaws in the equivalent of three personnel qualification sets. This high standard was set to ensure that the procedure is very robust and should lead to high pass rates for personnel. PNNL (Heasler et al. 2000) performed calculations showing how this would lead to higher pass rates and presented this information to the ASME Code. Thus, this information became part of the committee's records.
(6) The requirements of IWA-3000 shall be used to determine if closely spaced flaws are to be treated as separate flaws.	This relates accepted flaw proximity rules to how the flaws in the demonstration specimens are to be addressed.

Rationale for Requirement and Relation to Referenceable Documentation

2.2 Sizing Specimens

(a) Personnel qualification test sets shall include at least ten flaws. Procedure qualification demonstrations shall include the equivalent of three personnel qualification sets. At least 55% of the flaws shall be cracks and the balance shall be fabrication flaws (slag, lack of fusion).

This is the standard design requiring 10 flaws to be sized. Because many fabrication flaws are expected to be detected in service, they are also included in the sizing demonstration set.

(b) Sizing specimens shall conform with the requirements of 2.1 (b), 2.1 (c), 2.1 (d), and 2.1 (e), except that the test matrix shall be selected from the sizing and detection test flaws included in Table VIII-S6-1

TABLE VIII-S6-1
DETECTION AND SIZING TEST FLAWS AND LOCATIONS

	Flaw Through-Wall Dimension, in. (mm) [Note (2)]				
Flaw Location	0.075–0.200 (1.9–5.1)	0.201–0.350 (5.11–8.9)	0.351–0.550 (8.91–14)	0.551–0.750 (14.01–19)	0.751–2.00 (19.01–50)
Inner 10% [Note (1)]	X	X	S	S	...
Outer 10%	X	X	S	S	...
11–30% *T*	...	...	X	X	S
31–60% *T*	...	...	X	X	S
61–89% *T*	...	...	X	X	S

NOTES:
(1) Demonstrations conducted on clad vessel specimens in accordance with Supplement 4 may be used in lieu of these requirements. Demonstrations performed on unclad vessel specimens shall not be used for examination of clad vessels.
(2) Flaws smaller than 50% of the allowable flaw size specified in IWB-3500 need not be included as detection flaws.

LEGEND:
X applies to detection and sizing flaws.
S applies only to sizing flaws.
T is the thickness of the thickest specimen in the specimen set.

A range of flaw sizes is included in the detection and sizing demonstration samples. Because a flaw may occur anywhere in the through-wall location, the samples were designed with a range of flaw depth sizes through the thickness. This table provides guidance on how to include a range of flaw sizes and through-wall locations.

Rationale for Requirement and Relation to Referenceable Documentation

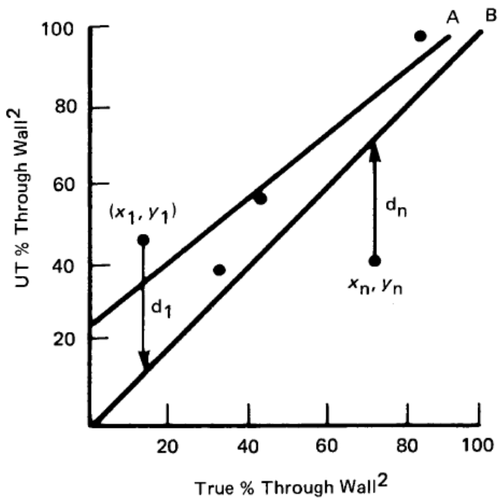
LINE A. Linear regression line, $y = a + bx$, giving the best fit of n data points $(x_1, y_1), \ldots (x_n, y_n)$ obtained by the least-square method where,

$$a = y \text{ intercept} = \frac{\Sigma y_i}{N} - b\,\frac{\Sigma x_i}{N}$$

b = slope of the regression line

$$= \frac{N\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{N\Sigma x_i^2 - (\Sigma x_i)^2}$$

n = number of data points



LINE B: Ideal line, $y = x$ (perfect UT measurements).

NOTES:
(1) *Standard Mathematical Tables*, 25th ed., William H. Beyer, Ph. D., Ed., CRC Press, Inc., Boca Raton, FL, 1979.
(2) Percent through-wall units apply to Supplements 2 and 3. Flaw depth units apply to Supplements 4 through 7.

FIG. VIII-S6-1 DEFINITION OF STATISTICAL PARAMETERS

This is a definition of statistical parameters for use with the sizing acceptance criteria.

SUPPLEMENT 6 — QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE	Rationale for Requirement and Relation to Referenceable Documentation
3.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS	
3.1 Detection Test	
(a) Flaw locations shall be obscured so as to maintain a "blind test." Divulgence of particular specimen results or candidate viewing of unmasked specimens is prohibited.	These tests are statistically designed and based on using blind test specimens where the examiner has no knowledge of the number, type, and/or location of flaws. Testing conducted in a nonblind manner may be biased and of reduced value.
(b) If a flaw is reported within the greater of 1.0 in. (25 mm) or 10% of the metal path length to the flaw from its true location (x, y, and z), it shall be considered detected. All other reported flaws shall be considered false calls.	This requirement originally was 0.5 in. (12.7 mm) but was found to be overly restrictive compared to what can be achieved in actual inspections on thick components. There are several reasons why location cannot be exact, such as small surface changes (cladding finish) that alter the inspection angle and the variation of acoustic velocity through the wall of a component. This new value was thought to be reasonable and achievable in examinations. In addition, it was argued that this location error would not generally have an impact on flaw severity.
3.2 Length and Depth Sizing Test	
(a) Each reported flaw shall be length sized.	The detected flaws are to be length sized, and 10 flaws must be used in the assessment of flaw length sizing performance.
(b) For the length sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region.	If only the length sizing is being tested, or if there are less than 10 flaws in the detection set, then additional flaws must be length sized. The location of the flaws shall be shown to the candidate.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(c) When only depth sizing is being tested, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	If only depth sizing is to be assessed, the candidate shall be shown the regions containing the flaws to be depth sized. In practice, depth sizing is almost always performed separately as there is little reason for the candidate to attempt sizing if they have not already passed detection and length sizing. Secondly, additional flaws are normally added to assure that the test set meets the requirements for depth sizing since there are substantial differences between the flaw test set requirements for detection versus depth sizing.
3.3 Single-Side Access	These requirements are consistent with the approach followed in Supplement 4 for single-side access.
(a) Qualification of personnel and procedures for single-side access shall be performed as in 3.1, except that access shall be restricted to one direction parallel and one direction perpendicular to the weld.	
4.0 ACCEPTANCE CRITERIA	
4.1 Detection Acceptance Criteria	
(a) Procedure qualification shall demonstrate detectability of each flaw within the scope of the procedure.	The procedure demonstration must detect all flaws in the equivalent of three demonstration sets.
(b) Personnel are qualified if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S4-1 and no surface-connected flaw greater than 0.25 in. (6 mm) depth or embedded flaw (distance from nearest surface exceeds 10%t) greater than 0.5 in. (13 mm) was missed.	No flaws can be missed until the demonstration test set gets to 12 flaws. In addition, if a flaw is allowed to be missed, it also must be small as specified and dependent on its through-wall location.
(c) For procedures and personnel demonstrations, the number of false calls shall not exceed A/10, rounded to the next whole number, where A is the total scan area of specimens in the test measured in square feet. The total scan area is defined as the area that would be scanned when scanning from all four directions.	This criterion is consistent with that used in Supplement 4.
4.2 Sizing Acceptance Criteria	
(a) The RMS error of the flaw lengths estimated by ultrasonics, as compared to the true lengths, shall not exceed 0.75 in. (19 mm).	This criterion is consistent with the length sizing criteria in the other supplements.

SUPPLEMENT 6 — QUALIFICATION REQUIREMENTS FOR REACTOR VESSEL WELDS OTHER THAN CLAD/BASE METAL INTERFACE

	Rationale for Requirement and Relation to Referenceable Documentation
(b) The RMS error of the flaw depths estimated by ultrasonics, as compared to the true depths, shall not exceed 0.25 in. (6 mm).	The need for flaw sizing accuracy in the outer 90% of the vessel is less than that for the inner 10% (based on IWB-3500 requirements). This criterion is increased from that used in piping and the near-surface clad to base metal zone. This was increased because metal paths may be very long; for example, a 45- or 60-degree inspection on a nozzle shell course that is 14 in. (356 mm) thick. These large distances increase the errors and uncertainty in the best estimates of the flaw through-wall size.
(c) The slope of the linear regression line, calculated as shown in Fig. VIII-S6-1, shall be at least 0.7.	Based on early experiences, it was found that the 0.25 in. (6.4 mm) RMS in (b), combined with the number and range of flaw sizes was not adequate to separate good performance from unacceptable performance, without (c). This requirement was originally included in the sizing performance, removed, and then has been put back in.

3.2.7 SUPPLEMENT 7 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE INSIDE SURFACE

Notice that this supplement addresses the inspection of nozzles from the inside surface only, whereas Supplement 5 addresses the inspection from the outside surface of nozzles. The original Supplement 7 covered both outside and inside inspections, and this has been changed to address inspection from the inside only.

SUPPLEMENT 7 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE INSIDE SURFACE	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This Supplement is applicable to examination of radial flaws in ferritic nozzle inside-radius sections. It is also applicable to examination of parallel flaws in ferritic nozzle-to-shell welds for examinations from the nozzle bore. Demonstrations on clad nozzle mockups may be used for examination of unclad nozzles. Demonstrations performed on unclad nozzle mockups shall not be used for examination of clad nozzles. Supplement 4 and Supplement 6 qualifications are required when scanning the nozzle-to-vessel weld from the vessel wall.	Defines the scope covered by this supplement and the prerequisites of Supplements 4 and 6 qualifications when scanning nozzle-to-vessel welds from the vessel wall.
2.0 CONDUCT OF PERFORMANCE DEMONSTRATION FOR NOZZLE INSIDE-RADIUS SECTION Demonstration on clad/base metal interface of reactor vessel plate specimens (Supplement 4) qualifies examination procedures, equipment, and personnel for nozzle inside-radius section examination when the following requirements are met.	The requirements described in this section are consistent with those found in Supplement 4 because essentially the same procedure is being used.
2.1 For detection and sizing, at least three additional flaws at the inside radius section in one or more full-scale nozzle mockups shall be added to the test set. (a) Specimens shall have sufficient volume to minimize spurious reflections.	
(b) Flaws shall be located in the radial-axial plane of the nozzle inside radius section as shown in Fig. IWB-2500-7. At least one mock-up shall have the minimum nozzle inside-corner radius covered by the procedure.	Specifies where the flaws are to be located and identifies that the minimum nozzle inside corner radius covered by the procedure is to be used for the demonstration because this is the most challenging condition.
(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions. (1) Demonstration on shielded metal arc welding (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad process.	Consistent with other supplements for cladding.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(2) Demonstrations on multiple-wire or strip-clad are considered equivalent but are not transferable to SMAW-type clad.	
(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.	Consistent with other supplements because surface conditions impact inspection effectiveness.
(e) The detection test matrix shall include flaws with the following description.	This is the same as the requirements for Supplement 5; the only difference is that the inspections are being conducted from the inside surface.
(1) *Flaw Type*. At least 50% of the flaws shall be cracks. The balance shall be machined notches. Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.5 mm).	The acceptability of this maximum tip radius/width requirement is not known. In reviewing the PISC II parametric studies, PISC II fabricated a number of artificial flaws having tip radii up to 0.0012 in. (0.03 mm), and these flaws provided tip responses within 1 dB of that for a hydraulically grown fatigue crack with a tip radius less than 0.000004 in. (0.0001 mm). PISC II did not quantify how the tip response would change as the tip radius becomes larger than 0.0012 in. (0.03 mm). The tip response is key since for inspections from the inside surface for shallow flaws, the specular response is not detected; only the tip response is. Thus, until further research is conducted to resolve this issue, a firm technical basis for the requirement does not exist.
(2) *Distribution of Flaw Sizes*. The flaw sizes shall be distributed in through-wall depths among the ranges (a) 0.075 to 0.200 in. (1.90 mm to 5.08 mm) (b) 0.201 to 0.350 in. (5.09 mm to 8.89 mm) (c) 0.351 to 0.550 in. (8.90 mm to 13.97 mm) (d) 0.551 to 0.750 in. (13.98 mm to 19.05 mm)	
2.2 Each of the flaws presented for demonstration shall be correctly identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path with no false calls.	Consistent with the other supplements.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
2.3 For depth sizing, the sizing results shall be combined with the sizing results from Supplement 4. The combined results shall meet the depth sizing acceptance criteria contained in Supplement 4.	This is the same process described in other supplements where the procedure is the same; thus, results can be combined and acceptance defined.
2.4 Personnel shall be qualified in accordance with the requirements of Supplement 4 using the same type of instruments and data recording and analysis equipment. For initial procedure and equipment qualification, test sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.	This is the same process described in other supplements where the procedure is the same; thus, results can be combined and acceptance defined.
3.0 CONDUCT OF PERFORMANCE DEMONSTRATION FOR EXAMINATION OF THE NOZZLE-TO-SHELL WELD FROM THE BORE	
Single-side access demonstration to Supplement 6 qualifies examination personnel for nozzle-to-vessel weld examination when the following requirements are met.	There are requirement for Supplement 6 single-side access demonstration and Supplement 4 demonstration, and by meeting the following requirements, the personnel, equipment, and procedures are qualified to inspect the nozzle-to-vessel weld from the bore. This is viewed like an add-on such that only a reduced number of specimens is required, consistent with the strategy that has been used for the Supplements 12 and 14.
3.1 For detection and sizing, a minimum of three additional flaws in one or more full-scale nozzle mock-ups shall be added to the test set.	This is an add-on type of qualification; thus, only a limited number of specimens is required.
(a) Flaws shall be oriented parallel to the weld and at either the inside or outside surface, or subsurface. At least one subsurface flaw shall be included, and there shall be no more than two flaws from each category.	
(b) Specimens shall have sufficient volume to minimize spurious reflections.	The intent of this provision is to make the specimens realistic and the test similar to field inspections.
(c) The performance demonstration shall be on the same type of cladding as that to be examined, with the following exceptions. (1) Demonstrations on shielded metal arc welding (SMAW) single-wire cladding are transferable to multiple-wire or strip-clad process.	These requirements are consistent with those of other supplements that contain cladding specifications.

SUPPLEMENT 7 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE INSIDE SURFACE

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(2) Demonstrations on multiple-wire or strip- clad are considered equivalent but are not transferable to SMAW-type clad.	
(d) The surface condition of the test specimens shall be representative of the general condition of the vessel scanning surface.	Surface conditions must be representative of those on components in service.
(e) The detection test matrix shall include flaws with the following description. (1) *Flaw Type*. At least 75% of the flaws shall be cracks. The balance shall be cracks, fabrication flaws (e.g., slag, lack of fusion), or machined notches.	Most flaws need to be cracks that are of concern based on service failures but need to include fabrication flaws because those are expected to be detected using high-sensitivity inspections.
(a) Notches shall have a maximum width of 0.010 in. (0.25 mm) at the tip. The width at the clad-to-base-metal interface shall not exceed 0.020 in. (0.50 mm).	The acceptability of this maximum tip radius/width requirement is not known. In reviewing the PISC II parametric studies, PISC II fabricated a number of artificial flaws having tip radii up to 0.0012 in. (0.03 mm), and these flaws provided tip responses within 1 dB of that for a hydraulically grown fatigue crack with a tip radius less than 0.000004 in. (0.0001 mm). However, PISC II did not quantify how the tip response would change as the tip radius becomes larger than 0.0012 in. (0.03 mm). The tip response is key since for inspections from the inside surface for shallow flaws, the specular response is not detected, only the tip response is. Until further research is conducted to resolve this issue, a firm basis for this requirement will not exist. However, it needs to be noted that the number of notches is limited to < 25%, and notches can only be used if examination is from the inside surface with the notches being less than 0.24 in. (6 mm) in depth and semi-elliptical in shape.
(b) Notches shall conform to the following: (1) Notch depth shall not exceed 1/4 in. (6 mm). (2) Notches shall be semielliptical.	
(2) At least one flaw parallel to the weld shall provide a metal path distance within 10% of the equivalent path length to the weld centerline of the thickest component to be examined.	

SUPPLEMENT 7 — QUALIFICATION REQUIREMENTS FOR NOZZLE EXAMINATION FROM THE INSIDE SURFACE

	Rationale for Requirement and Relation to Referenceable Documentation
(f) There shall be a representative distribution of flaw depths from Table VIII-S6-1.	Because this portion of the supplement is an add-on to Supplement 6, it is appropriate to reference the same requirements for a representative distribution of flaw depths as used in Supplement 6.
3.2 Each of the flaws presented for demonstration shall be correctly identified at the proper azimuth within the greater of ±1 in. (25 mm) or 10% of the metal path, with no false calls.	This criterion is consistent with the location accuracy needed for defining detection; note that no false calls are permitted.
3.3 For length sizing, the results shall be added to the combined results of Supplement 4 and Supplement 6. The combined results shall meet the length sizing acceptance standards of Supplement 4.	Because this is an add–on, the length sizing is a combination of the length sizing results from Supplements 4 and 6 with the new data. The pass/fail criterion remains the same and is 0.75 in. (19 mm) for the combined results.
3.4 For depth sizing, the inside surface and inner 15% results shall be combined with the sizing results from Supplement 4. The combined results shall meet the depth sizing acceptance criteria of Supplement 4. The remaining results shall be combined with the sizing results from Supplement 6. The combined results shall meet the depth sizing acceptance criteria of Supplement 6.	The depth sizing results for flaws located within the inner 15% are to be combined with the results from Supplement 4. Those depth sizing results for flaws in the remainder of the vessel wall are to be combined with the results from Supplement 6. The acceptance criteria of Supplement 4 are to be used in the first case, while the acceptance criteria from Supplement 6 are to be used for the latter case.
3.5 Personnel shall be qualified in accordance with the requirements of Supplement 6 for single-side access, using the same type of instruments and data recording and analysis equipment. For initial procedure and equipment qualification, test sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.	The purpose of this provision is just to require that the single-side access requirements of Supplement 6 be used. No additional personnel qualifications are required.

3.2.8 SUPPLEMENT 8 — QUALIFICATION REQUIREMENTS FOR BOLTS AND STUDS

SUPPLEMENT 8 — QUALIFICATION REQUIREMENTS FOR BOLTS AND STUDS	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure.	
1.1 Specimens shall conform to the following requirements. (a) The qualification process shall be performed with a full-scale section bolt or stud that is sufficient to contain the beam path and demonstrate the scanning technique.	The requirements for the test specimens were developed by EPRI staff and presented to the Ad Hoc Task Group. The Ad Hoc Task Group agreed with the requirements for the specimens.
(b) The qualification specimen shall be of similar chemical composition, tensile properties, and metallurgical structure as the bolt or stud to be examined. The scan surface of the qualification specimen shall have a configuration similar to the bolt or stud to be examined.	
(c) Circumferentially oriented notches shall be located in the qualification specimen at the minimum and maximum qualified metal paths. Notches located within one diameter of the end of the bolt or stud are suitable for demonstrating the metal path distance. These notches are required on the outside threaded surface, with maximum depths and reflective areas as specified in Table VIII-S8-1.	The flaws in the bolts or studs are notches as opposed to cracks. It was the opinion of the Ad Hoc Task Group that notches were an acceptable demonstration flaw because the most probable type of defect in bolts or studs is a crack that initiates at the thread root and is relatively planar in morphology. The process for fabricating notches produced very repeatable flaws.
(d) Additional notches may be located within the range specified in (c) above, provided they do not interfere with the detection of other notches.	

TABLE VIII-S8-1
MAXIMUM NOTCH DIMENSIONS

Bolt or Stud Size	Depth, in. (mm) [Note (1)]	Reflective Area, sq. in. (mm^2)
Greater than 4 in. (100) diameter	0.157 (4)	0.059 (38)
2 in. (50) diameter and greater, but not over 4 in. (100) diameter	0.107 (2.7)	0.027 (17)

NOTE:
(1) For threaded surfaces, depth is measured from the bottom of the thread root to bottom of notch.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

Specimen identification and notch locations shall be obscured so as to maintain a "blind test." A flaw shall be considered detected when the notch, as defined in 1.1, is found. The notch axial location correlation shall be ±1/2 in. (±13 mm) or ±5% of the bolt or stud length, whichever is greater.

SUPPLEMENT 8 — QUALIFICATION REQUIREMENTS FOR BOLTS AND STUDS	Rationale for Requirement and Relation to Referenceable Documentation
3.0 ACCEPTANCE CRITERIA	
3.1 Examination procedures, equipment, and personnel are qualified for detection when each qualification notch (as described in 1.1) has been detected and its response equals or exceeds the reporting criteria specified in the procedure. The notch response shall have a minimum peak signal to peak noise ratio of 2:1.	The number of notches or flaws is not stated in the requirements. Therefore, the number of notches in the sample set is unknown to the candidate. Bolt and stud examination is a screening test; detection of a crack almost always results in a replacement of the bolt or stud. Demonstration of a readily detectable response (2:1 SNR) from a properly sized (maximum-allowable depth/area) notch was thought to be sufficient. U.S. utilities requested that the personnel, procedures, and equipment are demonstrated on an exact replica of the bolting to be examined during calibration in the field.

3.2.9 SUPPLEMENT 9 — QUALIFICATION REQUIREMENTS FOR CAST AUSTENITIC PIPING WELDS

(In the course of preparation.)

This supplement has not been developed because reliable ultrasonic methods have been slow to be developed. Recent work with phased arrays at low frequencies has shown some success (Diaz et al. 2011), and the ASME Code, Section XI Task Group on Cast Stainless Steel has been meeting and working on developing this supplement. Because of the research showing the effectiveness of inspections for piping less than 1.6 in. (40.6 mm) in wall thickness, the ASME Code, Section XI Task Group on Cast Stainless Steel is working on addressing this supplement by first developing requirements for piping less than 1.6 in. (40.6 mm) in wall thickness, and then developing requirements for piping having wall thicknesses equal to or greater than 1.6 in. (40.6 mm). The first step in this process will most likely be to rewrite Appendix III prescriptive requirements for ultrasonic examinations and immediately get the improvements into the Code in parallel with developing this supplement. Further, work on acceptance standards for cast stainless steels is being performed through the ASME Code Flaw Evaluations Standards Group and will define the detection needs for performance demonstration to support development of Supplement 9.

3.2.10 SUPPLEMENT 10 — QUALIFICATION REQUIREMENTS FOR DISSIMILAR METAL PIPING WELDS

This supplement was on the verge of being implemented when the hot leg nozzle-to-pipe weld failure at V. C. Summer occurred (Casto 2001; Grimmel 2005). The experience from V. C. Summer provided valuable guidance on the type of flaws and their NDE response that would need to be contained in the demonstration set. This demonstrates that the industry (EPRI) needs to continue collecting failure data from reported flaws and compare them to the responses from fabricated defects in an effort to strengthen the technical basis of the PDI program. To date these correlations have been positive and there has not been a need to alter the flaw making processes or include additional flaw types in the test sets.

SUPPLEMENT 10 — QUALIFICATION REQUIREMENTS FOR DISSIMILAR METAL PIPING WELDS	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE Supplement 10 is applicable to dissimilar metal piping welds examined from either the inside or outside surface. Supplement 10 is not applicable to piping welds containing supplemental corrosion-resistant clad (CRC) applied to mitigate intergranular stress corrosion cracking (IGSCC).	This section defines the scope of applicability of this supplement.
2.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, weld joint configuration, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.	This is a general requirement regarding what requirements must be met.
2.1 General. The specimen set shall conform to the following requirements. (a) The minimum number of flaws in a specimen set shall be ten.	If the test set is to be used potentially for both detection and sizing, then it must contain at least 10 flaws.
(b) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.	The purpose of this provision is to make sure there are no confusing supplemental signals that result from the test specimen and which would not occur on full-sized components.
(c) The specimen set shall include the minimum and maximum pipe diameters and thicknesses for which the examination procedure is applicable. Pipe diameters within a range of 1/2 in. (13 mm) of the nominal diameter shall be considered equivalent. Pipe diameters larger than 24 in. (600 mm) shall be considered to be flat. When a range of thicknesses is to be examined, a thickness tolerance of ±25% is acceptable.	The purpose of this provision is to ensure that the extremes of minimum and maximum pipe diameters and wall thicknesses are included in the demonstration process.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(d) The specimen set shall include examples of the following fabrication conditions: (1) geometric and material conditions that normally require discrimination from flaws (e.g., counterbore or weld root conditions, cladding, weld buttering, remnants of previous welds, adjacent welds in close proximity, weld repair areas) (2) typical limited scanning surface conditions shall be included as follows (a) for outside surface examinations, weld crowns, diametrical shrink, single-side access due to nozzle, and safe end external tapers (b) for inside surface examinations, internal tapers, exposed weld roots, and cladding conditions	The purpose of this provision is to ensure that the tests are realistic and include fabrication conditions that are commonly found in service.
(e) Qualification requirements shall be satisfied separately for outside surface and inside surface examinations.	The inspections from the O.D. and the I.D. involve different equipment; accordingly, the qualification process must be demonstrated separately for each inspection surface (I.D. and O.D.).
2.2 Flaw Location. At least 80% of the flaws shall be contained wholly in weld or buttering material. At least one and no more than 10% of the flaws shall be in ferritic base material. At least one and no more than 10% of the flaws shall be in austenitic base material.	The dominant failure process is stress corrosion cracking (SCC) in Inconel weldments. Therefore, the majority of the flaws must be located in these weldments.
2.3 Flaw Type (a) At least 60% of the flaws shall be cracks, and the remainder shall be alternative flaws. Specimens with IGSCC shall be used when available. Alternative flaws shall meet the following requirements:	Service degradation has been found to be SCC, so the flaws for demonstration must in large part be cracks. However, some alternative flaws can be included in the demonstration.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
(1) Alternative flaws, if used, shall provide crack-like reflective characteristics and shall only be used when implantation of cracks would produce spurious reflectors that are uncharacteristic of service-induced flaws.	It is not possible to implant axial flaws by welding without disturbing the metallurgical properties of the surrounding material and creating spurious reflections. The response amplitude of these alternative flaws was demonstrated to be in the same range as flaws found during field examinations. This information was provided to the ASME Code committees.[3]
(2) Alternative flaws shall have a tip width of no more than 0.002 in. (.05 mm).	These requirements are consistent with those developed in the PISC II parametric studies to simulate the tip response of fatigue cracks.
(b) At least 50% of the flaws shall be coincident with areas described in 2.1(d).	This reflects where SCC has been found in service.
2.4 Flaw Depth. All flaw depths shall be greater than 10% of the nominal pipe wall thickness. Flaw depths shall exceed the nominal clad thickness when placed in cladding. Flaws in the specimen set shall be distributed as follows.	This is to provide guidance on what flaw sizes to include but at the same time to be vague so that the test will remain blind.

Flaw Depth (% Wall Thickness)	Minimum Percentage of Flaws
5-30%	20%
31-60%	20%
61-100%	20%

At least 75% of the flaws shall be in the range of 10 to 60% of wall thickness.

2.5 Flaw Orientation	Based on field experience, the majority of flaws found in service for PWRs have been oriented axially, and thus need to be included. Both orientations have been found in BWR and PWR units. Circumferential flaws are considered to be more of a challenge to the integrity and function of a component as compared to axial flaws.

(3) Information from this EPRI work was presented to ASME Code Committees. The authors have not reviewed the EPRI report, but it can be purchased from EPRI for $142,500 and is titled Dissimilar Metal Piping Weld Examination – Guidance and Technical Basis for Qualification TR1008007 (2003).

SUPPLEMENT 10 — QUALIFICATION REQUIREMENTS FOR DISSIMILAR METAL PIPING WELDS	Rationale for Requirement and Relation to Referenceable Documentation
(a) For other than sizing specimens, at least 30% and no more than 70% of the flaws, rounded to the next higher whole number, shall be oriented axially. The remainder of the flaws shall be oriented circumferentially.	This provision provides guidance on the number of flaws to include based on orientation but is intentionally vague to ensure that test "blindness" is maintained.
(b) Sizing specimen sets shall meet the following requirements.	
(1) Length-sizing flaws shall be oriented circumferentially.	Because axial cracks tend to grow the full width of the weldment and thus are constrained by the weldment width, a performance demonstration test using 0.75-in. (19-mm) RMS error as the pass criterion is not meaningful; blindly guessing a flaw length size of ½ to ¾ the weldment width would likely meet the RMS error sizing requirement. Furthermore, axial cracks tend to grow rapidly, tend to crack the entire width of weld and buttering, and the depth is most important since it is used to assess which mitigation approaches can be implemented. Thus, the length of an axial flaw is not meaningful, so length sizing is performed only on circumferential flaws.
(2) Depth-sizing flaws shall be oriented as in 2.5(a).	Need to demonstrate that if an axial flaw or a circumferential flaw is detected, it can be sized accurately.
3.0 PERFORMANCE DEMONSTRATION Personnel and procedure performance demonstration tests shall be conducted according to the following requirements.	
(a) For qualifications from the outside surface, the specimen inside surface and specimen identification shall be concealed from the candidate. When qualifications are performed from the inside surface, the flaw location and specimen identification shall be obscured to maintain a "blind test." All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.	This section provides guidance on maintaining a blind test.
3.1 Detection Test (a) The specimen set shall include detection specimens that meet the following requirements.	

	Rationale for Requirement and Relation to Referenceable Documentation
(1) Specimens shall be divided into grading units. (a) Each grading unit shall include at least 3 in. (75 mm) of weld length. (b) The end of each flaw shall be separated from an unflawed grading unit by at least 1 in. (25 mm) of unflawed material. A flaw may be less than 3 in. (76 mm) in length. (c) The segment of weld length used in one grading unit shall not be used in another grading unit. (d) Grading units need not be uniformly spaced around the pipe specimen.	Requirements similar to those used in Supplement 2, 1.2a, where the developers recognized the complexity and trade-off between keeping the test blind, the number and size of test specimens, pass/fail criterion, and testmanship, which were based on the experiences with conducting round-robin tests and the IEB 83-02 demonstrations.
(see Table VIII-S10-1 below)	Table for acceptance criteria for this supplement. Note that it is very similar to Table VIII-S2-1, but there are differences. The material available for this demonstration was limited; thus, the number of unflawed grading units has been reduced. As a result, this changes the pass/fail criterion versus that in Table VIII-S2-1.

TABLE VIII-S10-1
PERSONNEL PERFORMANCE DEMONSTRATION DETECTION TEST ACCEPTANCE CRITERIA

Detection Test Acceptance Criteria		False Call Acceptance Criteria	
No. of Flawed Grading Units	Minimum Detection Criteria	No. of Unflawed Grading Units	Maximum No. of False Calls
10	8	15	2
11	9	17	3
12	9	18	3
13	10	20	3
14	10	21	3
15	11	23	3
16	12	24	4
17	12	26	4
18	13	27	4
19	13	29	4
20	14	30	5

SUPPLEMENT 10 — QUALIFICATION REQUIREMENTS FOR DISSIMILAR METAL PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
(2) Personnel performance demonstration detection test sets shall be selected from Table VIII-S10-1. The number of unflawed grading units shall be at least 1-1/2 times the number of flawed grading units.	Note that in Supplement 2, the number of unflawed grading units was 2 times the number of flawed grading units. In this case, it is at least 1.5 times the number of flawed grading units.
(3) Flawed and unflawed grading units shall be randomly mixed.	
(b) Examination equipment and personnel are qualified for detection when personnel performance demonstrations satisfy the acceptance criteria of Table VIII-S10-1 for both detection and false calls.	Defines what qualified means.
3.2 Length-Sizing Test (a) Each reported circumferential flaw in the detection test shall be length sized.	Note that this is only for circumferentially oriented flaws for the reason explained above.
(b) When the length-sizing test is conducted in conjunction with the detection test, and less than ten circumferential flaws are detected, additional specimens shall be provided to the candidate such that at least ten flaws are sized. The regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.	Need to have 10 flaws for length sizing; this is the guidance needed to achieve that number for computing RMS error for assessing acceptability.
(c) For a separate length-sizing test, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.	
(d) Examination procedures, equipment, and personnel are qualified for length-sizing when the RMS error of the flaw length measurements, compared to the true flaw lengths, do not exceed 0.75 in. (19 mm).	Pass/fail criterion is consistent with that of the other supplements.
3.3 Depth-Sizing Test (a) The depth-sizing test may be conducted separately or in conjunction with the detection test. For a separate depth-sizing test, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	Guidance on what to do if doing only a depth-sizing test.
(b) When the depth-sizing test is conducted in conjunction with the detection test, and less than ten flaws are detected, additional specimens shall be provided to the candidate such that at least ten flaws are sized. The regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	If the detection test set is used and 10 flaws are not detected, this provision guides how to include other flaws for depth sizing.
(c) Examination procedures, equipment, and personnel are qualified for depth-sizing when the RMS error of the flaw depth measurements, as compared to the true flaw depths, do not exceed 0.125 in. (3 mm).	Pass/fail criterion consistent with that of Supplement 2. However, to date no inside surface-applied procedure has successfully satisfied this criterion.

Rationale for Requirement and Relation to Referenceable Documentation

4.0 PROCEDURE QUALIFICATION

Procedure qualification shall include the following additional requirements.

This section requires that a stringent procedure demonstration consistent with other supplements be met along with other requirements, to ensure that only robust procedures make it through the qualification process. The procedure must demonstrate that all flaws can be detected; otherwise, if a flaw is not detectable and is included in a test set, the personnel will now be taking an 8 out of 9 test versus an 8 out of 10 test. This will reduce personnel pass rates because it is a limitation of the procedure and not the personnel. Thus, the procedure test is very stringent and it must be improved to demonstrate all flaws are detectable or the procedure will need to be listed with limitations identifying what it cannot detect.

(a) The specimen set shall include the equivalent of at least three personnel performance demonstration test sets. Successful personnel performance demonstrations may be combined to satisfy these requirements.

(b) Detectability of all flaws in the procedure qualification test set that are within the scope of the procedure shall be demonstrated. Length and depth sizing shall meet the requirements of 3.2 and 3.3.

(c) At least one successful personnel performance demonstration shall be performed.

(d) To qualify new values of essential variables, at least one personnel performance demonstration set is required. The acceptance test criteria of 4.0(b) shall be met.

3.2.11 SUPPLEMENT 11 — QUALIFICATION REQUIREMENTS FOR FULL STRUCTURAL OVERLAID WROUGHT AUSTENITIC PIPING WELDS

Overlaid piping has been used extensively in BWRs to mitigate IGSCC and has recently been used to mitigate SCC in Inconel alloys of PWRs. However, the Inconel alloys are not covered by this supplement. Currently, this supplement is in the course of being revised to address lessons learned from implementation and to include the capability to qualify procedures that are capable of penetrating larger examination volumes below the overlay itself. In order to use the current qualifications, licensees have to seek permission to use alternative qualification criteria, but the changes made are consistent with the overall technical basis described below. The scope is also being expanded to cover dissimilar metal welds susceptible to primary water stress corrosion cracking (PWSCC).

SUPPLEMENT 11 — QUALIFICATION REQUIREMENTS FOR FULL STRUCTURAL OVERLAID WROUGHT AUSTENITIC PIPING WELDS	
	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, weld joint configuration, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.	
1.1 General. The specimen set shall conform to the following requirements. (a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.	The specimens need to be representative and not have spurious signals.
(b) The specimen set shall consist of at least three specimens having different nominal pipe diameters and overlay thicknesses. They shall include the minimum and maximum nominal pipe diameters for which the examination procedure is applicable. Pipe diameters within a range of 0.9 to 1.5 times a nominal diameter shall be considered equivalent. If the procedure is applicable to pipe diameters of 24 in. (600 mm) or larger, the specimen set must include at least one specimen 24 in. (600 mm) or larger but need not include the maximum diameter. The specimen set shall include at least one specimen with overlay not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, and at least one specimen with over lay not thinner than 0.25 in. (6 mm) less than the maximum for which the examination procedure is applicable.	This provision provides generic guidance on the number of samples and the range of essential specimen variables that need to be included. This involves the pipe diameters, wall thicknesses, and the thickness of the overlay.
(c) The surface condition of at least two specimens shall approximate the roughest surface condition for which the examination procedure is applicable.	Surface conditions can impact inspection effectiveness and, as such, must be representative of field conditions.

	Rationale for Requirement and Relation to Referenceable Documentation
(d) Flaw Conditions	
(1) *Base metal flaws*. All flaws must be in or near the butt weld heat-affected zone, open to the inside surface, and extending at least 75% through the base metal wall. Intentional overlay fabrication flaws shall not interfere with ultrasonic detection or characterization of the base metal flaws. At least 70% of the flaws in the detection and sizing tests shall be actual cracks. Specimens containing IGSCC shall be used if they are available. If implantation of actual cracks produces spurious reflectors that are not characteristic of actual flaws, alternative flaws may be used but shall comprise not more than 30% of the total of base material flaws. Alternative flaws, if used, shall provide crack-like reflective characteristics and shall be semielliptical. The tip width of the alternative flaws shall not exceed 0.002 in.	For IGSCC, the flaws are in the heat-affected zone of welds; thus, they must be in this location in the test samples. This demonstration is to provide evidence that if a flaw is at least 75% though-wall, it will be detected, and, as such, all flaws must be this size or larger. At least 70% of the flaws need to be cracks and need to use IGSCC if they are available. The alternative flaw tip width is based on Type A PISC II parametric studies on simulating the UT response of cracks.
(2) *Overlay fabrication flaws*. At least 40% of the flaws shall be noncrack fabrication flaws (e.g., sidewall lack of fusion or laminar lack of bond) in the overlay or the pipe-to-overlay interface. At least 20% of the flaws shall be cracks. The balance of the flaws shall be of either type.	These are the type of welding flaws expected to be produced and need to be included in the demonstration test set. Guidance is given with some vagueness to ensure the testing remains blind.
(e) Detection Specimens	
(1) At least 20% but less than 40% of the base metal flaws shall be oriented within ±20 deg of the pipe axial direction. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access.	Guidance is given with some vagueness to ensure the testing remains blind.
(2) Specimens shall be divided into base metal and overlay fabrication grading units. Each specimen shall contain one or both types of grading units. Flaws shall not interfere with ultrasonic detection or characterization of other flaws.	Guidance is given with some vagueness to ensure the testing remains blind.
(a) (1) A base metal grading unit includes the overlay material and the outer 25% of the original overlaid weld. The base metal grading unit shall extend circumferentially for at least 1 in. (25 mm) and shall start at the weld centerline and be wide enough in the axial direction to encompass one half of the original weld crown and at least ½ in. (13 mm) of the adjacent base material. For axially-oriented discontinuities, the axial dimension of the base metal grading unit may encompass the original weld crown and at least ½ in. (13 mm) of the adjacent base materials.	
(2) When base metal flaws penetrate into the overlay material, the base metal grading unit shall not be used as part of any overlay grading unit.	
(3) Sufficient unflawed overlaid weld and base metal shall exist on all sides of the grading unit to preclude interfering reflections from adjacent flaws.	

SUPPLEMENT 11 — QUALIFICATION REQUIREMENTS FOR FULL STRUCTURAL OVERLAID WROUGHT AUSTENITIC PIPING WELDS

	Rationale for Requirement and Relation to Referenceable Documentation
(b) (1) An overlay fabrication grading unit shall include the overlay material and the base metal-to-overlay interface for a length of at least 1 in. (25 mm). (2) Overlay fabrication grading units designed to be unflawed shall be separated by unflawed overlay material and unflawed base metal-to-overlay interface for at least 1 in. (25 mm) at both ends. Sufficient unflawed overlaid weld and base metal shall exist on both sides of the overlay fabrication grading unit to preclude interfering reflections from adjacent flaws. The specific area used in one overlay fabrication grading unit shall not be used in another overlay fabrication grading unit. Overlay fabrication grading units need not be spaced uniformly about the specimen. (3) Detection sets shall be selected from Table VIII S2-1. The minimum detection sample set is five flawed base metal grading units, ten unflawed base metal grading units, five flawed overlay fabrication grading units, and ten unflawed overlay fabrication grading units. For each type of grading unit, the set shall contain at least twice as many unflawed as flawed grading units. For initial procedure qualification, detection sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.	
(f) Sizing Specimen	
(1) The minimum number of flaws shall be ten. At least 30% of the flaws shall be overlay fabrication flaws. At least 40% of the flaws shall be open to the inside surface. To assess sizing capabilities, sizing sets shall contain a representative distribution of flaw dimensions. For initial procedure qualification, sizing sets shall include the equivalent of three personnel qualification sets. To qualify new values of essential variables, at least one personnel qualification set is required.	This provision requires the use of a minimum of 10 flaws and ensures robustness of the procedure by having to meet the equivalent of three personnel qualifications test sets. Essential variables are extended by having successful personnel performance qualification.
(2) At least 20% but less than 40% of the flaws shall be oriented axially. The remainder shall be oriented circumferentially. Flaws shall not be open to any surface to which the candidate has physical or visual access.	Guidance is given with some vagueness to ensure the testing remains blind.
(3) Base metal flaws used for length sizing demonstrations shall be oriented circumferentially.	This is consistent with other supplements regarding flaw orientation for length sizing because axial flaws are limited in length by the size of the weldments.
(4) Depth sizing specimen sets shall include at least two distinct locations where a base metal flaw extends into the overlay material by at least 0.1 in. (2.5 mm) in the through-wall direction.	The ability to determine that an existing flaw has not propagated into the overlay material is important in determining the continued effective-ness of the overlay repair.

Requirement	Rationale for Requirement and Relation to Referenceable Documentation
2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS The specimen inside surface and identification shall be concealed from the candidate. All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited. The overlay fabrication flaw test and the base metal flaw test may be performed separately.	Guidance on keeping the demonstrations blind.
2.1 Detection Test. Flawed and unflawed grading units shall be randomly mixed. Although the boundaries of specific grading units shall not be revealed to the candidate, the candidate shall be made aware of the type or types of grading units (base metal or overlay fabrication) that are present for each specimen.	Guidance is given with some vagueness to ensure the testing remains blind.
2.2 Length Sizing Test (a) The length sizing test may be conducted separately or in conjunction with the detection test. (b) If the length sizing test is conducted in conjunction with the detection test and the detected flaws do not satisfy the requirements of 1.1 (f), additional specimens shall be provided to the candidate. The regions containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region. (c) For a separate length sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the length of the flaw in each region. (d) For flaws in base metal grading units, the candidate shall estimate the length of that part of the flaw that is in the outer 25% of the base wall thickness.	Guidance on how to conduct length sizing demonstration testing.
2.3 Depth Sizing Test (a) Depth sizing consists of measuring the metal thickness above the flaw (i.e., remaining ligament), and may be conducted separately or in conjunction with the detection test. (b) If the depth sizing test is conducted in conjunction with the detection test and the detected flaws do not satisfy the requirements of 1.1 (f), additional specimens shall be provided to the candidate. The regions containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region. (c) For a separate depth sizing test, the regions of each specimen containing a flaw to be sized shall be identified to the candidate. The candidate shall determine the maximum depth of the flaw in each region.	Guidance on how to conduct depth sizing performance qualification testing.

	Rationale for Requirement and Relation to Referenceable Documentation
3.0 ACCEPTANCE CRITERIA	
3.1 Detection Acceptance Criteria	
(a) Examination procedures shall be qualified as follows:	The section provides stringent requirements for the procedure. This is consistent with other supplements.
(1) All flaws within the scope of the procedure shall be detected, and the results of the performance demonstration shall satisfy the acceptance criteria of Table VIII-S2-1 for false calls. (2) At least one successful personnel demonstration shall be performed meeting the acceptance criteria defined in 3.1(b).	
(b) Examination equipment and personnel shall be considered qualified for detection if the results of the performance demonstration satisfy the acceptance criteria of Table VIII-S2-1 for both detection and false calls.	
(c) The criteria in 3.1 (a) and 3.1(b) shall be satisfied separately by the demonstration results for base metal grading units and by those for overlay fabrication grading units.	
3.2 Sizing Acceptance Criteria. Examination procedures, equipment, and personnel are qualified for sizing when the results of the performance demonstration satisfy the following criteria.	
(a) The RMS error of the flaw length measurements, as compared to the true flaw lengths, is less than or equal to 0.75 in. (19 mm). The length of a base metal flaw is measured at the 75% through-base-metal position.	This is consistent with all of the supplements.
(b) The RMS error of the flaw depth measurements, as compared to the true flaw depths, is less than or equal to 0.125 in. (3.2 mm).	This requirement is consistent with that of Supplement 2.

3.2.12 SUPPLEMENT 12 — REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SELECTED ASPECTS OF SUPPLEMENTS 2 AND 3

This set of requirements was based on the experience from the round-robin studies (NUREG/CR-5068, Heasler and Doctor 1996), which showed that ferritic steel is much easier to inspect than austenitic stainless steel. Statistical theory states that, if one is certain that one test is more difficult than another, one may demonstrate the equivalent capability on the easier test with fewer numbers of samples. This supplement assumes that essentially the same inspection procedure will be used for ferritic piping as for austenitic piping. This supplement is specifically for inspections conducted from the outside of the piping.

SUPPLEMENT 12 — REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SELECTED ASPECTS OF SUPPLEMENTS 2 AND 3

	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This Supplement provides for expansion of Supplement 2 qualifications to permit coordinated qualification for Supplement 3.	
2.0 DETECTION AND LENGTH SIZING **2.1 Ferritic Piping** Examination personnel, equipment, and procedure qualification requirements for detection and length sizing for Supplements 2 and 3 are satisfied when the following requirements are met.	Guidance is given for what needs to be done to include ferritic piping as an add-on to a Supplement 2 qualification.
(a) For detection qualification, at least three additional flawed grading units and six additional unflawed units in ferritic piping shall be added to the test set. A grading unit shall include at least 3 in. (75 mm) continuous weld length. All nine ferritic grading units shall be correctly identified.	
(b) The demonstration shall meet the requirements of Supplement 2, except that for length sizing qualification, the minimum number of flaws shall be ten, and the specimen set shall include at least three, but not more than four, flaws in ferritic material.	
3.0 DEPTH SIZING Examination personnel, equipment, and procedure qualification requirements for depth sizing for more than one of Supplements 2 and 3 are met by the following demonstration.	
(a) Specimens (1) The minimum number of flaws shall be ten.	Need to have a minimum of 10 flaws in order to adequately assess sizing effectiveness.

SUPPLEMENT 12 — REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SELECTED ASPECTS OF SUPPLEMENTS 2 AND 3

	Rationale for Requirement and Relation to Referenceable Documentation
(2) The specimen set shall include at least four but no more than five Supplement 3 flaws.	Supplement 3 on ferritic material is one of the easiest materials to inspect, so this requirement limits the test set to have a maximum of five Supplement 3 flaws; the other flaws must meet the requirements of Supplement 2.
(3) The overall flaw depth distribution shall meet the requirements of Supplement 2, 1.3(b).	Guidance is given for getting a range of flaw sizes, but again there is some vagueness to ensure that the testing remains blind.
(b) The demonstration shall be conducted in accordance with the requirements of Supplement 2, 2.2(b).	
(c) The examination procedure, equipment, and personnel are qualified for depth sizing under each of the Supplements addressed by the demonstration when the RMS error of the flaw depth measurements, as compared to the true flaw depths, does not exceed 0.125 in. (3.2 mm).	Both supplements have the same requirement for depth sizing, and this is just citing what that is.

3.2.13 SUPPLEMENT 13 — DELETED

This supplement was originally designed to provide a coordinated implementation of selected aspects of Supplements 4, 5, 6, and 7. However, when these four supplements were substantially modified to their present form, this supplement would never be used and was deleted from the Code.

3.2.14 SUPPLEMENT 14 — QUALIFICATION REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SUPPLEMENTS 10, 2, AND 3 FOR PIPING EXAMINATIONS PERFORMED FROM THE INSIDE SURFACE

This supplement is like Supplement 12 but is now addressing the coordination of several supplements when the inspection is conducted from the inside surface of the piping. The strategy followed is the same as that for Supplement 12 regarding the challenge for conducting an effective examination. Note that the most challenging is a Supplement 10 examination followed by a Supplement 2 and then a Supplement 3 examination.

SUPPLEMENT 14 — QUALIFICATION REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SUPPLEMENTS 10, 2, AND 3 FOR PIPING EXAMINATIONS PERFORMED FROM THE INSIDE SURFACE

	Rationale for Requirement and Relation to Referenceable Documentation
1.0 SCOPE This supplement is applicable to wrought austenitic, ferritic, and dissimilar metal piping welds examined from the inside surface. This supplement provides for expansion of Supplement 10 qualifications to permit coordinated qualification for Supplements 2 and 3.	In the case of PWRs, the inspections of dissimilar metal welds at the reactor pressure vessel are conducted from the inside surface. When these welds are inspected, the plan is to also inspect the Supplement 10 nozzle to safe end and the safe end to pipe weld/elbow, which is a Supplement 2 or 3 inspection depending upon the design. This scope is to define what the procedure is being applied to in the field.
2.0 SPECIMEN REQUIREMENTS Qualification test specimens shall meet the requirements listed herein, unless a set of specimens is designed to accommodate specific limitations stated in the scope of the examination procedure (e.g., pipe size, access limitations). The same specimens may be used to demonstrate both detection and sizing qualification.	This is an integration of the requirements from Supplements 10, 2, and 3. The specimen test set must represent all of the fabrication conditions as well as include the maximum and minimum pipe diameters and wall thicknesses.
2.1 General. The specimen set shall conform to the following requirements. (a) Specimens shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process. (b) The specimen set shall include the minimum and maximum pipe diameters and thicknesses for which the examination procedure is applicable. Applicable tolerances are provided in Supplements 2, 3, and 10. (c) The specimen set shall include examples of the following fabrication conditions: (1) geometric and material conditions that normally require discrimination from flaws (e.g., counterbore or weld root conditions, cladding, weld buttering, remnants of previous welds, adjacent welds in close proximity, and weld repair areas) (2) typical limited scanning surface conditions (e.g., internal tapers, exposed weld roots, and cladding conditions)	

	Rationale for Requirement and Relation to Referenceable Documentation
2.2 Supplement 2 Flaws (a) At least 70% of the flaws shall be cracks; the remainder shall be alternative flaws.	Requires that most of the flaws be cracks and IGSCC to be used when available. Alternative flaws such as an isostatically hipped notch can be used. Provides guidance on what an acceptable alternative flaw is. Again, this requires the flaws to simulate cracks based on the Type A PISC II parametric study results for tip width.
(b) Specimens with IGSCC shall be used when available. (c) Alternative flaws, if used, shall provide crack-like reflective characteristics and shall comply with the following. (1) Alternative flaws shall be used only when implantation of cracks produces spurious reflectors that are uncharacteristic of service-induced flaws. (2) Alternative flaws shall have a tip width of no more than 0.002 in. (0.05 mm).	
2.3 Supplement 3 Flaws. Supplement 3 flaws shall be mechanical or thermal fatigue cracks.	This requirement is based on the fact that cracks are needed and the most likely cracking process in ferritic steel is fatigue.
2.4 Distribution. The specimen set shall contain a representative distribution of flaws. Flawed and unflawed grading units shall be randomly mixed.	This requirement was discussed extensively by the ASME Code Task Group Appendix VIII. Because there are three supplements and a wide range of material variables, it was not possible to come up with definitive guidance on what the distribution of flaws needs to be. It was decided that the implementers of this supplement would need to assemble a range of flaws in terms of their locations and sizes. It would be the responsibility of the implementer to make the case for how they have sampled all of these conditions and how they are represented in the specimen test set. The implementer in the United States is the performance demonstration administrator (PDA), which is the EPRI NDE Center. There are currently no requirements in the Code for the PDA, but it should be noted that

	Rationale for Requirement and Relation to Referenceable Documentation
	the Task Group Appendix VIII is developing a supplement to provide clarity to the role and responsibility of the PDA.
3.0 PERFORMANCE DEMONSTRATION	
Personnel and procedure performance demonstration tests shall be conducted according to the following requirements.	
(a) The same essential variable values, or, when appropriate, the same criteria for selecting values as demonstrated in Supplement 10 shall be used.	Because Supplement 10 is the most challenging, it drives the range of essential variables to be demonstrated.
(b) The flaw location and specimen identification shall be obscured to maintain a "blind test."	These keep the test blind.
(c) All examinations shall be completed prior to grading the results and presenting the results to the candidate. Divulgence of particular specimen results or candidate viewing of unmasked specimens after the performance demonstration is prohibited.	These requirements are needed to keep the demonstration process blind.
3.1 Detection Test	
(a) The specimen set for Supplement 2 qualification shall include at least five flawed grading units and ten unflawed grading units in austenitic piping. A maximum of one flaw shall be oriented axially.	This is considered an add-on to the Supplement 10 qualification and, as such, is requiring at least five Supplement 2 flaws. This is being done because the Supplement 10 is the hardest inspection and the Supplement 2 is the next most challenging.
(b) The specimen set for Supplement 3 qualification shall include at least three flawed grading units and six unflawed grading units in ferritic piping. A maximum of one flaw shall be oriented axially.	Supplement 3 is easier than Supplements 10 and 2. Thus, there is only a need to add at least three ferritic flaws and six unflawed grading units.
(c) Specimens shall be divided into grading units.	These are the generic requirements to make sure that the grading units are isolated and do not have any interaction with each other. This simplifies the scoring of the test results.
(1) Each grading unit shall include at least 3 in. (76 mm) of weld length.	
(2) The end of each flaw shall be separated from an unflawed grading unit by at least 1 in. (25 mm) of unflawed material. A flaw may be less than 3 in. (76 mm) in length.	
(3) The segment of weld length used in one grading unit shall not be used in another grading unit.	
(4) Grading units need not be uniformly spaced around the pipe specimen.	

SUPPLEMENT 14 — QUALIFICATION REQUIREMENTS FOR COORDINATED IMPLEMENTATION OF SUPPLEMENTS 10, 2, AND 3 FOR PIPING EXAMINATIONS PERFORMED FROM THE INSIDE SURFACE

	Rationale for Requirement and Relation to Referenceable Documentation
(d) All grading units shall be correctly identified as being either flawed or unflawed.	Guidance on how to interpret the test results.
3.2 Length-Sizing Test	This provides the guidance on how to conduct the length sizing demonstration by adding on Supplement 2 and 3 specimens.
(a) The coordinated implementation shall include the following requirements for personnel length-sizing qualification. (b) The specimen set for Supplement 2 qualification shall include at least four flaws in austenitic material. (c) The specimen set for Supplement 3 qualification shall include at least three flaws in ferritic material. (d) Each reported circumferential flaw in the detection test shall be length sized. When only length-sizing is being tested, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the length of the flaw in each region.	
(e) Supplement 2 or Supplement 3 examination procedures, equipment, and personnel are qualified for length-sizing when the flaw lengths estimated by ultrasonics, as compared with the true length, do not exceed 0.75 in. (19 mm) RMS, when they are combined with a successful Supplement 10 qualification.	The pass/fail criterion is to combine the results from the Supplement 2 and 3 length sizing results with the length sizing results from Supplement 10 to determine if the combined results still meet the criterion of ≤ 0.75 in. (19 mm) RMS error.
3.3 Depth-Sizing Test. The coordinated implementation shall include the following requirements for personnel depth-sizing qualification. (a) The specimen set for Supplement 2 qualification shall include at least four circumferentially-oriented flaws in austenitic material. (b) The specimen set for Supplement 3 qualification shall include at least three flaws in ferritic material. (c) For a separate depth-sizing test, the regions of each specimen containing a flaw to be sized may be identified to the candidate. The candidate shall determine the depth of the flaw in each region.	This provides requirements for adding on Supplement 2 and 3 specimens for depth sizing.
(d) Supplement 2 or Supplement 3 examination procedures, equipment, and personnel are qualified for depth-sizing when the flaw depths estimated by ultrasonics, as compared with the true depths, do not exceed 0.125 in. (3 mm) RMS, when they are combined with a successful Supplement 10 qualification.	Because the Supplement 2 and 3 are add-ons to a successful Supplement 10 qualification, the pass/fail criterion is the same (≤ 0.125 in. [3 mm]) when the depth sizing data is combined with the Supplement 10 data. To date, no inside surface-applied procedure has successfully satisfied this criterion for Supplements 2 or 10.

	Rationale for Requirement and Relation to Referenceable Documentation
4.0 PROCEDURE QUALIFICATION Procedure qualification shall include the following additional requirements.	
(a) The specimen set shall include the equivalent of at least three personnel performance demonstration test sets. Successful personnel performance demonstrations may be combined to satisfy these requirements.	The procedure qualification requires meeting the stringent requirement of the equivalent of at least three personnel performance demonstration test sets.
(b) Detectability of all flaws in the procedure qualification test set that are within the scope of the procedure shall be demonstrated. Length and depth sizing shall meet the requirements of 3.1, 3.2, and 3.3.	This requires that all flaws be detected and at least one personnel demonstration be successful to have the procedure become qualified for detection. For depth and length sizing, the criteria already described in 3.0 must be met.
(c) At least one successful personnel demonstration shall be performed.	
(d) To qualify new values of essential variables, at least one personnel performance demonstration is required. The acceptance criteria of 4.0(b) shall be met.	For a qualified procedure, if a new value for an essential variable is being proposed for the procedure, then at least one personnel performance demonstration is required. This is based on the fact that the procedure is already qualified and now a change is being made to the essential variables. It was discussed, and the ASME Code members felt that a full procedure demonstration would not be required. They thought it was sufficient to show that the procedure is still effective through an additional blind personnel performance demonstration.

4 DISCUSSION

There is clear evidence that the performance demonstration requirements adopted by Section XI of the ASME Code for Boiler and Pressure Vessels has resulted in a positive impact on the reliability of ultrasonic examinations that are performed on piping and pressure vessels (Doctor 2008). Figure 4-1 shows the progress that has been made on piping welds since performance demonstration has been adopted.

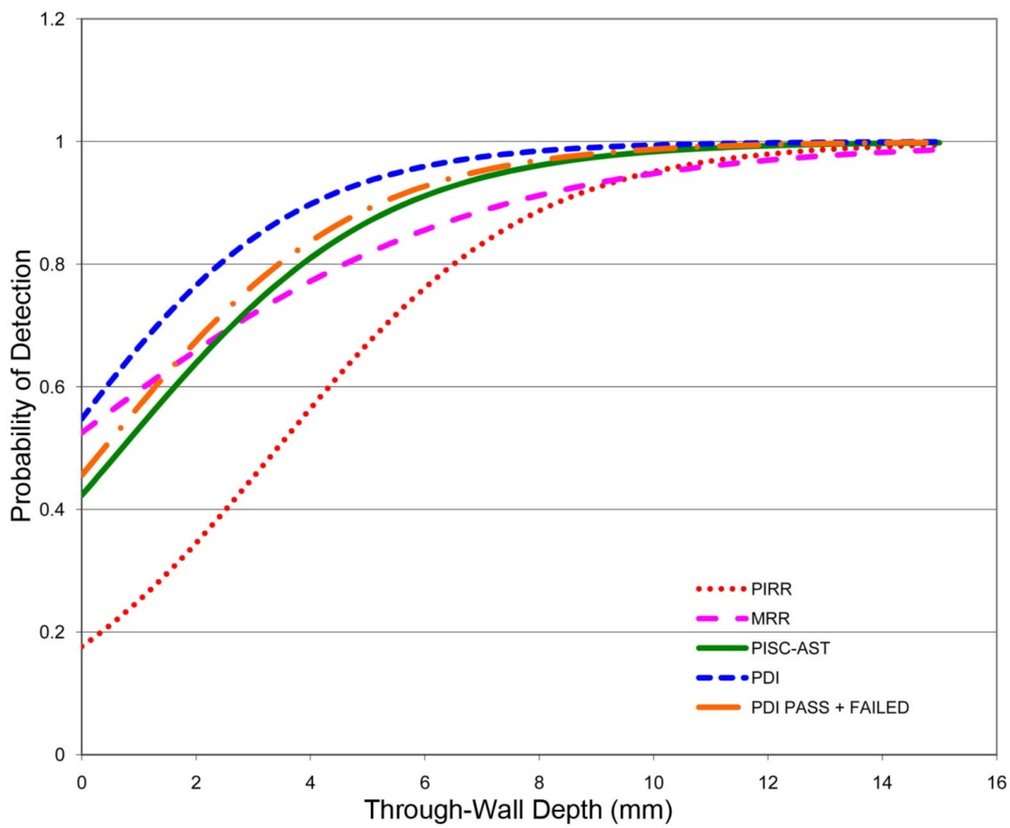


Figure 4-1 Comparison of Probability of Detection from Three Round Robins and PDI Data between 1981 and 2001 (wrought stainless steel piping)

The lowest performance level is shown for the PIRR study that took place in 1981. This study has become a benchmark on performance in the early 1980s. The Mini Round Robin (MRR) results in 1985 showed that smaller flaws could be detected more reliably with a moderate increase in performance for intermediate flaws that was attributed to the performance demonstration mandated at that time. The PISC-AST (Austenitic Steel Testing) results of 1990 show a significant improvement over the PIRR and, except for very small flaws, display improvement over the MRR results.

Two plots shown for the PDI data represent performance up to 2001. The PDI data were plotted for all inspectors who successfully passed the performance demonstration requirements stipulated in Appendix VIII; and a second curve plots all inspectors who attempted the performance demonstration test (passed plus failed). It can be seen that both of these PDI-based curves show improvements over the preceding three round-robin studies, indicating that there has definitely been improvement in piping inspection reliability. Similar results can be shown for reactor pressure vessel inspection if one compares the results of the PVRC studies in the 1970s and PDI data for reactor pressure vessel examinations (Becker 2001). Additionally, recent field experience indicates that performance-demonstrated ultrasonic techniques provide significantly improved sensitivities and signal-to-noise ratios as compared to the prescriptive techniques previously applied. However, this process needs further improvement as exemplified by the recent failure of ISI at North Anna where SCC was not detected but was discovered when the dissimilar metal weld was being prepared for an overlay (Anderson et al. 2012). There were a number of issues relating to the probe design, use of manual inspection, quality of the technical justification, and the site-specific mockup process that was followed. A number of these issues will be best resolved by creating improved requirements in ASME Code, Section XI, Appendix VIII.

Most U.S. operating nuclear power plants have implemented risk-informed ISI (RI-ISI) programs for safety-related piping welds. A fundamental assumption for all of these RI-ISI programs is that highly effective ISI is being performed. In order to have confidence that highly effective inspections are being performed, it is important to use those combinations of personnel, procedures, and equipment (NDE systems) that have shown objective statistical evidence supporting acceptable performance levels. Currently, UT systems are required to provide this evidence by successfully demonstrating their capabilities through blind performance demonstration in accordance with Appendix VIII; this concept is valid for other forms of NDE as well, but is yet to be required by ASME Code.

The previous discussion on austenitic piping welds clearly shows the improvement in performance that has been achieved for the detection of service-induced cracking in these components. Similar arguments could possibly be made for UT inspection on components addressed by other supplements in Appendix VIII through analyses of the existing PDI database. Unfortunately, this database is no longer being periodically analyzed to provide this type of objective evidence on performance achievements. When assessing the effectiveness and consequences of periodic inspections, it is necessary to quantify and evaluate certain characteristics for the population of active field inspectors. Given that we have minimal field data that is acceptable for such evaluation, these characteristics are best estimated from qualification data such as that residing in the PDI database.

Also, if there is interest in re-evaluating the original criteria and basic assumptions to assess whether improvements could be made to the overall qualification process, for example, passing more candidates with high performance or failing more candidates with low performance, an analysis of the PDI data could provide information needed for this type of assessment. The significant point here is that the PDI database currently provides the only available information on examination personnel capabilities for all of the Appendix VIII supplements, and is therefore an important resource for assessing/improving the performance demonstration process. It is recommended that the PDI database be analyzed for quantifying characteristics of inspector populations for each supplement and developing potential improvements to the performance demonstration process.

Another recommendation concerns the absence of performance-based examination requirements for other safety-related items. There are several component examinations that are listed in Mandatory Appendix I where examination qualification standards continue to refer to using prescriptive-based, Section V requirements. These include:

- Article I-2100 for reactor vessel-to-flange welds, closure head-to-flange welds, integral attachment welds, and reactor vessel control rod drive housing welds;
- Article I-2120 for other vessels greater than 2 in. (50 mm), such as the pressurizer and steam generator shell welds;
- Article I-2210 for vessels 2 in. (50 mm) and less, for example, heat exchangers, storage tanks;
- Article I-2200 for threads in the reactor pressure vessel closure flange; and
- Article I-2400 for all other welds or materials for which the requirements of I-2100, I-2200, or I-2300 do not apply.

These examinations should be upgraded to performance-based qualification requirements, and Appendix VIII should be modified through the development of new supplements to address their specific needs.

Appendix VIII was developed to address NDE performance issues that were of major concern in the 1980s, when many inservice degradation mechanisms such as IGSCC were leading to failures in piping systems. This approach, as one part of managing IGSCC in BWR piping welds, has been quite successful, but recent issues have shown that a re-examination of the existing requirements in Appendix VIII may be needed. For example, the presence and impact of fabrication flaws on effective UT performance was not addressed in Appendix VIII because the focus was on service degradation that normally emanates from the (inner or outer) surface of components. Recent events on dissimilar metal welds have highlighted the need for qualified examinations to provide objective evidence for UT capability to distinguish fabrication flaws from service-induced cracks. It is believed that in certain cases, embedded fabrication flaws have been incorrectly interpreted as service-induced PWSCC, which resulted in unnecessary and expensive repairs to components. The inability to correctly discern fabrication from service-induced flaws may also lead to uncharacterized (undetected) degradation, which could challenge the continued integrity of safety-related components. It is therefore recommended that new ASME Code, Appendix VIII rules be developed to address this issue.

In addition, there are currently no requirements in Appendix VIII for accurately estimating the remaining ligament of unflawed material adjacent to embedded flaws. This becomes an issue when embedded flaws are located near a surface. For fracture mechanics analyses, a flaw that is located within a certain proximity to the surface must be analyzed as if it were surface-connected. Thus, the measurement of remaining ligament can be extremely important and the capability to estimate this value should be demonstrated. A limited analysis of PDI RPV qualification data performed in 2009 indicated that when this data was collapsed across all candidates, the ligament sizing error would have met an RMS error value of 0.125 in. (3 mm). Hence, the goal should be to quantify this capability for each candidate, establish acceptable performance criteria, and give recognition for achieving an effective ligament sizing performance, thus providing more confidence for values used in flaw evaluation. It is recommended that ligament sizing rules should be added to the requirements of Appendix VIII.

Another area where Appendix VIII should be strengthened includes ensuring that any candidate for qualification must provide documented evidence for meeting all of the training and experience requirements before they are permitted to be tested. The basis for this comment is that Appendix VIII has been developed as a screening test, with limited numbers of flawed specimen conditions that are presented to each candidate. This limited, screening approach was designed to only *confirm* that experienced candidates have the necessary skills and knowledge. As a screening approach, there remains a very small statistical probability that a candidate with clearly inadequate skills and experience may pass the demonstration test. However, the screening test may pass candidates with borderline skills. This limited approach and realization was part of the fundamental assumptions used in the basis for Appendix VIII development. If the rules of Appendix VIII are used in another manner (i.e., if anyone is allowed to take these limited tests, regardless of their training and experience), then the basis for demonstration must be reanalyzed, and the test sets must be redesigned to become more challenging. Only in this manner can one maintain the low probability that a candidate with inadequate skills and experience might pass the demonstration test. This is potentially an area where guidance for the performance demonstration administrator could be defined in Appendix VIII to ensure that validated documentation of adequate qualification through training and experience be implemented in accordance with the fundamental assumptions that were used to develop Appendix VIII.

The Appendix VIII rules are a living document and are undergoing continuous review at the quarterly ASME Code meetings. This document, which provides the rationale basis for the Appendix VIII rules and supplements, may be useful when evaluating these rules and supplements as nondestructive testing techniques evolve, as possible new degradation mechanisms emerge, or as known degradation processes occur in components/materials thought to be immune to them.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

Ultrasonic inspection requirements specified in the ASME Code, Section XI were written in a very prescriptive fashion until an accumulation of field experience in examinations that failed to detect defects in piping and pressure vessels, coupled with evidence from round-robin tests conducted by the Pressure Vessel Research Council, the Programme for the Inspection of Steel Components, and Pacific Northwest National Laboratory, demonstrated that improvements in ultrasonic inspection reliability were needed.
At an October 1984 meeting held between the NRC) nd industry in Rockville, Maryland, a draft qualification document was proposed and discussed as the basis for an NRC Regulatory Guide. This meeting resulted in the formation of an ASME Code Ad Hoc Task Group of industry experts charged with developing new Code rules that would improve the reliability of ultrasonic inspection. This Ad Hoc Task Group developed the initial rules that were later documented in Appendix VIII. 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 Ad Hoc Task Group developed the concept of ultrasonic system qualification through performance demonstration.
This report addresses the technical bases that support the requirements of the performance demonstration specified in the 2007 Edition, 2008 and 2009 Addenda of ASME Boiler and Pressure Vessel Code, Section XI, Appendix VIII. The intent of this report is to provide the reader with an understanding of the technical rationale for the requirements stated in Section XI, Appendix VIII.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
ASME Code, ISI, Performance Demonstration

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