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Qualification Process for Ultrasonic Testing in Nuclear Inservice Inspection Applications

Prepared by J. C. Spanner, S. R. Doctor, T. T. Taylor/PNL
J. Muscara/NRC

Pacific Northwest Laboratory
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Prepared by
J. C. Spanner, S. R. Doctor, T. T. Taylor/Pacific Northwest Laboratory
J. Muscara/U.S. Nuclear Regulatory Commission

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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ABSTRACT

This report documents a project whose objective was to develop recommended requirements and processes for qualifying ultrasonic testing/inservice inspection (UT/ISI) systems for ISI of nuclear power plant components. An overall qualification process intended to achieve statistically designed performance validations including prerequisite training and other qualification recommendations is described. The report also contains recommendations for the test specimens, environment, and other conditions under which the qualification processes should be conducted.

Active involvement in the ASME Section XI Subgroup on Nondestructive Examination (SGNDE) and an Ad Hoc Task Group authorized by the SGNDE became an integral part of this task after a PNL draft document was presented in November 1984. The major areas where specific enhancements to Section XI were recommended in this document included more stringent criteria for Level III qualifications, explicit recommendations for requalification, inauguration of periodic (annual) training, and recommendations for coordinating and administering the entirely new qualification process on a national (rather than local employer) basis.

EXECUTIVE SUMMARY

Nuclear inservice inspection and plant operating experience, round-robin tests of inspection reliability, plant aging and life extension considerations, and evaluations of the flaw detection reliability necessary to achieve specific failure probabilities for certain nuclear power plant components have focused attention on the need for improving the reliability of ultrasonic testing for inservice inspection (UT/ISI).

In view of this need, the Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research requested that Pacific Northwest Laboratory (PNL) recommend more rigorous qualification processes than those presently in effect. Although a general upgrading of qualification requirements does not automatically assure more effective field inspections, it does increase the intrinsic capability for a reliable inspection and intensifies the awareness of field inspection personnel to the significance of their work. This report documents work in support of the qualification process and provides recommended processes for use in qualifying the three essential UT/ISI elements (personnel, equipment, and procedures).

Effective use of fracture mechanics analysis to evaluate system integrity and safety is strongly dependent upon reliable detection and accurate sizing of flaws. Hence, these qualification processes include performance demonstrations to validate the flaw detection probability and characterization accuracy of candidate UT/ISI systems.

The following technical issues are addressed in this report:

- Reliability of UT/ISI as applied to
  - boiling-water reactor (BWR) pipe cracking (intergranular stress corrosion cracking [IGSCC] problem)
  - piping with weld overlay (IGSCC repair)
  - inspection of pressure vessels including clad and underclad areas as well as nozzles
  - inspection of dissimilar metal welds and cast materials.
- The NRC Piping Review Committee recommendation A-2 in NUREG-1061 (Vol. 5) quoted (in part) below:

  > Development of advanced techniques and procedures for crack detection and depth sizing should continue for incorporation into Code requirements. Included should be analysis of the human factors, equipment qualification and certification, and inspection techniques for detecting and dimensioning flaws....

The scope of this project included developing a working draft document to provide guidance and recommendations for ultrasonic testing on nuclear ISI applications. Development of the final working draft included input obtained during an October 1983 industry workshop plus reviews, comments, and concurrence by the NRC technical staff. The final draft was presented during an industry workshop in Rockville, Maryland, in November 1984 to obtain final industry input on the proposed recommendations. This project also involved active participation in an ASME Ad Hoc Task Group and continued active involvement in the ASME Section XI Subgroup on Nondestructive Examination (SGNDE), its two working groups, and various task groups. The overall objective of this effort has been to develop recommended requirements and processes for qualifying UT/ISI systems toward improving the reliability of ISI of the nuclear power plant components covered by ASME Section XI.

EVOLUTION OF ISI QUALIFICATION

The NDE qualification requirements within the nuclear industry prior to approval of Appendices VII and VIII to ASME Section XI are summarized below.

Personnel. The applicable qualification criteria for NDT personnel were defined in SNT-TC-1A, an American Society for Nondestructive Testing publication, as supplemented by the ASME Code (Section III or XI, as applicable). Personnel must be certified by their employers and SNT-TC-1A implied (but did not require) application-specific training. 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 must meet the ASME Section V and XI requirements regarding vertical response and attenuator linearity, and the capability for calibrating the instrument. Other critical electronic performance characteristics were not addressed in the ASME Code.

Procedures. Ultrasonic examination procedures must be based on the applicable edition of ASME 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 that were collected during UT/ISI.

As noted above, the controlling document for personnel requirements was SNT-TC-1A, a publication issued by the American Society for Nondestructive Testing (ASNT). SNT-TC-1A provided guidelines, not requirements, and its major limitations were 1) the absence of requirements for periodic training to maintain/upgrade technical skills, 2) insufficient baseline competence criteria and no specific training requirements for Level III personnel, and 3) the qualification and certification of NDE personnel was the exclusive responsibility 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. This coordination plan replaced the interim program established in response to IEB 83-02. The program in effect at the EPRI NDE Center has undergone improvements since it was initially established in the 1982-1983 era; however, it primarily addresses only the IGSCC problem and applies only to personnel since the equipment and procedures are 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's 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. There was agreement by the industry, Code, and NRC representatives present 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 Section XI Code committees should review the document and develop qualification requirements on a priority basis. It was recommended that this action be undertaken by the ASME 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 that were used to perform ISI in nuclear power plants.

Following the November 1984 meeting with industry, ASME Section XI established an 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 seven 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 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 Main Committee in early 1989 and was approved by the Board on Nuclear Codes and Standards (BNCS) in mid-1989. This appendix is expected to be published as part of the 1989 Addenda to ASME Section XI. While 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.

RECOMMENDED QUALIFICATION PROCESS

All UT/ISI systems used to examine nuclear power plant components should successfully complete a performance validation test that satisfies the recommended processes described herein. These recommendations should apply to all UT/ISI systems (personnel, equipment, and procedures) that examine or re-examine welds and materials; record, process, classify, and/or interpret indications; and size flaws.

The process described herein is intended to assure minimum levels of UT/ISI capabilities. Performance validation demonstrations are recommended for both general and specific plant applications. These processes require that 1) all UT personnel, equipment, and procedures be qualified; and 2) the qualification process include successful completion of a statistically designed performance validation using a "blind test" sample set.

Since the safety significance of each component, the inspection difficulty, and the appropriate degree of inspection reliability vary with each application, the detection probability and characterization accuracy requirements should vary correspondingly. Guidelines are provided for designing and conducting performance validation tests.

All NDE Level I, II, and III personnel that perform UT/ISI should attend nationally uniform training courses that strengthen the basic technical competence and enhance the individual skills required to perform UT/ISI applications. The ASNT-recommended course outlines that are widely used throughout industry are generally adequate, but the quality of the actual training should be upgraded. In addition, the importance of "hands-on" laboratory training using specimens of actual plant components should be emphasized. Personnel should be qualified for each examination activity they perform such as system calibrations, data acquisition, data analysis, and flaw sizing.

For all manual UT/ISI applications, and whenever the performance of automated UT/ISI equipment depends on an operator's nondestructive testing (NDT) skills, the personnel should successfully complete the appropriate training course(s) followed by performance validation tests to qualify for those operations and/or activities they will perform during UT/ISI applications. These performance validation processes should not apply to personnel whose involvement is limited to mounting a scanner device, monitoring a fully computerized operation, or other situations where the operator's knowledge of NDT principles and practices cannot adversely affect the ISI results.

Level I personnel should be certified in accordance with SNT-TC-1A plus successfully complete a performance validation exam prior to performing UT/ISI applications. Level I personnel should complete at least 20 hours of application-oriented classroom and laboratory training prior to the performance validation and complete at least 20 hours of training annually thereafter.

Level II personnel should be certified in accordance with SNT-TC-1A plus successfully complete a performance validation exam prior to performing UT/ISI applications. In addition, each Level II should complete 40 hours of application-oriented training prior to the performance validation and complete 40 hours of like training annually thereafter.

Level III personnel should be certified in accordance with SNT-TC-1A plus successfully complete a performance validation exam prior to performing UT/ISI applications. In addition, all Level IIIs should hold a valid ASNT Level III certificate for the UT method and should complete at least 40 hours of application-oriented classroom and laboratory training prior to the performance validation. Level III personnel should also complete 40 hours of like training annual thereafter.

A national registry of qualified personnel should be established and maintained. Personnel qualified to perform UT/ISI applications should lose their qualified status and be removed from the national registry when any one of the following are not met:

- Successful completion of a performance validation test at five-year intervals

- Successful completion of periodic augmented training as required for Level I, II, or III personnel

- Responsible participation during any 12-month period in 1) the performance of at least 80 hours of qualified UT/ISI examinations or 2) a successful performance validation test.

Candidates for the NDE Instructor position should be qualified, but not necessarily employer certified, as a Level III in the ultrasonic method. NDE Instructors should hold a valid ASNT Level III certificate for the UT method and should possess documented evidence of their teaching qualifications.

Nationally uniform training courses should be developed and administered on an industry-wide basis. These training courses should include both classroom and "hands-on" training and should emphasize current UT/ISI applications and problems. Periodic quizzes and examinations should be used to measure comprehension of the training materials; a nationally uniform final examination should be given; and a course grade should be formally entered into the candidate's qualification records. Additional training, based on areas of demonstrated weakness, should be required when an individual fails the final course examination.

Only equipment models that have been qualified as described herein should be used for UT/ISI applications. Qualification for selected portions of UT operations should be permitted, and equipment models that have been qualified in accordance with this document should be characterized electronically and the results documented.

Prior to the performance validation exam, a written UT/ISI examination procedure should be submitted for review. The examination procedure should contain a scope statement that specifically defines the limits of procedure applicability. The examination procedure should also specify a single value or a range of values for each of the essential variables listed in this document. Changes to any of these variables should be permitted without requalification provided such changes satisfy the recommendations described in this document.

RECOMMENDED REQUALIFICATION PROCESS

The recommended requalification processes for personnel, equipment, and procedures are as follows. Requalification of personnel by completing a performance validation exam is recommended at each five-year interval for all three levels of NDT personnel. Personnel that have not participated in the performance of at least 80 hours of qualified UT/ISI examinations, or have not passed a successful performance validation exam, during the preceding 12 months should requalify by successfully completing a performance validation exam. Personnel that have not received NDE training during the preceding 12 months should successfully complete the appropriate training and then requalify via performance validation.

The electronic characteristics of the equipment should be measured and documented at least once every 12 months. These measurements should verify that the equipment parameters have not deteriorated with respect to the baseline measurements. Requalification of equipment by performance validation should not be required at fixed time intervals; however, requalification of the UT/ISI equipment by performance validation should be performed whenever any of the equipment items defined as essential variables are replaced with items that have not been previously qualified.

Requalification of procedures should not be required at fixed time intervals; however, the procedures should be requalified whenever one or more of the essential variables are changed. Procedure requalification should be done according to performance validation only.

PERFORMANCE VALIDATION PROCESS

The specimens utilized during the performance validation process should be representative of actual components and conservative with respect to inspection difficulty. Flaw size, location, shape, orientation, tightness, and morphology should ensure that anticipated flaw conditions are included. A significant fraction of the test specimens should contain no flaws (i.e., blanks), and geometric and metallurgical reflectors should be present in the test specimen set to represent actual plant components.

Provisions should be made for changing and augmenting the test specimen sets to inhibit industry familiarization with the specimens and provide specimens for training and technique development. Recommendations describing the number and configuration of test specimens and the number, type, location, shape, size, and orientation of flaws are provided in Section 6 of this report.

COMPARISON OF QUALIFICATION PROCESSES

A detailed comparison of the qualification processes defined in selected industrial documents was conducted and this analysis is presented in tabular form in Section 7 of this report. In general, the recommendations described in this document are more stringent than the current industry requirements; however, there are exceptions. The major areas where specific enhancements are recommended include more stringent criteria for Level III qualifications, explicit recommendations for requalification, greater emphasis on periodic (annual) training, and recommendations for coordinating and administering the qualification processes on a national (rather than an individual employer) basis.

CONTENTS

GLOSSARY

The following list of key terms and abbreviations is provided along with definitions to clarify the use of these terms within the context of this document.

ASME - American Society of Mechanical Engineers

ASNT - American Society for Nondestructive Testing

ASTM - American Society for Testing and Materials

BNCS - ASME Board on Nuclear Codes and Standards

BWR - boiling-water reactor

BWROG - Boiling Water Reactors Owner's Group

candidate UT/ISI system - The ultrasonic (UT) personnel/equipment/ procedure combination attempting performance validation. UT/inservice inspection (ISI) subsystem refers to one or two of these three elements (personnel, equipment, and/or procedure).

defect - One or more discontinuities whose aggregate size, shape, orientation, location, or characteristics do not meet specified acceptance criteria.

discontinuity - An interruption (either intentional or unintentional) in the normal physical structure or configuration of a material or component.

EPRI - Electric Power Research Institute

evaluate - Determine the acceptability of relevant ultrasonic indications with respect to the applicable acceptance criteria.

false call - Interpreting an ultrasonic indication to be from a flaw when no flaw exists.

false indication - An ultrasonic response that is interpreted to be caused by a flaw when no flaw exists.

flaw - A defect, fabricated discontinuity, or other imperfection in materials, components, or structures (includes service-induced flaws). A flaw is not necessarily rejectable (see "defect").

flaw characterization - The process of estimating the size, shape, orientation, location, or other properties of a flaw based on its ultrasonic response.

IEB - Inspection and Enforcement Bulletin

IGSCC - intergranular stress corrosion cracking indication - The response(s) obtained during an ultrasonic examination.

interpret - To classify ultrasonic indications with respect to relevance.

MC - ASME Main Committee

MRR - mini-round robin

NDE - nondestructive examination

NDT - nondestructive testing

nonrelevant indication - An indication that is either a false indication or is caused by a condition or discontinuity type that is not potentially rejectable.

NRC - Nuclear Regulatory Commission

performance validation - For candidate ultrasonic inservice inspection systems, the process of demonstrating the capability to achieve a specified flaw recording probability, probability of flaw detection, and/or flaw characterization accuracy.

PISC I - Plate Inspection Steering Committee

PISC II - Program for the Inspection of Steel Components

PIRR - pipe inspection round robin

PNL - Pacific Northwest Laboratory

probability of detection (POD) - The probability that the ultrasonic inservice inspection system response from a given flaw will be detected and correctly interpreted as a signal caused by a flaw.

PSI - preservice inspection

PTCC - Personnel Training and Certification Committee

PVRC - Pressure Vessel Research Committee

qualification process - Includes all activities required to set up, demonstrate, and evaluate the performance validation of a an ultrasound inservice inspection system.

RIL - Research Information Letter

SGNDE - Subgroup on Nondestructive Examination

SUTARS - search unit tracking and ranging system recording probability (RP) - The probability that the ultrasonic inservice inspection system response from a given flaw will be correctly recorded.

relevant indication - An indication that is caused by discontinuities or conditions that are potentially rejectable.

ultrasonic testing/inservice inspection (UT/ISI) - All of the ultrasonic examination activities specified in the American Society of Mechanical Engineers (ASME) Section XI and the U.S. Nuclear Regulatory Commission (NRC) regulations, including preservice (baseline) examinations.

UT - ultrasonic testing

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It is appropriate to recognize that this work was motivated by prior results from parametric and round-robin testing conducted under the NDE Reliability Program; an NRC-sponsored program performed by PNL. The philosophy and recommendations discussed in this report were also influenced by our participation in various ASME Code, ASNT, and ASTM activities. Significant among these were the numerous meetings of the ASME Ad Hoc Task Group and, later, the discussions of this subject by the Section XI Subgroup on Nondestructive Examination and its two Working Groups. In addition, involvement in the ASNT Personnel Training and Certification Committee (PTCC), the Ad Hoc SNT-TC-1A Rewrite Committee, and various subcommittees of the ASTM E-7 Committee on Nondestructive Testing also influenced our views in this area.

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QUALIFICATION PROCESS FOR ULTRASONIC TESTING
ON NUCLEAR INSERVICE INSPECTION APPLICATIONS

1.0 INTRODUCTION

This report documents a task conducted by the Pacific Northwest Laboratory (PNL)[a] under a U.S. Nuclear Regulatory Commission (NRC)-sponsored program entitled "Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors" (NDE Reliability Program). The objective of this task was to develop, analyze, and recommend evaluation parameters and processes for qualifying the personnel, equipment, and procedures used for ultrasonic testing/inservice inspection (UT/ISI) of nuclear power plant components. The overall qualification process is intended to achieve statistically designed performance validation demonstrations. Also included are recommendations for prerequisite training and other aspects of the qualification process, as well as recommendations for implementation.

The document also contains recommendations for the test specimens, environment, and other conditions under which the qualification processes should be conducted. Implementation of the process discussed herein requires that all NDE personnel performing UT/ISI satisfactorily complete a performance validation/demonstration involving representative test specimens containing simulated or actual flaws.

This report reviews the background and need for this activity within the nuclear industry and identifies the technical issues that are addressed. The scope of this task is outlined, and the overall qualification process is discussed with respect to specific needs for qualification and performance validation. Existing requirements, and the assumptions and concepts upon which these recommendations are based, are also described.

A major goal of this effort has been to develop UT/ISI qualification criteria that are both relevant and meaningful. The need to maintain an intrinsic applicability of these evaluation parameters to both existing and future UT/ISI systems, as well as potential applicability to other nondestructive testing (NDT) applications performed in accordance with the rules of ASME Section XI, has been a guiding influence throughout this effort.

Evaluation of nuclear power plant integrity is strongly dependent on reliable detection and accurate sizing of flaws. Hence, the qualification process described in this report includes performance demonstrations that validate the flaw detection probability and characterization accuracy of candidate UT/ISI systems. In this context, the term "performance validation" is used extensively throughout this document.

(a) PNL is operated for the U.S. Department of Energy by Battelle Memorial Institute.

The key definitions and abbreviations used in this report are listed in the Glossary. Since a significant fraction of the effort within this task was devoted to active participation in relevant industry and American Society of Mechanical Engineers (ASME) Code activities, Section 2 summarizes and discusses prior and concurrent industry and ASME Code activities. Section 3 describes and discusses the recommended qualification process and addresses recommendations for personnel, equipment, procedures, and overall system performance validation. Requalification is described in Section 4, and the modification of qualified procedures is addressed in Section 5. Section 6 describes the philosophy and recommendations for the test specimens, flaws, performance factors, and other parameters that affect the performance demonstrations. Section 7 compares the qualification processes recommended in this document with the existing industry documents. The appendixes provide relevant documentation and discuss recommendations for the agencies that conduct training and qualification and performance validation.

1.1 BACKGROUND AND NEED

Nuclear ISI experience, round-robin tests of overall inspection reliability, plant aging and life-extension considerations, and evaluations of the flaw detection reliability necessary to achieve specific failure probabilities for certain nuclear power plant components have received focused attention because of the need for improving UT/ISI reliability. This background experience includes

- The inability to detect intergranular stress corrosion cracks (IGSCC) in the primary piping at the Nine Mile Point Power Plant. This incident caused the NRC to mandate specific performance capability demonstrations (NRC Inspection and Enforcement Bulletin [IEB] 82-03, 1982; NRC IEB 83-02, 1983).

- Additional incidents where UT/ISI failed to detect, or incorrectly sized, cracks in the piping systems of boiling-water reactors (BWRs) (NRC 1984).

- The discouraging flaw detection and sizing performance, plus the large variability between procedures, that were observed during national and international studies coordinated by the Pressure Vessel Research Committee (PVRC), Plate Inspection Steering Committee (PISC I), and the Programme for the Inspection of Steel Components (PISC II) (Chockie 1980; Commission of the European Communities 1979; Commission of the European Communities 1986).

- The equally discouraging UT/ISI performance measured during the Pipe Inspection Round Robin (PIRR) (summarized in Doctor et al. 1984) and the Mini-Round Robin (MRR) (summarized in Taylor et al. 1990 and detailed in Taylor et al. 1990) that were conducted at PNL under NRC sponsorship.[a]

(a) Detailed information will be published in 1990: Heasler, P. G. and S. R. Doctor. Piping Inspection Round Robin. NUREG/CR-5068, PNL-6356, Pacific Northwest Laboratory, Richland, Washington.

- During implementation of IEB 83-02 at the Electric Power Research Institute (EPRI) NDE Center, the pass/fail statistics over a two-year period showed only a 40% pass rate during the first attempt and an overall 70% pass rate (including repeated attempts) (Stephens 1986). This activity was only applicable to near-side UT of wrought austenitic stainless piping welds to detect IGSCC.

- Subsequent "requalification program" statistics for IGSCC detection in wrought stainless steel piping specimens showed that only 39% of some 300 IEB 83-02 qualified candidates could "requalify" during their initial attempt (Edelman, Sasahara, and Taylor 1987). The requalification test required that 8 out of 10 possible cracks be detected and included a penalty for false calls. (In contrast, the initial performance demonstration program at the EPRI NDE Center required detection of 4 out of 5 cracks with virtually no penalty for false calls).

- Verified incidents of false calls (i.e., misinterpreting geometric and/or metallurgical reflectors to be flaws) during ISI of piping to detect IGSCC.

On the basis of the experience described above, it appears that the overall effectiveness of the personnel, equipment, and procedures used for UT/ISI is inadequate to guarantee reliable ISI of nuclear power plants. Even when the UT/ISI system elements (personnel, equipment, and procedures) appear individually adequate for a given task, round-robin tests of overall inspection effectiveness consistently reveal wide variations in performance (whether the participants are teams or individuals and whether the UT equipment is conventional or "advanced") (Commission of the European Communities 1986; Heasler et al. 1987).

In view of the preceding, the NRC Office of Nuclear Regulatory Research included in its NDE Reliability Program at PNL the task of reviewing, evaluating, and developing recommendations for an improved qualification process. Although a general upgrading of qualification requirements does not automatically ensure more effective field inspections, it does increase the intrinsic capability for a reliable inspection and intensifies the awareness of field inspection personnel to the significance of their work. This report documents that activity and discusses the recommended process for qualifying the three essential UT/ISI elements (personnel, equipment, and procedures).

1.2 TECHNICAL ISSUES

The following technical issues are addressed in this report:

- The reliability of nondestructive testing/inservice inspection (NDT/ISI) as it applies to
  - BWR pipe cracking (IGSCC problem)
  - piping with weld overlay (IGSCC repair)

- inspection of pressure vessels including clad and underclad areas and nozzles

- the UT/ISI of dissimilar metal welds and cast materials.

- NRC Piping Review Committee Recommendation A-2 in NUREG-1061 (Volume 5) as quoted (in part) below (NRC 1984b)

> Development of advanced techniques and procedures for crack detection and depth sizing should continue for incorporation into Code requirements. Included should be analysis of the human factors, equipment qualification and certification, and inspection techniques for detecting and dimensioning flaws....

1.3 SCOPE AND OBJECTIVES

The scope of this task included the following:

- Develop a working draft document on recommended qualification processes for ultrasonic testing on nuclear inservice inspection applications.

- Review revised document with various NRC offices and conduct workshops with industry to obtain input from a cross section of the cognizant technical community representing the nuclear industry, ASME Code, and regulatory interests.

- Iteratively revise the working draft document, as appropriate, to reflect the input obtained from industry and the NRC.

- Actively participate in an ASME Section XI Ad Hoc Task Group formed in response to an industry recommendation from the second workshop.

- Continue the active involvement of PNL personnel in the ASME Section XI Subgroup on Nondestructive Examination (SGNDE) and its two working groups.

The overall objective of this extended effort has been to develop recommended processes for qualifying UT/ISI systems toward improving the reliability of inservice inspection of the nuclear power plant components covered by ASME Section XI.

The qualification processes described in this report are intended to address the following needs:

1. Qualification processes that are potentially applicable to all UT/ISI required by ASME Section XI; not just the inspections performed to detect IGSCC in BWR piping.

2. Performance validation processes that provide an accurate measure of UT/ISI flaw detection and flaw sizing capability, as well as false call probability.

3. Quantification of the combined performance of the personnel, equipment, and procedures used for UT/ISI based on actual flaw types rather than machined discontinuities.

4. Nationally uniform written examinations to ensure a baseline technical capability for the Level II and III personnel that perform UT/ISI.

5. National registry of qualified personnel and procedures.

6. Coordination and administration of the entire qualification process on a national basis, rather than on an individual employer basis.

7. Inherent applicability to both existing and future UT/ISI systems, as well as to all NDT/ISI performed in accordance with the rules of ASME Section XI (ASME 1975).

With the exception of bolting, none of the pre-1987 ASME Section XI requirements explicitly specified a minimum capability for detecting and/or characterizing flaws or a demonstration of that capability. Evaluation of nuclear power plant component integrity is strongly dependent on reliable flaw detection and accurate characterization (i.e., flaw sizing). Hence, the qualification process described in this report includes performance demonstrations to validate the flaw detection probability and flaw characterization accuracy of candidate UT/ISI systems.

1.4 EXISTING REQUIREMENTS, ASSUMPTIONS, AND CONCEPTS

The following discussion applies to the relevant requirements, assumptions, and concepts as they existed prior to final Code committee approval of proposed Mandatory Appendixes VII and VIII to ASME Section XI.

1.4.1 Existing Requirements

The previously applicable requirements within the nuclear industry are summarized below.

1. Personnel. The applicable qualification criteria were described in SNT-TC-1A as supplemented by ASME Section XI (see Section 2). Personnel had to be certified by their employer, and SNT-TC-1A implied (but did not explicitly require) application-specific training. Written examinations (covering both general principles and specific applications) and a practical examination (demonstrating the ability to perform general UT examinations) 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, but no training of Level III personnel was required.

2. Equipment. Ultrasonic instruments and search units had to meet the ASME Section V and XI requirements regarding vertical response linearity and attenuator linearity, and the capability for calibrating the instrument. Other critical electronic performance characteristics were not addressed in Sections V and XI, or their references.

3. Procedures. Ultrasonic examination procedures had to be based on the applicable edition of ASME Section XI, but could be (and often were) quite generic with respect to several critically important variables (see Section 3.3 of this document).

1.4.2 Assumptions and Concepts

The recommendations provided in this report reflect the following assumptions:

1. The current prerequisites (qualification requirements) for conducting UT/ISI in accordance with ASME Section XI are not adequate.

2. The qualification criteria should address the equipment and procedures to be used for UT/ISI, in addition to the NDT personnel.

3. The examination processes and criteria used to assess the technical qualifications of personnel that perform UT/ISI should be nationally uniform.

4. Periodic training should be mandatory for all NDT personnel to introduce new requirements, equipment, and procedures and to mitigate the effects of technological obsolescence.

The controlling document for certifying NDE personnel is generally referred to as SNT-TC-1A which is published by the American Society for Nondestructive Testing (ASNT 1975, 1980, 1984). The major limitations of SNT-TC-1A are: 1) the absence of requirements for periodic training to maintain/upgrade technical skills; 2) insufficient baseline competence criteria such as type of experience, education, and quality of training and the lack of specific training requirements for Level III personnel; and 3) the qualification and certification of NDT personnel is the exclusive responsibility of each employer; hence, significant variations in the minimum technical competence for NDT personnel exist throughout U.S. industry. Furthermore, SNT-TC-1A does not address the qualification of equipment and procedures.

The concepts listed below were developed to address the inherent limitations of SNT-TC-1A, as well as shortcomings in the ASME Section XI rules pertaining to the qualification of NDT personnel.

1. uniform compliance with, as well as uniform implementation of, the applicable requirements

2. nationally uniform training and qualification processes including

   a. recommended criteria for NDE training and qualification agencies

   b. recommended criteria for NDE performance validation agencies

3. upgraded criteria for NDT Level III personnel

4. qualification criteria for NDT instructors

5. mandatory periodic training (especially the "hands-on" type of training)

6. application-specific training and performance validation processes involving

   a. representative test specimens (part configurations, origin, fabrication variables, flaw types, and quantity)

   b. statistically designed performance validation tests

7. national registry of qualified Level II and Level III personnel

8. electronic characterization of UT equipment parameters

9. realistic requalification criteria and intervals

10. the use of qualified UT/ISI systems (personnel/equipment/procedures) for conducting the ultrasonic examinations specified in ASME Section XI

11. qualification processes that can be extended to all of the NDE methods and systems used for ISI and preservice inspection (PSI).

2.0 HISTORY AND STATUS OF ISI QUALIFICATION

This section reviews the recent history and status of ISI qualification activities in the U.S. It also reviews relevant activities and documents issued by organizations such as the American Society for Nondestructive Testing (ASNT), the ASME boiler and pressure vessel committees, and the electric utility industry. Interactions between the PNL/NRC activities and the various committee and industry activities are also reviewed and discussed.

The activities at PNL began when the NRC-funded NDE Reliability Program was started in 1978. Part of the focus of this work was to develop means to fabricate laboratory samples containing machined reflectors and service-induced type degradation and to conduct a series of measurements to assess the influence of flaw characteristics (i.e., roughness, tightness, and orientation) on UT/ISI reliability. The results of this work were reported by Becker et al. (1981). These studies on the influence of flaw parameters were very revealing and large variations in the UT response were found as a function of the flaw characteristics. The work included ferritic steel, wrought austenitic stainless steel, and centrifugally cast stainless steel. The stainless steels tended to compound the inspection problem due to their higher attenuation and beam distortion effects. As a consequence of this work, the NRC Office of Nuclear Regulatory Research issued a Research Information Letter (RIL) to summarize and highlight these important results for rapid access by the NRC staff. This RIL was issued in January 1981 as RIL #113, "Reliability of Inservice Inspection for Primary Piping Systems" (see Appendix A). In particular, paragraph 4.2.8 stated

> It is expected, due to the range of inspection variables involved, that the most suitable method for assuring effective inspection of austenitic or dissimilar metal welds, will be through a program for procedure and personnel qualification. Guidelines and requirements for such a program are under investigation. It is expected that samples containing artificial as well as defects typical of those found in service will be required. Specific qualification requirements and methods of defect fabrication are currently under investigation....

This defined the major thrust of PNL's NDE Reliability Program effort for the following years. A round robin was conducted to further evaluate the reliability of procedures, equipment, and personnel to detect and size thermal fatigue cracks in ferritic, wrought austenitic, and centrifugally cast stainless steel piping, and intergranular stress corrosion cracking in wrought austenitic stainless steel pipe (Doctor et al. 1982). This round robin further demonstrated the extreme variability of inspection results with personnel using similar equipment and procedures. During the round-robin tests, the inspectors were observed and the actual scanning was monitored with a search unit tracking and ranging system (SUTARS) to determine the specimen coverage and signal in the locations where defects existed. From this study, it was apparent that an effective procedure and good equipment must be employed. Furthermore, the personnel had a significant effect on the outcome of the inspection. Thus, it became apparent that any useful qualification process must include both the procedures and equipment, as well as the personnel.

The requirements for qualifying and certifying NDT personnel are uniform (in principle) throughout the nuclear industry. The controlling document, SNT-TC-1A, was initially published by the ASNT in 1968 and was revised in 1978, 1980, 1984, and 1989. This document is entitled "Personnel Qualification and Certification in Nondestructive Testing" (ASNT 1975, 1980, 1984). Although SNT-TC-1A is a "recommended practice" document, most of its contents have become mandatory requirements throughout the nuclear industry by virtue of the way in which it is invoked by the ASME Code. The major limitations of SNT-TC-1A are 1) the lack of usable baseline competence criteria for Level III personnel, 2) the absence of requirements for periodic training to maintain/upgrade technical skills, 3) the absence of explicit training requirements for Level III personnel, and 4) the qualification and certification of NDT personnel is the exclusive responsibility of each employer; hence, significant variations in minimum technical competence exist throughout the industry for all levels of NDT personnel. Furthermore, the qualification of NDE equipment and procedures is not addressed in SNT-TC-1A; these topics are outside the scope of this document.

In 1983, an ad hoc committee of the electric utility industry prepared a modified version of SNT-TC-1A entitled "NUC-MR-1A, Minimum Requirements for Qualification and Certification of Nondestructive Examination Personnel for the Nuclear Power Industry." This document was developed and proposed as a replacement for SNT-TC-1A for NDE applications conducted in accordance with the rules of ASME Section XI. Although this document was formally submitted to the NRC in August 1983, it was not adopted by the NRC and its use to date has been limited to occasional voluntary implementation by individual utilities. While many of the SNT-TC-1A guideline criteria were upgraded to some extent, the major difference between the two was that NUC-MR-1A specified minimum requirements, rather than guidelines, and it also included an additional section entitled "Qualification for Special Applications." In principle, this section should have corrected a serious deficiency in the SNT-TC-1A qualification criteria. However, when NUC-MR-1A was published, this section simply stated that

> When circumstances require the demonstration of additional examination capabilities, the Level III examiner shall determine the need for qualification of personnel for such special applications.

The NUC-MR-1A document also specified that the Level III examiner was to be responsible for assuring that the personnel received sufficient training and demonstrated their performance using one or more flawed samples. This requirement was addressed in NUC-MR-1A as follows:

> When special techniques and/or equipment are required for specific examinations, the personnel performing the examination shall receive training and be qualified to the satisfaction of the Level III.

Although documented evidence of such qualifications was to be maintained by the employer, this requirement also fell far short of the recognized need.

In 1983, a workshop organized by the NRC and PNL was held in Seattle, Washington to review and discuss working draft #1 of a document entitled "Qualification of Ultrasonic Testing for Nuclear Inservice Inspection Applications." The meeting attendees included representatives from the utilities, commercial inspection organizations, authorized inspection agencies, and various NRC offices. In addition to discussions of the draft document, a dialogue was established with industry regarding the need, philosophy, and approach for qualification of UT/ISI systems. Although the controversial nature of this important subject was quite evident, this two-day meeting proved to be very productive. The input obtained during this workshop provided the basis for extensive revisions to the document resulting in working drafts #2 and #3.

In October 1984, working draft #3 of the proposed qualification document was reviewed and discussed extensively during a meeting of the NRC's NDE Research Review Group and other interested NRC staff in Bethesda, Maryland. Agreement and support was received at this meeting for the concepts and recommendations outlined in working draft #3. 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 purpose was to review the contents of the document, obtain technical input, and advise the attendees of the NRC staff's intent to develop a regulatory guide on NDE system qualification based on the recommendations of the document. There was agreement by the industry, Code, and NRC representatives present 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 the ASME Section XI Code committees should review the document and develop qualification requirements on a priority basis in lieu of NRC issuing a regulatory guide. It was recommended that this action be undertaken by the ASME Section XI 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 used to perform ISI in nuclear power plants.

Consequently, ASME Section XI authorized an Ad Hoc Task Group to address this action in late November 1984, and the Ad Hoc Task Group was organized under the ASME Section XI SGNDE in December 1984. Three separate subtask groups were established 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, the Ad Hoc Task Group met seven times and the subtask groups each met 10 times. The collective output of this Ad Hoc Task Group was a proposed mandatory appendix (identified as Appendix VII) to ASME Section XI. This document addressed items 1) and 2) above, but not 3). This document was formally approved for submission to the SGNDE in February 1986 and is reproduced in its entirety in Appendix B of this report. The Ad Hoc Task Group mailing list is also included in Appendix B.

During the April 1986 SGNDE meeting, a decision was made to submit two of the three parts of Appendix VII as separate Code Cases and to temporarily discontinue work on Appendix VII as an overall entity. The two proposed Code Cases separately addressed the requirements for a) training and qualification of personnel, and b) performance demonstrations. Work on the third part, relating to implementation, was discontinued.

In October 1986, the SGNDE approved both Code Cases for submittal to Section XI. During that same Code meeting, the Section XI Subcommittee approved submittal of these Code Cases to the ASME Main Committee (MC). Concurrently, the SGNDE chairman assigned the task of transforming the content of the Code Cases into the ASME Section XI rules to the two SGNDE working groups. The issue of industry implementation of the requirements specified in the two proposed Code Cases received essentially no direct attention by the SGNDE. During the next meeting, the SGNDE voted to withdraw these two Code Cases from SC-XI and MC consideration pending a strategy decision (i.e., Code Cases vs. Mandatory Appendixes).

In April 1987, the SGNDE decided to discontinue all work on the two-Code Case approach, and instead convert these documents into two proposed Mandatory Appendixes. Proposed Appendix VII entitled "Qualification of Nondestructive Examination Personnel for Ultrasonic Examination" was approved by the SGNDE in August 1987, by the SC-XI Subcommittee in January 1988, by the ASME Code Main Committee in May 1988, and by the ASME Board on Nuclear Codes and Standards (BNCS) in October 1988. This document was published as Appendix VII to ASME Section XI in the Winter 1988 Addenda, which was issued in early 1989 to all holders of the 1986 Edition of the ASME Code.

Proposed Appendix VIII entitled "Performance Demonstration for Ultrasonic Examination Systems" was first approved by the SGNDE in November 1987 and again in January 1988. However, on both occasions, the approval motion was almost immediately rescinded for administrative reasons. Subsequently, Appendix VIII was approved both by the SGNDE and the SC-XI Subcommittee in April 1988, and by the MC in February 1989. The proposed Appendix VIII received BNCS approval in mid-1989 and is expected to be published in the 1989 Addenda to ASME Section XI, which will be published in early 1990.

A number of changes, compared to the Ad Hoc Task Group's 1986 Appendix VII, were made in the final Appendices VII and VIII as detailed in Section 7.

Concurrently, a major revision to Code Case N-409 (N-409-1 now N-409-2) to incorporate and enhance the NRC/industry practice for UT piping examination performance demonstrations had been approved by the entire ASME Code review process and was published in February 1988. This Code Case change imposes additional requirements beyond the BWROG/NRC/EPRI Coordination Plan process now in effect at the EPRI NDE Center. The current EPRI NDE Center process only qualifies UT/ISI personnel to detect and size IGSCC indications in BWR piping systems. This action was perceived as an interim accomplishment as well as a notable precedent for the ASME Code rule-making process. The requirements in N-409-2 described important improvements to the existing ASME Section XI requirements and provided improved, referenceable requirements and criteria compared to the BWROG/NRC/EPRI Coordination Plan process in effect through the EPRI NDE Center. These improvements were as follows.

1. The requirements for performance demonstration for UT/ISI for piping were in IEB 83-02 and NUREG-0313, Rev. 2. However, neither document contained guidance for conducting a performance demonstration. Nor does the BWROG/NRC/EPRI Coordination Plan provide guidance for conducting performance demonstrations. Code Case N-409-2 was the first available document to provide referenceable requirements and criteria for conducting performance demonstrations for both flaw detection and flaw sizing.

2. The performance demonstrations conducted at the EPRI NDE Center were designed specifically for IGSCC detection. Code Case N-409-2 provided more extensive requirements that included all ultrasonic piping examination applications.

3. The performance demonstration activities at the EPRI NDE Center did not provide requirements for controlling or qualifying procedures (only personnel were qualified; procedures were not). Code Case N-409-2 provided explicit requirements for procedures, personnel, and equipment. Code Case N-409-2 also provided controls inhibiting unlimited revisions to qualified procedures (i.e., essential equipment variables and calibration requirements).

4. Code Case N-409-2 provided explicit requirements for evaluating performance demonstrations (both grading and pass/fail criteria). The EPRI NDE Center program did not provide referenceable, binding requirements for evaluating performance demonstrations.

5. Code Case N-409-2 provided explicit requirements pertaining to the specimens used in performance demonstrations; whereas, the EPRI NDE Center program did not. As an example, N-409-2 specifies that test specimens must cover the range of piping diameters and schedules from the minimum to the maximum size applicable to the procedure being qualified. N-409-2 also contains guidance for specimen geometry, as well as defect types and sizes.

6. Code Case N-409-2 is more stringent since the grading units for false calls and cracks are based on a 3-inch grading unit rather than the 1-inch grading unit used at the EPRI NDE Center. The larger grading unit provides more accurate measurement of the defect detection rates and false call rates by reducing the effects of "testmanship."

Code Case N-409-2 was developed with extensive industry input over a 4-year period. Industry recognized the need for improvements and supported the improvements contained in this Code Case. It is generally recognized that Code Case N-409-2 has increased the performance demonstration requirements to more technically acceptable levels, and provided an enforceable set of requirements and criteria to govern the conduct of performance demonstrations.

Although Code Case N-409-2 was a step forward, it did not pertain to all ISI applications and it was not mandatory. Code approval and publication of Appendices VII and VIII were sorely needed, and they now provide a basis for thorough and technically encompassing mandatory requirements.

3.0 RECOMMENDED QUALIFICATION PROCESS FOR UT/ISI SYSTEMS

This section describes recommendations for qualifying ultrasonic testing/inservice inspection (UT/ISI) systems prior to performing UT/ISI on nuclear power plant components. The process described herein is intended to assure minimum acceptable levels of UT/ISI capability, and performance validation demonstrations are recommended for specific plant applications. The recommended process requires that 1) all UT personnel, equipment, and procedures be qualified; and 2) the qualification include successful completion of a statistically designed performance validation/demonstration.

The recommended qualification process should include the following

1. Training in accordance with the applicable sections of SNT-TC-1A with respect to topical content and training hours, and prerequisite experience in accordance with the applicable sections of SNT-TC-1A.

2. Certification to Level I, II, or III status (as applicable) in accordance with SNT-TC-1A.

3. Additional, nationally uniform training as described herein.

4. Participation in the application-specific performance demonstration process described in Section 6.

The need for limited qualification is recognized (e.g., an individual may be qualified to interpret UT indications, but not to characterize (e.g., size) those indications that are interpreted to be flaws).

This document also contains recommendations for designing and conducting "blind test" performance validations to qualify the capability of candidate UT/ISI systems. Statistical analysis of the performance validation process is patterned after a previously published report (NUREG/CR-4464) that provides detailed guidance on this subject (Heasler et al. 1986).

The qualification process for personnel is described in Section 3.1, the qualification process for equipment is described in Section 3.2, the qualification process for procedures is described in Section 3.3, the UT/ISI system performance validation process is described in Section 3.4, and the termination of qualifications is described in Section 3.5.

3.1 PERSONNEL

All NDT Level I, II, and III personnel that perform UT/ISI should periodically attend nationally uniform training courses that strengthen the basic technical competence and enhance the individual skills required to perform UT/ISI applications. The existing course outlines currently recommended by ASNT are generally adequate, but the quality of the actual training given should be upgraded. In addition, a significant portion of the time spent on training should consist of "hands-on" laboratory training using realistic specimens or actual plant components. Recommended criteria for personnel training and qualification agencies are described in Appendix C.

3.1.1 Level I Personnel

All Level I candidates should be certified in accordance with SNT-TC-1A and, in addition, should successfully complete at least 20 hours of application oriented classroom and laboratory (hands-on) training during the six months prior to participating in a performance validation and annually thereafter.

3.1.2 Level II Personnel

All Level II candidates should be certified in accordance with SNT-TC-1A and, in addition, should successfully complete at least 40 hours of application oriented classroom and laboratory (hands-on) training during the six months prior to participating in a performance validation and annually thereafter.

3.1.3 Level III Personnel

All Level III candidates should be certified in accordance with SNT-TC-1A and should hold a valid ASNT Level III certificate for the ultrasonic testing (UT) method. In addition, all Level III candidates should successfully complete at least 40 hours of application oriented classroom and laboratory (hands-on) training during the six months prior to participating in a performance validation and annually thereafter.

3.1.4 NDE Instructors

Candidates being considered for qualification as an NDE Instructor should be qualified, but not necessarily employer certified, as a Level III in the ultrasonic method in accordance with SNT-TC-1A. The candidate should hold a valid ASNT Level III certificate for the ultrasonic testing (UT) method, and should possess documented evidence to comply with one or both of the following

a. A current teacher or vocational instructor certificate issued by a state, provincial, or federal authority.

b. Successful completion of at least forty (40) hours instruction in training and teaching techniques.

3.1.5 Training Courses

Nationally uniform training courses should be developed and administered on an industry-wide basis (see Appendix C). All NDT personnel should attend and successfully complete the appropriate training course(s), relative to their area of qualification, prior to participating in the performance validations described herein and annually thereafter. When upgrading from Level I to Level II, or from Level II to Level III, successful completion of the applicable training course(s) is recommended.

The training courses should include both classroom and hands-on training and should emphasize current UT/ISI applications and problems. Training should address both fundamental contemporary topics such as the influence of stainless steel cladding, the O.D. and I.D. geometric configurations of piping and fittings; UT techniques for austenitic and dissimilar metal welds, etc.; the currently applicable codes, standards, and regulatory requirements; the characteristics and expected locations of flaws occurring in nuclear power plants; and the UT/ISI equipment and systems that are in general use within the nuclear industry.

Quizzes and examinations should be used to evaluate comprehension of the training material. A nationally uniform, final examination should be given and a course grade recorded for each candidate.

Additional training should be required when a candidate fails a final course examination. The extent of the additional training should be determined by the NDE Instructor based on the areas of weakness exhibited by the candidate.

3.1.6 Experience

Personnel being considered for UT/ISI qualification should have sufficient experience to assure the needed skills. Table 3.1 lists recommended minimum experience for initial qualification. As used herein, experience means actual performance of the activities described in SNT-TC-1A for the applicable NDT Level.

The two experience options listed in Table 3.1 for qualification as a Level III are as follows

Option 1: Graduate of a four-year accredited engineering or science college or university with a degree in engineering or science plus two years experience in nondestructive examination with responsibilities at least equivalent to those of an NDE Level II. At least one year of this experience should be in nuclear applications involving the ultrasonic examination method.

Option 2: Successful completion of at least the equivalent of two full years of engineering or science study at a university, college, or technical school plus four years experience comparable to that of a Level II in the ultrasonic examination method. At least two years of this experience should be in nuclear applications including the ultrasonic examination method, and should include the actual performance of examinations and the evaluation of examination results.

Experience gained during previous employment, or with the current employer, prior to certification under a program based on these recommendations may be accepted toward meeting the minimum experience requirements where such experience is supported by documentation. Such documentation should be a copy of an experience record from the employer or a written statement signed by a Level III on the employer's staff attesting to the type and extent of

TABLE 3.1. Recommended Minimum Experience in Months for Initial Qualification in Ultrasonic Examination

Trainee	Level I	Level II	Level III
None	3	9	24/12 (Option 1) 48/24 (Option 2)

Notes to Table 3.1:

1. For Level II qualification, the experience should consist of time at Level I. To qualify a candidate directly to Level II with no time at Level I, the total months of experience required for Level I plus Level II should apply.

2. When exercising the options for Level III which relate to education and experience (e.g., Option 1: 24/12), the first figure specifies the total experience, and the second figure specifies the amount of experience involving nuclear applications. Prior certification as a Level I or Level II is not required.

3. The experience (in months) shown in the table is based on a normal 40-hour workweek (173 hours per month). When work is performed in excess of a 40-hour week, credit for experience may be based on total hours.

4. The simultaneous experience provision in SNT-TC-1A is not applicable.

experience to be credited, and must be accepted by the cognizant current employer's Level III.

3.2 EQUIPMENT

Only equipment models that have been qualified as recommended herein should be used for UT/ISI applications (see Sections 3.4 and 6). Qualification for selected UT operations or portions of UT operations is permitted.

Automated UT/ISI equipment should successfully complete a performance validation meeting the same criteria as for manual UT techniques for those operations or functions that are automated. Automated operations or functions that have not been qualified should not be used for UT/ISI applications. Such qualified, or partially qualified, automated equipment should only be used in the mode and configuration that has been qualified (i.e., the scan coverage, beam angles, wave modes, recording processes, pattern recognition algorithms, discrimination training sets, etc. must be the same as those used during the performance validation test).

Equipment models that have been used during a successful performance validation in accordance with 3.4 should be regarded as qualified with respect to the criteria described herein. Such qualifications are limited to those

UT/ISI operations or functions, and those UT/ISI applications, that were successfully accomplished during the performance validation(s).

Equipment models that have been qualified in accordance with this document should be electronically characterized in accordance with Section 4 and the results documented.

At least annually, before and after each period of extended use at each plant site, and at the discretion of the cognizant Level III, each equipment item should be electronically characterized to assure conformance with the criteria described in Section 4. These measurements should be performed at the plant site to the maximum practicable extent. Equipment items found to be performing outside a specified tolerance should not be used for UT/ISI applications until repaired/replaced and shown to be performing within the criteria/tolerances described in Section 4.

3.3 PROCEDURES

Prior to the performance validation, a written examination procedure (EP) should be submitted to the performance validation center for review (see Appendix D). The EP should contain a statement of scope that specifically defines the limits of procedure applicability. The EP should specify a single value or a range of values for the listed variables. The procedure qualification test should demonstrate that acceptable performance can be achieved using the essential variables listed in the examination procedure including, where applicable, the minimum and maximum values. Any change in an EP that causes an essential variable to exceed a qualified range should cause the examination procedure to be requalified. Within the context of this document, any two procedures whose essential variables are the same (within the specified tolerances) are considered to be the same specific examination procedure. The examination procedure should specify the following essential variables

1. instrument or system, including manufacturer and model or series of pulser, receiver, and amplifier

2. search units, including

   a. center frequency and either bandwidth or waveform duration as defined in 5.3.3
   b. mode of propagation and nominal inspection angle
   c. number, size, shape, and configuration of active elements

3. wedges or shoes, including

   a. size
   b. configuration

4. search unit cable, including

   a. type
   b. maximum length

c. maximum number of connectors

5. couplant material

6. technique parameters, including

   a. scan pattern and beam directions
   b. maximum scan speed
   c. minimum allowable beam overlap
   d. minimum and maximum pulse repetition rate
   e. minimum sampling rate (automatic recording systems)
   f. extent of scanning and action to be taken for access restrictions

7. calibration methods including all those actions required to assure that the sensitivity and accuracy of the signal amplitude and temporal outputs of the examination system (whether displayed, recorded, or automatically processed) are repeated from examination to examination. Any method of achieving system calibration is acceptable; however, a description of the calibration process should be included in the procedure.

8. minimum data to be recorded

9. method of data recording and recording equipment (strip chart, analog tape, digitizing), if used

10. method, logic, and criteria for the discrimination of indications (e.g., geometric versus flaw) and for sizing the length and depth of flaws, including the name and revision of data analysis software for computer-based systems

11. surface condition requirements

Changes to any of the variables listed above may be made without requalification provided such changes satisfy the criteria described in Section 4.

3.4 <u>UT/ISI SYSTEM PERFORMANCE VALIDATION</u>

All UT/ISI systems that are used to examine nuclear power plant components in accordance with ASME Section XI should successfully pass a performance validation test that satisfies the recommendations described in Section 6. These prerequisite requirements should apply to all UT/ISI systems (personnel, equipment, and procedures) that scan welds and materials, record and/or interpret indications, size flaws, and re-examine welds and materials. One or more national qualification centers should be established to satisfy the need for uniformity and high quality in the important areas of a) training and qualification of UT personnel and b) performance validation of UT/ISI systems. Recommendations for the establishment and operation of facilities that could function as national qualification centers are provided in Appendices C and D.

For all manual UT/ISI applications and whenever the performance of automated UT/ISI equipment is dependent on an operator's NDT skills, the NDT personnel should be certified in accordance with SNT-TC-1A, successfully complete the appropriate training course(s), and successfully complete performance validation tests to qualify for those operations and/or activities they will perform during UT/ISI applications.

Personnel should be qualified for those examination activities they perform, such as system calibration, data acquisition, data analysis, flaw sizing, etc. Personnel should demonstrate their proficiency by successfully completing a performance validation using a specific examination procedure. Recommended criteria for performance validation centers are provided in Appendix D.

The performance validation criteria described herein do not apply to personnel whose involvement is limited to activities and practices that do not impact the UT/ISI results.

A national registry of Level II and Level III personnel whose qualifications satisfy the recommendations specified herein should be established and maintained. Procedures, equipment items, and equipment combinations that have successfully completed the performance validation process should also be uniquely identified in the national registry. This recommendation is consistent with the precedent established through implementation of IEB 83-02 and the subsequent NRC/EPRI/BWROG Coordination Plan.

3.5 TERMINATION OF QUALIFICATIONS

Personnel qualified to perform the UT/ISI applications specified herein should lose their qualified status when any one of the following are not met

- Successful completion of a performance validation test at five-year intervals.
- Successful completion of periodic training as follows:

Certification Level	I	II	III
Hours/year of training	20	40	40

- Responsible participation, during any twelve (12)-month period, in:
  - the performance of at least 80 hours of qualified UT/ISI examinations or
  - a successful performance validation test.

4.0 MODIFICATION OF QUALIFIED PROCEDURES

Modification of a qualified procedure to substitute or replace pulser(s), receiver(s), and search unit(s) should be permitted without requalification provided

4.1 Equipment with reject, damping, and/or pulse tuning have controls with discrete settings, and these settings are specified in the procedure.

4.2 The ultrasonic instrument has been characterized using the procedures described in Appendix E.

4.3 The requirements for the UT system (ultrasonic instrument and search unit) are evaluated as a single unit[(a)] and are separated into the following parameters.

4.3.1 Gain. The gain is accommodated by adjusting the system gain.

4.3.2 Bandwidth. The bandwidth must be controlled to within ±10% in order to ensure that the response does not vary by more than 2 dB.

4.3.3 Center Frequency. The center frequency must be limited to ±10% for systems with bandwidths greater than 28% and ±5% for systems with bandwidths less than 28%.

4.4 When the qualification test uses prerecorded data, algorithms for automated decisions may be altered if they can be demonstrated equivalent to those qualified by applying them to the data used for qualification. If the examination results so obtained meet the acceptance criteria of Appendix VIII to ASME Section XI, the algorithm may be considered equivalent.

4.5 Alternate calibration methods may be demonstrated equivalent to those described in the qualified procedure as follows

4.5.1 Calibrate the examination system components in accordance with the alternate methods.

4.5.2 Compare the alternate calibration state of the system with the qualified calibration state.

(a) The early PNL work involved a matrix of test measurements for which engineering judgement indicated that controlling a large number of equipment parameters would limit the variation resulting from equipment variables. This work was the basis for the requirements in ASME Code Appendix VIII. In recent, more extensive PNL modelling work to better understand the reason for the variations, it became apparent that some parameters could be controlled less stringently and others needed to be controlled more stringently. This results in the differences between these recommended requirements and those in Appendix VIII.

4.5.3 If the system sensitivity is within ±2 dB of that obtained by the qualified method, the alternate method is acceptable.

This demonstration of equivalence should be conducted for each beam angle and mode of propagation to be used during the intended ISI.

5.0 RECOMMENDED REQUALIFICATION PROCESS

The recommended requalification criteria for each element of the UT/ISI system are as follows.

5.1 PERSONNEL

Requalification by successful completion of a performance validation is recommended at five-year intervals for all Levels of NDT personnel. In addition, ASME Section XI requires that employer certification of personnel be conducted and maintained in accordance with SNT-TC-1A (ASME 1975; ASNT 1975, 1980, and 1984).

Personnel that have not participated in the performance of at least 80 hours of qualified UT/ISI examinations, or a successful performance validation, during the preceding twelve (12) months should requalify by successfully completing a performance validation prior to performing UT/ISI examinations.

Personnel that have not received NDE training during the preceding twelve (12) months should successfully complete the appropriate training and then requalify by successfully completing a performance validation prior to performing UT/ISI examinations. The minimum recommended periodic training is 20 hours per year for Level I personnel, and 40 hours per year for Level II and Level III personnel.

5.2 EQUIPMENT

5.2.1 Electronic Characterization

The electronic characteristics of the equipment should be measured and documented at least once every 12 months. These measurements should verify that the equipment parameters have not deteriorated with respect to the baseline performance measurements, and should consist of measuring and/or characterizing the electronic parameters listed in Section 4.

5.2.2 Performance Validation

Requalification of equipment by performance validation should not be required at fixed time intervals. However, requalification of the UT/ISI equipment, or any affected portions thereof, by performance validation should be performed whenever any of the items listed in 3.3 as essential variables are replaced with a model that has not been previously qualified.

5.3 PROCEDURES

Requalification of procedures should not be required at fixed time intervals. However, procedure requalification should be required whenever one or more of the items listed in 3.3 as essential variables are changed, except that an increase in the scan path overlap, or a decrease in the scanning rate, should not require requalification. Procedure requalification should be by performance validation only.

6.0 DISCUSSION AND RECOMMENDATIONS FOR THE PERFORMANCE VALIDATION PROCESS

This section discusses rationale and provides recommendations for the test specimens, reference flaws, performance factors, and other parameters for the performance validation process described in this report. The bases that should be used for establishing the number and configuration of test specimens, and the number, type, location, shape, size, and orientation of flaws are provided in the following paragraphs.

To ensure that the performance validation tests are relevant to actual inspection problems, the specimens utilized during the validation process should be representative of the actual components to be inspected. Since the number of significantly different plant component configurations is too great for each to be specifically modeled, the configuration of the test specimens should be conservative with respect to the inspection difficulty for the plant components they represent.

At least one-half of the flaws should be conservative with respect to recording, interpretation, and characterization difficulty compared to the flaws expected to occur in plant components. Flaw size, location, shape, orientation, tightness, and morphology should be such as to ensure that the anticipated flaw conditions are included. The flaws should be positioned in the specimens to approximate expected actual flaw locations, and the flaw locations should also be randomized within this constraint. Flaw density (flaws per specimen, or flaws per unit volume of specimen) should be limited to reduce the interference between flaw signals, unless a higher flaw density is required to adequately represent the actual flaw situation expected in the plant components.

Some of the test specimens should contain no flaws (i.e., blank specimens). In addition to modeling the expected in-plant situation, this inhibits candidates from taking the approach of calling every specimen flawed. Geometric and metallurgical reflectors should also be present to the extent necessary to adequately represent actual plant components.

The number of test specimens and the number of flaws must be sufficient to accommodate the specified probability of detection and flaw characterization (sizing) criteria at the appropriate statistical confidence levels (Heasler et al. 1986). Specific criteria and requirements for each plant component should be specified in a separate document (e.g., application supplement) that is tailored to the needs of that particular component. This approach has been utilized in the Mandatory Appendix VIII document that was approved by BNCS in 1989 for publication in ASME Section XI.

While the primary consideration for design of the test specimens and flaws should be to simulate existing and expected field conditions, the specimens and flaws should also be designed to constitute a challenge for the UT/ISI system. Provisions should be made for changing and augmenting the content of the specimen sets. This should inhibit industry familiarization with the specimens and should also provide specimens for training and technique development purposes.

6.1 TEST SPECIMEN CONFIGURATION

The configuration and surface condition of the test specimens should be representative of the actual components, and partial sections or full-size mockups should be used if possible (e.g., sections of pipe, vessels, nozzles, valves, fittings, etc.). Components that have been removed from service should receive primary consideration as a source of test specimens.

6.2 NUMBER OF SPECIMENS

The number of test specimens should be sufficient to accommodate the specified number of flaws, while providing a flaw density that is not overly unrealistic. To permit a measure of overall performance including the false call criteria, at least 75% of the pipe test specimens should be flaw-free (blanks), and for vessels and nozzles at least 75% of the weld length should be free of both natural and artificial flaws.

6.3 NUMBER OF FLAWS

The minimum number of flaws should be determined from the specified probability of detection (POD) or detection test acceptance criteria, and the specified confidence levels. More than the minimum number of flaws should be included if at all possible. As a general guideline, each test specimen set should contain at least 10 flaws. If only the minimum number of flaws are available, then all flaws should be detected to constitute a successful performance validation.

6.4 FLAW TYPES

The test specimen set used for the performance validation demonstrations should include all flaw types expected to occur in the actual components. When the most probable flaw type(s) can be identified, 40 to 60% of the flaws should be of that type. When the most probable flaw type(s) cannot be identified, thermally induced (tight) fatigue cracks should be used. The test specimens used to validate performance for augmented UT/ISI applications (directed toward a specific flaw type) should generally contain only flaws of that flaw type.

6.5 FLAW SIZES

The rationale for the distribution of flaw sizes is predicated on an intent to provide assurance that flaws can be reliably detected and characterized in the size ranges of primary interest.

The flaw sizes in each test specimen set should be as follows:

Minimum Number of Flaws	Range of Through-Wall Flaw Depth(1) Piping(2)	Vessels(3)	Nozzles(3)
20%	5-20%		
20%	21-40%		
20%	41-100%		
30%		2-10%	2-10%
20%		11-20%	11-20%
20%		21-30%	21-30%
10-20%		31-50%	31-50%

(1) The remaining flaws may be in any depth category consistent with Notes 2-3 below.

(2) No flaws should be less than 5% deep, and no more than 10% of the flaws should be more than 75% deep.

(3) No flaws should be less than 2% deep, 10-20% of the flaws should be between 31% and 50% deep, and no flaws should be more than 50% deep.

The flaw lengths available in each test specimen set should provide a distribution of flaw aspect ratios (length/depth) as follows

Minimum Number of Flaws	Aspect Ratio*
20%	Less than 3:1
20%	Greater than 6:1

*All other flaws should have aspect ratios that are 2:1 or greater.

An example analysis of the factors that should be considered in the selection of flaws for pressure vessel specimens is included in Appendix F. This analysis illustrates an engineering approach that may be useful during the design of specimen sets for performance validation.

6.6 LOCATION AND ORIENTATION OF FLAWS

Measurement of flaw location and orientation should be part of the qualification criteria for all performance validations. The flaws in the test specimen set should be located and oriented such as to represent both the most serious and the most probable conditions expected in the applicable plant component.

6.7 PROBABILITY OF DETECTION

Heasler, et al. (1986) provides a valuable discussion on the statistical aspects of selecting and implementing probability of detection tests. This reference was used to develop the statistical parameters contained in this document, ASME Code Case N-409-2, and Mandatory Appendix VIII to ASME Section XI.

6.8 FLAW CHARACTERIZATION (SIZING) ACCURACY

Assessment of flaw sizing capability requires a knowledge of the true characteristics of each flaw. Since it is impractical to destructively measure all test specimen flaws, each flaw should be nondestructively characterized prior to use for performance validations. Destructive measurements should be made to verify the accuracy of the techniques that were used to provide the nondestructive flaw characterization data and to verify the flaw fabrication processes with respect to intended size, orientation, etc.

6.9 TIME LIMITS FOR PERFORMANCE VALIDATION

Many UT/ISI applications require that the inspection personnel be in relatively close proximity to the test object when manually scanning plant components; however, ALARA radiation considerations prohibit unlimited inspection times. The scanning and recording validation demonstration should be performed within specified time limits. These time limits should apply only to the time spent actually scanning the specimens. The time spent calibrating equipment, evaluating data, etc. should not be included.

If additional scanning is performed during the data interpretation or flaw characterization (sizing) operations, the time period allowed for these two functions should also be specified.

6.10 TREATMENT OF FALSE CALLS

A maximum false call limit is needed to preclude qualification based on an examination strategy that arbitrarily calls all specimens flawed. The maximum acceptable number of false calls should be specified for each application (e.g., piping, vessel shell welds, nozzles, etc.). Heasler, et al. 1986 provides a valuable discussion of the factors to consider in selecting false call test values, and a maximum false call limit between 10% and 20% is recommended.

6.11 SCOPE OF TRAINING COURSES

The annual training recommendations described herein are in addition to the initial training requirements currently imposed by ASME Section XI via reference to SNT-TC-1A. This supplemental training is recommended on an annual basis to impart knowledge of new developments, component failure modes, revisions to applicable codes and standards, changes to the required procedures, new equipment, and other relevant topics as determined by the employer. These annual training courses should be organized so that at least 50% of the required training hours involve conducting simulated inspections (i.e., "hands-on" training should be strongly emphasized).

7.0 COMPARISON OF QUALIFICATION PROCESSES

This section provides a comparison of the qualification processes in this document with ASNT's SNT-TC-1A, the Ad Hoc Task Group's 1986 Appendix VII, and Appendices VII and VIII to ASME Section XI. Comparisons were developed for each of the parameters listed below.

Prerequisite (Initial) Experience (Months)	(Table 7.1)
Initial and Periodic Training (Hours)	(Table 7.2)
NDE Instructor Qualifications	(Table 7.3)
Training Course Content	(Table 7.4)
Certification Examinations	(Table 7.5)
National Registry and Cause for Revoking Qualification	(Table 7.6)
Requalification of UT/ISI System	(Table 7.7)
Administration of Qualification Program Activities	(Table 7.8)

Comparison of this document's recommended requirements and criteria for test specimens with other documents is difficult because this document recommends ranges and directions, and does not provide as much specificity as the Code documents (Appendix VIII and N-409-2). For grading of test performance, this document proposes a statistically based approach that is essentially the same as the Appendix VIII requirements, except that a few of the parameters are not identical.

TABLE 7.1. Prerequisite (Initial) Experience (Months)

	SNT-TC-1A	Qual Document[1]	Ad Hoc T.G. 1986 App. VII[1,2]	Section XI Appendix VII[1,2]
Level I	3	3	3	1.4 (250 hrs)
Level II	9	9	6	4.6 (800 hrs)
Level III[3] (4 yr degree)	12	24/12[4] Plus valid ASNT L-III certificate	24/12[4]	24/12[4]
Level III[3] (2 yr degree)	24	48/24[4] Plus valid ASNT L-III certificate	36/24[4]	36/24[4]
Level III[3] (no college)	48	Not applicable	48/24[4]	48/24[4]

[1]The simultaneous experience provisions in SNT-TC-1A are not applicable.

[2]Written practice to specify any additional experience required for special applications.

[3]Prior certification as a Level I or Level II is not required.

[4]Total experience/nuclear experience.

TABLE 7.2. Initial and Periodic Training (Hours)

	SNT-TC-1A	Qual Document	Ad Hoc T.G. 1986 App. VII	Section XI Appendix VII
Level I	40	Same as SNT-TC-1A, plus 20 hours initial and 20 hrs/yr.[1]	Initial 40/40 (classroom/ laboratory), plus 10 hrs/yr.	Initial 40/40 (classroom/ laboratory), plus 10 hrs/hr.
Level II	40	Same as SNT-TC-1A, plus 40 hours initial and 40 hrs/yr.[1]	Initial 40/40 (classroom/ laboratory), plus 10 hrs/yr.	Initial 40/40 (classroom/ laboratory), plus 10 hrs/yr.
Level III	0	40 hours initial, plus 40 hrs/yr.[1]	Initial 80, plus 10 hrs/yr.[1]	Initial 40/40 (classroom/ laboratory), plus 10 hrs/yr.

[1]Must include both classroom and laboratory (hands-on) training.

TABLE 7.3. NDE Instructor Qualifications

SNT-TC-1A - Not addressed

Qualification Document - Qualified, but not necessarily certified, as L-III in UT per SNT-TC-1A. Also, maintain valid ASNT L-III certificate in UT, plus a current teacher or vocational/technical instructor certificate, or have completed a 40-hour course in training and teaching techniques.

Ad Hoc T.G. 1986 Appendix VII - Qualified by written examination (Basic and Method). Maintain current teacher or vocational/technical instructor certificate, or have completed a 40-hour course in training and teaching techniques.

Section XI Appendix VII - Qualify by taking written Basic and Method examinations per IWA-2300. Maintain current teacher or vocational/technical instructor certificate, or complete a 40-hour course on training and teaching techniques.

TABLE 7.4. Training Course Content

SNT-TC-1A - This is the basic reference document. It contains a detailed outline for generic UT training courses.

Qualification Document - Nationally uniform training courses should be administered on an industry-wide basis. Courses should emphasize "hands-on" training using actual and/or simulated components. SNT-TC-1A outline is adequate, but the quality of the actual training should be upgraded.

Ad Hoc T.G. 1986 Appendix VII - SNT-TC-1A outline tailored to emphasize nuclear applications for L-III training courses. Implies that training is coordinated locally (by employer, et al.). National uniformity or upgrading quality of training is not addressed (except that NDE Instructor is defined).

Section XI Appendix VII - SNT-TC-1A outline tailored to emphasize nuclear applications for L-III training courses. Implies that training is coordinated locally (by employer, et al.). National uniformity or upgrading quality of training is not addressed (except that NDE Instructor is defined).

TABLE 7.5. Certification Examinations

SNT-TC-1A

Level I and II	General (40 questions) Specific (20 questions) Practical (10 check points using one or more specimens)
Level III	Basic (50 questions) Method (65 questions) Specific (20 questions)
Passing Grades:	70% each examination; 80% composite.

Qualification Document - Same as SNT-TC-1A

Ad Hoc T.G. 1986 Appendix VII

Level I and II	General (40 questions) Specific (40 questions)[1] Practical (10 check points using one or more specimens)[2]
Level III	Basic (50 questions)[3] Method (65 questions)[3] Specific (30 questions)[3] Practical (Similar to a Level II Practical, or the performance demonstration described in VII-4000 may be used.)
Passing Grades:	80% each examination; 80% composite.

Section XI Appendix VII

Level I and II	General (40 questions)[4] Specific (40 questions)[4,5] Practical (10 check points using a specimen set per Notes 6 and 7)[2]
Level III	Basic and Method examinations to be in accordance with SNT-TC-1A Specific (30 questions)[8]
Passing Grades:	80% each examination; 80% composite.

TABLE 7.5. Certification Examinations (contd)

[1] Approximately 50% of Specific questions must cover ASME Section XI requirements.

[2] Six specific check points are listed in document.

[3] Topical coverage of questions essentially same as SNT-TC-1A.

[4] "Question Bank" must contain at least twice the minimum number of questions per examination.

[5] 40-60% of Specific questions must cover ASME Section XI requirements.

[6] For practical examination, "Specimen Bank" must contain at least 5 flaws, plus blank specimens so that no more than 1/3 of the specimens contain flaws to be detected.

[7] Specimens must be masked to conceal flaws/blanks and specimen identity.

[8] 40-60% of questions must cover ASME Section XI UT examination, evaluation, and acceptance criteria.

TABLE 7.6. National Registry and Cause for Revoking Qualification

SNT-TC-1A

- National registry not addressed.
- Personnel should be recertified every three years (Level I and II) or five years (Level III) by examination, or by evidence of continuing satisfactory performance.
- Personnel may be reexamined any time at employer's discretion and certifications may be extended or revoked.
- Certifications shall be deemed revoked when employment is terminated.

Qualification Document

- The identity of qualified personnel, equipment, and procedures should be maintained in a national registry.
- The qualifications of personnel should be removed from any individual that has not passed a performance validation for five years, or has not completed the annual training, or has not performed either 80 hours of UT/ISI or passed a performance validation for one year.

Ad Hoc T.G. 1986 Appendix VII

- National registry not addressed.
- Revoking personnel qualification not addressed except that the certifications for Level I, II, and III personnel are valid for five years.

Section XI Appendices VII and VIII

- National registry not addressed.
- Revoking personnel qualification per IWA-2300 [i.e., requalify by examination every three years (Level I and II) or every five years (Level III)].

TABLE 7.7. Requalification of UT/ISI System

SNT-TC-1A

Recertification of Level I, II, or III by either a) evidence of continuing satisfactory performance or b) re-examination in those areas deemed necessary at the following intervals:

Level I and II - every 3 years
Level III - every 5 years

Qualification Document

Personnel - Requalify by performance validation at 5-year intervals provided 80 hours of UT/ISI are performed each year and the necessary annual training requirement is met (20 hours for L-I, 40 hours for L-II and L-III); otherwise more often.

Equipment - Characterize electronic performance annually. Requalify UT/ISI equipment, or affected portions, whenever items listed as essential variables are replaced with an unqualified model.

Procedures - Requalify by performance validation whenever an essential variable is changed.

Ad Hoc T.G. 1986 Appendix VII

Personnel - Recertify all NDE personnel by written examination (only) every 5 years.

Equipment - Requalification not addressed.[1]

Procedures - Requalification not addressed.[1]

Section XI Appendices VII and VIII

Personnel - Recertify (Levels I and II every 3 years; Level III every 5 years) by examination (only) per IWA-2300. Requalification, per se, not addressed in Appendix VII.

Equipment - Requalification, per se, not addressed in Appendix VIII.

Procedures - Requalify whenever a change causes an essential variable to exceed a qualified range.

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[1] Document states, "Requalification Requirements - (In course of preparation)."

TABLE 7.8. Administration of Qualification Program Activities

	SNT-TC-1A	Qual Doc.	Ad Hoc T.G. 1986 App. VII	Section XI App. VII & VIII
Training	Not specified	Nationally uniform and coordinated (NDE Instructor)	Approved Agency (NDE Instructor)	Not specified (NDE Instructor)
Written Examinations L-III. Agency.	Employer or Outside Agency	NQC[1]	Approved Agency	Level I & II exams by L-III Basic & Method by Outside L-III Specific by Outside Agency or Employer L-III.
Personnel Certification	Employer	Employer and NQC	Employer	Employer
Test Specimens	Level III	NQC	Approved Agency	Owner, Vendor, or Outside Agency
Procedure Review	Not addressed	NQC	Approved Agency	Not addressed
Performance Demonstration	Not addressed	NQC	Approved Agency	Owner, Vendor, or Outside Agency
Maintain Records	Employer	NQC	Employer and Approved Agency	Employer

[1]NQC = National Qualification Center(s)

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APPENDIX A

RESEARCH INFORMATION LETTER #113

"RELIABILITY OF INSERVICE INSPECTION OF PRIMARY PIPING SYSTEM"

January 29, 1981

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JAN 29 1981

MEMORANDUM FOR: Victor Stello, Director
Office of Inspection and Enforcement

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Ray G. Smith, Acting Director
Office of Standards Development

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER # 113, "RELIABILITY OF INSERVICE INSPECTION FOR PRIMARY PIPING SYSTEMS"

1.0 Introduction

This Research Information Letter (RIL) describes the results of the first phase of a four-phased, 5-year program, being conducted at Battelle Pacific Northwest Laboratory (PNL), entitled, "Integration of NDE Reliability and Fracture Mechanics." Based on these results, four recommendations are presented in this RIL. The implementation of these recommendations should result in a substantial improvement in the effectiveness and reliability of inservice inspection (ISI) for primary piping systems.

The initial phases of the program are focused on ISI of primary piping systems. The objectives of the program include the following:

- Determine the reliability of ultrasonic ISI performed on commercial LWR primary piping systems.
- Using fracture mechanics analysis, determine the impact of nondestructive examination (NDE) unreliability on system safety and determine the level of inspection reliability required to assure a suitably low probability of piping failure.
- Evaluate the degree of reliability improvement that could be achieved using improved and advanced NDE techniques.
- Based on material, service conditions and NDE uncertainties, formulate recommended revisions to ASME Section XI and regulatory requirements needed to assure a suitably low probability of system failure.

The Phase I effort was directed primarily toward an evaluation of the ASME Code procedures for ISI and identification of major problem areas of primary piping inspection effectiveness and reliability.

Ultrasonic preservice and inservice inspections of primary piping systems are performed under provisions of the ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components." Operating reactors currently use either the 1974 Revision of the Code through Summer of 1975 or the 1977 Revision through Summer of 1978. Both revisions have been endorsed by NRC. Inspection procedure requirements are controlled by Appendix III of Section XI and/or Article 5 of Section V. Acceptance standards are specified in IWB 3500.

The acceptance standards of IWB 3500 are based on a conservative methodology using linear elastic fracture mechanics (Reference 1). However, the requirements for ultrasonic inspection provide little assurance that flaws larger than the acceptance standards will be detected. Further, the 1977 revision of the Code resulted in a reduction of inspection sensitivity of 6 to 16 dB (6 dB represents a reduction in flaw signal amplitude by 50 percent, while 16 dB represents a reduction in flaw signal amplitude by 84 percent.) The revision does not appear to be justified based on measurements performed on real and artificial defects of less than optimum reflectivity characteristics (i.e., roughness, tightness and orientation). In addition, the Code provides no guidance in addressing the problems of weld and base metal attenuation which limit the effectiveness of inspections performed on austenitic and dissimilar metal welds.

2.0 Discussion

Approximately 5,000 measurements have been made on artificial (notches) and fatigue flaws in flat plate and pipe samples to determine the influence of inspection variables on the effectiveness and reliability of ISI of primary piping system welds (Reference 2). These data, along with measurements and estimates of operator and inspection team variability, have been used to estimate the effectiveness of current (Section XI, Summer 1978) inspection practices. Measurements of the reduction in ultrasonic inspection sensitivity resulting from use of ASME Section XI 1977 through Summer of 1978, as compared to the 1974 Revision through Summer of 1975, were made on 34 (approximately 500 measurements) pipe inspection calibration standards. The standards ranged in diameter from 4.0 to 30.0 inches and nominal wall thickness 0.237 to 2.343 inches.

Inspection variables investigated in Phase I include the influence of ultrasonic search unit selection, flaw orientation, the influence of counterbore angle, flaw roughness, and flaw tightness. These measurements are described in the Phase I report (Reference 2).

Results of the measurements noted above were used in a model which was developed (Reference 2) to determine the probability that an inservice defect would produce an ultrasonic response sufficiently large to require it to be reported for any given threshold level. Specific inputs to this model are: the expected mean response of flaws as a function of their depth, the variability resulting from flaw characteristics (tightness, roughness and orientation), the variability within an operator (repeatability), and the variability between operators, which was derived from available literature (References 3 and 4). The model has been used to obtain approximations of current levels of inspection reliability. Information gained by the round robin tests to be performed in Phase II of the program will be used to refine and substantiate the inspection reliability model.

3.0 Results

3.1 Ultrasonic Measurements

The results of the measurement program are described in Reference 2 and summarized below. Inspection results using the 1977 Code revision are 6 to 16 dB less sensitive than inspection results from use of the 1974 Code for 45° shear wave inspection. The results of the measurements are shown in Figure 1. The measured results shown in Figure 1 represent the amplitude produced by the side-drilled holes (SDH) (1974 Code) divided by the amplitude produced by notches (1977 Code). The notch reflects a larger amplitude (lower inspection sensitivity) and the ratio (in terms of dB) is negative. The measured data also agree well with theoretical calculations.

The inspection reliability model described in Section 2.0 above was applied to provide baseline estimates of inspection reliability. Inputs used in the calculations are based on measurements performed during the course of this program and are described in Section 7 of Reference 2. The results of these calculations are shown in Figure 2. The calculations are based on inspections performed according to ASME Section XI, Appendix III, 1977 Revision through Summer of 1978. Reporting or corrective action is only required for flaws which exceed 100 percent distance amplitude correction (DAC) level. Probabilities for 50 percent and 20 percent DAC are shown to indicate the reliability improvement which would result from lowering the reporting level.

The inspection reliability estimates, described above, are based on measurements made primarily on fatigue cracked 0.6-inch wall thickness samples. The measurements were extrapolated to a thickness of 1.8 inches by measurements performed on ideal reflectors. It is estimated that the calculations are applicable over the thickness range of 0.3 inches to 2.5 inches for ferritic piping and flaws in wrought austenitic base material where both sides of the weld are accessible. The estimates do not apply for cast austenitic, dissimilar metal welds or in any case where the sound must propagate through austenitic weld metal. In these latter cases, it is expected that the inspection reliability will be substantially lower. The estimates were based primarily on flaws of aspect ratio (depth/length) of 0.2. The estimates may be overly conservative for long flaws particularly in ferritic pipe greater than 1.5 inches in thickness. It should be noted that the inspection reliability will be measured by the round robin tests in Phase II of the program.

Two general conclusions, from the inspection variability measurements, can be stated. First, real defects can produce reflected amplitudes substantially lower than the ideal reflectors which are used for calibration. Second, reflected ultrasonic amplitudes do not necessarily indicate the severity of the defect, particularly for flaws of less than optimum orientation. Specific conclusions from the measurement program for flaw variability are as follows:

A. ASME Section XI, Appendix III calibration requirements, coupled with a lack of search unit selection and control, provide no assurance that even ideal reflectors of reportable size will produce reportable indication signals.

B. Ultrasonic transparency produced by flaw tightness and/or fluid in the crack can reduce reflected signal amplitudes by as little as 2 or 3 dB to as much as 32 dB. This effect is qualitatively similar to the theoretical calculated reflection from closely-spaced, smooth plane parallel surfaces.

C. Non-optimum orientation of surface-connected reflectors can produce substantial loss in signal amplitudes, compared to ideal reflectors, and exhibit little relationship to reflector through-wall depth for 45° incidence. In all cases, the condition is less severe for 60° incidence. This condition is frequency and search unit dependent.

D. The influence of crack roughness in the range of 10 to 30 μm RMS can reduce reflected signal amplitude by 1 to 12 dB relative to an ideal reflector of the same size. The amplitude decreases monotonically as the degree of surface roughness increases.

3.2 Deficiencies in Inspection Requirements

From a review of the Code (ASME, Section XI, 1977 Revision through Summer of 1978) and the literature, as well as the measurements and evaluation program, several shortcomings in the current inspection requirements are defined. These deficiencies follow.

3.2.1. Calibration Sensitivity

The calibration sensitivity, established by the 1977 Code, is inadequate to assure the reporting of unacceptably large flaws, as defined by IWB 3514. This results from the depth and length of the specified calibration reflector. The sensitivity is also dependent on transducer diameter, which is presently uncontrolled by the Code. The 100 percent DAC reporting level does not allow for the differences between the ideal calibration reflector and real defects. It is generally assumed that larger flaws will produce larger reflected signal amplitudes. This, however, is not the case. Flaws which are rough, tight, filled with water, or of less than optimum orientation may yield substantially smaller reflected amplitudes than ideal reflectors.

3.2.2. Inspection Angle

Nearly all pipes contain a counterbore taper of up to 15°. A flaw located on a 15° counterbore may yield a reflection by as much as 10 dB less than an ideal reflector of the same size using 45° shear wave inspection. This signal loss increases as the flaw size increases. An inspection angle of 45° is required, however, other angles are allowed. Experiments have shown that 60° shear wave inspection is far less sensitive to flaw orientation than 45° inspection. In some cases, 60° shear waves may actually provide larger signal amplitudes for non-optimum flaw orientations.

3.2.3. Sizing

The Code (Section XI, Appendix III, 1977 Revision through Summer of 1978), IWA-2232 (C) (3) states that "the size of reflectors shall be measured between points which give amplitudes equal to 100 percent of the reference level." This technique ignores the fact that flaw tightness, roughness and orientation substantially affect reflected amplitude. Probe motion measurements (6 dB or 20 dB drop techniques) are often used. However, they are also subject to large errors. Measurements made as a part of this program cannot recommend any particular conventional technique capable of accurately sizing flaws over the range of conditions expected in service. Where flaw sizing is to be performed, application of techniques qualified under the particular conditions of that case is appropriate.

3.2.4. Surface Condition and Contour

The Code states only that "the finish on the surface of the calibration sample shall be representative of the surface finish of the piping." This is indeed an important parameter. However, without a statement of maximum allowable surface roughness, reliable inspection cannot be assured. In addition, the surface contour of the weld joint (crown and heat affected zone) may seriously limit inspection effectiveness. The presence of unground or partially-ground weld crowns limits inspection coverage of the required inspection volume. Diametrical shrink present in most welds also limits reliable inspection coverage. Diametrical shrink or surface contour can result in reduction of ultrasonic coupling efficiency as well as a change in the angle of propagation.

3.2.5. Scan Overlap

The Code currently requires that each scan overlap the previous scan by 10 percent of the transducer diameter. Experiments have shown that this overlap is not sufficient to assure recording of rejectable flaws. The overlap problem is particularly acute for automatic scanning procedures where the transducer is scanned parallel to the flaw or where data are recorded only at specified increments of transducer position.

3.2.6. Coverage of Inspection Volume

The requirement of Section XI, Appendix III 4420 (1977 Code) that "the angle beam examination for reflectors parallel to the weld shall be performed by a full Vee path from one side or a one-half Vee path from two sides of the weld, where practicable," does not assure effective inspection over the entire inspection volume. Full Vee path examinations may be adversely affected by counterbore conditions, through beam redirection and loss of energy through mode conversion, and in many instances does not cover the full inspection volume. Three-halves Vee path and other examination angles may be required for full coverage of the inspection volume.

3.2.7. Transducer and Instrument Performance

The Code does not require verification or measurement of transducer or instrument operating characteristics, other than vertical and horizontal linearity and attenuator calibration. Operating characteristics of the inspection system, such as center frequency, bandwidth and effective beam diameter can have considerable influence on inspection effectiveness particularly for flaws of less than optimum characteristics (roughness and orientation). Standardized methods for measuring inspection system performance do not yet exist. However, research is being conducted under this program to develop these methods and acceptance criteria.

3.2.8 Austenitic and Dissimilar Weld Inspection

Items 3.2.1. through 3.2.7. above are equally applicable to ferritic as well as austenitic and dissimilar metal welds. Further, the following items deal with deficiencies in the Code which pertain directly to inspection of austenitic and dissimilar metal welds.

A. The Code (Section XI, Appendix III and Section V, Article 5) does not address the specific difference between inspection of ferritic and dissimilar metal welds or austenitic welds.

B. Difference in attenuation and refracted angle between calibration samples and the pipe base metal can be substantial. This will affect the sensitivity and effectiveness of the inspection.

C. The attenuation of austenitic weld metal is substantially greater than the base material, which results in decreased sensitivity for flaws located within or beyond the weld. For inspections where only one side of the joint is accessible (single side access), flaws located on the far side of the weld may be undetectable (at present sensitivity levels) due to the increased attenuation through the weld metal.

4.0 Recommendations

The program results described above identify major problem areas which limit the effectiveness of preservice and inservice ultrasonic inspection of primary system piping. It should be recognized that this ongoing program cannot, at this time, offer specific recommendations and methods of implementation for each deficiency listed in Section 3.0 above. However, at this time, four recommendations can be made based on the investigations to date. Acceptance and implementation of these recommendations will assure a substantial increase in the effectiveness of primary piping system ISIs. These recommendations are equally applicable to both ferritic as well as austenitic and dissimilar metal weld inspection.

The direction of continuing research and our best estimate of the most appropriate solution for each problem area are described under the Continuing Research subheading.

4.1 Specific Recommendations

4.1.1. Calibration Sensitivity

Calibration sensitivity is regarded as the most serious limitation of the Code (Section XI, 1977 Revision through Summer of 1978). It has been shown that this sensitivity and the reporting levels of the Code are inadequate.

It is, therefore, recommended as an interim measure that the reporting and recording level as defined by Section XI, IWA-2232 and Appendix III be lowered to 50 and 20 percent, respectively, of the primary reference level, for those inspections of pipes with wall thickness equal to or greater than 0.312 inches. This requirement is less stringent than the 1974 Code (Summer of 1975) for piping thickness greater than 0.4 inches and only slightly more sensitive for thicknesses less than 0.4 inches and should, thus, place no undue burden on the inspection process. The relative increase in inspection effectiveness, resulting from this recommendation, can be estimated by comparing the 100 and 50 percent DAC recording probability curves of Figure 2.

The above is recommended as an interim measure for two reasons: (1) to avoid further approvals of ultrasonic inspections at inappropriate sensitivity levels in the near-term, and (2) to allow for development of more appropriate calibration reflectors in the longer term.

4.1.2. Inspection Angle

It has been demonstrated that the effectiveness of 45° shear wave inspection is adversely affected by flaw orientation, while the influence of 60° inspection is considerably less. It is, therefore, recommended that 60° shear wave inspection be required in addition to 45° inspection. Reporting and recording levels of 100 and 50 percent, respectively, are recommended for the 60° inspection. This additional inspection is required to detect flaws of unfavorable orientation, such as those located on a counterbore taper.

This additional requirement, coupled with the lower reporting and recording thresholds for 45° inspection of 4.1.1. above, will further increase the effectiveness of ISIs. The impact of such a requirement cannot be immediately calculated. However, it is known that at least one ISI organization routinely applies 60° in addition to 45° inspection. This organization based their decision on an internal study which indicated that 11 percent of defects detected could only be detected by the 60° inspection.

4.1.3. Sizing

It is not possible, at this time, to recommend any particular sizing technique which would be applicable to all conditions. It is recommended that in cases where flaws are to be accepted by analysis, the sizing techniques and their accuracy be qualified under conditions similar to that of the field application.

4.1.4. Scan Overlap

It is recommended that scan overlap requirements be revised to require that "the scan overlap shall be sufficient to provide recordable signals from minimum sized (length and depth) reportable defects specified in IWB 3500." Response from each recordable defect should then be optimized to establish its response relative to the reporting level.

4.2 Continuing Research

4.2.1. Calibration Sensititivy

Investigations are in progress to establish the most appropriate calibration reflectors as well as the recording and reporting levels. At this time, it is expected that a semicircular notch (a/l aspect ratio equal to 0.5) of depth equal to the allowable flaw size listed in IWB 3514-2 and -3 for preservice examinations will be most appropriate. The short length of the flaw will resolve many of the sensitivity problems associated with transducer selection as well as provide a more suitable calibration sensitivity.

4.2.2. Inspection Angle

Investigations concerning 45° and 60° inspection are continuing. Development of the new calibration reflector, 4.2.1. above may require modification of reporting and recording levels.

4.2.3. Sizing

Investigations are in progress to define the limits of applicability of the various sizing techniques and to establish qualification procedures. Advanced sizing techniques are also under investigation.

4.2.4. Scan Overlap

It is expected that the scan overlap recommendation above is the most appropriate requirement. The semicircular calibration reflector is expected to provide the most suitable method of assuring suitable scan overlap.

4.2.5. Surface Condition and Contour

Insufficient data are available on the quantitative effects of surface roughness and contour, on which recommendations for improved inspection requirements could be based. Investigations are in progress to supply the necessary data.

4.2.6. Coverage of Inspection Volume

Development of an effective requirement to assure adequate coverage of the required inspection volume will require resolution of items 2, 4 and 5 above. Based on current information, it is expected that an analysis based on I.D. and O.D. geometry as well as access conditions will be required for each weld joint.

4.2.7. Transducer and Instrument Performance

While there is considerable information which indicates that transducer and instrument performance can influence inspection effectiveness, definitive information concerning acceptable limits of performance and measurement techniques is not available. Research and evaluations are underway to establish appropriate limits or tests designed to demonstrate system adequacy.

4.2.8. Austenitic and Dissimilar Weld Inspection

It is expected, due to the range of inspection variables involved, that the most suitable method for assuring effective inspection of austenitic or dissimilar metal welds, will be through a program for procedure and personnel qualifications. Guidelines and requirements for such a program are under investigation. It is expected that samples containing artificial defects as well as defects typical of those found in service will be required. Specific qualification requirements and methods of defect fabrication are currently under investigation. Techniques designed to compensate for weld metal attenuation and differences between the calibration sample and the pipe base metal are also under investigation.

Immediate goals of this ongoing research program include the resolution of research areas described above as well as conducting the "round robin inspection" for the determination and validation of the reliability and effectiveness of primary piping system inspection, and the establishment of guidelines for procedure qualification. In the longer term, it is expected that recommendations will be developed which will provide the necessary assurance of system safety through effective application of ISI techniques.

Robert B. Minogue

Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Figure 1
2. Figure 2

References

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3. Silk, M. G., "Estimates of the Magnitude of Some of the Basic Sources of Error in Ultrasonic Defect Sizing," AERE-R-9023, February 1978.

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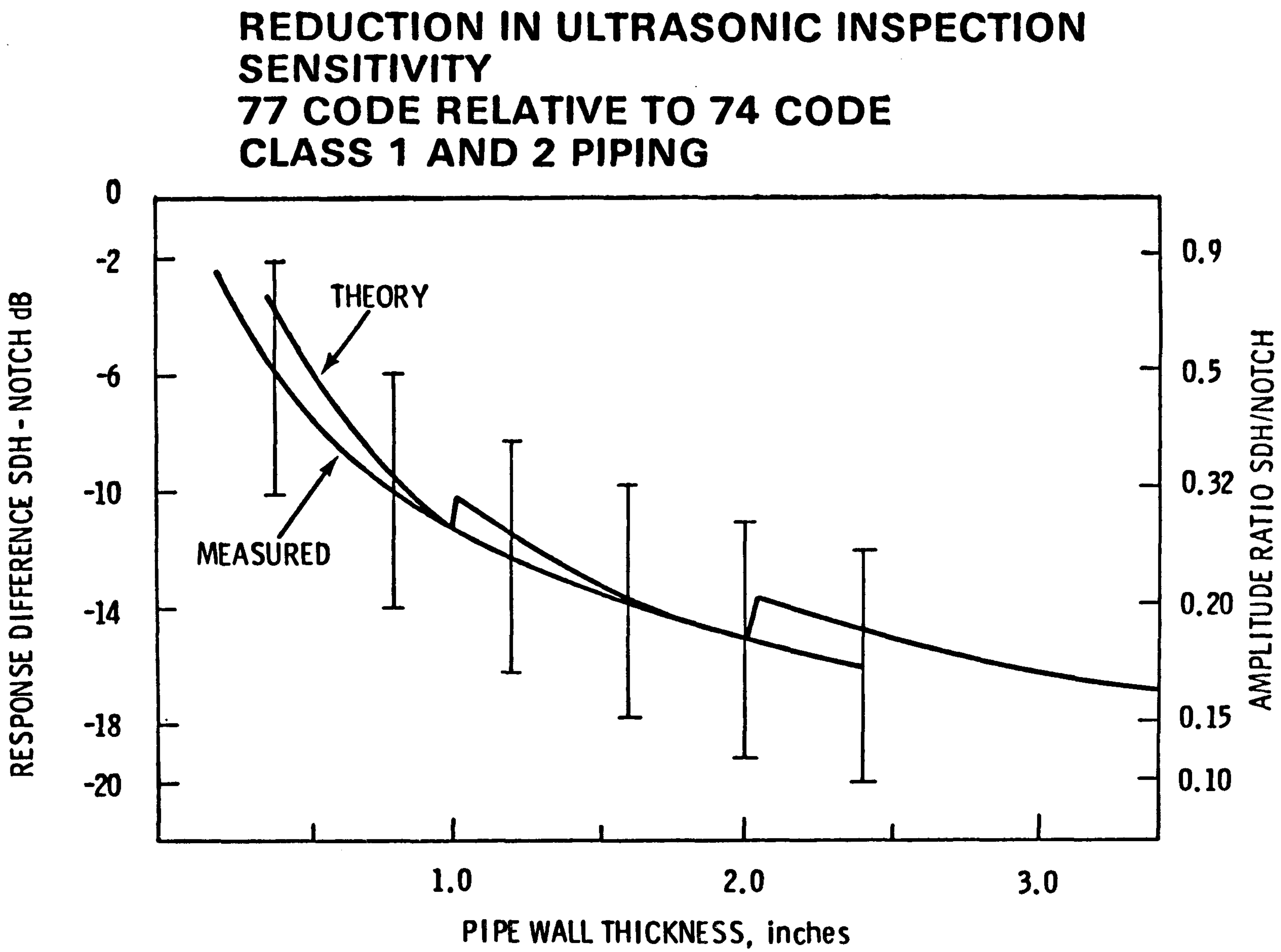


Figure 1. Measured and theoretical reduction in ultrasonic piping inspection sensitivity of the 1977 edition of the ASME Code, Section XI, as compared to the 1974 edition, using notched and side-drilled hole calibration specimens, respectively.

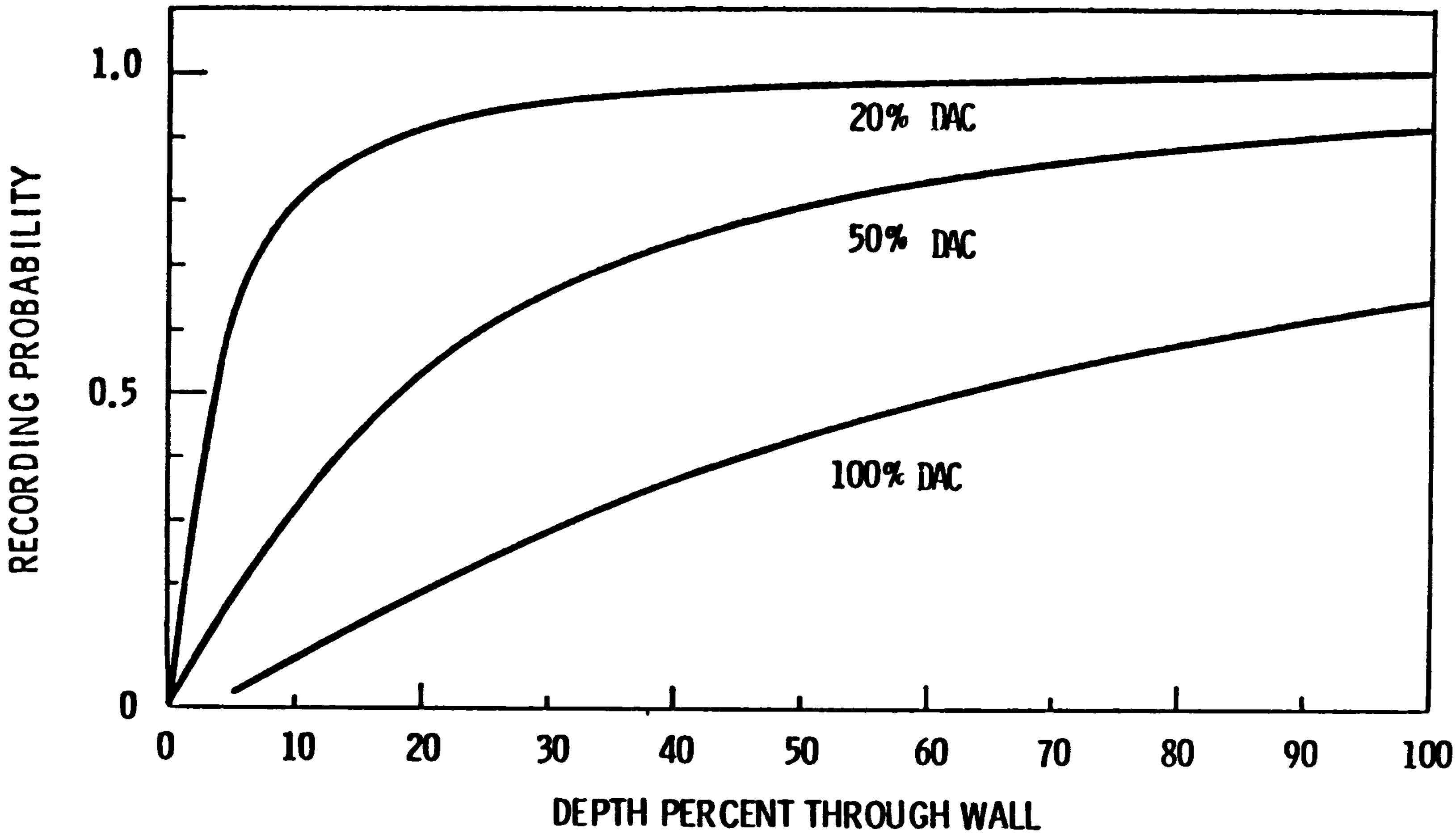


Figure 2. Estimated Recording Probability (i.e., the probability that the ultrasonic response will exceed a threshold value) versus flaw depth for 100, 50 and 20 percent DAC recording or reporting thresholds for piping wall thickness of approximately 0.3 through 2.5 inches.

APPENDIX B

ASME AD HOC TASK GROUP RECOMMENDATIONS (1986)

(Identified by SGNDE Ad Hoc Task Group as
"Proposed Appendix VII to Section XI")

PREFACE

This preface was written by the authors of this report and was not part of the Ad Hoc Task Group recommendations.

In late 1984, ASME Section XI established an Ad Hoc Task Group to develop input for recommended Code rules for the administration and control of NDE system qualification programs, as well as control of NDE performance of Section XI applications. Three separate subtask groups were organized to develop proposed ASME Code rules for: 1) improved personnel training and qualification requirements, 2) performance demonstrations for UT/ISI systems, and 3) ASME implementation. During the following 15-month period, this Ad Hoc Task Group met seven times and the three subtask groups each met ten times. This active effort provided a measure of industry's interest in this problem, as well as industry's willingness to participate.

The output of the Ad Hoc Task Group was a proposed Mandatory Appendix VII to ASME Section XI. This document was formally approved for submission to the Section XI Subgroup on Nondestructive Examination (SGNDE) in February 1986. Subsequently, the SGNDE revised and restructured this document into two separate proposed Mandatory Appendices; Appendix VII entitled "Qualification of Nondestructive Examination Personnel for Ultrasonic Examination," and Appendix III entitled "Performance Demonstration for Ultrasonic Examination Systems." At this writing, Appendix VII has been approved and was published in the 1988 Addenda to Section XI, and Appendix VIII received final approval via Board on Nuclear Codes and Standards (BNCS) letter ballot in June 1989.

The Ad Hoc Task Group's 1986 document is reproduced in its entirety in this appendix. The efforts of the numerous individuals who participated in the Ad Hoc Task Group activity, as well as their sponsoring organization, deserves acknowledgement. The names and companies included on the final mailing list used by the secretary of the Ad Hoc Task Group were as follows:

Gary Abell, Babcock & Wildox
Don Adamonis, Westinghouse Electric Corporation
F. Larry Becker, EPRI NDE Center
M. M. Behravesh, Electric Power Research Center
N. R. Bentley, Tennessee Valley Authority
Jerome Blake, Nuclear Regulatory Commission, Region II
A. L. Bradshaw, Gilbert Associates
Gary Brinson, Georgia Power Company
Boyd W. Brown, EG&G Idaho, Inc.
Frank Carr, Florida Power & Light Company
John E. Cavender, Duke Power Company
Vladimir Cech, Middle South Services
Burt Cheezem, Duke Power Company
C. Y. Cheng, Nuclear Regulatory Commission
Ronald J. Claverie, Nuclear Energy Services
William J. Collins, Nuclear Regulatory Commission
Jeff Cook, EG&G Idaho, Inc.

C. D. Cowfer, Nuclear Energy Services, Inc.
Gary Dau, Electric Power Research Institute
Eric A. DeBarba, Northeast Utilities
Paul Deeds, Jr., Ebasco Services
Oscar Demiranda, Gulf State Utilities
Michael H. Deter, Washington Public Power Supply System
Steven R. Doctor, Battelle, Pacific Northwest Laboratory
Frank Dodd, Dynacon
F. T. Duba, Hartford Steam Boiler
Don Dunavant, Southwest Research Institute
Steve Ebneter, Nuclear Regulation Commission, Region I
T. N. Epps, Southern Company Services
Michael P. Ferrante, American Nuclear Insurers
Donald A. Gavin, General Electric Company
Lucio Gentili, ENEL (Italy)
Michael E. Gothard, Tennessee Valley Authority
Douglas B. Hansen, Arizona Public Service
F. A. Hawksley, Niagara Mohawk Power Corporation
Chuck Hellier, BESTCO
Doug Henry, Southern California Edison
Douglas Henry, General Electric Company
Victor Hight, Gilbert/Commonwealth
James E. Hill, Pacific Gas & Electric
Martin Hum, Nuclear Regulatory Commission
Dan Kerr, Pacific Gas & Electric
William Key, Nuclear Regulatory Commission, Region III
Wally Koepke, Cygna Energy Services
Greg Krause, NSP Plant Maintenance
David Kurek, Westinghouse Electric Company
Ted Lambert, LMT, Inc.
Jack Lance, Yankee Atomic Electric Company
Fred Lockwood, Contra Costa College
Melinda Malloy, Nuclear Regulatory Commission
D. G. (Don) Martin, Ontario Hydro
Martin McCrary, Tennessee Valley Authority
Michael A. Melton, Arizona Public Service
C. V. Moore, General Electric - KAPL
Joe Muscara, Nuclear Regulatory Commission
Ron Newsome, Nuclear Regulatory Commission, Region II
Carl R. Osman, Carolina Power & Light
Earl Pade, Westinghouse
E. J. Parent, Combustion Engineering, Inc.
T. G. Parker, Rockwell International
George Pherigo, EPRI NDE Center
John P. Porter, Reinhart & Associates
G. J. Posakony, Battelle, Pacific Northwest Laboratory
Earl D. Potter, Potter Technological Advisory Services, Inc.
Aaron F. Raatz, George Power Company
Jerry M. Ray, Arkansas Power & Light
Michael J. Saporito, Rochester Gas & Electric Corporation
Charles Z. Serpan, Nuclear Regulatory Commission
Carl B. Shaw, Portland General Electric Company

M. F. Sherwin, Magnaflux Quality Services
A. L. Smith, Washington Public Power Supply System
W. Robert Sneed, Jr., Tennessee Valley Authority
Jack C. Spanner, Sr., Battelle, Pacific Northwest Laboratory
Jack C. Spanner, Jr., Pacific Gas & Electric
James E. Staffiera, Newport News Industrial Corporation
Timothy K. Steingass, Pennsylvania Power & Light
Gerald J. Stoll, Bechtel Group, Inc.
Robert M. Stone, EPRI NDE Center
Russ Tamminga, Commonwealth Edision
T. Thomas Taylor, Battelle, Pacific Northwest Laboratory
Bub Thomas, LMT, Inc.
Brychan Watkins, UKAEA-Risley Laboratory (United Kingdom)
George C. Wheeler, General Electric Company
James C. Yeh, Westinghouse Electric Corporation
M. A. Zaki, Duquesne Light Company

March 6, 1986

APPENDIX VII
NDE SYSTEMS QUALIFICATION

NOTE: This is a proposed Appendix to Section XI. VII was used as the next sequential Appendix number and may or may not be appropriate.

ARTICLE VII - 1000
INTRODUCTION

VII-1100 SCOPE

This Appendix specifies requirements for a) NDE Personnel Training and b) Qualification and Ultrasonic Testing/Inservice Inspection (UT/ISI) System Performance Demonstrations. The UT/ISI System is the combination of personnel, equipment, and procedure used to perform the UT/ISI examinations required by Section XI.

VII-1200 GENERAL REQUIREMENTS

The requirements for planning, managing, and conducting a UT/ISI program are described in VII-2000.

VII-1300 PERSONNEL TRAINING AND QUALIFICATION REQUIREMENTS

The requirements for training and qualifying NDE personnel prior to formal certification by the employer are described in VII-3000.

VII-1400 PERFORMANCE DEMONSTRATION REQUIREMENTS

The requirements for UT/ISI system performance demonstrations are described in VII-4000.

ARTICLE VII - 2000
GENERAL REQUIREMENTS

VII-2100 SCOPE AND APPLICABILITY

VII-2110 This Article specifies minimum requirements for planning, managing, and conducting a UT/ISI Program to control the quality of the nondestructive examinations of components and systems. This includes both training and qualification of NDE personnel, and UT/ISI performance demonstrations as required by this Appendix.

VII-2120 Organizations performing nondestructive examinations shall prepare a program that defines the scope of their UT/ISI services.

VII-2130 When used herein, the NDE Organization is defined as the Owner or contractor that performs UT/ISI in accordance with the requirements of this Appendix.

VII-2140 When used herein, UT/ISI includes all ultrasonic examinations performed in accordance with IWA-2000; and UT/ISI system is defined as the personnel, equipment, and procedures used to perform ultrasonic testing/inservice inspection.

VII-2200 UT/ISI PROGRAM

VII-2210 The UT/ISI Program shall include as a minimum:

(a) Organizational Responsibilities

(b) Written Practice for Training, Qualification, and Certification of NDE Personnel

(c) Procedure for Performance Demonstration

(d) Procedure for Document Control

(e) Procedure for Procurement

(f) Procedure for Control of NDE Performance including Personnel, Equipment, and Procedures

(g) Reports and Records Requirements

(h) Procedure for Verification of UT/ISI Program Implementation

Note: Reference to existing procedures or other documentation is acceptable.

VII-2220 A copy of the UT/ISI Program shall be maintained at the plant site and shall be made available to the jurisdictional and regulatory authorities.

VII-2300 ORGANIZATION

The Owner shall be responsible for establishing and implementing the UT/ISI Program. The Owner may delegate to others, such as contractors, agents, or consultants, the responsibility for establishing and implementing the UT/ISI Program, or any part thereof, but shall retain overall responsibility. The authority and duties of individuals and organizations performing UT/ISI activities shall be established and documented.

VII-2400 WRITTEN PRACTICE FOR TRAINING, QUALIFICATION, AND CERTIFICATION OF NDE PERSONNEL

VII-2410 Any organization that performs UT/ISI in accordance with this Appendix shall have a Written Practice that sets forth the specific requirements for qualification and certification of NDE personnel. The Written Practice shall comply with VII-3000.

VII-2420 The requirements of VII-3000 are prerequisite to performing UT/ISI in accordance with Section XI including performance demonstrations in accordance with VII-2500. Limited certification shall be permitted in accordance with ______________________________ (SGNDE to prepare).

VII-2430 Organizations that administer training and qualification programs shall comply with Annex 2-1.

VII-2500 PERFORMANCE DEMONSTRATIONS

VII-2510 Organizations that perform UT/ISI in accordance with this Appendix shall comply with the performance demonstration requirements for personnel, equipment, and procedures specified in VII-4000.

VII-2520 Organizations that administer performance demonstration programs shall comply with Annex 2-2.

VII-2600 DOCUMENT CONTROL

Provisions shall be established for the control of UT/ISI documents such as procedures and drawings. This shall include methods of identification, revisions, approval, and distribution.

VII-2700 PROCUREMENT

VII-2710 Procurement of material, equipment, and all subcontracted services shall be controlled to assure conformance with specified requirements. Procurement documents shall describe the scope of work to be performed or the materials to be furnished. All UT/ISI subcontractors shall prepare and maintain a UT/ISI Program consistent with the scope of work to be performed.

VII-2800 CONTROL OF NONDESTRUCTIVE EXAMINATION PERFORMANCE INCLUDING PERSONNEL, PROCEDURES, DATA, AND EQUIPMENT

VII-2810 All UT/ISI shall be performed in accordance with written procedures. A copy of the examination procedure shall be available to the examiner during the examination.

VII-2820 All UT/ISI shall be controlled and performed using only personnel, equipment, and procedures that comply with this Article.

VII-2830 Equipment/instruments are acceptable for use when the requirements of this Appendix are demonstrated (e.g., linearity verification). Instrument performance including linearity and automatic data acquisition that affects the UT/ISI results shall be monitored and controlled.

VII-2840 Provisions shall be established for the control, review, and approval of in-process UT/ISI data prior to records turnover to the Owner.

VII-2850 Verification of UT/ISI Program Implementation

(a) Provisions shall be established to verify implementation of the UT/ISI Program. Periodic verification of the UT/ISI Program implementation shall be in accordance with the applicable Quality Assurance program.

(b) The UT/ISI activities shall include verification of examination performance. This shall include reexamination by certified examiners functioning independent of the UT/ISI activities. At least 5 percent of the welds shall be selected by the Owner for reexamination. The reexamination should take into account known ultrasonic examination variabilities.

VII-2900 UT/ISI REPORTS AND RECORDS

Records shall be maintained to document the performance of UT/ISI activities and shall include the following (see IWA-6000):

(a) UT/ISI procedure and revision used
(b) UT/ISI personnel qualification(s) and certification(s)
(c) UT/ISI system qualification records
(d) Results of UT/ISI examinations
(e) UT/ISI verification records
(f) Final report including the NIS-1 form
(g) Records required by VII-3000
(h) Records required by VII-4000

ARTICLE VII-2000
ANNEX 2-1

REQUIREMENTS FOR PERSONNEL TRAINING AND QUALIFICATION AGENCIES

I. SCOPE

This Annex applies to any organization that conducts NDE personnel training and qualification in accordance with VII-3000. In this Appendix, such organizations are referred to as Personnel Training and Qualification Agencies (hereinafter Agency). An Agency may perform its functions internally, externally (on a contract or other commercial basis), or both.

The Agency shall have a written program plan that assures compliance with the requirements of this Annex and VII-3000. The program plan and supporting documentation shall be available for audit.

II. FACILITIES AND EQUIPMENT

The Agency shall provide classroom and laboratory facilities.

III. ENTRANCE REQUIREMENTS

The Agency's program plan shall specify minimum entrance requirements for training course candidates.

IV. TRAINING COURSES

The training program shall be administered by an NDE Instructor who shall be responsible for the following:

A. Training Outlines

Detailed outlines shall be available for each training course that is offered. Course outlines shall be reviewed by a curricula committee.

B. Training Materials

All training materials and supplemental information shall be available in the form of written documents, slides, viewgraphs, movies, etc. The written materials including key illustrations shall be assembled in notebook (or similar) form and a complete copy shall be provided to each candidate prior to the final, qualification examination.

C. Quizzes

Periodic quizzes shall be used to measure comprehension and retention by the candidates.

D. Written Examination

A written examination shall be administered to determine a final course grade. Such examinations shall reflect a comprehensive coverage of the training materials and information presented during the course.

E. Availability and Confidentiality

Training course materials shall be available for review and/or audit by potential clients and cognizant authorities. Training course materials shall not be subject to any confidentiality requirements other than the normally applicable copyright laws.

V. QUALIFICATION EXAMINATIONS

The qualification examination shall be administered by a Level III who shall be responsible for the following:

A. Content

Written Examination - A written examination shall be administered to determine a formal qualification grade. These qualification examinations shall comply with requirements specified in VII-3000. The written examination described in IV.D above may be used to satisfy this examination requirement as permitted by VII-3425. For each qualification examination offered by the Agency, a "question bank" containing at least two-times the minimum number of questions required per examination shall be available. Each qualification examination shall be assembled from the question bank using a random selection process.

Practical Examination - If a practical examination is administered as part of the qualification examination, test specimens containing at least two-times the minimum number of flaws that should be detected shall be available. Blank (sound) test specimens shall also be available so that no more than one-third of the test specimens contain flaws that should be detected.

B. Administration and Grading

Qualification examinations shall be administered and graded only by authorized representatives of the Agency. The basis for determining the overall, formal grade on qualification examinations shall be defined in the Agency's program plan.

C. Reexamination

Reexamination in accordance with VII-3438 shall use written examinations assembled either by a random selection process or shall contain at least 30% different or reworded questions. The practical examination shall be re-administered using a specimen set that has at least 50% different flaws than those used during the most recent practical examination that was not passed by the candidate.

D. Confidentiality

Provisions to assure the confidentiality of all qualification examinations shall be included in the program plan, and these shall be strictly enforced. Qualification examinations shall be maintained in secure files. Access to these files shall be limited to authorized Agency personnel.

VII. RECORDS CONTROL

A. Organization

Evidence of qualification as required by VII-3400 for Agency personnel shall be documented and available for audit.

B. Required Documentation

The Agency's program plan shall specify the documentation to be maintained in the qualification records. This documentation shall include such information as qualification examination identification, candidate's name and current NDE certification Level, date of examination, and the overall course grade and formal qualification examination grade that was attained.

C. Records Maintenance

A scheme shall be provided for the secure storage of all training and qualification records as required by VII-3000. All training and qualification records shall be treated as confidential, and access to such records shall be limited to authorized client representatives, cognizant regulatory authorities, and similarly authorized personnel. Copies of qualification records may be provided upon written request; however, the qualification examinations shall not be made available to clients and other users of the training and qualification Agency's services. The qualification examinations shall not be considered as part of the records and documentation that are subject to routine audit.

ARTICLE VII-2000
ANNEX 2-2

REQUIREMENTS FOR PERFORMANCE DEMONSTRATION AGENCIES

I. SCOPE

This Annex applies to any organization that conducts UT/ISI performance demonstrations in accordance with VII-4000. In this Appendix, such organizations are referred to as Performance Demonstration Agencies (hereinafter Agency). An Agency may perform it's function internally, externally (on a contract or other commercial basis), or both.

The Agency shall have a written program plan that assures compliance with the requirements specified in this Annex and VII-4000. This program and all supporting documentation shall be available for audit.

II. SPECIMEN CONTROL

A. Documentation of Specimen Characteristics

Each specimen to be used for qualification shall have a complete package of documentation which defines as a minimum the following:

material, size, and configuration
defect location, size, and orientation (with tolerances)
geometric reflectors
unique identification
method of determining defect parameters and confidence level
any unique characteristics of the specimen

B. Specimen Confidentiality

Measures shall be established to assure that the identity of specimens and their respective defects are kept confidential. During the interpretation of indications, the use of supplemental techniques such as reference to radiographs or weld profiling shall be permitted without being considered a violation of confidentiality, provided the examination procedure includes guidelines for their use. Access to the specimens and specimen documentation shall be controlled to minimize their exposure. Personnel being qualified shall not have had previous access to the specimens or the specimen documentation.

C. Specimen Quantity and Configuration

The quantity and configuration of specimens available for performance demonstrations shall be in accordance with VII-4000.

III. TEST ADMINISTRATION

A. Performance Demonstration

Provisions shall be established for controlling the time allowed for examination and data acquisition. The reporting and working conditions shall simulate the performance of examinations in a field environment as far as practicable. The performance demonstration shall be monitored by Agency personnel to assure adherence to these requirements.

B. Pass/Fail Criteria

The pass/fail criteria shall comply with VII-4000.

IV. RECORDS CONTROL

A. Required Documentation

The Agency's program shall specify the documentation to be maintained as qualification records. This documentation shall include such records as NDE procedure identification, personnel certifications, equipment specifications, specimens used during performance demonstrations, and results of the performance demonstration as required by VII-4000. These records shall be available for audit.

B. Records Maintenance

A scheme shall be provided for the secure storage of all performance demonstration records. These records shall include as a minimum all the required records of IV-A. All examination records shall be treated as confidential and copies shall not be allowed out of the control of the Agency.

ARTICLE VII - 3000
PERSONNEL TRAINING AND QUALIFICATION REQUIREMENTS

VII-3100 INTRODUCTION

This Article specifies the training, qualification, and certification requirements for UT nondestructive examination (NDE) personnel.

VII-3110 Scope

This Article specifies minimum requirements for the training and qualification of NDE personnel in preparation for certification of competency to perform nondestructive examinations for compliance with the requirements of this Appendix. These requirements address those skills needed to assure a baseline level of competency for conducting nondestructive examinations.

VII-3200 QUALIFICATION LEVELS

Five qualification levels and the skills and responsibilities associated with each level are defined below:

VII-3210 NDE Level III

An NDE Level III individual shall have the skills to:

(a) Establish techniques

(b) Interpret codes, standards, and specifications

(c) Designate the particular examination technique to be used

(d) Prepare and qualify procedures.

The individual shall be capable of overseeing, conducting, and directing the performance of nondestructive examinations and interpreting and evaluating results in terms of existing codes, standards, and specifications. The individual shall have sufficient practical background in applicable materials, fabrication, and/or product technology to establish techniques and to assist in establishing acceptance criteria where none are otherwise available. The individual shall have general familiarity with other commonly used NDE methods. The Level III shall be responsible for the administration of Level I and Level II examinations for those disciplines in which the Level III is certified.

VII-3220 NDE Level II

An NDE Level II individual shall have the skills to set up and calibrate equipment, to conduct examinations, and to interpret and evaluate results in accordance with written procedures. The individual shall be thoroughly familiar with the scope and limitations of the applicable method and should be capable of directing the work of trainees and NDE Level I personnel. The individual shall be able to organize and report nondestructive examination results.

VII-3230 NDE Level I

An NDE Level I individual shall have the skills to properly perform specific set-ups, calibrations, scanning, and data recording in accordance with written procedures. The individual may conduct nondestructive examinations in accordance with written procedures under the direct supervision of a certified NDE Level II or III individual. The Level I individual shall not evaluate the results of a nondestructive examination or supervise a Trainee.

VII-3240 Trainee

In the process of being qualified to achieve NDE Level I certification, an individual shall be considered a Trainee. A Trainee shall work under the direction of certified Level II or Level III personnel and shall not independently conduct any examination, or write a report of examination results.

VII-3250 NDE Instructor

An NDE Instructor individual designated by the NDE Instructor shall have the skills to present classroom and laboratory programs of instruction in accordance with approved course outlines. The NDE Instructor shall be thoroughly familiar with the NDE method(s) being taught, and shall be able to effectively present both the theoretical/technical and practical aspects of the method(s).

VII-3300 WRITTEN PRACTICE

VII-3310 General Requirements

Organizations performing training, examination, and qualification activities shall prepare a written practice for the control and administration of these functions.

VII-3311 Experience

The written practice shall specify the minimum experience requirements for each NDE Level in accordance with VII-3410, and shall specify the minimum additional experience required for special NDE applications.

VII-3312 Training

(a) The written practice shall specify the minimum classroom and laboratory training requirements for each NDE Level in accordance with VII-3420.

(b) Minimum training requirements shall be specified for any additional training required for special NDE applications.

(c) Course outlines for each qualification Level shall be specified and shall include the minimum number of instruction contact hours.

(d) Training shall be conducted by an NDE Instructor. Portions of the training may be presented by individuals designated by the NDE Instructor.

(e) Training materials shall be prepared and made available to the candidate.

VII-3313 Annual Training

The written practice shall specify the minimum requirements for annual training of all Levels of NDE personnel. The annual training shall be in accordance with VII-3426.

VII-3314 Examinations

The written practice shall specify the minimum examination requirements for each qualification Level in accordance with VII-3430.

VII-3320 Responsibilities

The employer's written practice shall establish the responsibilities and qualifications required for personnel involved in implementing the NDE personnel qualification program. The written practice shall specify the responsibilities of the NDE Instructor, the Level III, and any other individuals providing classroom or laboratory training and administering or grading written or practical demonstration examinations for Level I and Level II candidates. The written practice shall also specify the employer's responsibilities in the qualification of the NDE Instructor and Level III personnel.

VII-3330 Duties

The employer's written practice shall define the duties and responsibilities of each qualification Level.

VII-3340 Use of Outside Agencies

An outside agency may be used for training and qualifying NDE personnel. When an outside agency is used for training and qualification, the employer's written practice shall specify the requirements for assuring the outside agency's program meets the applicable requirements of this Appendix.

VII-3350 Confidentiality

Provisions to assure the confidentiality of all qualification examinations shall be included in the written practice, and these shall be strictly enforced. Qualification examinations shall be maintained in secure files. Access to these files shall be limited to authorized personnel.

VII-3400 QUALIFICATION REQUIREMENTS

VII-3410 Experience

VII-3411 Personnel being considered for certification in ultrasonic examination shall have sufficient experience to assure the skills needed for competent performance of ultrasonic activities.

VII-3412 Table VII-3412 lists the required minimum experience for initial certification in ultrasonic examination. As used herein, experience means actual performance of the skill activities described in VII-3200 for the applicable NDE Level.

Table VII-3412

Required Minimum Experience in Months for Initial Certification in Ultrasonic Examination

Trainee	Level I	Level II	Level III
None	3	6	24/12 (Option 1) 36/24 (Option 2) 48/24 (Option 3)

Notes to Table VII-3412:

1) For Level II certification, the experience shall consist of time at Level I. To certify a candidate directly to Level II with no time at Level I, the total experience hours required for Level I plus Level II shall apply.

2) When exercising the options for Level III (e.g., Option 1: 24/12), the first figure specifies the required total experience. The second figure specifies the amount of experience that shall be in nuclear

applications. Prior certification as Level I or Level II is not required.

3) The experience (in months) shown in the table is based on a normal 40-hour workweek (175 hours per month). When work is performed in excess of a 40-hour week, credit for experience may be based on total hours.

VII-3413 The three experience options identified in Table VI-3412 for qualification as a Level III are as follows:

(a) Option 1: Graduate of a four-year accredited engineering or science college or university with a degree in engineering or science plus two years experience in nondestructive examination in an assignment comparable to that of an NDE Level II in the ultrasonic examination method. At least one year of this experience shall be in nuclear applications of ultrasonic examination and shall include the actual performance of examinations and evaluation of examination results.

(b) Option 2: Completion with a passing grade of at least the equivalent of two full years of engineering or science study at a university, college, or technical school plus three years experience comparable to that of a Level II in the ultrasonic examination method. At least two years of this experience shall be in nuclear applications of ultrasonic examination and shall include the actual performance of examinations and evaluation of examination results.

(c) Option 3: Four years experience comparable to that of a Level II in the ultrasonic examination method. At least two years of this experience shall be in nuclear applications of ultrasonic examination and shall include the actual performance of examinations and evaluation of examination results.

VII-3414 Records substantiating experience for initial certification to each Level shall:

(a) Be kept on an hourly basis.

(b) Identify the activity performed and Level of certification.

(c) Be validated and maintained as part of the employer's records for the individual.

VII-3415 Documented experience gained with a current employer in positions and activities equivalent to those described in VII-3200 prior to certification by the same employer in a program in accordance with this Appendix may be considered as qualifying experience, subject to acceptance by the Level III.

VII-3416 Experience gained during previous employment may be accepted toward meeting the minimum experience requirements where such experience is supported by documentation from previous employers. The documentation may be a copy of an experience record form obtained from the previous employer or a written statement signed by a cognizant, responsible member of the previous employer's staff attesting to the type and extent of ultrasonic examination experience to be credited. The Level III shall be responsible for reviewing the documentation and judging previous experience for acceptability under the employer's NDE personnel qualification and certification program.

VII-3417 NDE Instructor Qualifications

Personnel being considered for qualification as an NDE Instructor shall be qualified in accordance with VII-3433 (a) and (b) in the ultrasonic method, and shall also meet one of the following requirements:

(a) The candidate shall maintain a current teacher or vocational instructor certificate issued by a state, provincial, or federal authority; or

(b) The candidate shall complete a minimum of forty (40) hours instruction in industrial or military training and teaching techniques.

VII-3420 Training

VII-3421 Program

Personnel shall successfully complete the training program specified in ______________________________.

VII-3422 Facility

Classroom and laboratory facilities shall be provided.

VII-3424 Training Course Content

(a) Training course content shall be in accordance with ________.

(b) The minimum initial training hours are specified in Table VII-3424.

Table VII-3424

Minimum Initial Training Hours

	Level I	Level II	Level III
Ultrasonic Method	40/40*	40/40*	80

*Classroom/Laboratory

Note: To certify a candidate directly to Level II with no time at Level I, the total hours of training required for Level I plus Level II shall apply.

VII-3425 Evaluation of Training Effectiveness

Quizzes and examinations shall be used in an appropriate manner throughout the training to measure comprehension of the training material. If the examination for qualification (VII-3430) is not given immediately at the conclusion of training, a final course examination shall be given by the NDE Instructor. A passing grade is necessary to receive credit for the training hours toward certification.

Additional training shall be required when an individual fails a final course examination. The extent of the additional training shall be based on the areas of weakness exhibited by the individual, and shall be documented by the NDE Instructor.

VII-3426 Annual Training

Additional training is required on an annual basis and is defined as training to impart knowledge of new developments, material failure modes, and any pertinent technical topics as determined by the employer. The extent of this training shall be a minimum of ten (10) hours per year. A record of attendance and the training subjects shall be maintained.

VII-3430 Qualification Examination

VII-3431 To be considered for examination, the Level I, II, and III candidates shall have successfully completed the training program required in VII-3420.

VII-3432 The examination to verify technical qualification shall consist of the following:

(a) General Examination (Level I and II)

(1) The general examination shall be a written (closed book) examination. The examination shall cover the basic principles relative to the ultrasonic (UT) method.

(2) The examination shall be approved by the Level III.

(3) Content:

Written Examination - A written examination shall be administered to determine a formal qualification grade. These qualification examinations shall comply with requirements specified in VII-3000. The written examination described in IV.D above may be used to satisfy this examination requirement as permitted by VII-3425. For each qualification examination offered by the Agency, a "question bank" containing at least two-times the minimum number of questions required per examination shall be available. Each qualification examination shall be assembled from the question bank using a random selection process.

Written Examination - If a practical examination is administered as part of the qualification examination, test specimens containing at least two-times the minimum number of flaws that should be detected shall be available. Blank (sound) test specimens shall also be available so that no more than one-third of the test specimens contain flaws that should be detected.

(4) Administration and Grading

Qualification examinations shall be administered and graded only by authorized representatives of the Agency. The basis for determining the overall, formal grade on qualification examinations shall be defined in the Agency's program plan.

(b) Specific Examination (Level I and II)

(1) The specific examination shall be a written examination. Necessary data, such as graphs, tables, specifications, procedures, and codes shall be furnished by the Level III.

(2) Approximately 50% of the examination questions shall cover ASME Section XI examination requirements. The remaining examination questions shall cover the employer's procedures

and specifications applicable to the NDE method. The examination shall be approved by the Level III.

(3) Content:

Written Examination - A written examination shall be administered to determine a formal qualification grade. These qualification examinations shall comply with requirements specified in VII-3000. The written examination described in IV.D above may be used to satisfy this examination requirement as permitted by VII-3425. For each qualification examination offered by the Agency, a "question bank" containing at least two-times the minimum number of questions required per examination shall be available. Each qualification examination shall be assembled from the question bank using a random selection process.

Written Examination - If a practical examination is administered as part of the qualification examination, test speciens containing at least two-times the minimum number of flaws that should be detected shall be available. Blank (sound) test specimens shall also be available so that no more than one-third of the test specimens contain flaws that should be detected.

(4) Administration and Grading

Qualification examinations shall be administered and graded only by authorized representatives of the Agency. The basis for determining the overall, formal grade on qualification examinations shall be defined in the Agency's program plan.

(c) Practical Examination (Level I and II)

(1) Candidates shall demonstrate to the satisfaction of the Level III that they are familiar with and can perform the applicable UT examination using suitable calibration block(s) and a written UT procedure prepared for examination of plant components.

(2) At least one specimen, drawn from a bank of two or more specimens, containing simulated maximum allowable flaws or actual flaws shall be used for the practical examination. The practical examination shall be performed using suitable calibration block(s) and a written UT procedure prepared for examination of plant components.

(3) An assessment report containing at least ten (10) check points shall be used to evaluate the candidate's performance using longitudinal and shear wave techniques.

The following check points shall be included in the ten check points:

- Scanning technique.
- Equipment set-up and calibration.
- Selection of search unit.
- Data recording (Level I and II).
- NDE report (Level II).
- Evaluation in terms of the recording criteria.

A description of the specimens and the calibration block(s), the procedure used, the assessment report, and the inspection report prepared by the candidate shall be retained as part of the certification record.

VII-3433 Level III Examination

To be considered as a candidate for Level III, the candidate shall meet the requirements of VII-3410 and VII-3420. The examination for the Level III shall consist of the following:

(a) The Basic Examination is required only once when more than one NDE method examination is taken. The Basic examination shall be a written (closed book) examination and shall cover the subjects specified in VII-3435(a). The minimum number of questions shall be as specified in VII-3435(a).

(b) The Method Examination shall be a written (closed book) examination. The Method examination shall cover the subjects specified in VII-3435(b). The minimum number of questions shall be as specified in VII-3435(b).

Note: A valid ASNT Level III Certificate in the method may be used as evidence of compliance with the Basic and Method examinations described in (a) and (b) above.

(c) Specific Examination

(1) The specific examination shall be a written examination. The examination questions shall be selected to cover the applicable code, specifications, equipment, techniques, and procedures for the UT method, and administration of the employer's program as specified in VII-3435(c).

(2) Approximately 50% of the examination questions shall cover ASME Section XI evaluation and acceptance criteria and required UT examination of welds and materials. The remaining examination questions shall address the employer's procedures, techniques, and the training, qualification, and certification program.

(3) Reference data such as tables, graphs, codes, etc. shall be furnished by the Level III.

(d) Practical Examination

The candidate shall demonstrate proficiency in performing the duties and functions listed in VII-3210.

VII-3434 Minimum Number of Examination Questions (Level I and II)

(a) There shall be a minimum of 40 questions on the Level I and Level II General examinations.

(b) There shall be a minimum of 40 questions on the Level I and Level II Specific examinations.

VII-3435 Subjects and Minimum Number of Examination Questions (Level III)

(a) Basic Examination

Subject	Minimum Number of Questions
Understanding training and qualification requirements	20
Applicable materials, fabrication, and products technology	15
Questions on applicable NDE methods, similar to published ASNT Level II questions	15

(b) Method Examination (for each method)

Subject	Minimum Number of Questions
Fundamentals and principles of the applicable method (similar to published ASNT Level III questions)	30
Application and establishment of techniques and procedures for the applicable method	15
Capability for interpreting codes, standards, and specifications	20

(c) Specific Examination (for each method)

Subject	Minimum Number of Questions
Questions relating to specifications, equipment, techniques, and procedures applicable to the product(s) and method, and the administration of the employer's program.	30

(d) Practical Examination (for each method)

(1) The Practical examination shall be in accordance with VII-3433(d).

VII-3436 Administration of Examinations

(a) Level I and II General, Specific, and Practical Examinations

(1) The General examination shall be prepared by the Level III or an outside agency (SNT-TC-1A) and approved by the Level III.

(2) The Specific examination shall be prepared, administered, and graded by the Level III.

(3) The Practical examination shall be prepared, administered, and graded by the Level III. The candidate shall perform the examinations on specimens not used for training, using the employer's procedures, techniques, and equipment.

(b) Level III Basic, Method, Specific, and Practical Examinations

(1) The Level III Basic and Method examinations shall be administered by an outside agency (per SNT-TC-1A).

(2) The Specific and Practical examinations shall be prepared, administered, and graded by the employer's Level III or by an outside agency (per SNT-TC-1A).

VII-3437 Grading

(a) A passing grade of 80% or greater is required for each section of the examination. The practical examination shall be graded such that failure to accurately detect, locate, identify, record, and interpret (as applicable for the examination) 80% of the known conditions in the test specimen(s) shall cause the candidate to fail the examination.

(b) When the examinations are graded by an outside agency (per SNT-TC-1A), a grade value of 80% shall be assigned for those portions of the examination the candidate passed unless actual numerical grades are provided, in which case the numerical grades shall be used.

VII-3438 Reexamination

(a) Those individuals failing to pass the examination must receive additional training as determined by the Level III. This determination shall be based on the topics and/or subjects on which the individual failed to attain a passing grade.

(b) The reexamination shall use written examinations assembled earlier by a random selection process or shall contain at least 30% different or reworded questions. The practical examination test specimen(s) shall contain at least 50% different flaws than those used during the most recent practical examination that was not passed by the candidate. No individual shall be reexamined more than twice within any consecutive 12-month period.

VII-3440 Interrupted Service

Personnel who have not performed the duties associated with their certification Level during any consecutive twelve (12) month period shall be considered to have interrupted service and shall be required to successfully complete a practical examination, administered by the Level III, to assure continued proficiency prior to further assignment to perform NDE. Results of the practical examination shall be documented and maintained as part of the individual's record.

VII-3450 Vision Examination Requirements

VII-3451 All NDE personnel shall be examined by the Level III or other qualified personnel to ensure that they have natural or corrected near distance acuity, in at least one eye, as determined by the ability to read the Jaeger Number 1 (J-1) letters on a standard test; or an equivalent near distance test pattern equivalent to a Snellen fraction of 14/14; or an Ortho-Rater Test Pattern #10. Personnel shall receive a color vision examination to verify the capability of distinguishing color and distinguishing contrast between colors used in the examination method.

VII-3452 The near distance acuity and color perception examinations shall be conducted prior to initial certification and at least once every twelve (12) months thereafter.

VII-3500 QUALIFICATION RECORDS

VII-3510 Prior to certification, the records of the individual shall include as a minimum the following:

(a) Name of the individual.

(b) Qualification level(s).

(c) Educational background and experience.

(d) Statement indicating satisfactory completion of training, which shall include training hours, dates attended, and training institution.

(e) Record of annual additional training.

(f) Results of vision examination(s).

(g) The current qualification examination results with traceability to the actual examination.

(h) Grade assigned to each qualification examination.

VII-3520 In addition to the records required in VII-3510, the records of certified individuals shall include as a minimum the following:

(a) Date of current certification and expiration date.

(b) Name and signature of certifying employer representative.

(c) Evidence of continuing satisfactory performance.

VII-3550 These records shall be maintained by the employer.

VII-3600 CERTIFICATION

VII-3610 Certification of all Levels of NDE personnel shall be the responsibility of the employer.

VII-3620 Certification of NDE personnel shall be based on compliance with the qualification requirements specified.

VII-3630 Recertification

VII-3631 Recertification of all NDE personnel shall be required at intervals not to exceed five (5) years. Recertification shall be by examination only in accordance with VII-3430.

VII-3632 NDE personnel may be reexamined at any time at the discretion of the employer and have their certifications renewed or revoked.

ARTICLE VII-3000
ANNEX 3-1

MINIMUM CONTENT OF TRAINING COURSES FOR THE ULTRASONIC EXAMINATION METHOD

	Subject
A2.1	Fundamental Properties of Sound
A2.1.1	Frequency, velocity, and wavelength
A2.1.2	Definition of ultrasonic vibrations
A2.1.3	General application of ultrasonic vibrations
A2.2	Principles of Wave Propagation
A2.2.1	Modes of vibration
A2.2.2	Acoustic impedance
A2.2.3	Reflection
A2.2.4	Refraction and mode conversion
A2.2.5	Diffraction, dispersion, and attenuation
A2.2.6	Fresnel and Fraunhofer effects
A2.3	Generation of Ultrasonic Waves
A2.3.1	Piezoelectricity and types of crystals
A2.3.2	Construction of ultrasonic search units
A2.3.3	Characteristics of search units
	(a) Frequency--crystal thickness relationships
	(b) Conversion efficiencies of various crystals
	(c) Damping and resolution
	(d) Beam intensity characteristics
	(e) Divergence
A2.3.4	Care of search units
A2.4	Ultrasonic Testing Techniques
A2.4.1	Contact testing
	(a) Straight beam
	(b) Angle beam
	(c) Surface wave
	(d) Lamb wave
	(e) Through transmission
A2.4.2	Immersion testing
	(a) Straight beam
	(b) Angle beam
	(c) Through transmission
A2.4.3	Modified immersion testing
	(a) Tests employing special devices

A2.4.4 Resonance testing
A2.4.5 Flaw sizing

A2.5 Ultrasonic Testing Equipment

A2.5.1 Description of basic pulse-echo instrument
- (a) Time-base (synchronizer) circuit
- (b) Pulser circuit
- (c) A-scan display circuit

A2.5.2 Special instruments
- (a) B-scan display
- (b) C-scan display
- (c) Monitors and recording devices

A2.5.3 Scanning equipment
- (a) Manipulators
- (b) Bridges
- (c) Special scanning devices

A2.6 Operation of Specific Equipment

A2.6.1 General operating characteristics
A2.6.2 Functional block diagram of circuits
A2.6.3 Purpose and adjustment of external controls
A2.6.4 Care of equipment and calibration blocks

A2.7 Specific Testing Procedures

A2.7.1 Selection of test parameters
- (a) Frequency
- (b) Search unit size and type
- (c) Water distance (for immersed test)
- (d) Scanning speed and index

A2.7.2 Test standardization
- (a) Ultrasonic reference blocks
- (b) Adjustment of test sensitivity

A2.7.3 Interpretation of results
- (a) Acceptance standards
- (b) Comparison between responses from discontinuities to those from ultrasonic reference standards
- (c) Estimated length of discontinuities
- (d) Location of discontinuities
- (e) Zoning

A2.7.4 Test records
- (a) Data sheets
- (b) Maps
- (c) Identification stamps and certification

A2.7.5 Equipment performance variations

A2.8 Variables Affecting Test Results

A2.8.1 Instrument performance variations
A2.8.2 Search unit performance variations

A2.8.3 Inspected parts variations
- (a) Entry surface condition
- (b) Part size and geometry
- (c) Metallurgical structure

A2.8.4 Discontinuity variations
- (a) Size and geometry
- (b) Distance from entry point
- (c) Orientation to entry surface
- (d) Type of discontinuity--reflecting characteristics

A2.9 Level III candidates shall receive the following additional training:

	Subject
A2.9.1	Nuclear power plant design, function and system operation
A2.9.2	Materials, metal processing, fabrication technology, failure mechanisms, and fracture mechanics techniques
A2.9.3	Review of NDE methods commonly used during ISI
A2.9.4	Administration of NDE personnel, qualification and certification, and instructional techniques
A2.9.5	Code, standards, and regulatory requirements
A2.9.6	Procedure preparation

ARTICLE VII - 4000

PERFORMANCE DEMONSTRATION REQUIREMENTS

VII-4100 INTRODUCTION

VII-4110 Purpose

The performance demonstration requirements specified herein are intended to provide assurance that a UT/ISI system, consisting of personnel, equipment, and procedure, is capable of detecting and sizing flaws reliably.

VII-4120 Scope

This Article provides requirements and specifications for a performance demonstration program for ultrasonic (UT) examination personnel, equipment, and procedures employed to detect and size flaws.

These performance demonstration requirements apply to personnel who record indications, interpret indications, or size flaws in welds or components. The performance demonstration requirements also apply to personnel who re-examine welds (e.g., during a verification audit).

The performance demonstration requirements specified in this Article do not apply to personnel whose involvement is limited to mounting a scanner device, marking pipe, or other activities where knowledge of ultrasonic testing principles is not important.

VII-4200 GENERAL EXAMINATION SYSTEM REQUIREMENTS

VII-4210 Procedure Requirements

Prior to qualification testing, a written examination procedure (EP) shall be submitted to the performance demonstration Agency for review. The examination procedure shall contain a statement of scope that specifically defines the limits of procedure applicability. The examination procedure shall specify a single value or a range of values for the listed variables. The procedure qualification test shall demonstrate that acceptable performance can be achieved using the essential variables listed in the examination procedure including, where applicable, ranges for minimum and maximum values. Any change in an examination procedure that causes an essential variable to exceed a qualified range shall cause the examination procedure to be requalified. Within the context of this Article, any two procedures whose essential variables are the same (within the specified tolerances) are considered to be the same specific examination procedure. The examination procedure shall specify the following essential examination variables:

(a) Instrument or system, including manufacturer and model or series of pulser, receiver, and amplifier.

(b) Search units, including

   (1) center frequency and either bandwidth or waveform duration as defined in VII-4500
   (2) mode of propagation and nominal inspection angle
   (3) number, size, shape, and configuration of active elements

(c) Wedges or shoes, including

   (1) size
   (2) configuration

(d) Search unit cable, including

   (1) type
   (2) maximum length
   (3) maximum number of connectors

(e) Couplant material

(f) Detection and sizing techniques, including

   (1) scan pattern and beam directions
   (2) maximum scan speed
   (3) minimum allowable beam overlap
   (4) minimum and maximum pulse repetition rate
   (5) minimum sampling rate (automatic recording systems)
   (6) extent of scanning and action to be taken for access restrictions

(g) Methods of calibration for detection and sizing. Calibration methods include all those actions required to assure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system (whether displayed, recorded, or automatically processed) is repeated from examination to examination. Any method of achieving the system calibration is acceptable; however, a description of the calibration shall be included in the procedure.

(h) Minimum data to be recorded

(i) Method of data recording and recording equipment (strip chart, analog tape, digitizing), if used

(j) Method and criteria for the discrimination of indications (e.g., geometric versus flaw) and for sizing length and depth of flaws, including the name and revision of data analysis software for computer-based systems

(k) Surface condition requirements

VII-4220 Equipment Requirements

Changes to any of the variables of VII-4210, items (a) and (b) may be made without requalification provided such changes meet the requirements of VII-4500.

VII-4230 Personnel Requirements

Personnel shall be qualified for those examination activities they perform, such as system calibration, data acquisition, data analysis, flaw sizing, etc. Personnel shall demonstrate their proficiency by successfully completing a qualification test that complies with requirements from the appropriate Annex. Personnel shall be qualified to use a specific examination procedure. (Examination procedure is defined in VII-4210.)

VII-4300 QUALIFICATION REQUIREMENTS

Examination systems shall be qualified for detection and sizing of flaws by qualification testing. The qualification test and test results shall meet the following requirements.

VII-4310 Examination Procedure Qualification

The EP shall be qualified for the essential variables specified in this Article.

If the EP requires more than one value or a range of values for any essential variable, the range of essential variables shall be qualified by repeating the qualification test with only one of the essential variables changed and all others remaining at nominal values. The qualification test shall then be performed at the minimum and maximum range for each essential variable.

VII-4320 Personnel Qualification

Personnel shall be considered qualified for detection and/or sizing when the criteria of Annex 4-1 and Article VII-3000 are met.

VII-4330 Qualification Specimen Requirements

Qualification specimens shall be used to demonstrate the capability of the examination system for detection and sizing of flaws. One set of specimens may be used to demonstrate both detection and sizing qualification. The specimens shall meet the requirements of Annex 4-1.

VII-4400 REQUALIFICATION REQUIREMENTS - (In course of preparation)

VII-4500 MODIFICATION OF QUALIFIED PROCEDURES

Modification of a qualified procedure to substitute or replace pulser(s), receiver(s), and search unit(s) may be made without requalification provided:

(a) When equipped with reject, damping, and/or pulse tuning controls, the instrumentation shall have controls with discrete settings, and these shall be specified in the procedure.

(b) The equipment is characterized using the following ASTM procedures:

- For pulsers and receivers - "Evaluating the Electronic Characteristics of Sections of Pulse-Echo Ultrasonic Inspection Instruments," ASTM E-7 Proposal: P-146, 1984 Edition.
- For search units, E 1065-85 - "Evaluating the Characteristics of Ultrasonic Search Units," 1985 Edition.

(c) The characterized component(s) to be replaced or substituted are within the following tolerances of the original equipment:

(1) Instrument or system pulser section as measured into a 50 ohm, noninductive, noncapacitive resistive load

- pulse amplitude ±10%
- pulse rise time ±10%
- pulse duration ±10%

(2) Receiver section of the instrument system

- lower and upper frequency limits ±0.2 MHz
- center frequency ±0.2 MHz

(3) Search units

- propagation angle is the same as the measured angle within ±3°
- frequency response: center frequency ±20%; and either bandwidth ±10% or waveform duration ±1/2 cycle or 20%, whichever is greater (measured at -20 dB).

Note: 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 must be the same within the limits of VII-4500(c)(1) above.

VII-4510 Qualification Using Prerecorded Data

When the qualification test uses prerecorded data, algorithms for automated decisions can be altered if the altered algorithms can be demonstrated equivalent to those qualified by applying them to the data used for qualification. If the examination results so obtained meet the acceptance requirements of Annex 4-1, Section 1.3.1, the algorithm may be considered equivalent.

VII-4520 Requirements for Alternate Calibration Methods

Alternate calibration methods may be demonstrated equivalent to those described in the qualified procedure as follows:

(a) Calibrate the examination system components per the alternate methods.

(b) Compare the alternate calibration state of the system with the qualified calibration state.

(c) If the system sensitivity is within 2 dB and the system time base within +1/8T of that obtained by the qualified method, the alternate method is acceptable.

This demonstration of equivalence shall be conducted for each beam angle and mode of propagation to be used during ISI.

ARTICLE VII-4000
ANNEX 4-1

QUALIFICATION REQUIREMENTS FOR PIPING WELDS

1.0 SPECIMEN REQUIREMENTS

Specimens to be used in the qualification test shall meet the requirements listed herein. However, a set of test specimens may be designed to accommodate specific limitations stated in the scope of the examination procedure (EP). The same specimens may be used to demonstrate both detection and sizing qualification. A piping specimen shall consist of a minimum of a 6-inch circumferential section of pipe.

1.1 Detection Specimens

Detection specimens shall conform to the following requirements:

(a) Specimens shall have sufficient area to minimize spurious reflections that may interfere with the interpretation process.

(b) Specimens shall include the maximum and minimum pipe diameters for which the procedure is applicable. Specimens shall include at least one specimen from each of the following categories:

- less than 12" nominal pipe diameter and less than 0.6" nominal wall thickness
- less than 12" nominal pipe diameter and 0.6" or greater nominal wall thickness
- 12" or greater nominal pipe diameter and less than 0.6" nominal wall thickness
- 12" or greater nominal pipe diameter and 0.6" or greater nominal wall thickness

(c) The set of specimens shall include examples of the following:

- unground weld reinforcement (crown)
- wide weld reinforcement, such that the total weld width is 1-1/2 to 2 times the nominal pipe wall thickness
- acceptable geometric conditions that normally require discrimination (e.g., counterbore close to the fusion line or root conditions such as weld dropthrough)
- typical limited scanning surface conditions, such as diametrical shrink, or single-side access due to safe ends, fittings, etc.

(d) Flawed specimens shall include an even distribution of mechanical fatigue, thermal fatigue, and IGSC cracks. The cracks used in the test specimens shall meet the following requirements:

- A minimum of 1/3 (rounded to the next highest whole number) of the flaws shall have through-wall depths ranging between 5% and 20% of the nominal pipe wall thickness. At least 1/3 (rounded to the next highest whole number) of the flaws shall have through-wall depths greater than 40% of the nominal pipe wall thickness.

- At least one and a maximum of 10% of the flaws (rounded to the next highest whole number) shall be oriented in the axial direction; the remainder of the flaws shall be oriented in the circumferential direction.

- When available, some of the flaws shall be service-induced.

(e) A grading unit shall consist of a minimum 3-inch continuous length of piping specimen weld.

If a grading unit is designed to be unflawed, then sufficient unflawed material must exist on either side of the grading unit to prevent ambiguous data interpretation. The specific segment of weld length used in one grading unit may not be used in another grading unit.
Grading units do not necessarily have to be uniformly spaced around the pipe specimen.

(f) The number and type (whether ferritic, austenitic, or a combination) of flawed grading units shall meet the requirements of Table A1. The number of blank grading units shall be at least twice the number of flawed grading units.

(g) Detection test sets shall be selected from Table A2. The minimum detection sample set is five flawed grading units and ten unflawed grading units.

1.2 <u>Sizing Specimens</u>

Sizing specimens shall conform to the following requirements:

(a) Specimens shall meet the requirements of Section 1.1.

(b) The minimum number of flaws shall be ten.

(c) The distribution of flaw depths in the sample set shall be as follows:

Flaw Depth	Minimum Number of Flaws
1) 5-30%	20%
2) 31-60%	20%
3) 61-100%	20%

The remaining flaws may be in any of the above depth categories.

2.0 CONDUCT OF PERFORMANCE DEMONSTRATIONS

2.1 Detection Test

Flawed and unflawed grading units shall be randomly mixed and presented to the candidate such that the inside surface and specimen identification are obscured (i.e., a blind test). All examinations shall be completed prior to grading the results and discussing the results with the candidate. The candidates shall not be permitted access to the test results for particular specimens, or access to unmasked specimens.

2.2 Length and Depth Sizing Test

(a) For the length sizing test, the inside surface and specimen identification shall be obscured. The region of the flawed area shall be defined and the candidate shall be required to determine the flawed length.

(b) For the depth sizing test, 80% of the flaws shall be sized at a specific location. For the remaining flaws, the flawed length shall be indicated and the candidate shall be asked to determine the maximum flaw depth.

3.0 ACCEPTANCE CRITERIA

3.1 The candidate UT/ISI system (personnel, equipment, and procedure) shall be considered qualified for detection after successfully completing a performance demonstration that satisfies the requirements of Table A2.

3.2 Personnel, equipment, and examination procedures may be qualified for austenitic and ferritic piping in combination or separately as shown in Table A1. Qualification for cast austenitic pipe shall be done separately.

3.3 Personnel and procedures shall be considered qualified for sizing if flaws characterized in the sizing test matrix meet the following criteria:

(a) The performance demonstration results, when shown on a two-dimensional plot (Figure A1) with the depth estimated by ultrasonics plotted along the ordinate and the depth determined as true depth plotted along the abscissa, satisfy the following parameters:

(1) Slope of the linear regression line ≥ 0.7
(2) Ordinate intercept of the linear regression line $\leq 15\%$ of pipe wall thickness
(3) Correlation coefficient ≥ 0.7
(4) Mean of deviation $\leq 12.5\%$ of pipe wall thickness calculated as shown in Figure A1.

(b) No flaw depth is undersized by more than the greater of 0.2 inches or 25% of the wall thickness.

(c) The flaw length estimated by UT shall be within 1 inch of the true length.

Table A1

Qualification Criteria

Category	Minimum Acceptance Criteria
Wrought Austenitic Pipe	Minimum requirements of 3.0
Ferritic Pipe	Minimum requirements of 3.0
Ferritic Pipe (if previously qualified on wrought austenitic	Detection of 3 out of 3 additional ferritic specimens with no false calls
Cast Austenitic Pipe	In course of preparation

Table A2

Acceptance Requirements for Performance Demonstration

ACCEPTANCE REQUIREMENTS FOR DETECTION		ACCEPTANCE REQUIREMENTS FOR FALSE CALLS	
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

Figure A1

Definition of Statistical Parameters[(a)]

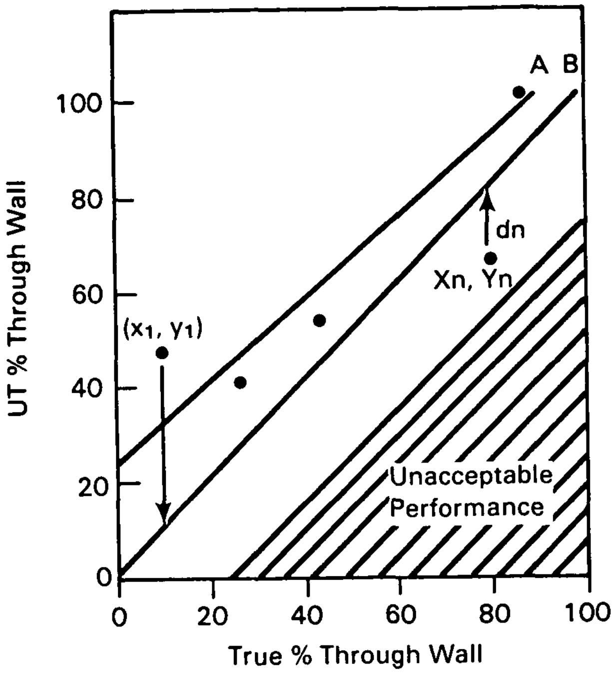
LINE A: Linear regression line, $y = a + bx$, giving the best fit of n data points (x_1, y_1), ... (x_n, y_n) obtained by the least-square method where,

$$a = \text{Y intercept} = \frac{\Sigma y_i}{n} - b\,\frac{\Sigma x_i}{n}$$

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).

CORRELATION COEFFICIENT: Correlation coefficient, defined as

$$r = \frac{n\Sigma x_i y_i - (\Sigma x_i)(\Sigma y_i)}{\sqrt{[n\Sigma x_i^2 - (\Sigma x_i)^2][n\Sigma y_i^2 - (\Sigma y_i)^2]}}$$

is a measure of "how well" the least-square regression line fits the data with respect to the ideal of $y = x$.

MEAN DEVIATION: Mean deviation is an indicator of accuracy of the measurements defined as

$$\text{Mean Deviation} = \frac{|d_1| + |d_2| + \dots |d_n|}{n}$$

(a) Standard Mathematical Tables. 1979. 25th Edition, William H. Beyer, Ph.D., Ed. CRC Press,Inc., Baco Raton, FL.

APPENDIX C

RECOMMENDED CRITERIA FOR PERSONNEL TRAINING AND QUALIFICATION CENTERS

APPENDIX C

RECOMMENDED CRITERIA FOR PERSONNEL TRAINING AND QUALIFICATION CENTERS

I. SCOPE

This Appendix applies to organizations that conduct NDE personnel training and qualification functions as described in this document. Such organizations are referred to as Personnel Training and Qualification Centers (PTQCs). A PTQC may perform its functions internally, externally (on a contract or other commercial basis), or both.

A. Coordination Group

A centralized Coordination Group should establish and enforce nationally uniform criteria to assure the quality of instruction provided by Personnel Training and Qualification Centers. These criteria should address both the administrative and technical functions of the PTQCs, and only PTQCs approved by the Coordination Group should conduct training and qualification activities.

B. PTQC Program Plan and Organization

Each PTQC should have a written program plan that assures compliance with the applicable administrative and technical requirements. This program plan should be approved by the Coordination Group.

All instructors of NDE courses should hold a valid ASNT Level III certificate in the UT method; however, NDE instructors need not be certified Level III personnel. PTQC personnel that teach NDE courses and who also prepare, administer, and grade qualification examinations should be organizationally independent of the candidates being trained and examined. The teaching and NDE credentials for PTQC personnel should be reviewed and accepted by the Coordination Group.

II. FACILITIES AND EQUIPMENT

The PTQC should provide classroom and laboratory facilities that contribute to a learning atmosphere. Sufficient space, facilities, and audio-visual equipment should be available to effectively utilize the necessary training aids.

Adequate laboratory facilities and equipment should be available to demonstrate the lecture topics and permit candidates to participate in laboratory projects and exercises. The NDT equipment used should be reasonably current so that candidates have access to contemporary commercial equipment and accessories. A sufficient quantity of equipment should be available so that no more than three candidates must use a given piece of equipment at any one time.

III. ENTRANCE REQUIREMENTS

The PTQC program plan should specify minimum entrance requirements for training course candidates. The bases for such entrance requirements are to assure that candidates have a reasonable probability for success and to eliminate candidates that are intrinsically incapable of successfully completing the training courses.

IV. TRAINING COURSES

The training programs should be administered only by authorized PTQC personnel and should be periodically audited by the Coordination Group.

A. Training Outlines

Detailed outlines should be available for each training course that is offered. Course outlines should be prepared by an NDE Instructor and approved by the Coordination Group.

B. Training Materials

All training materials and supplemental information should be available in the form of written documents, slides, viewgraphs, movies, etc. The written materials, including key illustrations, should be assembled in notebook (or similar) form and a complete copy should be provided to each candidate.

C. Quizzes

Periodic quizzes should be used to measure candidate comprehension and retention of the training materials and supplemental information.

D. Final Written Examination

A written examination should be administered to determine a final course grade. Such examinations should reflect a comprehensive coverage of the training materials and supplemental information presented during the course.

E. Availability and Confidentiality

All training course materials should be available for review by the Coordination Group, potential clients, and cognizant authorities. Training course materials should not be subject to any confidentiality requirements other than the normally applicable copyright restrictions.

V. QUALIFICATION EXAMINATIONS

The qualification examination should be administered only by an authorized PTQC representative who should be responsible for the following items.

A. Content

Written Examination - A written examination should be administered to determine a formal qualification grade. For each qualification examination offered by the PTQC, a "question bank" containing at least three-times the minimum number of questions required per examination should be available. The qualification examination should be assembled from the question bank using a random selection process.

Practical Examination - If a practical examination is administered as part of the qualification examination, a test specimen inventory containing at least two-times the minimum number of flaws to be detected should be available. Sufficient blank (flaw-free) test specimens should also be available so that no more than 25 percent of the test specimens contain flaws that should be detected.

B. Administration and Grading

Qualification examinations should be administered and graded only by authorized representatives of the PTQC. The basis for determining the overall, formal grade on qualification examinations should be defined in the PTQC's program plan.

C. Reexaminations

Reexaminations should contain at least 50 percent different or reworded questions. The practical examination should consist of at least 50 percent different flaws than those used during the most recent practical examination that was not passed by the candidate.

D. Confidentiality

Provisions to ensure the confidentiality of all qualification examinations should be included in the program plan. Qualification examinations should be maintained in secure files and access to these files should be limited to authorized PTQC personnel.

VII. RECORDS CONTROL

A. Organization

Evidence of qualification for all PTQC personnel should be documented and available for audit.

B. Required Documentation

The PTQC program plan should specify the documentation to be maintained in the qualification records for each candidate. This documentation should include such information as the candidate's name and current NDE certification level, qualification examination identification, date of examination, and the overall course and formal qualification examination grades that were attained.

C. Records Maintenance

A scheme should be provided for the secure storage of all training and qualification records. Access to such records should be limited to authorized client representatives, cognizant regulatory authorities, and similarly authorized personnel.

The qualification examinations should not be considered as part of the records and documentation that are subject to routine audit, and should not be made available to clients and other users of the PTQC's services.

APPENDIX D

RECOMMENDED CRITERIA FOR PERFORMANCE VALIDATION CENTERS

APPENDIX D

RECOMMENDED CRITERIA FOR PERFORMANCE VALIDATION CENTERS

I. SCOPE

This Appendix applies to organizations that conduct UT/ISI performance validations as described in this document. Such organizations are referred to as Performance Validation Centers (PVCs), and a PVC could perform its function internally, externally (on a contract or other commercial basis), or both.

A. Coordination Group

A centralized Coordination Group should establish and coordinate the Performance Validation Centers. This Coordination Group should direct both the administrative and technical functions of the regional PVCs, and only PVCs authorized and approved by the Coordination Group should conduct performance validation activities.

B. PVC Program Plan and Organization

The PVC should have a written program plan that assures compliance with the applicable administrative and technical requirements. This program plan, plus supporting documentation, should be approved by the Coordination Group.

The regional PVCs should be organizationally independent of the candidates or teams being qualified. However, since only certified NDT Level III personnel should administer performance demonstrations, personnel on temporary assignment with the PVC may utilize certifications issued by their permanent employer without violating this "organizationally independent" limitation.

II. SPECIMEN CONTROL

A. Documentation of Specimen Characteristics

Each specimen to be used for qualification should be accompanied by a traveler package that contains at least the following information

- material, size, and configuration
- flaw location, size, and orientation (with tolerances)
- geometric reflectors
- unique identification
- method of determining flaw parameters and confidence levels
- any unique characteristics of the specimen

B. Specimen Confidentiality

Measures should be established to assure that the identity of specimens and their respective flaws remain confidential. During the interpretation of indications, the use of supplemental techniques such as referring to radiographs or weld profiling should be permitted without being considered a violation of confidentiality, provided the examination procedure includes guidelines for using supplemental techniques. Access to the specimens and specimen documentation should be controlled to minimize their exposure. Personnel being qualified should not have had previous access to the specimens or the specimen documentation.

C. Specimen Quantity and Configuration

The quantity and configuration of specimens available for performance validations should be consistent with Section 6 of this document.

III. TEST ADMINISTRATION

A. Procedure Review

Unless previously qualified, the examination procedure (EP) to be qualified should be submitted to the PVC at least two (2) weeks prior to the scheduled performance validation. The PVC review should assure that the performance validation will evaluate the UT/ISI system at the limits of the essential variables specified in the EP.

B. Performance Validation

Provisions should be established for controlling the time allowed for scanning and data acquisition. The overall working conditions should simulate the performance of examinations in a field environment to the extent practicable. The performance validation should comply with the criteria recommended in this document, and should be monitored by PVC personnel.

IV. RECORDS CONTROL

A. Required Documentation

The PVC program plan should specify the documentation to be maintained as qualification records. This documentation should include such records as NDE procedure identification, personnel certifications, equipment specifications, specimens used during performance demonstrations, and the performance demonstration results.

B. Records Maintenance

A system should be provided for the secure storage of all performance validation records. These detailed records should be treated as confidential and should not be allowed out of the control of the PVC.

APPENDIX E

EVALUATING THE ELECTRONIC CHARACTERISTICS OF ULTRASONIC INSTRUMENTS

APPENDIX E

EVALUATING THE ELECTRONIC CHARACTERISTICS OF ULTRASONIC INSTRUMENTS

1.0 PULSE RISE TIME, DURATION, AND AMPLITUDE

1.1 The pulser evaluation shall be performed with a 50-ohm noninductive resistive load. Additional loads, including search units, may be used. However, significant impedance mismatches may occur, which can cause variable results. A description of any additional loads shall be included in the report.

1.2 Connect the ultrasonic instrument, cables, attenuator, terminators, and oscilloscope as shown in Figure E-1.

Caution: Pulser circuits can produce very high voltages that may exceed attenuator maximum voltage limits. Choose an attenuator that can handle the peak pulser voltage.

Set the pulser module frequency control to the frequency of interest. (This is only necessary if the instrument has a tuned pulse shape. Examples of tuned and broadband pulses are shown in Figure E-2). Set the pulse shape modification controls (e.g., pulse length, pulse tuning, damping) to obtain a minimum pulse length and adjust the oscilloscope to obtain a display as shown in Figure E-3 or E-4. (Note: In order to obtain a display that clearly shows the leading edge of the pulse, it may be necessary to trigger the oscilloscope externally from the clock logic signal or utilize an oscilloscope with built-in delay.)

1.3 The interconnection between the ultrasonic instrument and the oscilloscope shall be made such that a characteristic impedance of 50 ohms is maintained. The cable length shall be kept as short as possible.

Caution: Pulser circuit output pulses can exceed maximum oscilloscope input levels. Use protective probes where necessary.

1.4 Pulse Rise Time

(a) The pulse rise time (T_R) for a broadband pulse is the time interval (in ns) between the 10% and 90% points (relative to the peak amplitude) on the leading edge of the pulse shape as shown in Figure E-3.

(b) T_R for a tuned pulse is the time interval between the 10% and 90% points (relative to the peak amplitude) on the leading edge of the pulse shape as shown in Figure E-4.

(c) The PULSE RISE TIME-MIN for the 50-ohm load is the T_R with the pulse shape modification controls set for minimum pulse length. The PULSE

RISE TIME-MAX for the 50-ohm load is the T_R with the pulse shape modification controls set for maximum pulse length. These values shall be recorded.

1.5 Pulse Amplitude

(a) The pulse amplitude for a broadband pulse with a specified pulse load is the peak amplitude of the pulse (in volts) as shown in Figure E-3.

(b) For the tuned pulse, the pulse amplitude is determined by measuring the peak amplitude of the positive and the negative portions of the pulse as shown in Figure E-4 and summing these two values. The amplitude of the positive and the negative peaks shall be reported separately.

(c) The PULSE AMPLITUDE-MIN for the 50-ohm load is the pulse amplitude with the pulse shape modification controls set for minimum pulse length. The PULSE AMPLITUDE-MAX for the 50-ohm load is the pulse amplitude with the pulse shape modification controls set for maximum pulse length. These values shall be recorded.

1.6 Pulse Duration

(a) The pulse duration (T_D) for a broadband pulse with the 50-ohm pulse load is the time (in microseconds) corresponding to the time interval between the 10% point on the leading edge of the pulse shape and the 10% point on the tailing edge of the pulse shape (relative to the peak amplitude) as shown in Figure E-5.

(b) For a tuned pulse, T_D is determined by superimposing curves representing the envelope of the pulse as shown in Figure E-6. The pulse duration is determined in the following manner:

Step 1: Construct lines on the positive and negative sides of the zero voltage line at an amplitude equal to 10% of the respective peak amplitudes.

Step 2: T_D is the maximum time interval between the points where the 10% lines from Step 1 intersect the pulse envelope as shown in Figure E-6.

(c) The PULSE DURATION-MIN for this pulse load is T_D with the pulse shape modification controls set for minimum length. The PULSE DURATION-MAX for this pulse load is T_D with the pulse shape modification controls set for maximum pulse length. These values shall be recorded.

2.0 RECEIVER SECTION FREQUENCY CHARACTERISTICS

2.1 Connect the ultrasonic instrument, protective circuit, variable delay gate generator, function generator, oscilloscope, step attenuator, and terminator, as shown in Figure E-7. The variable delay gate generator is used to provide a function generator trigger which is time delayed. The oscilloscope is used to monitor the function generator output, which is the unattenuated input signal to the ultrasonic instrument receiver section. The ultrasonic instrument CRT is used to monitor the receiver output. The impedance of each portion of this system shall be matched.

2.2 CAUTION: The ultrasonic instrument shall be in the through-transmission mode to isolate the pulser circuit from the receiver section. This is to avoid possible damage to the step attenuator and/or function generator. The protective circuit is a diode clamp or voltage divider that keeps the high pulse voltage from damaging the variable delay gate generator input.

(a) For instruments that have a substantial portion of the receiver located before the through-transmission input, set the pulse length controls in their maximum position, disable the pulse output, and set the instrument in the pulse-echo mode.

(b) If the receiver provides variable signal filtering, the signal filtering control shall be set for minimum or zero filtering. Set the receiver reject control to minimum or OFF. Set the receiver frequency control to the frequency range of interest and adjust the gate generator and function generator to provide a five-cycle sine wave whose frequency corresponds to the ultrasonic instrument frequency setting. However, if the ultrasonic instrument will amplify and detect a single-cycle burst instead of a five-cycle, this may be used. Set the calibrated attenuator to 0 dB attenuation and adjust the variable delay gate generator to provide a signal located midway across the CRT. (The ultrasonic instrument sweep rate is irrelevant to these measurements.) Adjust the receiver section gain controls and the function generator output amplitude to 80% full scale. (A preliminary scan of the frequency range may be desirable to determine the frequency of maximum response.)

(c) Repeat the above measurements, varying the function generator frequency in 0.5-MHz increments above and below the receiver module frequency control setting until the CRT indication decreases to 10% of its maximum value. At each frequency increment, the function generator output amplitude shall be adjusted as required to maintain a constant amplitude input to the receiver section.(1) At each frequency increment, record the CRT amplitude (in percent full scale) versus frequency measured with the oscilloscope. Plot the results as shown in Figure E-8.

(d) If the ultrasonic instrument is to be operated with filtering, the measurements described shall be repeated at the corresponding filtering levels.

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(1) The 0.25-MHz and 20-MHz points shall normally be the extent of measurement necessary to determine the frequency characteristics of the receiver. These limits may be reached before the CRT indication decreases to 10% of its maximum value.

2.3 Receiver Frequency Results

(a) Lower Frequency Limit (F_L) - The lower frequency limit (in MHz) at a specific frequency control setting is the lowest frequency at which the instrument CRT indication is 6 dB below the maximum amplitude as shown in Figure E-8.

(b) Center Frequency (F_C) - The center frequency (in MHz) at a specific frequency control setting is the frequency at which the instrument CRT indication is maximum, as shown in Figure E-8. The center frequency shall be determined within ±0.1 MHz by decreasing the increment of frequency change in the region near the center frequency.

(c) Upper Frequency Limit (F_U) - The upper frequency limit (in MHz) at a specific frequency control setting is the highest frequency at which the instrument CRT indication is 6 dB below the maximum amplitude as shown in Figure E-8.

(d) The measurements described in 2.3(a) through (c) shall be repeated for each receiver module frequency control setting to determine the LOWER FREQUENCY LIMIT (in MHz) for each setting. These values shall be recorded.

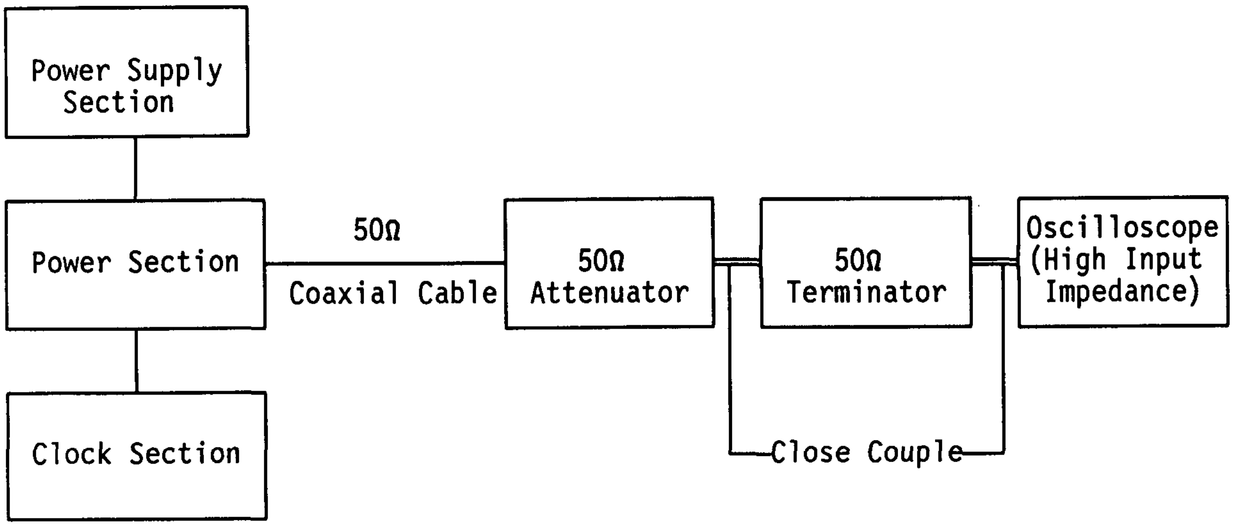


FIGURE E-1. Schematic for Pulse Risetime, Duration, and Amplitude Measurements

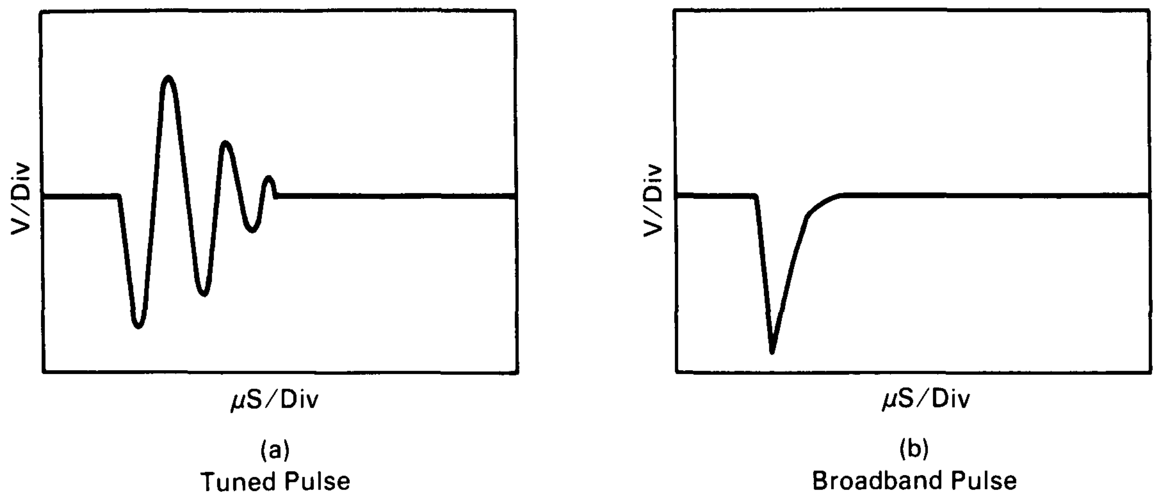


FIGURE E-2. Pulse Display

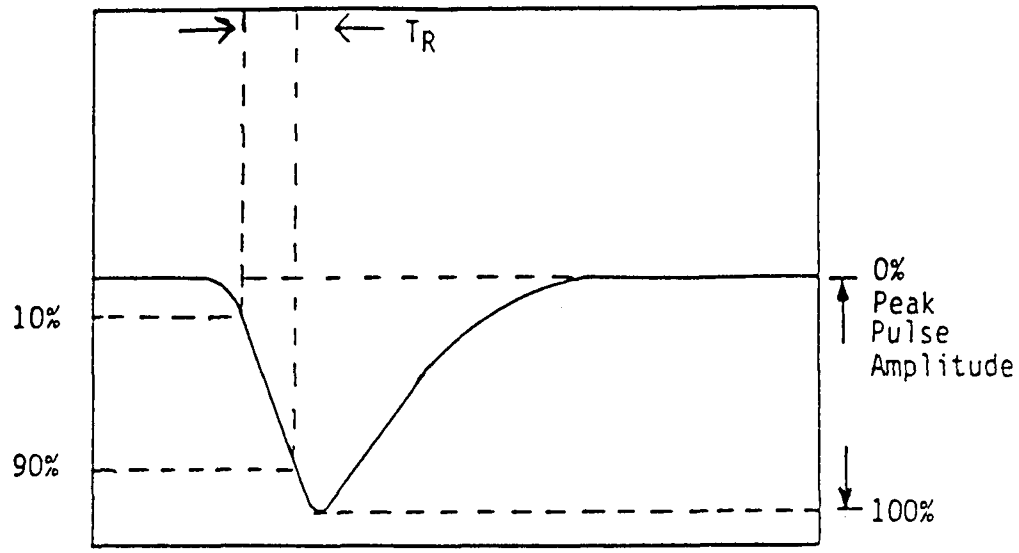


FIGURE E-3. Broadband Pulse Evaluation for Amplitude and Rise Time

Pulse Amplitude = Positive Side Amplitude + Negative Side Amplitude

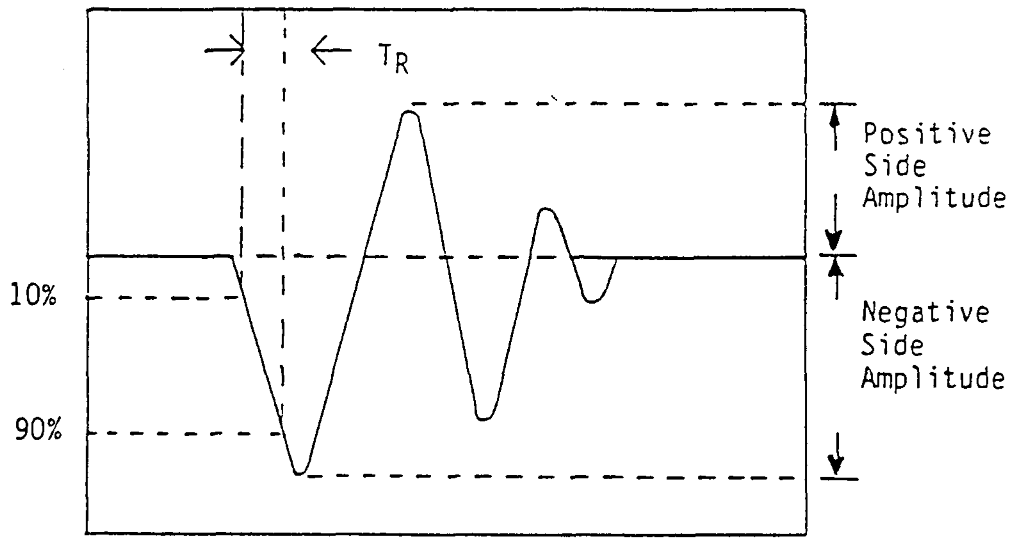


FIGURE E-4. Tuned Pulse Evaluation for Amplitude and Rise Time

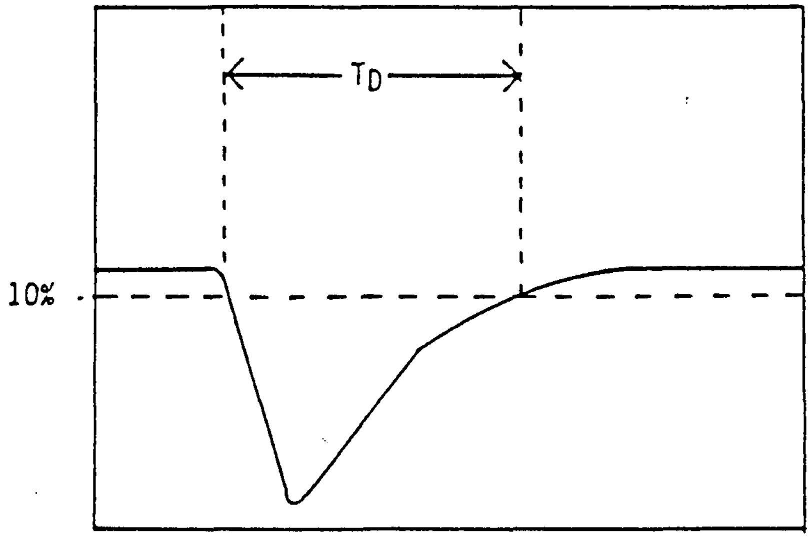


FIGURE E-5. Broadband Pulse Evaluation for Pulse Duration

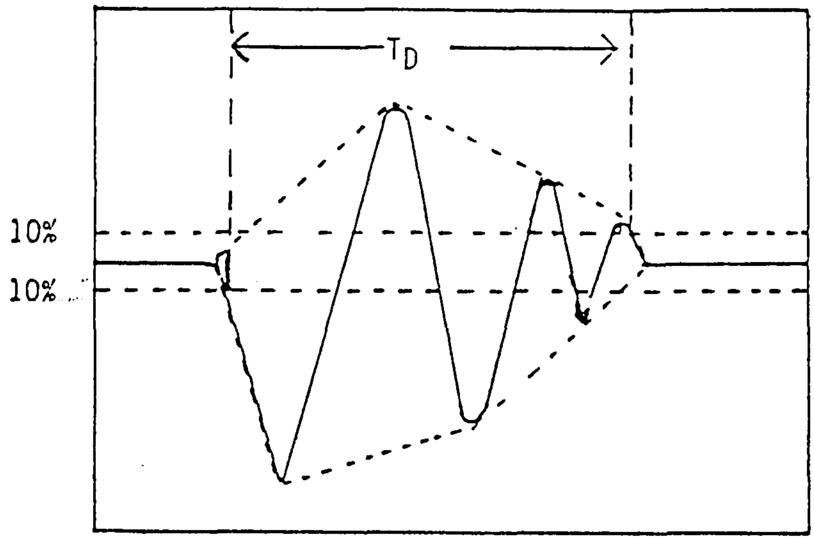
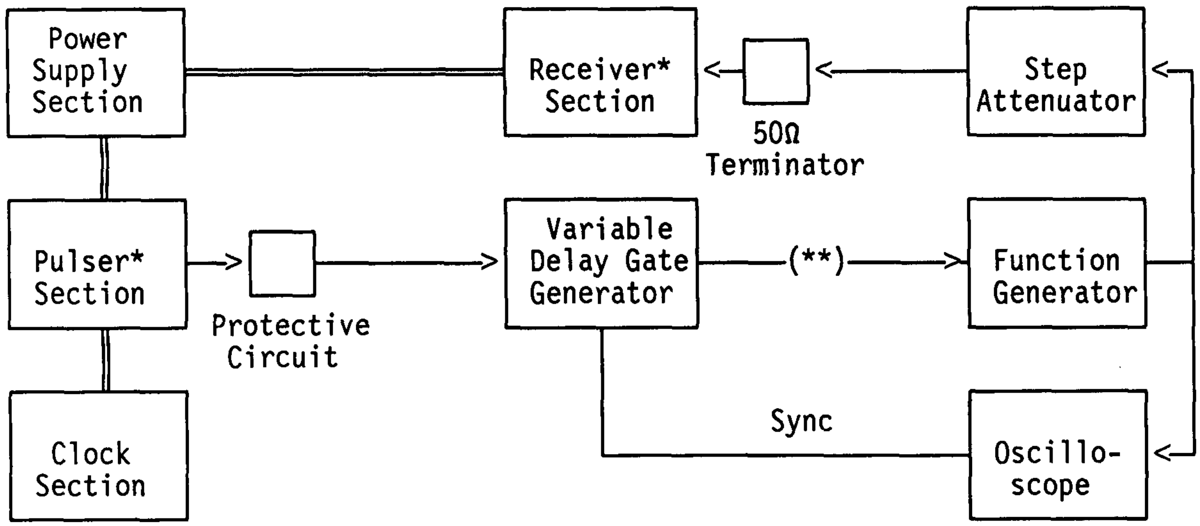


FIGURE E-6. Tuned Pulse Evaluation for Pulse Duration



*Thru-transmission mode
**Variable delayed, variable width gate for defining function generator gated burst output.

FIGURE E-7. Schematic for Receiver Section Bandwidth

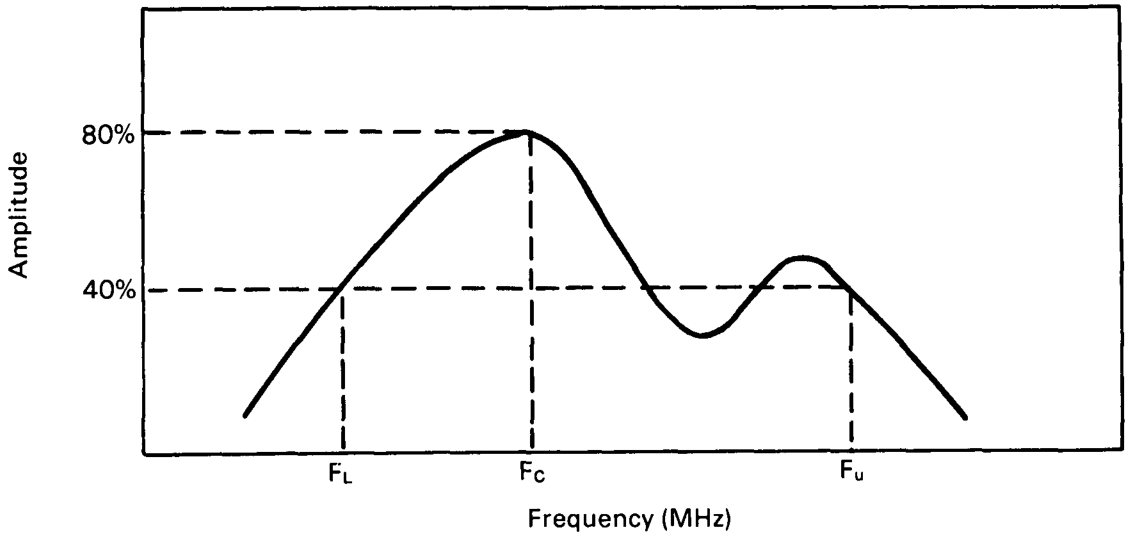


FIGURE E-8. Receiver Section Frequency Characteristics

APPENDIX F

RECOMMENDED FLAW SIZES AND LOCATIONS FOR VESSEL QUALIFICATION SPECIMENS

RECOMMENDED FLAW SIZES AND LOCATIONS FOR VESSEL QUALIFICATION SPECIMENS

F. A. Simonen

This Appendix provides recommendations for flaw sizes and flaw locations for vessel qualification specimens. Table F-1 provides a suitable combination of flaws for qualification specimens. Fracture mechanics considerations form the basis for these recommendations, which are discussed below.

FRACTURE MECHANICS CONSIDERATIONS

This discussion provides recommendations for both the flaw sizes and the flaw locations for the specimens to be used in the qualification of vessel ultrasonic (UT) inspection. These recommendations are based on considerations of vessel fracture mechanics calculations that have been performed at PNL (References 1-3). The scope of the recommendations is restricted to the inspection of seam and girth welds. Inspection of other parts of the vessel such as nozzles and flanges is specifically excluded from consideration. It should also be noted that the referenced fracture mechanics calculations were directed to welds in the vessel beltline region, which is the part of the vessel that is most subjected to irradiation induced embrittlement. Finally, the term "flaw location" as used herein is defined as the location of the flaw tip that is nearest to the inner surface of the vessel.

FRACTURE MECHANICS TRENDS

There have been a large number of calculations that predict the important factors that could contribute to the brittle fracture of the beltline region of the reactor pressure vessel. These fracture mechanics calculations suggest that the qualification requirements should emphasize flaws of relatively small size and flaws located near the inner surface of the vessel. However, it should be emphasized that there is perhaps no single "best" set of flaws for qualification specimens that can be developed on the basis of fracture mechanics or by other means.

The review of fracture mechanics data as given below, indicates that the most likely cause of vessel failures are flaws within the inner 30% of the vessel wall and flaws whose depth dimensions are about 25% or less of the vessel wall.

The inner part of the vessel wall is generally thought to be the most important location for ISI because it is more severely embrittled by neutron irradiation, and also because thermal stresses tend to be most severe near the inner vessel surface. However, flaws in the outer portion of the vessel sometimes can be significant and should not be ignored for ISI. For certain accidents involving over pressure at low temperatures (without thermal stresses from rapid cooling), outer surface flaws can be nearly as significant as inner surface flaws. Thus outer surface flaws should not be ignored in qualification and ISI requirements.

Smaller defects are shown to be more likely to cause vessel failure than very large flaws because such flaws are far more likely to exist in a vessel than are larger defects. However, if very large flaws exist, they are more likely to cause reactor pressure vessel failure and fortunately are not likely to exist. Statistics on defect populations for newly fabricated vessels and also fracture mechanics calculations of crack growth rates for older vessels both indicate that the presence of a very large defect within the beltline of a reactor vessel is highly improbable. On the other hand, fracture mechanics calculations do show that small defects (as small as 0.25 inch) could cause a vessel failure under pressurized thermal shock accident conditions.

Flaw sizes greater than about 25% of the wall appear to be of somewhat lower priority from the standpoint of probabilistic fracture mechanics, and thus the extra costs of fabricating more than a few such specimens for qualification tests would be hard to justify. In this regard, specimens with very deep cracks are likely to be the most difficult and costly to fabricate.

Fracture mechanics results suggest the inclusion of some specimens with defects at or near the outer surface of the vessel, and also the inclusion of some flaws somewhat larger than those suggested by the fracture calculations for the pressurized thermal shock accidents. The larger size flaws and the outer surface type flaws are useful as a means to validate the ability to detect and discriminate over a larger range of flaw catagories. Also, from the standpoint of vessel safety and reliability, the detection of such flaws (particularly in the less embrittled parts of the vessel) will serve a useful purpose of preventing through wall leaking cracks, and will also serve to minimize the potential for low probability modes of brittle and/or ductile fracture for the category of accidents described as "low temperature over pressure" (LTOP) events.

Fracture mechanics results suggest that the cracks in qualification specimens should have radial orientations, since only such flaws are important from the standpoint of fracture significance. However, there is also a rationale for a requirement that perhaps a few specimens contain flaws parallel to the vessel surfaces in order to simulate laminar type defects. While these defects are not significant to vessel fracture, they may be commonly encountered during vessel examinations. Specimens with such flaws would provide a test of NDE capabilities for discrimination and characterization of significant flaws from these less significant types of flaws.

PROBABILISTIC FRACTURE PREDICTIONS

Probabilistic fracture mechanics models provide useful information to indicate the sizes and the locations of those flaws that are most likely to be present in a reactor pressure vessel. The models also indicate those flaws that are both capable of and are most likely to cause a vessel to fail either under normal operating conditions or during a severe accident. The discussion below covers results of calculations performed using the VISA-II fracture mechanics computer code (see References 2 and 3).

The objective of the results presented here is to identify the sizes and locations of flaws that are most likely to cause vessel fracture. In this regard, the following considerations apply:

- Small flaws at locations of high service induced tensile stresses (e.g., at the vessel inner surface) can be more significant than much larger flaws at other locations of less severe stress.

- Small flaws at locations of low fracture toughness can be more significant than much larger flaws at locations of less embrittlement of the vessel material. For example, the inner wall of a vessel can exhibit much lower toughness than material at the outer vessel wall due both to more severe levels of neutron induced embrittlement and to the low temperatures produced by rapid cooling of the inner surface during thermal shock accidents.

- While large flaws are more likely to cause fracture of a vessel, their estimated probabilities of occurrence can be so low that it is inappropriate to direct inspection efforts to the detection of such flaws that have a small probability of being present in an actual vessel. Rather, it is the smaller but more commonly encountered flaws that pose the real threat to vessel integrity.

- Large flaws are important to structural integrity and the NDT/ISI must be capable of finding this condition if it exists.

Figures F-1 and F-2 show histograms derived from predicted scenarios of vessel failure as simulated by the VISA-II computer code. The plots show statistics that describe the depths and locations of the flaws that were the root cause of the simulated vessel failures.

Risk analyses have identified two types of operational accidents that are major contributors to vessel fracture probability. Figure F-1 addresses pressurized thermal shock (PTS) of a highly irradiated and embrittled vessel for a postulated over-cooling event (the so-called Rancho Seco transient). This type of accident presents a particular challenge to the inner wall of the vessel, and tends to focus concern on small flaws at inner wall locations.

The other class of accident is the low temperature over pressurization (LTOP) event. Results for a postulated event of this type are shown in Figure F-2. This type of accident does not generate preferential cooling of the inner surface of the vessel, nor are high tensile thermal stresses produced at the inner surface. Thus, the flaws expected to be of concern are likely to be somewhat larger than those for the PTS type of accident, and flaw locations of concern are not restricted to the region of the vessel inner wall.

Figure F-1 suggests that (for PTS accidents) there should be little concern for flaws outside the inner 30% of the vessel wall thickness. Also, flaw sizes (depths) greater than about 25% of the vessel wall need not be of great concern. For PTS conditions, the severity of both the embrittlement and the stress levels are more than sufficient to propagate the more probable and numerous flaws of smaller size. These results by themselves would suggest that a high quality near surface examination might even preclude the need for a full volumetric examination of the vessel wall.

Figure F-2 suggests that a volumetric examination of the full thickness of the vessel wall does in fact provide some potential benefit, although the examination of the inner part of the vessel wall for small flaws is again identified as a high priority concern. These calculations assumed zero thermal stresses and assumed only a moderate level of radiation induced embrittlement (i.e., the LTOP accident). As such, the results were intended to illustrate a particular situation for which larger flaws at outer wall locations can contribute to vessel failure. The plots in Figure F-2 show that flaws as large as 50% of the vessel wall and also flaws at any location within the vessel wall are possible causes of vessel failure.

In summary, the results as cited here highlight the trend that smaller flaws located near the inner vessel wall should be the first priority for inservice inspection. However, the fracture mechanics results do not preclude a need for inspection of the outer vessel wall nor do the results preclude concerns for the significance of larger flaws.

Table F-1 was generated as an example of the types of flaw categories (sizes and locations) that should be emphasized for qualification specimens. The number of flaws for each of the "checked" categories should be roughly equal. It would also be reasonable to include some flaws from the "unchecked" categories. Furthermore, the stated ranges for the size and location categories of Table F-1 were assigned rather subjectively, and could be modified on the basis of considerations other than fracture mechanics analysis.

TABLE F-1. Recommended Categories of Sizes and Locations of Flaws in Qualification Specimens for Vessel Inspection

	Through-Wall Flaw Depths, % of Wall		
Flaw Location	2.0 - 7.5%	7.5 - 15%	15 - 30%
Inside Surface	x	x	
Outside Surface	x	x	
Subsurface 2 to 30% T*		x	x
Subsurface 30 to 90% T*		x	x

*Location of flaw tip nearest to the inner or outer surface of vessel.

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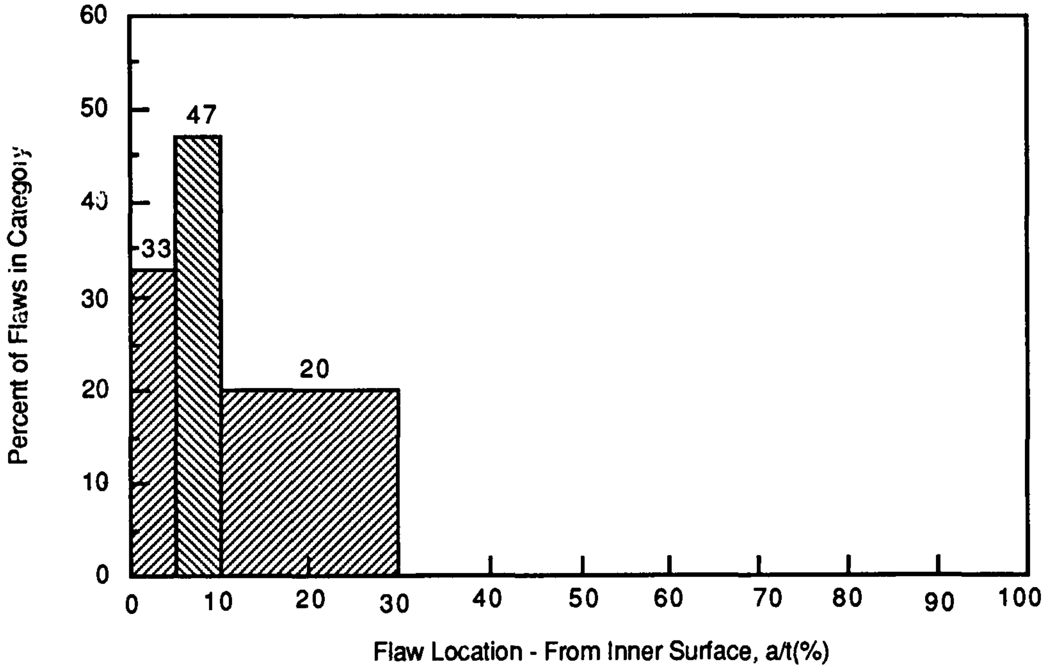
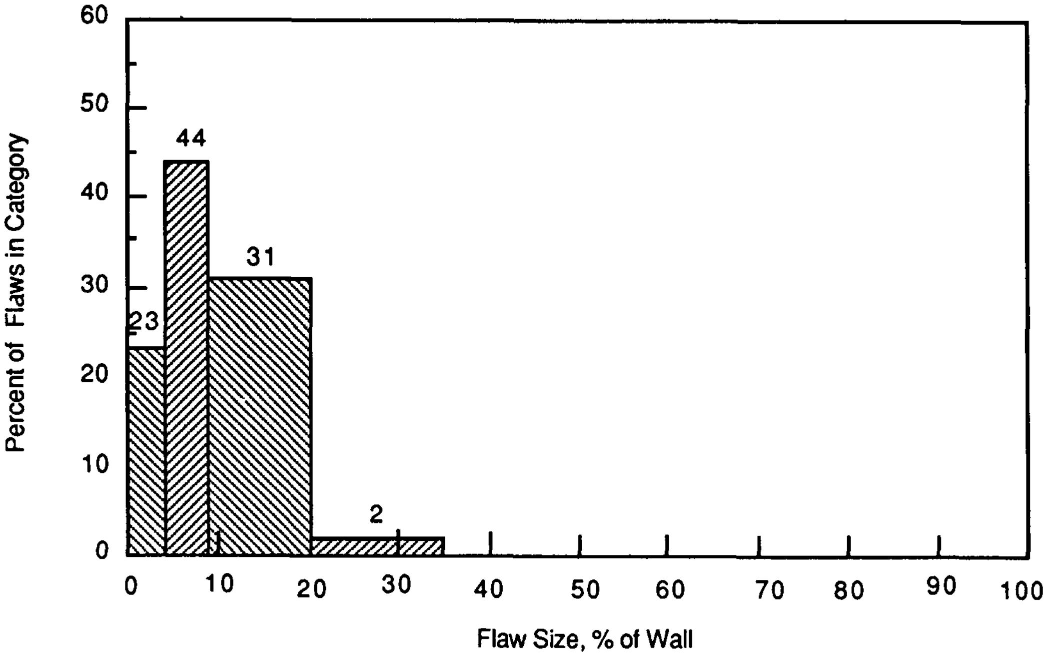
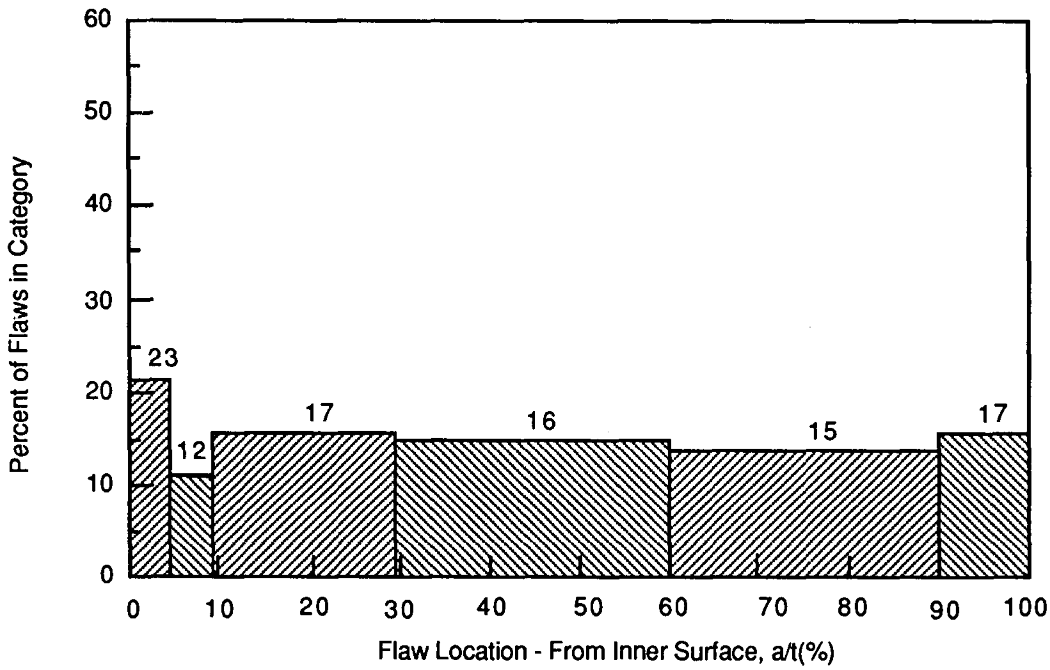


(a) Contribution of various flaw locations to vessel fracture probability

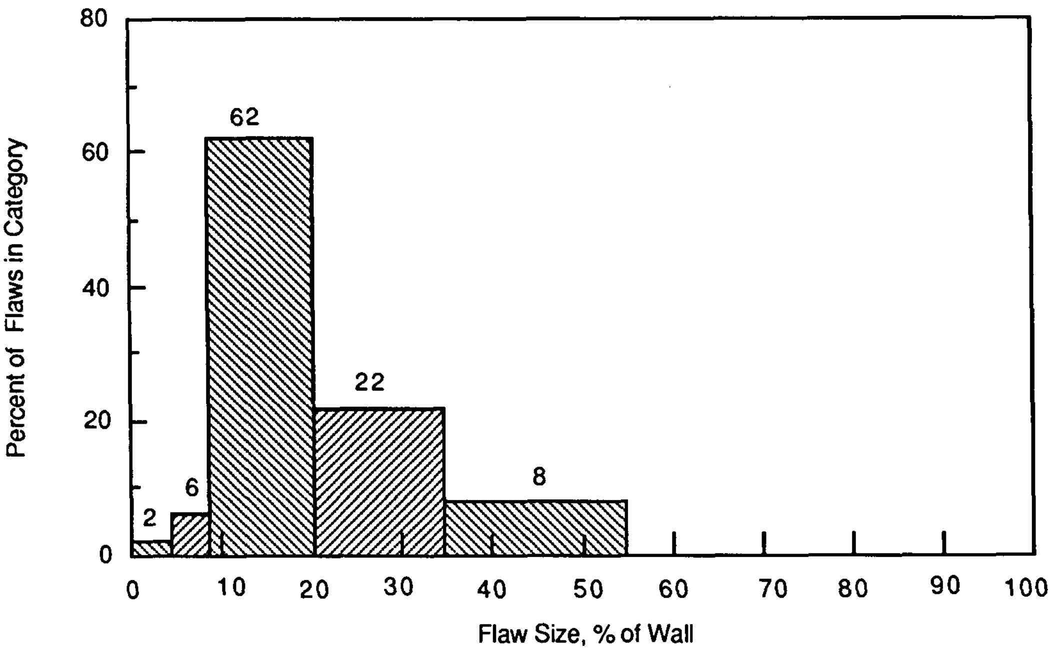


(b) Contribution of various flaw sizes to vessel fracture probability

FIGURE F-1. Significant Flaws for Vessel Fracture from Pressurized Thermal Shock Events



(a) Contribution of various flaw locations to vessel fracture probability



(b) Contribution of various flaw sizes to vessel fracture probability

FIGURE F-2. Significant Flaws for Vessel Fracture from Low Temperature Overpressure Events

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11. ABSTRACT *(200 words or less)*

This report documents one of the tasks conducted under a Pacific Northwest Laboratory (PNL) program entitled Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors (NDE Reliability Program). The objective of this task was to develop recommended requirements and processes for qualifying the UT/ISI systems (personnel, equipment, and procedures) for inservice inspection of nuclear power plant components. This report describes an overall qualification process intended to achieve statistically designed performance validations, as well as include the prerequisite training and other qualification recommendations. The document also contains recommendations for the test specimens, environment, and other conditions under which the qualification processes should be conducted.

In general, the recommendations described in this document are more stringent than the current industry requirements; however, there are exceptions. The major areas where specific enhancements are recommended include more stringent criteria for Level III qualifications, explicit recommendations for requalification, greater emphasis on periodic (annual) training, and recommendations for coordinating and administering the qualification processes on a national (rather than local employer) basis.

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