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Nondestructive Examination (NDE) Reliability for Inservice Inspection of Light Water Reactors

Semi-Annual Report
October 1987 – March 1988

Prepared by S. R. Doctor, J. D. Deffenbaugh, M. S. Good, E. R. Green,
P. G. Heasler, F. A. Simonen, J. C. Spanner, T. T. Taylor

Pacific Northwest Laboratory
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U.S. Nuclear Regulatory Commission

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ABSTRACT

The Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors (NDE Reliability) Program at the Pacific Northwest Laboratory was established by the Nuclear Regulatory Commission to determine the reliability of current inservice inspection (ISI) techniques and to develop recommendations that will ensure a suitably high inspection reliability. The objectives of this program include determining the reliability of ISI performed on the primary systems of commercial light-water reactors (LWRs); using probabilistic fracture mechanics analysis to determine the impact of NDE unreliability on system safety; and evaluating reliability improvements that can be achieved with improved and advanced technology. A final objective is to formulate recommended revisions to ASME Code and Regulatory requirements, based on material properties, service conditions, and NDE capabilities and uncertainties. The program scope is limited to ISI of the primary systems including the piping, vessel, and other inspected components. This is a progress report covering the programmatic work from October 1987 through March 1988.

EXECUTIVE SUMMARY[a]

A multi-year program entitled the Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors (NDE Reliability) was established at the Pacific Northwest Laboratory (PNL) to determine the reliability of current inservice inspection (ISI) techniques and to develop recommendations that would ensure a suitably high inspection reliability if fully implemented.

The objectives of this Nondestructive Examination (NDE) Reliability program for the Nuclear Regulatory Commission (NRC) include:

- Determine the reliability of ultrasonic ISI performed on the primary systems of commercial light-water reactors (LWRs).
- Use probabilistic fracture mechanics analysis to determine the impact of NDE unreliability on system safety and determine the level of inspection reliability required to ensure a suitably low failure probability.
- Evaluate the degree of reliability improvement that could be achieved using improved and advanced NDE techniques.
- Based on material properties, service conditions, and NDE capabilities and uncertainties, formulate recommended revisions to ASME Code, Section XI and Regulatory requirements needed to ensure suitably low failure probabilities.

The scope of the program is limited to the ISI of primary coolant systems, but the results and recommendations are also applicable to Class II piping systems.

The program consists of three basic tasks: a Piping task, a Pressure Vessel task, and a New Inspection Criteria task. Because of the problems associated with the reliable detection, correct interpretation, and accurate characterization of defects during inservice inspection of piping, the major efforts of this reporting period were concentrated in the Piping task and the New Inspection Criteria task.

The major highlights for this reporting period were:

PIPING TASK

This task is designed to address the NDE problems associated with piping used in light water reactors. The primary thrust of the work has been on wrought and cast stainless steel since these materials are more difficult to inspect than carbon steel. However, many of the task's results are equally applicable to carbon steel. The current subtasks are: Qualification Criteria for UT/ISI Systems, Cast Stainless Steel Inspection, Round-Robin Tests, and

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(a) RSR FIN Budget No. B2289; RSR Contact: J. Muscara

UT Equipment Interaction Matrix. Major highlights during this reporting period for each of these subtasks were as follows:

- Qualification Criteria for UT/ISI Systems - The objective of this subtask is to improve the reliability of ultrasonic testing/inservice inspection (UT/ISI) through the development of new criteria and requirements for qualifying UT/ISI systems. Revisions to the Qualification Document (NUREG/CR-4882) to address comments and resolve various technical issues were completed. This document was submitted to NRC for final pre-publication review, and is also being processed through PNL clearance.

- Cast Stainless Steel Inspection - The objective of this subtask is to determine the effectiveness and reliability of ultrasonic inspection of components containing cast stainless steel material. Far-side weld inspection is included in the scope of this subtask since by definition the ultrasonic beam passes through weld material. Activities within the U.S. were monitored and a status report was provided in the form of draft input for use in developing a Research Information Letter (RIL) by the NRC. The sources of information included personnel at ANL, the University of Tulsa, Nutech, Structural Integrity Associates, and Computational Mechanics, Inc.

  The data acquisition system was upgraded to enable RF signal digitization, microprobe development, and development of a data analysis program. Maps of both 0° and 45° L-wave fields were acquired from an assorted matrix of CCSS microstructures. These maps illustrated the degree of distortion incurred by 1-MHz L-waves at the selected refracted angles.

- Surface Roughness Conditions - The objective of this subtask is to establish specifications such that an effective and reliable ultrasonic inspection is not precluded by the condition of the exposed surface. This subtask involves a cooperative effort with EPRI in establishing a mathematical model to be used to derive guidelines for surface specifications. Activities included the formulation of a Coordination Plan between EPRI, the NRC, the Center for NDE (CNDE) at Ames Laboratory, and PNL; a visit by CNDE personnel to PNL; and a data exchange between CNDE and PNL.

  MRR Report - Work on the Mini-Round Robin (MRR) report continued, and all comments received to date have been incorporated; however, additional review comments are expected during the next reporting period.

  PISC III - PNL representatives participated in selected PISC-III activities including Action No. 1 on Real Contaminated Structures Tests (RCS), Action No. 2 on Full-Scale Vessel Tests (FSV), Action No. 3 on Round-Robin Tests on Ferritic Steels (FST), Action No. 4 on Round-Robin Tests on Austenitic Steels (AST), Action No. 6 on Ultrasonic Testing Modeling (MOD), and Action No. 7 on Human Reliability Exercises (REL). These actions are being followed to ensure that conditions, materials, and practices in the U.S. are being included in this PISC-III activity so that the results are transferable and usable to the U.S.

Field Pipe Characterization - Pipe weld specimens have been accumulated and decontaminated in support of the PISC-III program. A variety of pipe weld specimens have been decontaminated (by an off-site contractor), and weld profile measurements and penetrant examinations have been conducted at PNL. Five weld specimens were packaged in an overseas-approved shipping container and are awaiting shipment to Europe.

- UT Equipment Interaction Matrix - The objective of this work is to evaluate the effects of frequency domain equipment interactions and determine tolerance values for improving ultrasonic inspection reliability. An analysis is being performed to evaluate frequency domain effects using a computer model to calculate the flaw transfer function. Model predictions were compared with data from single-frequency experiments, and as expected since this is a 2-D model, the model predictions were excellent for smooth strip flaws but poor for circular flaws. The model was used to perform case studies to determine the effects of flaw size, flaw orientation, and probe position on the flaw transfer function. It was found that probe position, flaw size, and orientation strongly effected the transfer function. A total ultrasonic inspection system model was completed and is ready for execution of the equipment parameter sensitivity study.

CODE ACTIVITIES TASK

The objective of this task is to develop and/or evaluate new criteria and requirements for qualifying ultrasonic testing/inservice inspection (UT/ISI) systems. The primary goal is for these criteria and requirements to be incorporated into Section XI of the ASME Boiler and Pressure Vessel Code. Participation in ASME Section XI activities continued toward achieving Code acceptance of NRC-funded PNL research to improve the reliability of NDE/ISI. The proposed Appendix VII on Personnel Qualification and Certification was approved by the Section XI Subcommittee but received two negative votes during initial Main Committee consideration. The proposed Mandatory Appendix VIII on Performance Demonstration was approved by the SC-XI Subgroup on Nondestructive Examination (SGNDE) pending resolution of an open issue regarding the implementation approach. A proposed revision to Code Case N-409 (N 409-1) was finally approved, published, and distributed to all ASME Section XI Code holders toward the end of this reporting period.

PRESSURE VESSEL INSPECTION TASK

The objective of this task is to ascertain the reliability of current UT/ISI for the pressure vessel by evaluating existing data from inspection round robins conducted under the PISC-II program. The PISC-II round-robin data base was received from the Joint Research Centre (JRC), Ispra, Italy and entered in a PNL VAX computer. Confusion existed in how to correctly interpret the data files and further clarification was requested from the JRC. This clarification was received, and the data files were prepared and sent to the U.S. participants in the PISC-II program who had requested these data.

NEW INSPECTION CRITERIA TASK

The objective of this task is to develop methodologies and criteria for improving ISI (type, extent, frequency, effectiveness) to meet goals of failure probability, radiation releases, or core melt probabilities. Efforts during this reporting period emphasized the application of probabilistic risk assessment (PRA) and probabilistic fracture mechanics (PFM) to determine the level of inspection required to assure a suitably low failure probability for primary system reactor components. Particular attention was directed to requirements for inspection intervals and weld inspection sampling plans.

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NONDESTRUCTIVE EXAMINATION (NDE) RELIABILITY FOR INSERVICE INSPECTION OF LIGHT WATER REACTORS

1.0 INTRODUCTION

The Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors (NDE Reliability) Program at Pacific Northwest Laboratory (PNL) was established to determine the reliability of current inservice inspection (ISI) techniques and to develop recommendations that would ensure a suitably high inspection reliability if fully implemented. The objectives of this program for the Nuclear Regulatory Commission (NRC) are:

- Determine the reliability of ultrasonic ISI performed on commercial light-water reactor (LWR) primary systems.
- Use probabilistic fracture mechanics analysis to determine the impact of NDE unreliability on system safety and determine the level of inspection reliability required to insure a suitably low failure probability.
- Evaluate the degree of reliability improvement that could be achieved using improved and advanced NDE techniques.
- Based on material properties, service conditions, and NDE capabilities and uncertainties, formulate recommended revisions to ASME Code, Section XI, and Regulatory requirements needed to ensure suitably low failure probabilities.

The scope of this program is limited to ISI of primary coolant systems, but the results and recommendations are also applicable to Class II piping systems.

The program consists of three basic tasks: a Piping task, a Pressure Vessel task, and a New Inspection Criteria task. Because of the problems associated with the reliable detection and accurate characterization of defects during inservice inspection of piping, the major efforts were concentrated in the Piping task and the New Inspection Criteria task.

This report is divided into several sections. The second section contains a description and progress report for each subtask of the Piping task. The third section contains a description and progress report on ASME Code activities. The fourth section describes work on the Pressure Vessel Inspection task. The fifth section provides a review of activities regarding the need and basis for new ISI criteria.

2.0 PIPING TASK

This task is designed to address the NDE problems associated with piping used in light water reactors. The primary thrust of the work has been on wrought and cast stainless steel since these materials are more difficult to inspect than carbon steel. However, many of the task's results are equally applicable to carbon steel. The current subtasks are: qualification criteria for UT/ISI systems; cast stainless steel inspection; round robin tests (pipe inspection round robin report, mini-round robin, PISC III, and field pipe characterization); and UT equipment interaction matrix.

2.1 SUMMARY

The work accomplished during this reporting period is summarized in the following:

- Qualification Criteria for UT/ISI Systems - Revisions to the Qualification Document (NUREG/CR-4882) to address NRC comments and resolve various technical issues were completed. Accommodation of the NRC comments involved changing the title of this document to "Qualification Process for Ultrasonic Testing on Nuclear Inservice Inspection Applications." The document was submitted to the NRC for final pre-publication review, and is also being processed through PNL clearance.

- Cast Stainless Steel Inspection - Activities were conducted in two areas: a) ultrasonic inspection of weld-overlaid pipe joints and b) ultrasonic inspection of centrifugally cast stainless steel (CCSS) piping. Activities continued in developing more effective and reliable UT inspection techniques for weld-overlaid pipe joints, and a status report was provided in the form of draft input for use by the NRC in developing a Research Information Letter (RIL). Information was obtained by contacting personnel at the Argonne National Laboratory, the University of Tulsa, Nutech, Structural Integrity Associates, and Computational Mechanics, Inc.

  The data acquisition system was upgraded to enable RF signal digitization, microprobe development, and development of a data analysis program. Maps of both 0° and 45° L-wave fields were acquired from an assorted matrix of CCSS microstructures. These maps illustrate the degree of distortion incurred by 1-MHz L-waves at selected refracted angles.

- Surface Roughness Conditions - This activity involves a cooperative program with EPRI in establishing a mathematical model to be used to derive guidelines for surface specifications. Activities included the formulation of a Coordination Plan between EPRI, NRC, the Center for NDE (CNDE) at Ames Laboratory, and PNL; a visit by CNDE personnel to PNL; and an exchange of data between CNDE and PNL. Comparisons of experimental measurements with model predictions was initiated, and ultrasonic field maps are being acquired for analysis.

- Round Robin Tests

PIRR Report - Work on the Pipe Inspection Round Robin report (PIRR) was deferred during this reporting period.

MRR Report - A report on the Mini-Round Robin (MRR) was prepared and submitted for NRC review. All comments that have been received to date have been incorporated, and further review comments are expected.

PISC III - PNL representatives participated in selected PISC-III activities including Action No. 1 on Real Contaminated Structures Tests (RCS), Action No. 2 on Full-Scale Vessel Tests (FSV), Action No. 3 on Round-Robin Tests on Ferritic Steels (FST), Action No. 4 on Round-Robin Tests on Austenitic Steels (AST), Action No. 6 on Ultrasonic Testing Modeling (MOD), and Action No. 7 on Human Reliability Exercises (REL). These actions are being followed to ensure that conditions, materials, and practices in the U.S. are being included in this PISC-III activity so that the results are transferable and usable to the U.S.

Field Pipe Characterization - Pipe weld specimens have been accumulated and decontaminated in support of the PISC-III program. A variety of pipe weld specimens have been decontaminated (by an off-site contractor), and weld profile measurements and penetrant examinations have been conducted at PNL. Five weld specimens were packaged in an overseas-approved shipping container and are awaiting shipment to Europe.

- UT Equipment Interaction Matrix - Model predictions were compared with data from single-frequency experiments. The model predictions, as expected for a 2-D model, were excellent for smooth strip flaws but poor for circular flaws. The model was used to perform case studies to determine the effects of flaw size, flaw orientation, and probe position on the flaw transfer function. It was found that probe position, flaw size, and orientation strongly affected the transfer function. A total ultrasonic inspection system model was completed and is ready for execution of the equipment parameter sensitivity study.

2.2 QUALIFICATION CRITERIA FOR UT/ISI SYSTEMS

2.2.1 Summary

The objective of this subtask is to improve the reliability of ultrasonic testing/inservice inspection (UT/ISI) through the development of new criteria and requirements for qualifying UT/ISI systems. Revisions to the Qualification Document (NUREG/CR-4882) to address NRC comments and resolve various technical issues were completed. Accommodation of the NRC comments involved changing the title of this document to "Qualification Process for Ultrasonic Testing on Nuclear Inservice Inspection Applications." The document was submitted to the NRC for final pre-publication review, and is also being processed through PNL clearance.

2.2.2 Status of Work Performed

Development of criteria and requirements for qualifying ultrasonic testing/inservice inspection (UT/ISI) systems continued with final restructuring of the Qualification Document as a formal report. Extensive revisions were made to the Qualification Document (NUREG/CR-4882) to accommodate NRC review comments. A detailed, internal review was conducted and this review identified a series of technical issues to be addressed.

Extensive revisions were made to accommodate comments resulting from the NRC review, as well as the various technical issues that were identified during the PNL internal review. A draft of the document was submitted to the NRC for final pre-publication review near the end of this reporting period. The document was also submitted for PNL clearance. These actions constituted on-schedule completion of Milestone 6.3.

2.2.3 Future Work

Upon receipt of PNL clearance and NRC pre-publication approval, NUREG/CR-4882 entitled "Qualification Process for Ultrasonic Testing on Nuclear Inservice Inspection Applications" will be submitted for publication by the NRC. When published, this document will describe recommended qualification processes for all nondestructive examination/inservice inspection (NDE/ISI) systems, although the document is primarily directed toward criteria and qualification processes for UT/ISI systems.

2.3 CAST STAINLESS STEEL INSPECTION

2.3.1 Summary

The objective of this subtask is to determine the effectiveness and reliability of ultrasonic inspection of components containing cast stainless steel material. Due to the coarse microstructure of this material, many inspection problems exist and are common to structures such as cladded pipe, vessels, statically cast elbows, statically cast pump bowls, centrifugally cast piping, dissimilar metal welds, and weld-overlay-repaired pipe joints. Far-side weld inspection is included in the cast material work scope since by definition the ultrasonic beam passes through weld material. Activities included two areas: a) ultrasonic inspection of weld-overlay-repaired pipe joints and b) ultrasonic inspection of centrifugally cast stainless steel (CCSS) piping.

2.3.2 Status of Work Performed

2.3.2.1 Weld Overlay

Weld-overlay repair is currently being used as a temporary repair mechanism for BWR piping weakened by IGSCC and is being proposed as a longer-term repair mechanism. NUREG/CR-4484, Status of Activities for Inspecting Weld Overlaid

Pipe Joints, was published in 1986. Activities continued in developing more effective and reliable ultrasonic inspection techniques. Therefore, these activities were monitored and a status report was provided in the form of a Research Information Letter (RIL).

Draft input for use by the NRC in developing a RIL was mailed to the NRC program manager on April 30, 1987. The draft input was based on the final letter report that was submitted in February 1987. The primary conclusion in the draft input was that a great amount of work has been performed to demonstrate the effective ultrasonic inspection of weld-overlay-repaired pipe joints; however, insufficient data exists to classify this inspection as effective and reliable. A suggestion from the NRC program manager was to quantify the amount of data needed to estimate whether a reliable inspection is or is not feasible and include this information along with other comments into another draft version.

A second draft on weld-overlay inspectability was mailed to the NRC program manager on April 27, 1988. Major changes from the first draft include a discussion of modeling the stress intensity factors at the crack tip via elastic-plastic finite-element calculations, and the design of an inspection procedure test to aid in quantifying the data needed to assess whether an effective and reliable inspection exists for weld-overlay-repaired pipe joints.

Finite-element calculations could have been used many years ago to model the stress state of weld overlays. However, such computations are lengthy and assumptions are generally used for efficiency. Furthermore, such analyses are generally performed by designers of weld-overlay repairs for a utility and, therefore, are used privately. They may have also been reported to the NRC during design reviews. Such analyses are generally not available in the open literature.

Our information was gathered by contacting Bill Shack at ANL, Ed Rybicki at the University of Tulsa, personnel from both NUTECH and Structural Integrity Associates, and Randy Stonesifer at Computational Mechanics, Inc.

2.3.2.2 Centrifugally Cast Stainless Steel

Centrifugally cast stainless steel (CCSS) piping is used in the primary reactor coolant loop piping of 27 pressurized water reactors (PWRs) manufactured by the Westinghouse Electric Corporation. However, CCSS piping inspection procedures continue to perform unsatisfactorily due to the coarse microstructure that characterizes this material. Activities for the past work period include redrafting input for use in developing a RIL, upgrading the ultrasonic field mapping system, acquiring ultrasonic field maps, attending the 8th Annual EPRI NDE Information Meeting, and photographing etched surfaces from a CCSS sample.

A redraft of the input for use by the NRC in developing a RIL entitled "Progress Review: Ultrasonic Inservice Inspectability of Centrifugally Cast Stainless Steel" was mailed to the NRC program manager on February 17, 1988. The redraft was based on comments received from the NRC program manager during a site visit to PNL on September 17, 1987. The primary conclusion was that progress in both understanding and performance is being made and that hope does exist that effective and reliable ultrasonic inservice inspection (ISI) of CCSS piping may be possible in the future.

Three CCSS pipe sections are on loan to PNL from Southwest Research Institute (SwRI). These pipe sections are reserved for use as ultrasonic calibration blocks. Mr. Wayne Flach of SwRI has been very helpful with this material acquisition. The first SwRI piece was previously etched, and the resulting macrographs were illustrated in a previous semi-annual report (Doctor et al. 1987).

One of the other two pipe sections was selected and prepared for etching. A small slab of material was removed from each end face (axial-radial plane at both 0° and 270°) of the pipe to permit undisturbed material to be etched. Etching these slabs indicated that the second piece is a coarse columnar microstructure having different characteristics than previously encountered. A small amount of material was then removed from the circumferential faces of the piece to permit undisturbed material to be etched (Figure 2.1).

The third pipe section was believed to be the mating section of the first piece. (The first piece was a 90° circumferential section while the third piece was a 270° section with the same pipe diameter, wall thickness, and axial length.) Therefore, work on etching of the third piece will be delayed until October 1988.

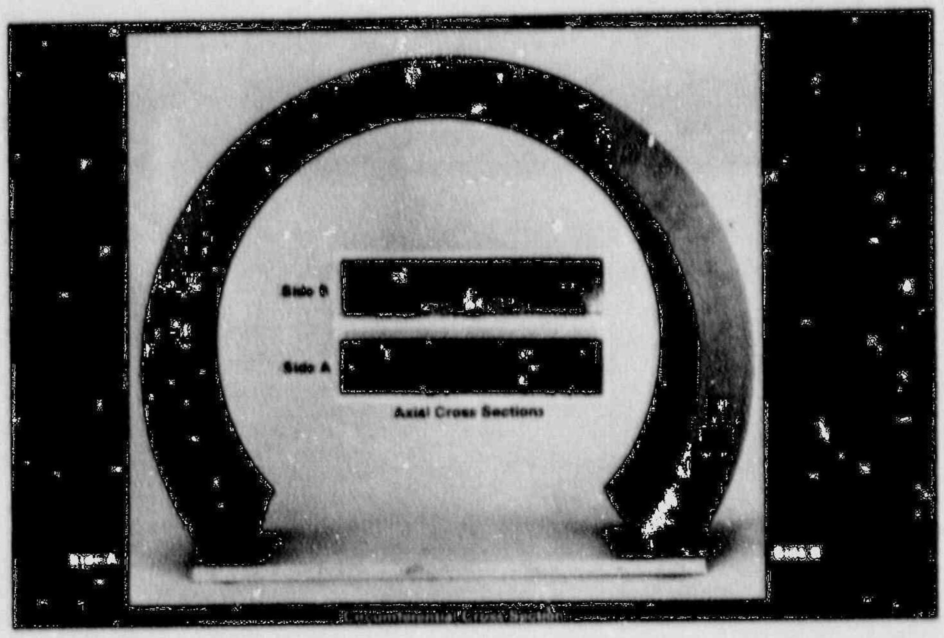


FIGURE 2.1. Coarse Columnar Microstructure - Centrifugally Cast Stainless Steel Pipe (Source: Southwest Research Institute)

Past work began with an evaluation of distortion incurred by an ultrasonic beam after it had propagated through the thickness of a pipe wall. A matrix of different wave modes (both longitudinal and vertically polarized shear waves) at different resolution settings (6, 3, and 1.5 mm) were passed through either a pure equiaxed or a pure columnar CCSS microstructure and the resulting ultrasonic field maps were collected (Good and Van Fleet 1988). To acquire ultrasonic field maps in the more complex microstructures, it was obvious that an upgrade to the data acquisition and analysis system had to be performed. This upgrade was needed since the signal patterns of the complex material forms have numerous spurious signals that interfere with the data acquisition process of the previous system. To circumvent this, a system upgrade was implemented and included hardware changes to enable RF signal digitization, microprobe development, and software development of an analysis program.

Since continued system upgrade previously included the completion of scanning hardware and related computer interface control, work has now focused on improved ultrasonic signal generation and reception. The 300-watt RF amplifier that will be used to excite the various transmitter probes is scheduled to be delivered in May 1988. S-wave microprobe development was nearly completed and several designs of ultrasonic RF preamplifiers are being evaluated. These designs include a newly available monolithic current feedback loop amplifier that should have a beneficial impact on signal reception for either L-wave or S-wave microprobes.

In January 1988, 45° SV-wave field maps were made and sent to Ames Laboratory as part of the Surface Conditions Subtask. At that time, it was determined that the performance of the S-wave microprobe, which was used for one field map in this data set, was not satisfactory because: 1) sensitivity was low [The signal-to-noise ratio (SNR) was 6 dB at best. This leads to a system dynamic range of 6 dB. For meaningful data to be acquired, a dynamic range on the order of 20-30 dB should exist.]; and 2) spurious signals such as reverberation within the receiving cone made quantitative measurements difficult. It was clear that the shear-wave microprobe would have to be improved if the sensor was to be used in the more difficult CCSS measurements.

To increase the SNR of the S-wave microprobe and the time interval between cone reverberating signals of the shear-wave microprobe, a study of the effect of the cone shape was performed. The microprobe cone is a steel cone that makes contact with the sample with its point and accomplishes signal detection via a piezoelectric element at its other end (Figure 2.2). It was discovered during the cone study that acoustic energy was transferred from the cone point to the piezoelectric element as a surface wave rather than the previously assumed bulk shear wave. The cone was redesigned to take advantage of the surface-wave phenomenon.

A redesigned shear-wave microprobe was constructed. Preliminary investigations indicated that the new design will perform well enough for CCSS measurements with a significantly increased SNR. The significant advance was possible by understanding how the cone worked and redesigning the cones for reception of surface waves traveling up the cone. The cones have suffered from noise problems and orientation effects; however, these are now solved to the degree that they should be usable in the CCSS scan matrix.

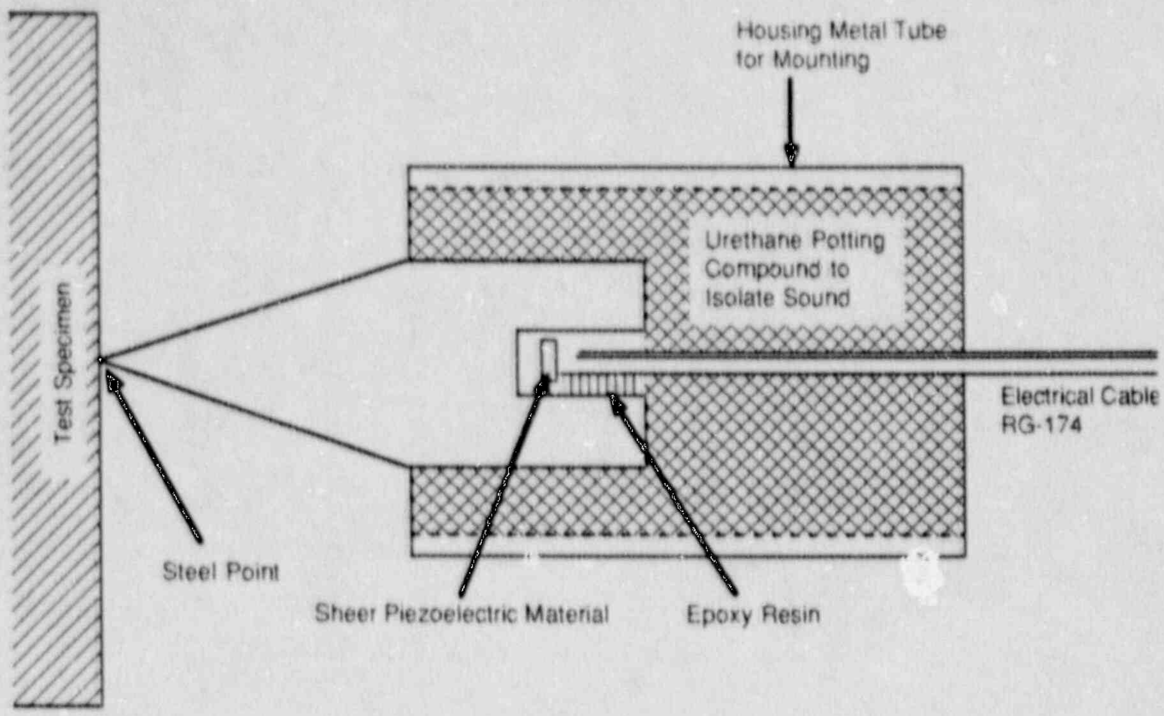


FIGURE 2.2. Sketch Illustrating Assembled Shear-Wave Microprobe (Previous Design)

Procedures for L-wave microprobe characterization are being developed. Impedance measurements of a L-wave microprobe are plotted in Figure 2.3. To acquire sensitivity measurements, a through-transmission technique is used where a reference transmitter is used and the microprobe receiver is used in combination with a PNL amplifier. Transmitter characteristics are shown in Figure 2.4, while characteristics of the received signal are shown in Figure 2.5. Note that the data shown in Figure 2.5 is dependent on the transmitter characteristics. However, the test is repeatable and does provide a measure of microprobe sensitivity.

A procedure was developed for marking coordinate reference points on CCSS samples. This was accomplished using a fixture which both located the section's pipe axis and permitted the piece to be aligned to two collinear laser beams pointing in opposite directions. The fixture aligns itself to the pipe axis since two parallel line contacts are made with the pipe outer diametrical surface. Once the fixture has determined the pipe axis, then the pipe section and attached fixture are aligned to the laser beams by means of an optical instrument on the fixture. After completing the alignment procedure, the two laser beams locate two points on the inner and outer diametrical surfaces, respectively, which have the same axial and circumferential positions. These points are used to determine spatial references for section alignment, probe alignment, and probe positioning at the start of an ultrasonic field map. Thus, effective refracted angles may be quantified on the ultrasonic field maps by using this information and the pipe wall thickness.

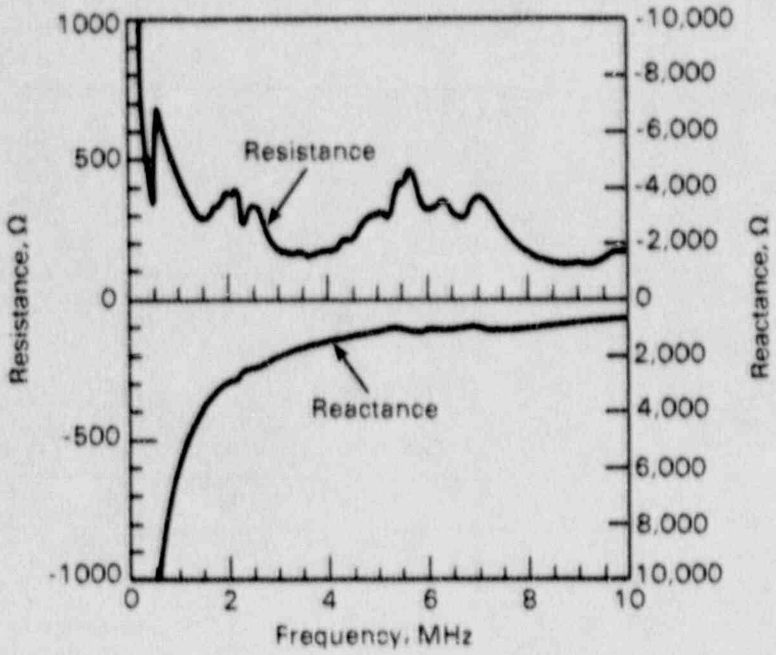
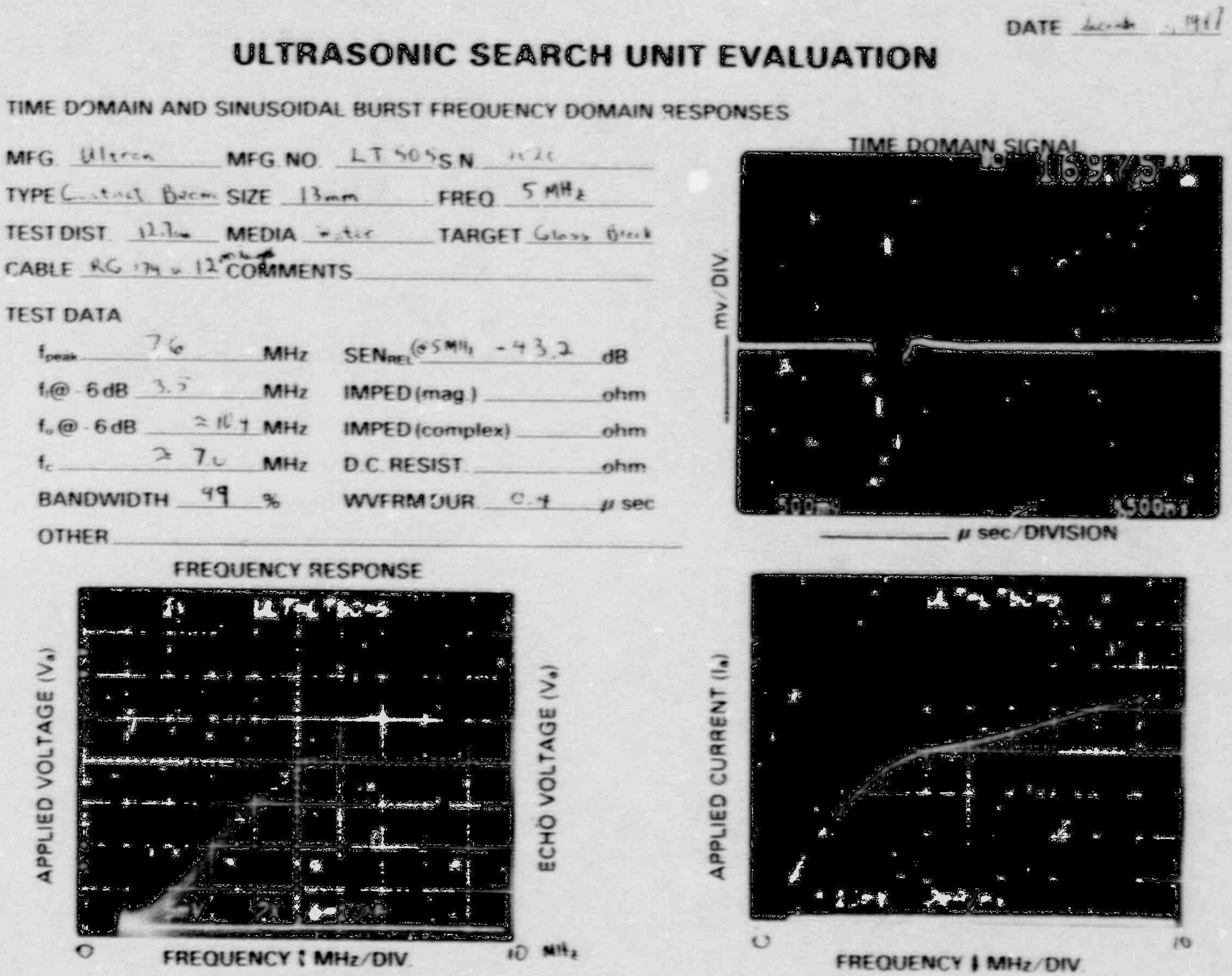


FIGURE 2.3. Impedance of L-Wave Microprobe P87-2A

Another area where system upgrade is continuing is preamplifier development. A newly available monolithic current feedback loop amplifier is being evaluated for use in a preamplifier for the microprobe receivers.

Maps of both 0° and 45° L-wave fields were acquired from an assorted matrix of CCSS microstructures (Figures 2.6-2.15). These maps illustrate the degree of distortion incurred by 1-MHz L waves at the selected refracted angles. (Note that previous work indicated that 1-MHz L waves were not severely distorted in either columnar or equiaxed microstructures.) For the 0° L waves, the following was observed:

Microstructure/Figure No.	Observation
Columnar/2.7	Field widths (-6 dB) (circumferential/axial) were 160/160% of the reference (carbon steel). Low amplitude responses were observed at large distances away from the field center.
Equiaxed/2.8	Field widths (circumferential/axial) were 170/140% of the reference.
Mixed Columnar-Equiaxed/2.9	Field widths (circumferential/axial) were 150/120% of the reference.



DATE [illegible], 1981

ULTRASONIC SEARCH UNIT EVALUATION

TIME DOMAIN AND SINUSOIDAL BURST FREQUENCY DOMAIN RESPONSES

MFG. Ultran MFG. NO. LT 505 S.N. [illegible]

TYPE Contact Beam SIZE 13mm FREQ. 5 MHz

TEST DIST. 12.7cm MEDIA water TARGET Glass Block

CABLE RG 174 u 12" COMMENTS

TEST DATA

f_{peak} 7.6 MHz

f_l @ -6 dB 3.5 MHz

f_u @ -6 dB ≈ 10.4 MHz

f_c ≈ 7.0 MHz

BANDWIDTH 49 %

SEN_{REL} @5MHz -43.2 dB

IMPED (mag.) ohm

IMPED (complex) ohm

D.C. RESIST. ohm

WVFRM DUR. 0.4 μ sec

OTHER

FIGURE 2.4. Transducer Characterization of Reference Transmitter

DATE [illegible]

ULTRASONIC SEARCH UNIT EVALUATION

TIME DOMAIN AND SINUSOIDAL BURST FREQUENCY DOMAIN RESPONSES

MFG PNL MFG NO P87-2A S N

TYPE μprobe SIZE FREQ

TEST DIST 13.6cm MEDIA Water TARGET

CABLE PNL Preamp 111185-01 COMMENTS [illegible] with 50 Ω [illegible] of 75 Ω (MR10K [illegible])

TEST DATA

f_{peak} MHz SEN$_{REL}$ dB

f_l @ -6 dB MHz IMPED (mag.) ohm

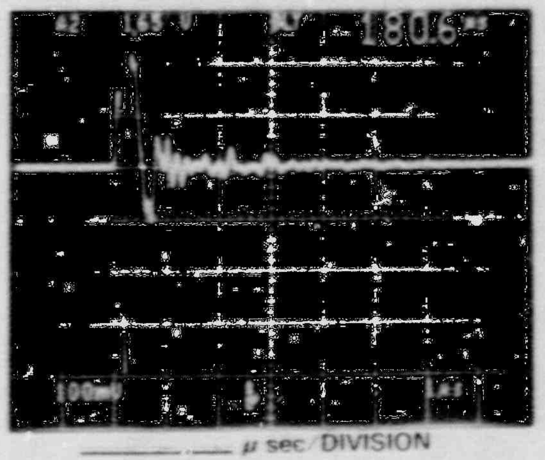
f_u @ -6 dB MHz IMPED (complex) ohm

f_c MHz D.C. RESIST. ohm

BANDWIDTH % WVFRM DUR EAD-10-04 0.6 μ sec

OTHER

TIME DOMAIN SIGNAL



mv/DIV

μ sec/DIVISION

FREQUENCY RESPONSE

APPLIED VOLTAGE (V_a)

ECHO VOLTAGE (V_e)

FREQUENCY - MHz/DIV.

APPLIED CURRENT (I_a)

FREQUENCY - MHz/DIV.

FIGURE 2.5. Characteristics of L-Wave Microprobe Using a Through-Transmittion Technique

Layered Columnar-Equiaxed/2.10	Field widths (circumferential/axial) were 140/150% of the reference. Low amplitude responses were observed throughout the entire scan region (more severe than the columnar microstructure).

For the 45° L waves, the following was observed:

Microstructure/Figure No.	Observation
Columnar/2.12	Field width (circumferential/axial) were 100/70% of the reference (carbon steel). Low amplitude responses are more confined to the field center than the reference.
Equiaxed/2.13	Field widths (circumferential/axial) were 120/95% of the reference. Low amplitude responses were observed in the low refracted angle region.
Mixed Columnar-Equiaxed/2.14	Field widths (circumferential/axial) were 95/95% of the reference. Low amplitude responses were observed in the low refracted angle region.
Layered Columnar-Equiaxed/2.15	Field widths (circumferential/axial) were 100/90% of the reference. Low amplitude responses were observed in the form of side lobes in both the low and high refracted angle regions.

Note that the observations cited for the various CCSS microstructures are dependent on the refracted angle and that some of the observations of the 0° scans are opposite to the observations cited for the 45° scans..

The scan sequence used to acquire these data represents the first full utilization of the ultrasonic field mapping system since upgrading it. Difficulties were incurred in precisely locating various spatial references marked on the CCSS samples due the refracted angle wedge and water covering the marks on the outer diametrical surface when setting up for a field map. It was determined that measures be examined to ensure proper placement of the transmitter relative to the spatial references on the samples for future scans.

The 8th Annual EPRI NDE Information Meeting (November 13-19, 1987) was attended due to the number of presentations devoted to CCSS inspection. A trip report was generated on the PNL evaluation of the EPRI activities.

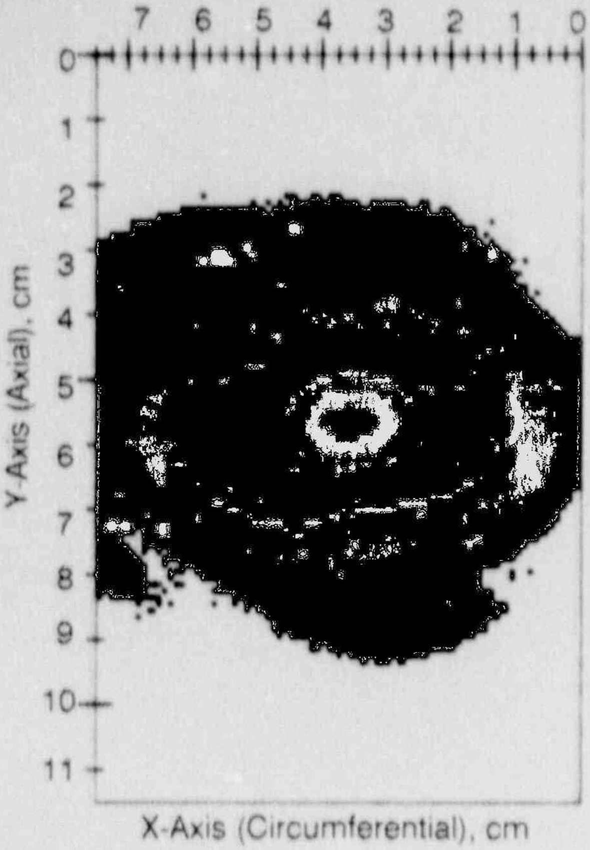


Figure 2.6. Ultrasonic Field Map, 0° L-Wave, Carbon Steel

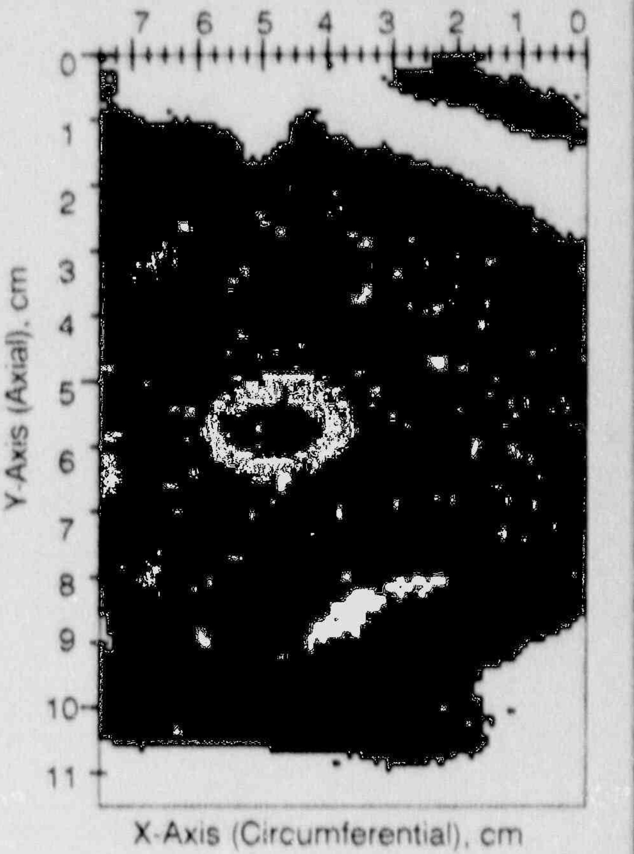


Figure 2.7. Ultrasonic Field Map, 0° L-Wave
CCSS-Columnar Microstructure

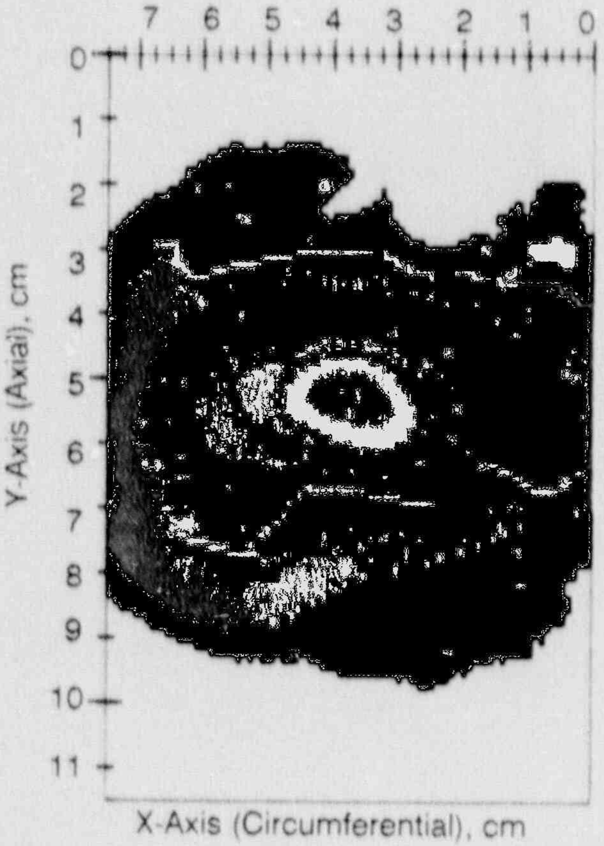


Figure 2.9. Ultrasonic Field Map, 0° L-Wave, CCSS-Mixed Columnar-Equiaxed Microstructure

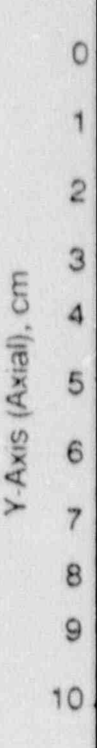


Figure 2.10. Ultra
Colu

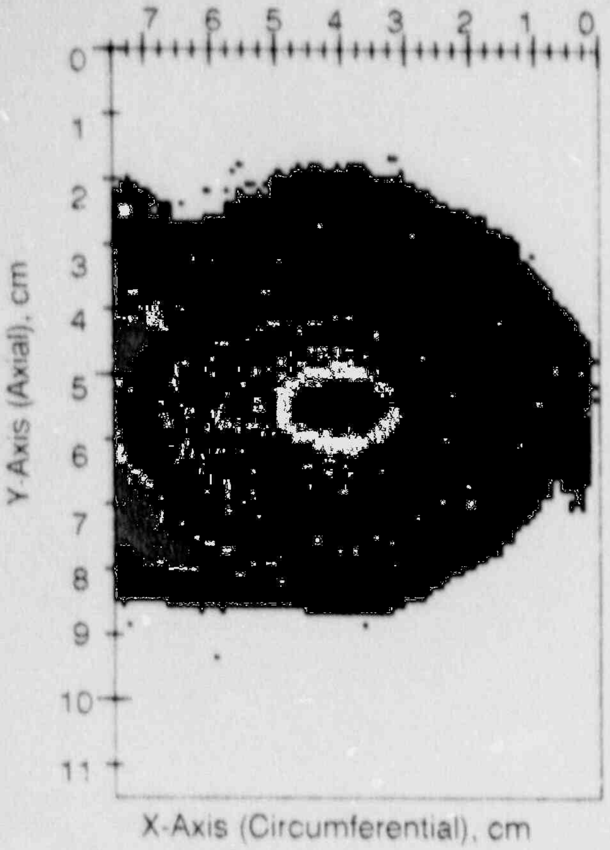


Figure 2.8. Ultrasonic Field Map, 0° L-Wave, CCSS-Equiaxed Microstructure

sonic Field Map, 0° L-Wave, CCSS-Layered
mnar-Equiaxed Microstructure

SI
APERTURE
CARD

Also Available On
Aperture Card

Amplitude Color Key

▨	0 to -1 dB
▨	-1 to -2 dB
▨	-2 to -3 dB
▨	-3 to -4 dB
▨	-4 to -6 dB
▨	-6 to -10 dB
▨	-10 to -14 dB
▨	-14 to -20 dB

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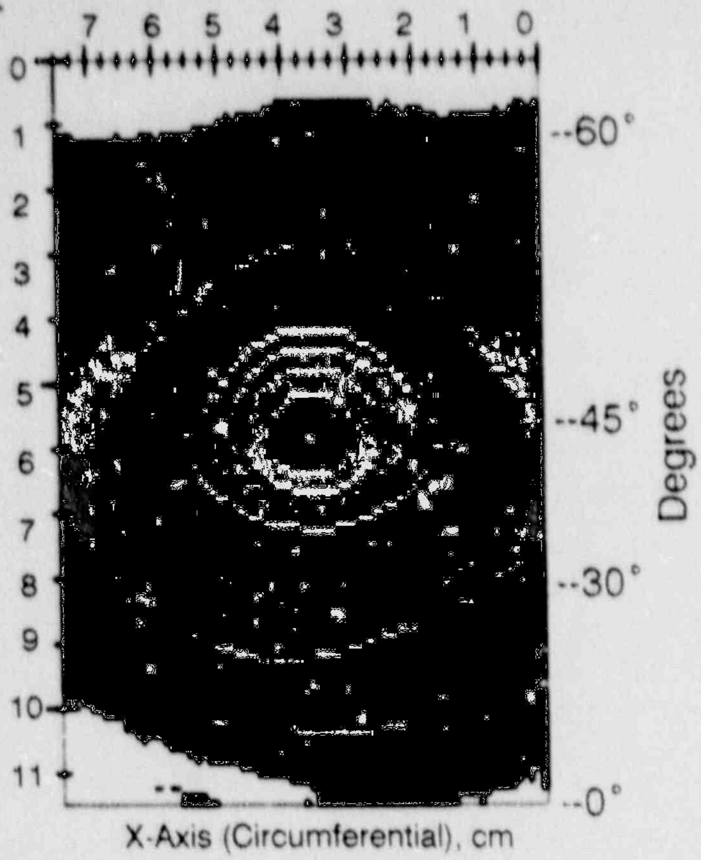


Figure 2.11. Ultrasonic Field Map, 45° L-Wave, Carbon Steel

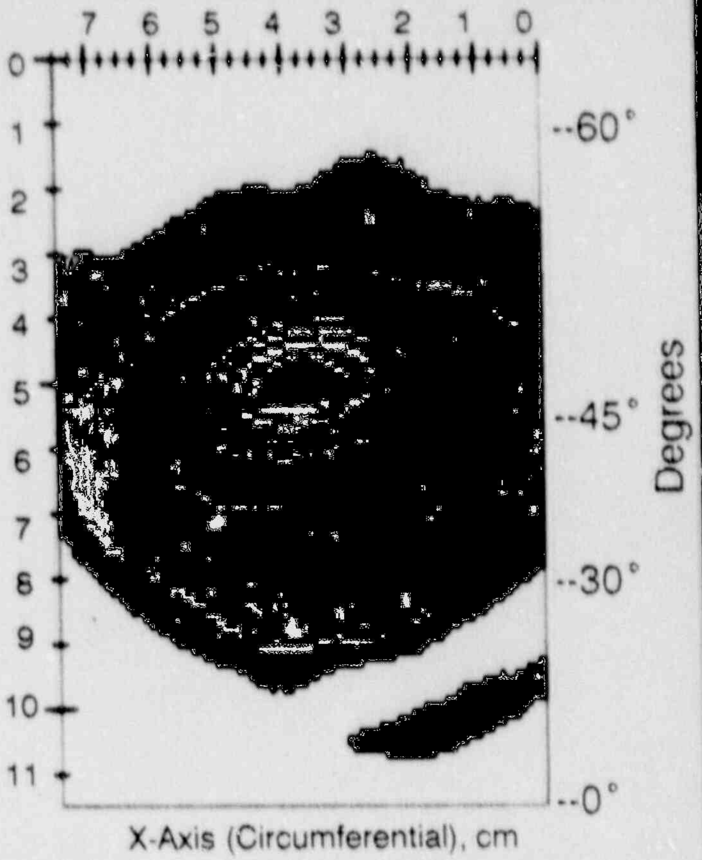


Figure 2.12. Ultrasonic Field Map, 45° L-Wave, CCSS-Columnar Microstructure

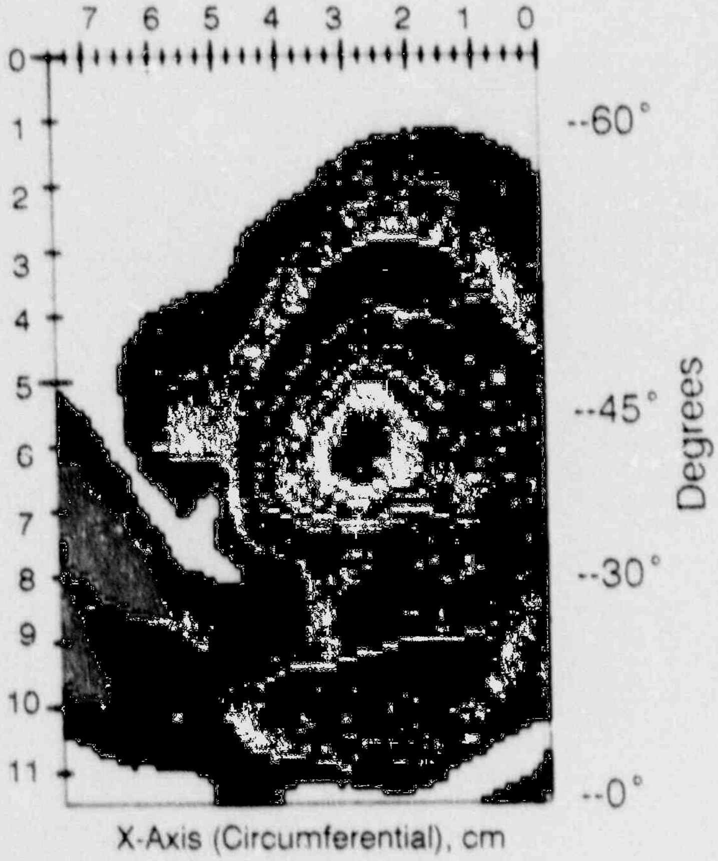


Figure 2.14. Ultrasonic Field Map, 45° L-Wave, CCSS-Mixed Columnar-Equiaxed Microstructure

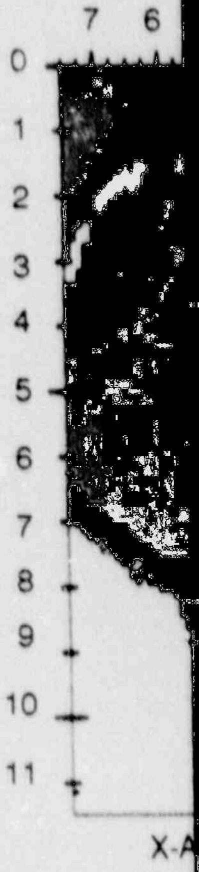


Figure 2.15. Ultrason
Column

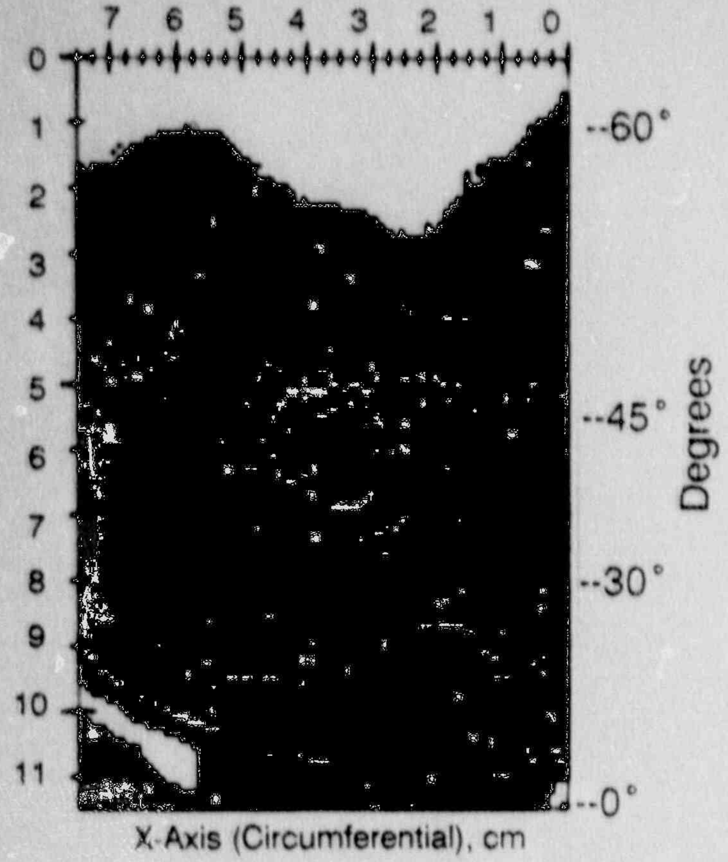
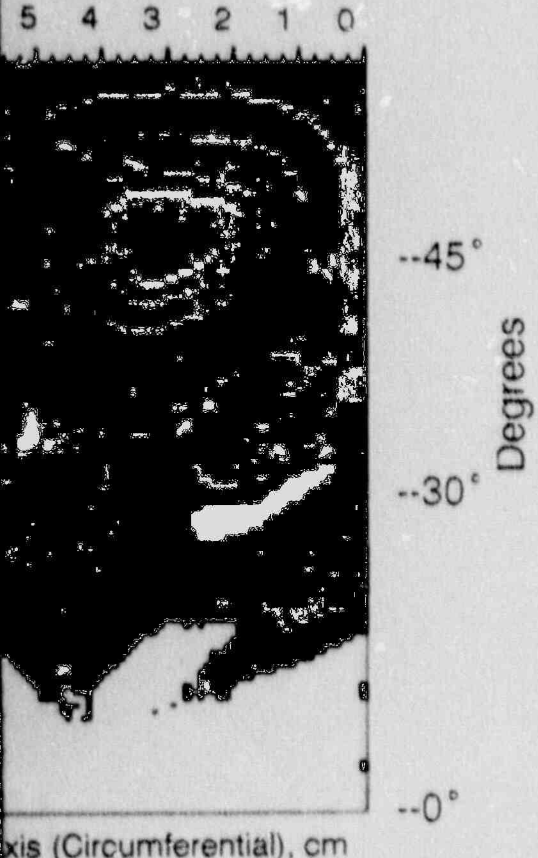


Figure 2.13. Ultrasonic Field Map, 45° L-Wave, CCSS-Equiaxed Microstructure



ic Field Map, 45° L-Wave, CCSS-Layered
r-Equiaxed Microstructure

Amplitude Color Key

▬ 0 to -1 dB
▬ -1 to -2 dB
▬ -2 to -3 dB
▬ -3 to -4 dB
▬ -4 to -6 dB
▬ -6 to -10 dB
▬ -10 to -14 dB
▬ -14 to -20 dB

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2.3.3 Future Work

Work should be completed concerning the ultrasonic inspection of weld-overlay-repaired pipe joints. An exception would be a request by the NRC program manager to redraft the RIL and/or restructure the report as a draft of a NUREG report.

CCSS work will continue to acquire field material, document microstructures, and acquire ultrasonic field maps from the complex material microstructures. Scanning will be initiated in May to be completed in July.

A one-year study on reducing microstructural background noise of ultrasonic signals is planned to begin October 1988. This study is to include all coarse microstructural materials such as weld material as well as both centrifugally and statically cast materials.

2.4 SURFACE ROUGHNESS CONDITIONS

2.4.1 Summary

The objective of this work is to establish specifications such that an effective and reliable ultrasonic inspection is not prevented by the condition of the exposed surface. Past efforts included an attempt to quantify the effect produced by an outer surface irregularity (Phase 1). This effort showed that a 1.5-mm (0.060-inch) step discontinuity can produce a -12 dB change for the Code-required 10% crack when inspecting the girth weld of a 305-mm (12-inch) diameter, Schedule 80 pipe. Present efforts involve cooperative work with EPRI in establishing a mathematical model to be used to derive guidelines for surface specifications. Activities included the formulation of a coordination plan between EPRI, NRC, the Center for NDE (CNDE) at Ames Laboratory, and PNL concerning Phase 2 work; a visit by CNDE personnel to PNL; and an exchange of data between CNDE and PNL.

2.4.2 Status of Work Performed

A specification is needed that will assure surface conditions do not prevent a reliable and effective ultrasonic inspection from being performed. An approach for accomplishing this is to use an ultrasonic model as an engineering tool for determining such a surface-condition specification. This may be implemented by using the guidelines and the model that have been established as a technical base from which recommendations can be made to the ASME Boiler and Pressure Vessel Code committees.

Both EPRI, through the Center for NDE (CNDE) at Ames Laboratory, and the Office of Nuclear Regulatory Research of the NRC, through PNL, have developed capabilities that are uniquely suited for establishing a validated model. First, CNDE has extensive experience in the computational modeling of ultrasonic wave propagation in various materials. Second, PNL has experience in mapping ultrasonic fields in solid materials. For this reason, EPRI and the NRC have established a two-year time frame in which the two organizations, through the referenced institutes, will cooperate in attempting to determine and validate an ultrasonic computer model.

To facilitate the cooperation between CNDE and PNL, a coordination plan was formulated. This plan assigned individual and joint responsibilities to both CNDE and PNL.

Although the coordination plan was neither finalized nor approved, work proceeded as if it was in effect. Mr. Byron P. Newberry of CNDE visited PNL on October 6, 1987, for the purpose of overviewing with PNL the capabilities of the model, touring the experimental facilities at PNL for ultrasonic field measurements, and discussing the interaction between CNDE and PNL. Dr. M. S. Good of PNL met with Dr. R. Bruce Thompson of CNDE while attending the 8th Annual EPRI NDE Information Meeting to establish the ultrasonic setup parameters that would be used by both PNL to experimentally map the field and CNDE to predict the field by usage of the mathematical model. These parameters are listed in Table 2.1. The first exchange of data was completed in February and comparison between experimental measurement and model prediction began. Acquired ultrasonic field maps and an analysis of the data will be included in the next semi-annual report.

TABLE 2.1. Ultrasonic Setup Specification

Ultrasonic Technique:	Immersion
Transducer Characteristics:	38-mm (1.5-in.) diameter, 1 MHz
Transducer Excitation:	1.0 MHz continuous wave
Incident Angles:	18.9° in water to effect a 45° refracted angle by vertically polarized shear waves in the sample 10.2° in water to effect a 45° refracted angle by longitudinal waves in the sample
Sample Characteristics:	13.3-cm (5.25-in.) thick carbon steel block (flat and co-planar surfaces)
Couplant:	Water (room temperature)
Stand-off Distance:	24.5 cm (9.6 in.) (1.0 near-field in water)
Measured Quantity:	Ultrasonic amplitude map on sample side opposite transducer

2.4.3 Future Work

A two-year program is planned. During the next year, work will involve collection of experimental data for both development and evaluation of the CNDE model. Upon model validation, PNL will acquire the mathematical model and use the model during the second year as an engineering tool to derive guidelines for surface specifications.

2.5 ROUND ROBIN TESTS

2.5.1 Pipe Inspection Round Robin Report

Work deferred on this subtask during this reporting period.

2.5.2 Mini-Round Robin

2.5.2.1 Summary

The Mini-Round Robin (MRR) was conducted to provide an engineering data base for UT/ISI that would help:

- quantify the effect of training and performance demonstration testing that resulted from IEB 83-02
- quantify the differences in capability between detecting long (greater than 3-in.) cracks versus short (less than 2-in.) cracks
- quantify the capability of UT/ISI technicians to determine length and depth of intergranular stress corrosion cracks (IGSCC).

2.5.2.2 Status of Work Performed

All final review comments were not received by the end of this reporting period. The review comments that were received have been incorporated in the final report.

2.5.2.3 Future Work

After all final review comments have been received and incorporated, the report will be submitted for publication.

2.5.3 PISC III

2.5.3.1 Summary

The objective of this work is to contribute to the international Programme for the Inspection of Steel Components III (PISC III) to facilitate current studies on the reliability, capability, and parametric analysis of NDE techniques and procedures. This includes full scale vessel testing, piping inspections, and human reliability and modeling studies on ultrasonic interactions. This data will be used in quantifying the inspection reliability of ultrasonic procedures and the sources and extent of errors impacting the reliability.

2.5.3.2 Introduction

The primary areas in which PNL participated include Action No. 1 on Real Contaminated Structures Tests (RCS), Action No. 2 on Full-Scale Vessel Tests (FSV), Action No. 3 on Round-Robin Tests on Ferritic Steels (FST), Action No. 4 on Round-Robin Tests on Austenitic Steels (AST), Action No. 6 on Ultrasonic

Testing Modeling (MOD), and Action No. 7 on Human Reliability Exercises (REL). These actions are being followed to ensure that conditions, materials, and practices in the U.S. are being included in the work so that the results are transferable to the U.S.

The RCS work is being followed and efforts have been expended to provide some safe-ends removed from the Monticello plant for this Action. These safe-ends became available when the recirculation system was replaced. These safe-ends are extremely hot, and most of them have contact readings on their storage cylinders in excess of 1 R at the hottest place. Five safe-ends are being considered of which two have weld overlays and three were not overlaid. One of the weld overlays had reported a through-wall crack during the weld overlay process. Problems have been encountered because the safe-ends have high alpha contamination, and the hot cells at Ispra are set up for shielding and were not designed to handle high alpha contamination. This activity is on hold until the alpha contamination issue can be resolved.

Discussions have been held with the FSV Action leaders to be sure that the defect sizes and types are of interest to the U.S.

Participation in the FST has focused on providing a plate that is referred to as Plate No. 20. This plate is a section from the discontinued Hope Creek reactor pressure vessel that contained two recirculation input nozzles and an instrumentation nozzle. This plate was prepared and shipped to Ispra under a small contract with Ispra to do this activity.

Since PNL is co-Action leader on the AST, planning has occurred with emphasis on the field-removed IGSCC and on methods to introduce defects into the large cast stainless steel specimens. Two methods are being followed with MPA in Stuttgart, West Germany to use a hydraulic method and the CEGB in England to use a hot isostatic press process. These two methods will be evaluated with several trials that should be completed by the end of the next reporting period. This information is to be used to guide the plan for introducing the defects.

Since the NDE Reliability program is doing some modeling work in support of studying the equipment interactions effects, the MOD work is being followed and will be used where and if appropriate. In particular, the codes that handle the diffraction effects will be examined for potential use.

The REL activities are being followed and input provided via review of work proposals for this action. This work is considered to be of high importance since there is not other comparable activity in progress anywhere else for all aspects of ultrasonic inspection.

2.5.3.3 Future Work

These activities will be followed with appropriate input as needed and directing information to the NRC or Code committees as it becomes available and is pertinent to their needs.

2.5.4 Field Pipe Characterization

2.5.4.1 Summary

The objective of this subtask is to provide pipe weld specimens that can be used to help determine the effectiveness and reliability of ultrasonic inservice inspection (ISI) that is performed on BWR piping. This goal will be accomplished by supporting PNL laboratory studies and providing specimens that will be used in other studies such as the PISC III program.

2.5.4.2 Introduction

Weld specimens have been acquired from the Monticello and Vermont Yankee BWR nuclear power plants. The welds were sectioned from the pipe remnants in FY 1986. Due to high amounts of alpha contamination on the Monticello specimens, it was decided to decontaminate only the 11 Vermont Yankee specimens and wait until FY 87 to have the 28 Monticello weld specimens decontaminated. A complete characterization of the 11 Vermont Yankee weld specimens was performed by PNL personnel; this included ultrasonic and penetrant examinations. The 28 Monticello weld specimens were decontaminated by an off-site contractor in FY87. Upon completion of the decontamination, weld profile measurements and penetrant examinations were performed. These results were recorded on data sheets in summary form.

2.5.4.3 Status of Work Performed

A manual and SAFT ultrasonic evaluation was completed on a selection of Monticello and Vermont Yankee weld specimens. The data that was compiled was thoroughly analyzed. A specimen matrix is being assembled for the PISC III international round robin exercise. When completed, selected weld specimens will be packaged and shipped to Europe.

The Monticello safe-end weld specimens were sorted and five of the weld specimens (C, E, F, G, and H) were packaged in an overseas-approved shipping container and are awaiting shipment to Europe. The remaining five safe-ends (A, B, D, J, and K) were packaged and sent to the Hanford project burial ground facility in Richland, Washington.

2.5.4.4 Future Work

The safe-ends and weld specimens will be shipped to Europe, and the field pipe summary report and data package on decontaminated weld specimens will be completed.

2.6 UT EQUIPMENT INTERACTION MATRIX

2.6.1 Summary

The objective of this work is to evaluate the effects of frequency domain equipment interactions and to determine tolerance values for improving ultrasonic inspection reliability. An analysis is being performed to evaluate frequency domain effects using a computer model to calculate the flaw transfer function.

2.6.2 Introduction

The goal of this activity is to define operating tolerance requirements for UT/ISI equipment that minimize the effects of frequency domain interactions, thus improving ISI reliability. This is to be accomplished in the following steps:

1. development and validation of a flaw model
2. integration of the flaw model into the previously developed UT/ISI equipment models
3. conduct a sensitivity study on equipment parameters
4. recommend equipment tolerance requirements for UT/ISI.

2.6.3 Status of Work Performed

Introduction. A previous report (Doctor et al. 1988) provides a detailed description of a two-dimensional, elastodynamic-physical-optics, ray-tracing model to calculate the transfer functions (frequency responses) of various flaws in a steel sample. Since that time, the following work has been completed:

1. The model predictions were compared with results from a number of single-frequency (tone-burst signal) experiments, and based on favorable comparisons, development of the model is considered complete.
2. Several multifrequency experiments were conducted.
3. The model was used to perform case studies to determine the effects of flaw size, flaw orientation, and probe position on the flaw transfer function. The results of the case studies were used to predict which flaws might be particularly sensitive to frequency domain equipment variations. These flaws are referred to herein as "worst-case flaws."
4. The response from a particular worst-case flaw was analyzed, and the effects of changes in equipment center frequency and bandwidth were considered.
5. The flaw model was integrated with previously developed equipment models in preparation for an equipment parameter sensitivity study.

Model Validation. To validate the flaw model, model predictions were compared with results from a number of single-frequency experiments. The first experiment was a 90° corner measurement at 5 MHz. Figure 2.16 shows the variation in signal amplitude of a 45° SV, pulse-echo probe as a function

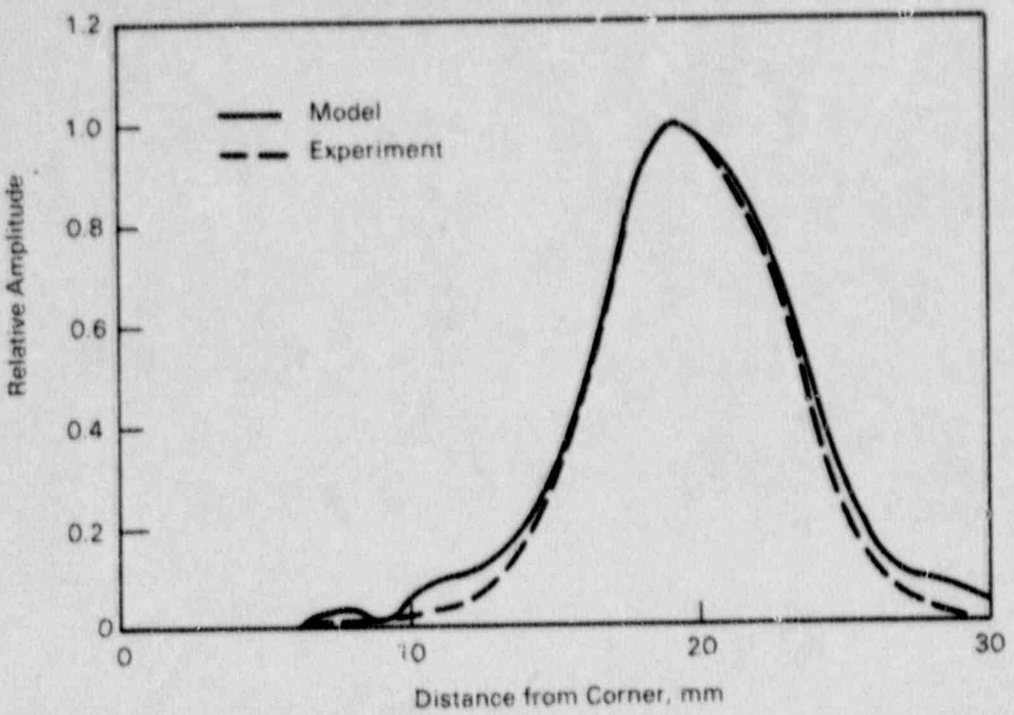

FIGURE 2.16. Pulse-Echo Response of a 90° Corner in 20.8-mm-thick Carbon Steel

of distance from a 90° corner in a 20.8-mm-thick steel block. The signal was made up of ultrasound from two different paths within the block -- the probe/end/bottom/probe and probe/bottom/end/probe paths. Agreement between the model prediction and experimental measurement was excellent. The excellent agreement was especially significant, since it showed that under certain conditions a two-dimensional model can be used to model more complex three-dimensional inspection configurations such as this measurement in which a circular transducer was used.

In a second set of experiments, the centerline beam patterns of 45° longitudinal and 45° SV transmission through a 133-mm-thick steel block were measured at 1 MHz. An immersion setup was used with a non-focused probe for excitation and PNL L-wave and S-wave microprobes for L-wave and S-wave reception, respectively. The comparisons between model predictions and experimental measurements for the two cases are shown in Figures 2.17 and 2.18. The comparison for 45° L-wave transmission was excellent for both the main lobe (centered at 110 mm) and the secondary lobe (centered at 160 mm). The comparison for 45° SV-wave transmission was good but not excellent. It was believed that differences between model and experiment results were due to the directivity pattern of the S-wave microprobe.

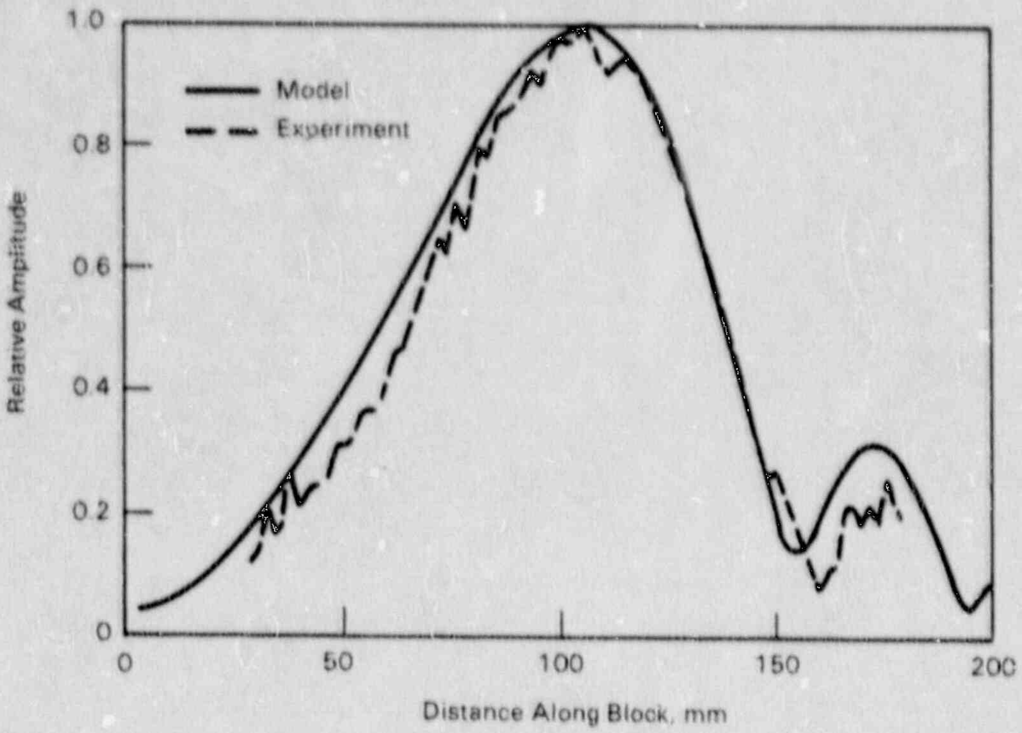

FIGURE 2.17. Centerline Beam Pattern for 45° Longitudinal Wave Transmission through a 133-mm-thick Carbon Steel Block

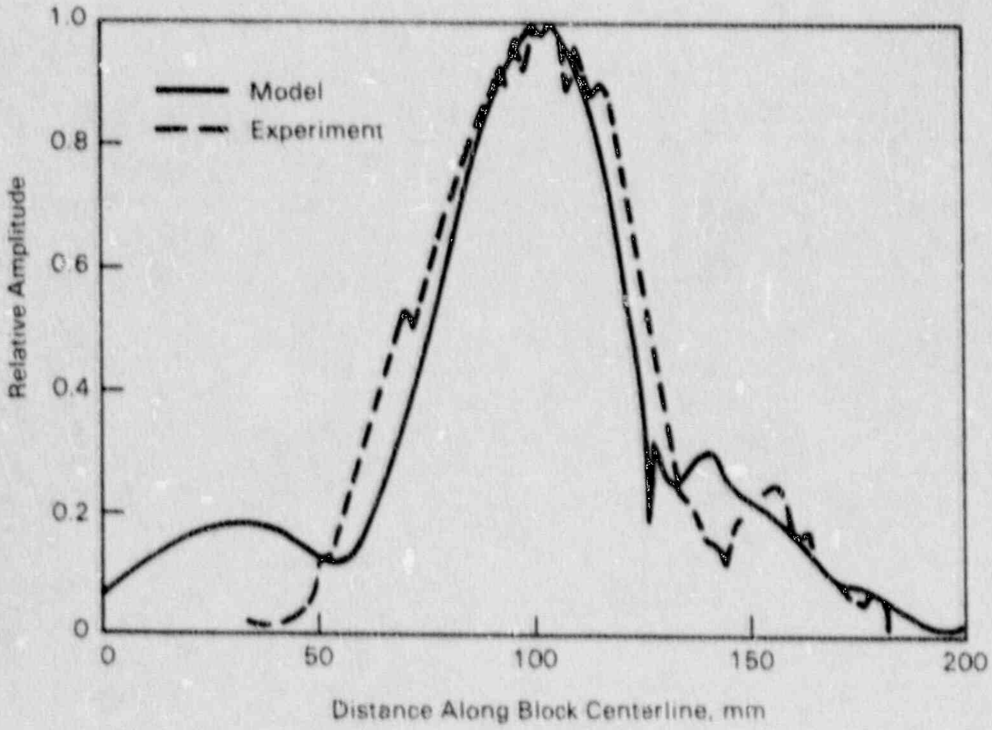

FIGURE 2.18. Centerline Beam Pattern for 45° Vertically Polarized Shear Wave Transmission through a 133-mm-thick Steel Block

Experimental data from an independent source was used for the final set of comparisons. Through the PISC III program, S. R. Doctor obtained tandem-probe inspection data taken at Risley and Harwell UKAEA laboratories.(a) Comparisons were made for specular reflection from these three flaw types:

Flaw Type	Tilt	Finish	Figure
25-mm-diameter re-entrant machined flat-bottom hole	0°	Smooth	2.19
10 x 50-mm strip	0°	Smooth	2.20
25 x 125-mm strip	0°	Smooth	2.21

Comparisons for the strip flaws were very favorable with only small offsets caused by small differences in probe angle. The model versus experiment comparison was not acceptable for the 25-mm flat-bottom hole. It was concluded that the 2-D PNL model performed well for specular reflection from strip flaws, but it was not valid for flaws that did not behave as long strips such as

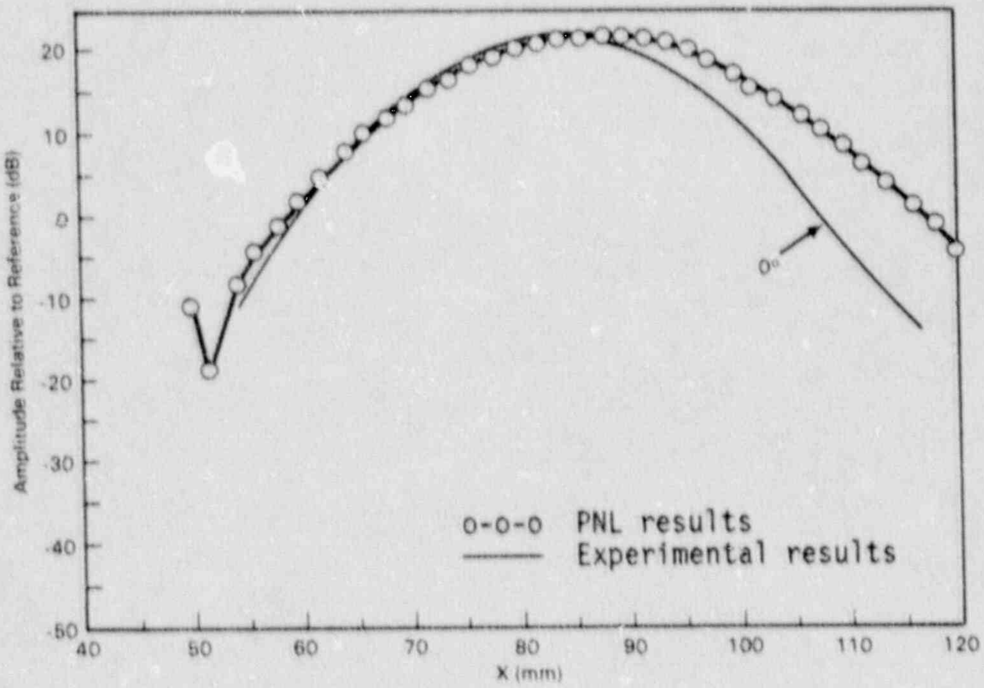

FIGURE 2.19. Echo-Dynamic Plots for Test Block with 25-mm-diameter Re-entrant Machined Flat-Bottom Hole

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(a) Murgatroyd, R. A., P. J. Highmore, S. F. Birch, T. Bann, and A. T. Ramsey. September 12, 1987. Flaw Characterization Using the Tandem and TOFD Techniques, Draft Final Report on EEC/UKAEA Contract No. 2871-85-12EN Isp GB. Risley Nuclear Laboratories, Harwell, United Kingdom.

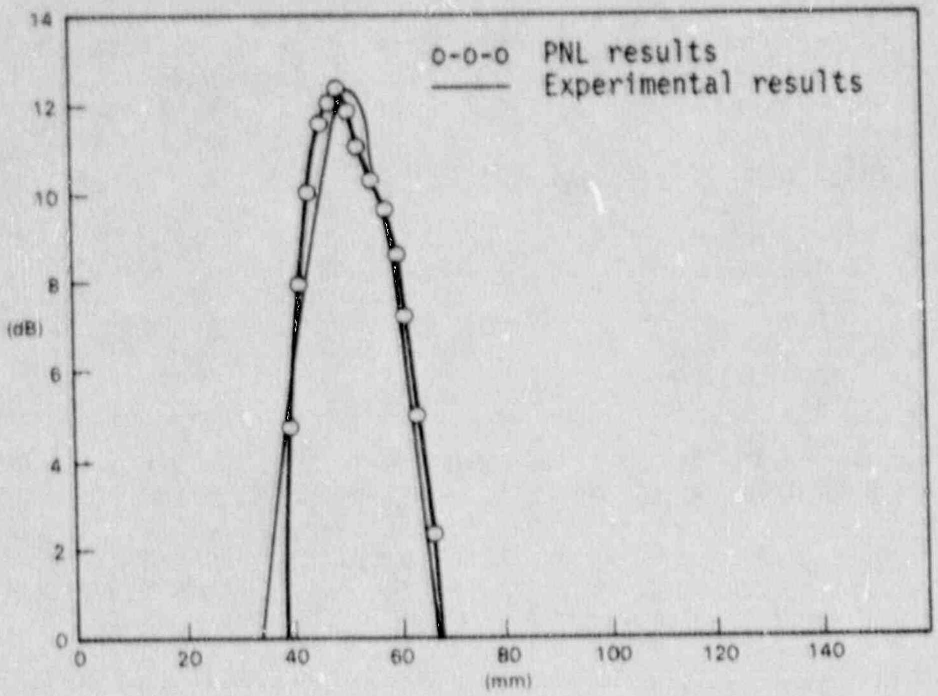

FIGURE 2.20. Echo-Dynamic Plot for Test Block with 10 x 10-mm Strip Flaw

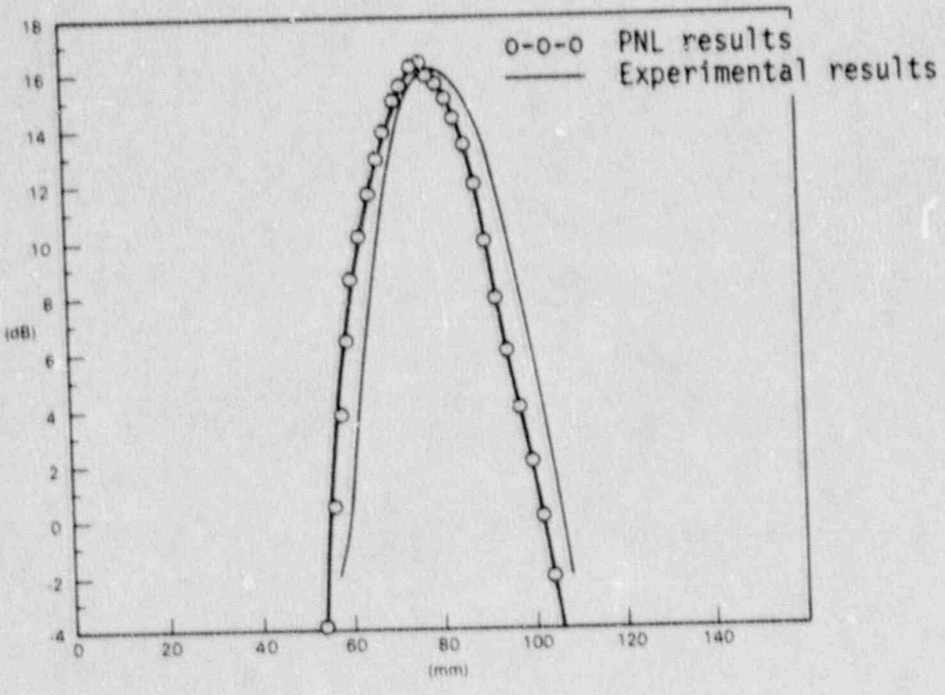

FIGURE 2.21. Echo-Dynamic Plot for Test Block with 25 x 125-mm Strip Flaw

small circular flaws. A report on comparisons between model results and experimental data was sent to the Risley Laboratory.

To summarize, it was shown that the model was valid for specular reflection from essentially two-dimensional flaws such as strip flaws and 90° corners. The model did not prove to be valid for small circular flaws.

Multifrequency Experiments. Multifrequency (ultrasonic spectroscopy) measurements are currently being performed to:

1. validate model transfer function (frequency response) predictions for specular reflection from flaws

2. confirm model predictions for worst-case flaws

3. measure transfer functions for the equipment parameter sensitivity study of flaw types not included in the flaw model.

To perform the multifrequency (ultrasonic spectroscopy) measurements, an ultrasonic spectroscopy system was developed. The system is basically the existing PNL computer-based, data-acquisition system as used for ultrasonic field mapping studies with the addition of fast Fourier transform (FFT) analysis. The system has the following features:

1. 160-MHz maximum sampling frequency (6.25 ps sample rate)

2. removal of wedge reflections (a.k.a. shoe ghosts)

3. continuous display of the A-scan (time response) and either its frequency spectrum (FFT) or a transfer function relative to some calibration frequency spectrum (e.g., the flaw transfer function with the equipment effects removed).

At the time of this writing, transfer functions for several different worst-case flaws were measured for comparison with model predictions, but the results were not yet thoroughly examined.

Case Studies. The model was used to perform case studies to determine the effects of flaw size, flaw orientation, and probe position on the flaw transfer function. The transfer functions were calculated for various sizes and orientations of bottom-surface-connected flaws as shown in Figure 2.22. The results were normalized with the 0 dB level corresponding to the 2.25-MHz response level of a vertical 10% through-wall flaw with the probe at the maximum amplitude position.

Effect of Flaw Size - The effect of flaw size on the transfer function of vertical flaws (CANG = 90°) is shown in Figure 2.23. The amplitude increased approximately 6 dB with each doubling of flaw size up to 5 mm, after which the response no longer increased. The transfer functions were approximately straight lines with a response drop of 6 dB from 300 kHz to 10 MHz. For this well-behaved case, a variation of equipment parameters such as center frequency or bandwidth would have had little effect on the A-scan amplitude.

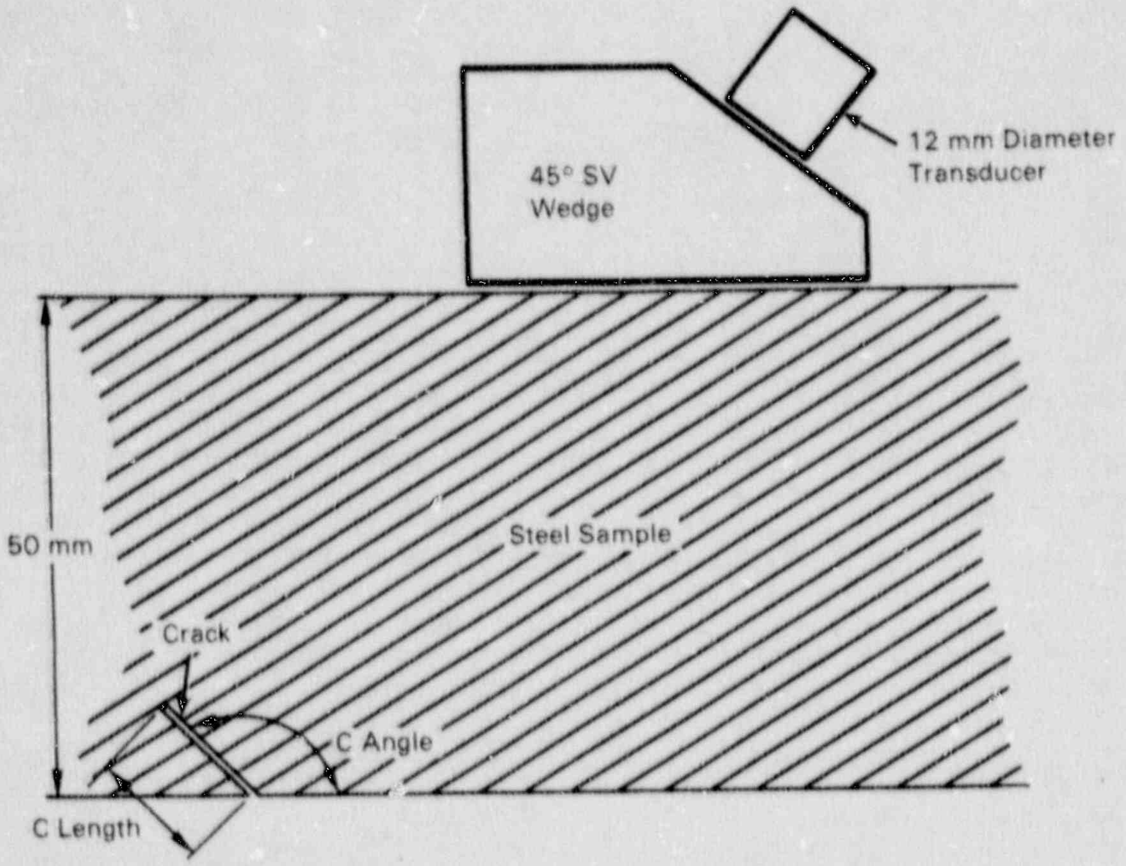

FIGURE 2.22. Pulse-Echo Ultrasonic Test System

Figure 2.24 shows the transfer function curves for various size flaws at an angle of 85°. The two largest flaws (20 mm and 50 mm) had transfer functions with a steep slope at 2.25 MHz. The signal amplitude returned from such flaws would have been very sensitive to changes in the center frequency of a typical 2.25 MHz inspection system especially one with narrow bandwidth. The model predicted no correlation between flaw size and response amplitude for these non-vertical flaws.

Effect of Flaw Angle - The effects of flaw angle on the flaw transfer function of a 5-mm flaw and a 25-mm flaw are illustrated in Figure 2.25 and 2.26, respectively. In both cases, there was no direct correlation between flaw angle and amplitude or slope. Comparison of Figures 2.25 and 2.26 showed two trends. First, larger flaws had a wider range of angles over which there was specular reflection. Second, the larger flaw transfer functions fluctuated more as a function of frequency. A variation of frequency domain equipment parameters would not have had a strong effect on the 5-mm flaw response, but equipment parameters would have had a large effect on several of the 25-mm flaw responses. The 25-mm flaw at 80° with a frequency response minimum at 2 MHz was a good example of a worst-case flaw.

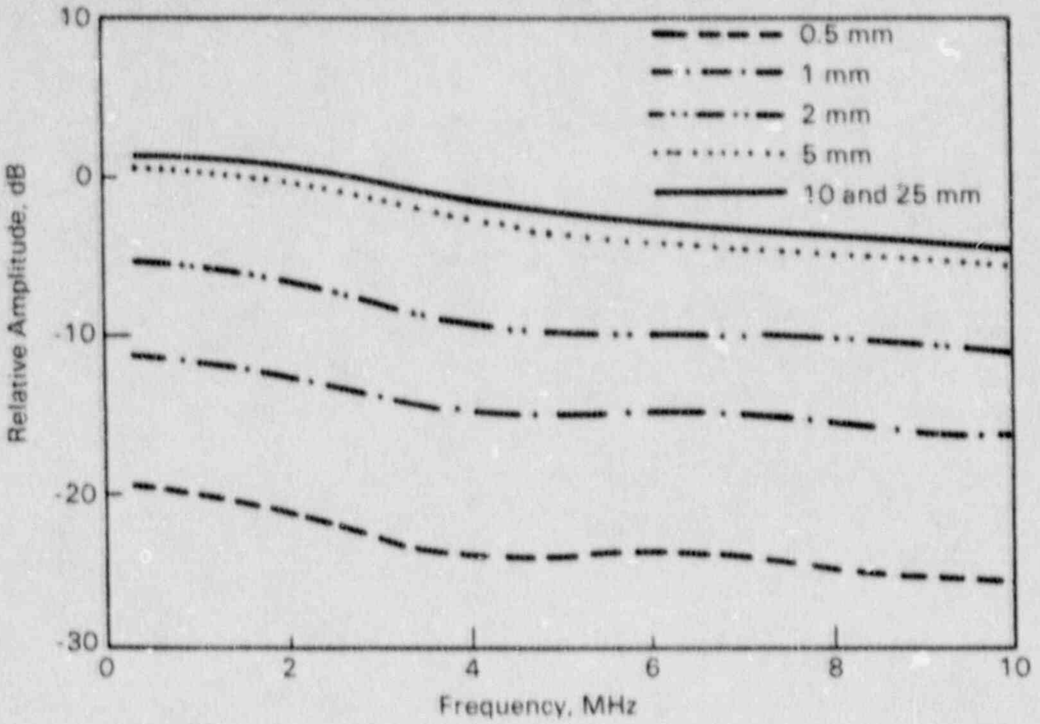

FIGURE 2.23. Transfer Functions for Vertical Flaws of Various Lengths

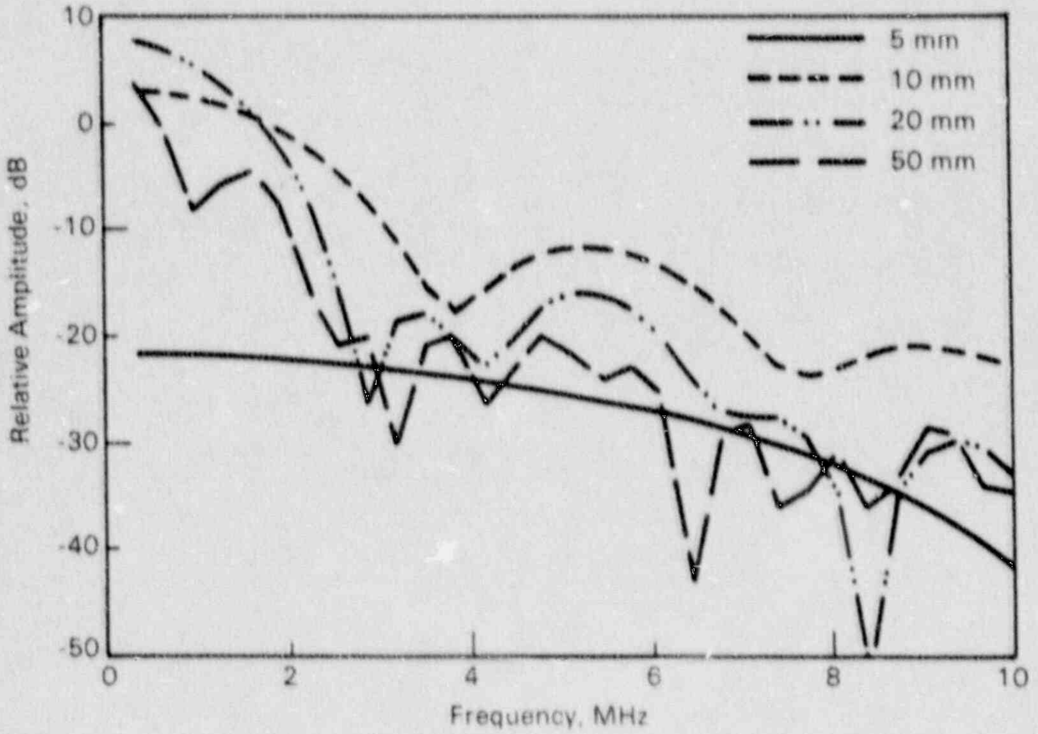

FIGURE 2.24. Transfer Functions of Various Sizes of 85° Flaws

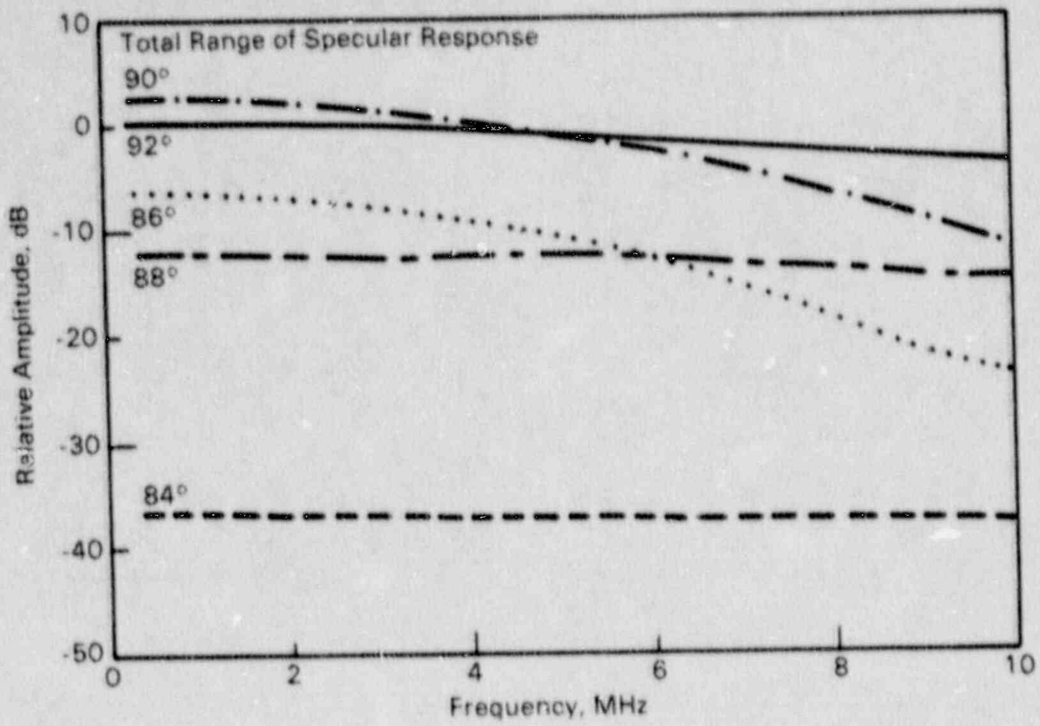

FIGURE 2.25. Transfer Functions for 5-mm Flaws at Various Angles

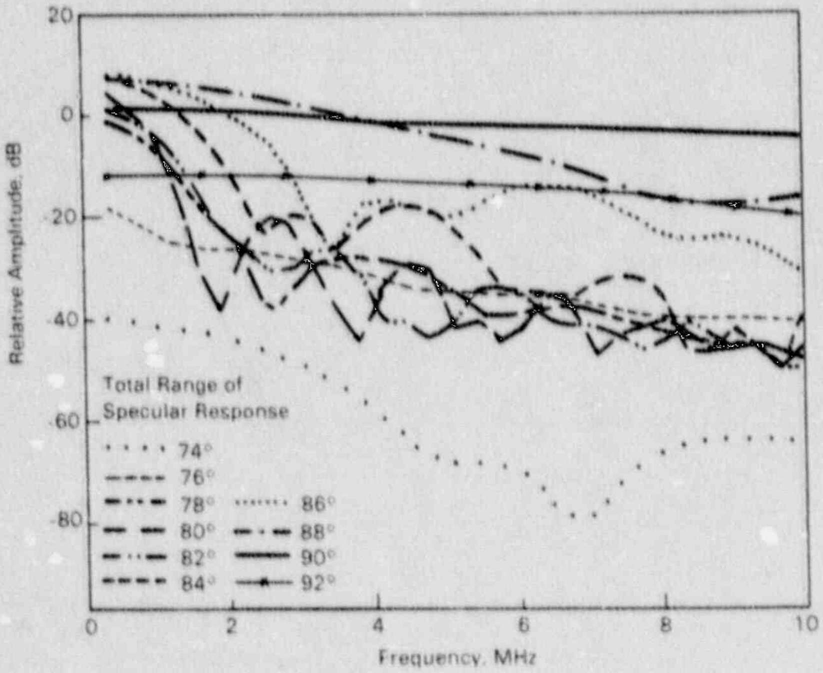

FIGURE 2.26. Transfer Functions for 25-mm Flaws at Various Angles

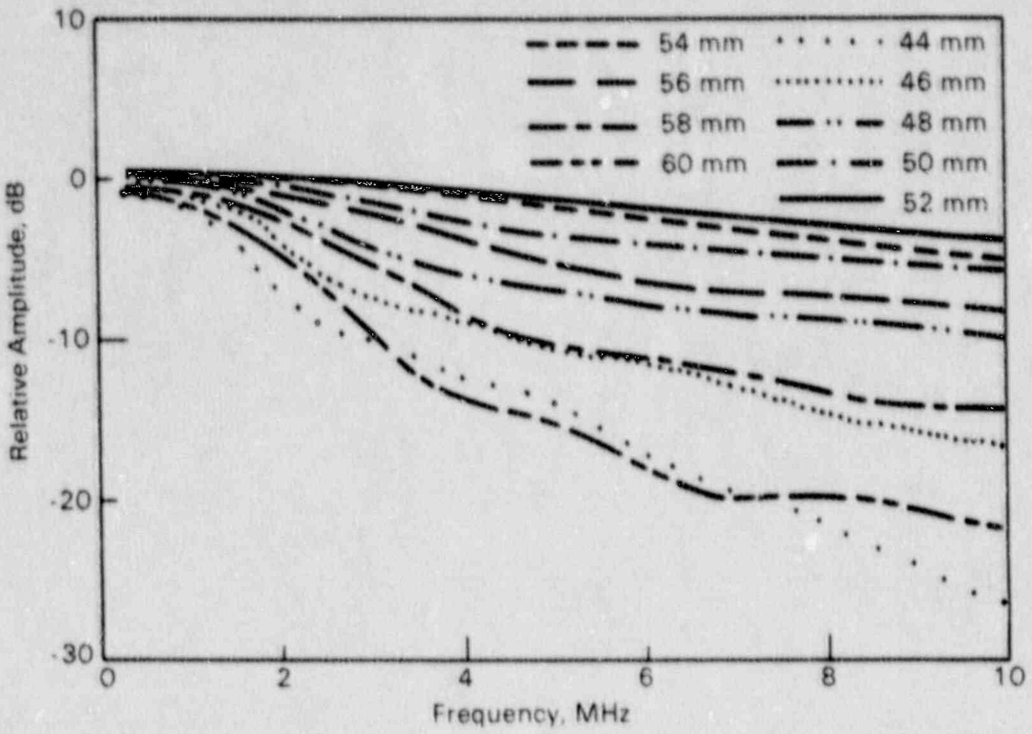

FIGURE 2.27. Transfer Functions of 5-mm, Vertical Flaws for Various Probe Exit Points

Effect of Probe Position - The effect of probe position was also investigated because: 1) measuring amplitude versus position is a sizing technique; and 2) in actual inspection situations, accessibility to an inspection location can be limited. Figure 2.27 shows the transfer functions for a vertical 5-mm flaw for various probe positions. A variation of equipment center frequency would have influenced sizing. A change in equipment bandwidth would have had a much smaller effect than a center frequency change, since the transfer functions have a gentle slope. As seen above, a change in flaw angle would have increased the fluctuation in the transfer functions and would have increased the sizing sensitivity to equipment bandwidth and center frequency.

Worst-Case Flaw Analysis. An analysis was performed to predict the effect of a worst-case flaw on an ultrasonic inspection. The 80°, 25-mm worst-case flaw identified above was used for the analysis. The signal produced by the inspection system (i.e., pulser, cables, transducer, receiver) is shown in Figure 2.28a along with its frequency spectrum. The signal was relatively broad-band with a bandwidth of 2 MHz and a center frequency of 2 MHz. Figure 2.28b shows the predicted pulse-echo response (A-scan) from a large vertical flaw. Because the vertical flaw transfer function was relatively flat as shown in Figure 2.28b, the response closely resembled the input signal except that it was inverted due to acoustic reflection. Figure 2.28c shows the predicted response from the worst-case flaw whose transfer function is also shown in Figure 2.28c. The worst-case flaw acted as a low-pass filter eliminating almost all of the spectral content above 2 MHz. The filtering

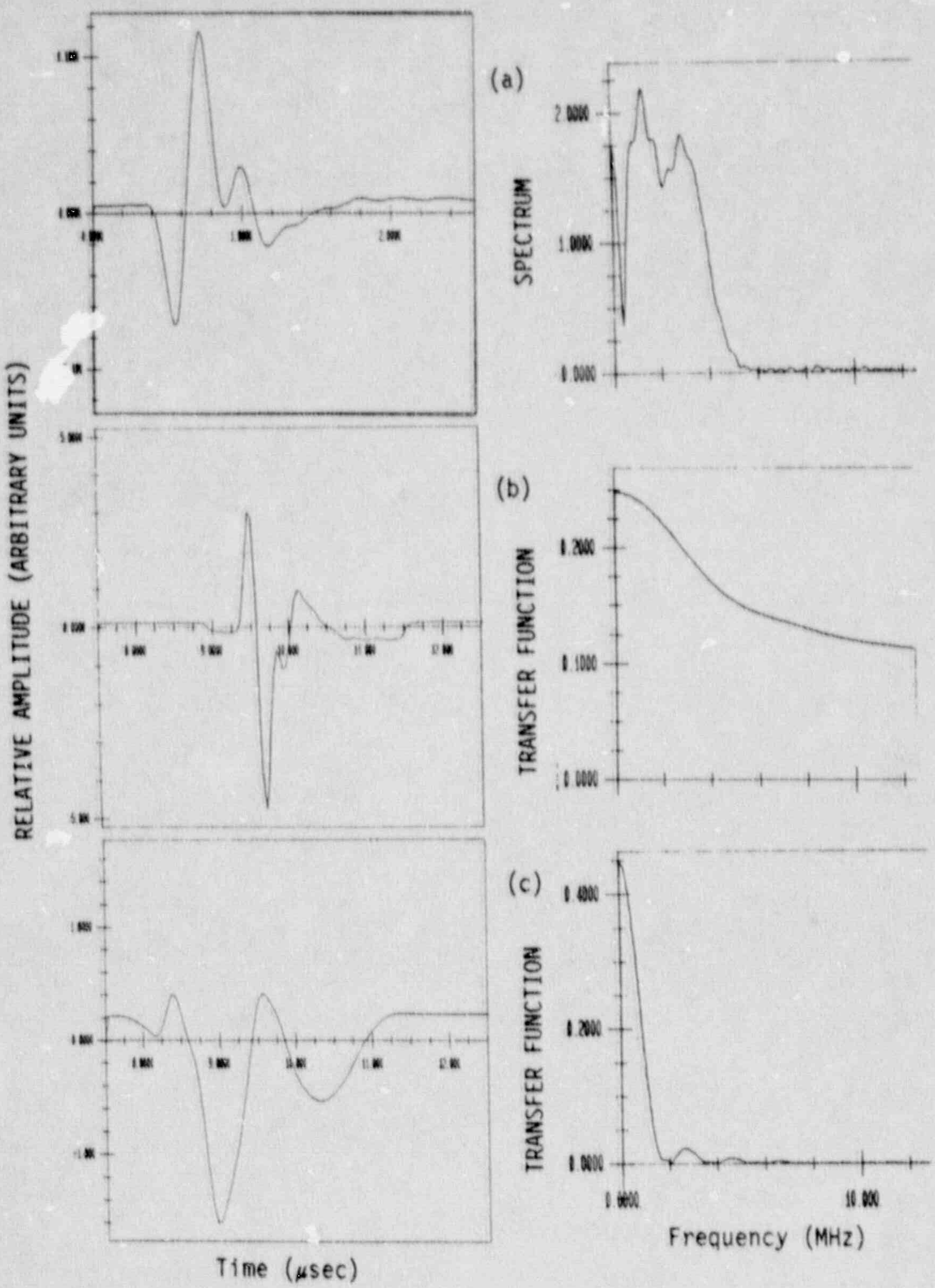

FIGURE 2.28. Transfer Function Analysis Results: (a) input signal and spectrum, (b) output signal from a vertical flaw and flaw T.F., (c) output signal from a flaw 10° from vertical and flat T.F. Note filtering effect.

reduced the response amplitude to 1/4 that of the vertical flaw and completely changed the shape and length of the signal.

Inspection of the transfer function (Figure 2.28c) of the worst-case flaw revealed how equipment changes would have affected the response signal and thus the reliability of inspection. Because the worst-case flaw transfer function had a strong minimum at 2 MHz, a very narrow-band inspection system with a center frequency of 2 MHz would have been practically blind to specular reflection from this flaw. A change in equipment bandwidth about a center frequency of 2 MHz would have had a significant effect on inspectability especially for already narrow-band systems. Because the worst-case flaw transfer function declines rapidly until 2 MHz, changes in equipment center frequency would also have strongly affected inspectability. A 1-MHz center frequency, narrow-band system would have detected this worst-case flaw easily, while a 2-MHz center frequency, narrow-band system would have been practically blind to this flaw. As inferred by this discussion, inspectability would also have been influenced by the combination of center frequency and bandwidth with narrow-band equipment more sensitive to center frequency changes than broad-band equipment. In recommendations to the appropriate standards committees, it may be necessary to have separate center frequency tolerances for narrow-band and broad-band inspection systems.

Model Integration. The flaw model was integrated with previously developed equipment models in preparation for an equipment parameter sensitivity study. The flaw model in combination with the equipment models represents a total ultrasonic system model. The only component not modeled was the pulser because it was a non-linear component whose response was strongly dependent upon the characteristics of the cable and the transducer. It was not strictly necessary to model the pulser analytically, since measured data for several different pulser/transducer combinations was available for the equipment parameter sensitivity study.

Summary. The work performed is summarized as follows:

- Model predictions were compared with data from single-frequency experiments. As expected, model predictions were excellent for smooth strip flaws but poor for circular flaws. Based on the favorable comparisons, development of the model is considered complete.
- Several multifrequency experiments were conducted, but the results have not yet been thoroughly examined.
- The model was used to perform case studies to determine the effects of flaw size, flaw orientation, and probe position on the flaw transfer function. It was found that probe position, flaw size, and orientation had a strong effect on the transfer function. A possible worst-case flaw was identified.
- An analysis was performed to predict the effect of a worst-case flaw on an ultrasonic inspection. The worst-case flaw was found to act as a low-pass filter. It was explained how such a flaw would

have been sensitive to changes in equipment center frequency and bandwidth. It was concluded that in recommendations to the appropriate standards committees, it may be necessary to have separate center frequency tolerances for narrow-band and broad-band inspection systems.

- A total ultrasonic inspection system model was completed and is ready for execution of the equipment parameter sensitivity study.

2.6.4 Future Work

The following work remains to be completed:

1. Multifrequency validation of the flaw model and worst-case flaw predictions.
2. Equipment parameter sensitivity study for thin sections (piping) using worst-case flaws.
3. Equipment parameter sensitivity study for thick sections (reactor pressure vessel) using worst-case flaws.
4. Standards recommendations for equipment parameter tolerances for piping and pressure vessel inspection.

3.0 CODE ACTIVITIES

3.1 SUMMARY

Participation in ASME Section XI activities continued toward achieving Code acceptance of NRC-funded PNL research to improve the reliability of nondestructive testing/inservice inspection (NDE/ISI). The proposed Appendix VII on Personnel Qualification and Certification was approved by the Section XI Subcommittee but received two negative votes during initial Main Committee consideration. The proposed Mandatory Appendix VIII on Performance Demonstration was approved by the SC-XI Subgroup on Nondestructive Examination (SGNDE) pending resolution of an open issue regarding the implementation approach.

3.2 INTRODUCTION

The objective of this task is to develop and/or evaluate new criteria and requirements for qualifying ultrasonic testing/inservice inspection (UT/ISI) systems. The primary goal is for these criteria and requirements to be incorporated into Section XI of the ASME Boiler and Pressure Vessel Code. If that goal cannot be met or if the requirements adopted by ASME Section XI (SC-XI) are inadequate, input has also been submitted for a draft Regulatory Guide as a backup approach. A NUREG report (NUREG/CR-4882) has been prepared to document the criteria and requirements developed to date, as well as to document the background and rationale associated with these activities.

The "proposed Appendix VII" developed in 1986 by an ASME Ad Hoc Task Group has been extensively restructured and revised by the SC-XI Subgroup on Nondestructive Examination (SGNDE). The SGNDE initially restructured the Ad Hoc Task Group document as two separate Code Cases; however, it later became evident to the SGNDE that this approach would be a virtual nightmare with respect to implementation. In mid-1987, the SGNDE discontinued efforts on the approach involving two separate Code Cases, and instead, initiated a major effort toward the preparation of two companion Mandatory Appendices. These two Appendices are usually identified as a) Appendix VII on Personnel Training and Qualification, and b) Appendix VIII on UT System Performance Demonstrations.

3.3 STATUS OF WORK PERFORMED

Proactive participation of PNL personnel in ASME Code activities continued toward achieving Code acceptance of NRC-funded research to improve the reliability of NDE/ISI. Agendas and minutes of SGNDE meetings held in conjunction with Section XI Subcommittee meetings were prepared and distributed by J. C. Spanner who serves as SGNDE Secretary. During this reporting period, Section XI meetings were held November 9-12, 1987, in Dallas, Texas and January 18-21, 1988, in San Diego, California. T. T. Taylor attended a Special Task Group meeting October 29, 1987, in Chicago, Illinois to finalize the proposed Mandatory Appendix VIII document. Input was provided to an NRC-NRR staff member who was giving a presentation on qualification and certification of NDT personnel at the Fall ASNT National Conference. Input was also prepared for an annual program review held in conjunction with the 15th Water Reactor

Safety Research Information Meeting. In both cases, the requested input consisted of summaries of our ASME Section XI Code activities to review progress and place this effort in the proper perspective.

During the November Section XI meetings, the proposed Mandatory Appendix VII on NDE Personnel Training and Qualification (including revisions to IWA-2300) was unanimously approved by the SGNDE. The proposed Mandatory Appendix VIII on Performance Demonstrations for Ultrasonic Examination was also tentatively approved by the SGNDE. A strategy suggested by the SC-XI Chairman for preparing "enabling" Code Cases to accompany both of these Appendices was rejected by the SGNDE for philosophical, rather than technical, reasons. Concurrently, a proposed revision to Code Case N-409 (N 409-1) was approved by the Main Committee during second consideration, and was also approved by the Board of Nuclear Codes and Standards (BNCS) during second consideration. Code Case N 409-1 was finally approved, published, and distributed to all ASME Section XI Code holders toward the end of this reporting period.

Also during the November SC-XI meetings, a proposed Non-mandatory Appendix on Acoustic Emission was approved at the Task Group and Working Group levels, but SGNDE action was deferred until January pending resolution of concerns regarding the implementation process. The Task Group responsible for a major update and rewrite of Appendix IV (Multifrequency Eddy Current Examination of Steam Generator Tubes) submitted a draft for consideration by the Working Group on Surface Examination (WG-S) and the SGNDE.

In preparation for the January Section XI meetings, discussions with the SC-XI Chairman and Secretary and the Chairman and members of the Special Working Group on Editorial Review (SWGER), key editorial revisions were made to the proposed new, Non-mandatory Appendix on Acoustic Emission. This document, along with an implementation approach, was provided to the SC-XI Secretary for distribution with the SC-XI and Main Committee (M.C.) agendas. Also, edited versions of both Appendix VII and Appendix VIII were placed in a PNL word processing system so that prompt incorporation of changes/revisions made by cognizant Code committees could be performed to preclude delays due to possible "foot-dragging" or "stonewalling" by various committee members.

During the January Section XI Subcommittee meetings, proposed Mandatory Appendix VII was approved by Section XI. The proposed Mandatory Appendix VIII was withdrawn from the SC-XI agenda due to confusion within SGNDE regarding implementation. Presentations describing the historical and technical aspects of both Appendices VII and VIII were given to SC-XI, and the response was quite favorable. The proposed Non-mandatory Appendix on AE was unanimously approved by the SGNDE; however, SC-XI tabled consideration of this item and requested that a technical indoctrination presentation be given during the April meeting. The proposed rewrite of Appendix IV was approved by the SGNDE; however, a strong concern was expressed that this document perpetuates the prescriptive approach, rather than reflecting the conscious SGNDE change to performance criteria. This trend toward performance criteria is evident in Code Case N 409-1, and in Appendix VIII which was unanimously approved by the SGNDE in January.

3.4 FUTURE WORK

In preparation for the Section XI meetings to be held in Atlanta, Georgia April 18-21, 1988, a proposed implementation approach for Appendix VIII was prepared and distributed. This approach consisted of selected revisions to Article I-2100. Also, a letter was prepared and distributed in response to the two negatives received on Appendix VII following the February Main Committee meeting. Final preparations for attending the April SC-XI meeting included a special mailing of New Business items received subsequent to distribution of the January minutes.

4.0 PRESSURE VESSEL INSPECTION TASK

4.1 SUMMARY

The objective of this task is to ascertain the reliability of current UT/ISI for the pressure vessel by evaluating existing data from inspection round robins conducted under the PISC-II program. The PISC-II round robin data base was received from the Joint Research Centre (JRC), Ispra, Italy and put on a PNL VAX computer. Confusion existed in how to correctly interpret the data files and further clarification was requested from the JRC. This clarification was received, and the data files were prepared and sent to the U.S. participants in the PISC II program who had requested these data.

4.2 INTRODUCTION

A complete set of the PISC-II round robin data on the four plates was received by PNL from the JRC in June 1986. PNL's immediate responsibilities were to organize the data so that it could be used to interpret these data for applicability to U.S. reactors and be disseminated to interested third parties in the U.S. We had requested ALL of the PISC-II data (including the raw team results) and the JRC honored our request. The raw team results contain several types of team inspection errors (i.e., coordinate and transcription errors) that were corrected in the "cleaned" version of the data that Ispra used for analysis.

Several iterations were required with the JRC before we understood these data and managed to assemble all the ancillary information to make the data intelligible. In January 1987, we had assembled a data base and description that the JRC could endorse and provided it to U.S. organizations who participated in the PISC-II program.

4.3 STATUS OF WORK PERFORMED

During the last reporting period, a task plan was developed for analyzing the PISC II data base. The task plan is presented below.

4.3.1 PISC Data Analysis

The PISC II data base will be analyzed to provide a quantitative estimate of UT capability for ISI of reactor pressure vessels.

The analysis of the PISC II data will be divided into two subtasks: a) analysis of detection performance, and b) analysis of sizing (length and depth) performance. The scope of work for each task is outlined below.

Detection - Inspection results from the PISC II round robin exercise will be analyzed to:

- Determine which procedures tended to work best for above inspection problems.

- Determine if the same procedure produced both "acceptable" and "unacceptable" results depending on personnel.

- Determine probability of detection and false call statistics for each team.

- Assess the condition of the PISC II round-robin blocks as to how well they reflect conditions in U.S. RPV and thus what is the significance of the PISC II data for U.S. ISI.

- Determine how many teams performed acceptably under the guidelines of proposed Mandatory Appendix VIII for:

  a) under clad cracks (flat block)
  b) shell welds (flat block)
  c) nozzle inner radius section
  d) nozzle-to-vessel welds (if possible).

<u>Sizing</u>

- Inspection results from the PISC II round robin exercise will be analyzed to develop the sizing statistics required by proposed Mandatory Appendix VIII (e.g., slope, mean deviation, and correlation coefficient) and to determine how many teams would have passed the Appendix VIII acceptance criteria for:

  a) under clad cracks (flat block)
  b) nozzle shell welds (flat block)
  c) nozzle inner radius
  d) vessel-to-shell welds.

- An analysis of the errors in PISC II sizing data will be used to determine effects of:

  a) flaw location
  b) specimen geometry
  c) defect size
  d) defect type
  e) defect implantation method.

- Variability in sizing results will be determined where teams used the same or similar sizing techniques.

4.3.2 Task Descriptions for Project

<u>Check and Complete True-State Data</u> - The true-state data we have should be assembled according to the ASME proximity rules. We need to check to see if this is correct and also compare the results to the destructive report. Are there any extra or missing cuboids? We also need the missing information in the true-state data filled in, such as flaw type and defect implantation method. Another important bit of information is the coordinate system used

on nozzle 3; we need to know exactly how it was laid out. The results of this task should be summarized in a small report.

Attempt to Verify Defect Detection Probabilities (DDPs) Presented in Report 5 - We want to determine whether or not the results presented in PISC report 5 can be reproduced from the data set we have. If some of the results can be reproduced, we will have at least some evidence that we have the correct data and are interpreting it correctly.

We will attempt to verify the DDPs listed in Tables 4.3 through 4.6 of Report 5. These tables contain defect detection probability for selected inspections. The tables should have been produced from the data set "clean.proc" so we will use that. The results of this task will be summarized in a small report.

Determine Relationship between Raw and Cleaned Data Sets - The PISC "cleaning" procedure is a mysterious process that was performed subjectively by a committee. In order to assess this process, we would like to compare some of the PISC data files to the original data sheets sent to us from EPRI. We have selected two teams' results for comparison, team LB's inspection of Nozzle 3 and team IS's inspection of Nozzle 9. We already know the results we have in the data books do not agree with what is in the PISC-II files. We need to determine why these data were altered.

Another question that needs to be resolved is what the relationship between the "cleaned" and "raw" data sets are. Related to this question is the taxonomy PISC employs for identifying inspections. This taxonomy identifies where the inspection comes from and which inspections in the data set it may be derived from. Is our information regarding this taxonomy correct?

One would expect that both the raw and cleaned data sets would contain the same set of inspections, but this is not the case. Furthermore, the "raw" data sets do not really seem to contain the original list of inspector indications as claimed in the PISC reports. (It appears that false calls are deleted and indication clusters may have been combined.) The strategy will be to concentrate on the results of team LB and team IS to resolve these problems.

We will summarize the discovered problems in a small report. If we understand the cleaning process and the inspection "taxonomy" correctly, a list of inspections for analysis will be identified. We want a list of "raw" inspections that include results most applicable to U.S. inspections.

Create "Scoring" Software for PISC Data - The objective of this task is to put together a scoring program that does what we did for the data in round-robin tests conducted at PNL. With the PISC data, scoring is three dimensional, as opposed to the one-dimensional problem faced with the PNL data. This scoring algorithm will be written in FORTRAN and hooked to "S" (a statistical software package) because it is computationally intensive.

We already have a program that calculates detection statistics using the PISC-II method of associating flaws and indications. The PISC-II associations are present in the data base. The end result of this task will be an "S" scoring function.

Determine Grading Units for Blocks - In order to perform an analysis that resembles our previous analyses, we need to define reasonable three-dimensional grading units. It will be difficult to define grading units of one size that are reasonable. We also require blank grading units to be constructed. The end result of this task will be a list of grading units for each block.

Perform Contingency Table Fit to Determine Relative Importance of Variables - Use log-linear models to determine which variables have the largest influence on POD. Prospective variables are team, procedure type, flaw type, flaw location, and flaw size. The results will be summarized as a section in the final report.

POD Curve Analysis to Determine Flaw/Procedure Effects - POD curves will be produced for important sets of conditions, and these results will also be summarized as a section in the final report.

ROC Curve Analysis for POR - ROC curves will be generated which describe the relationship between "Probability of Correct Rejection" and "Probability of False Rejection." These results will also be included as a section in the final report.

Sizing Analysis - Sizing errors will be evaluated using a regression model and approaches based on log-normally distributed errors will be incorporated into the models. Once the data are fit to the model, we will compare the results implications with the requirements in Mandatory Appendix VIII's performance demonstration testing for sizing (e.g., slope, mean deviation, and correlation coefficient). These results will be summarized as sections in the final report.

A final report summarizing our analysis of PISC II RRT results will be published.

4.3 FUTURE WORK

Analysis of the PISC II data should be completed and this draft report submitted to the PISC program manager for approval prior to publication.

5.0 NEW INSPECTION CRITERIA

5.1 SUMMARY

Work continued on assessing the adequacy of existing ASME Code requirements for ISI and on developing technical bases for improving these requirements to assure safe nuclear power plant operation. Efforts during this reporting period emphasized the application of probabilistic risk assessment (PRA) and probabilistic fracture mechanics to determine the level of inspection required to assure a suitably low failure probability for primary system reactor components. Particular attention was directed to requirements for inspection intervals and weld inspection sampling plans.

5.2 INTRODUCTION

Several interrelated activities on this task have been directed to the development of probabilistically based inspection requirements. The PNL program has been interacting with other industry efforts, notably through a newly organized ASME Task Group on Risk-Based Inspection Guidelines, which held its first meeting on February 18, 1988, in Washington, D.C. We have also continued contacts with other organizations such as the Electric Power Research Institute and the Idaho National Engineering Laboratory. PNL hosted a one-day workshop on January 20, 1988, that permitted a free exchange of ideas for using probabilistic methods to establish inspection priorities. In an effort to bring the various concepts for probabilistic inspection criteria together, PNL prepared a first draft of a "road map" document on improved inspection requirements. This document will be issued for review during the next reporting period.

During the first half of FY88, significant progress was made in a pilot study for the application of PRA methods to the inspection of reactor piping systems. This study is based on an existing PRA for the Oconee-3 reactor, and we completed a preliminary ranking of the important piping systems for purposes of inspection. We also looked at the complementary approach of using available and organized data from past operating history as a guide for inservice inspection requirements. From the best available and most detailed sources, a sample set of data on piping failures and repairs was obtained by performing a computer search of the Nuclear Power Plant Reliability Data System (NPRDS). An assessment of the usefulness of these data was in progress at the end of the current reporting period.

5.3 WORKSHOP ON PRA METHODS

A one-day workshop was held at PNL on January 20, 1988. Attending the workshop were six individuals from the PNL project team and three contributors invited from outside organizations; namely, Dr. J. Muscara, program monitor for the NDE Reliability Program, Dr. T. Margulies of the NRC staff, and K. Balkey of Westinghouse Electric Corporation who serves as Chairman of the ASME Task Group on Risk-Based Inspection Guidelines.

The workshop focused on the use of PRA methods and probabilistic fracture mechanics to establish priorities for inservice inspection of pressure boundary systems and components. Parallel applications of PRA methods currently used to prioritize plant aging issues were noted, but further discussions on this subject were postponed to a future meeting when individuals active in the plant aging area would be available to participate. Instead, the workshop focused on the ASME effort being lead by Balkey. In was noted that the goals of the ASME group had much in common with the goals of PNL's NDE Reliability Program. The meeting addressed future support of the ASME effort, both through PNL participation on the ASME Working Group and through NRC grants of funds to ASME.

The workshop presentation and discussions covered the following topics and issues:

- historical bases for current ASME Section XI requirements
- probabilistic evaluations already performed as part of the NDE Reliability Program
- overview of current and planned industry efforts to upgrade inspection requirements
- historical development of probabilistic methods of structural mechanics, and their application to concerns with reliability and safety
- applications of PRA methods by industries other than nuclear power generation
- safety goals for nuclear power plants and the role of inspection in ensuring that plants measure up to such goals
- PRA modeling issues and the use of PRA-based importance measures to guide inspection priorities

The workshop concluded that the ASME Task Group effort should be endorsed, its schedule accelerated, and its efforts integrated with the goals of the NDE Reliability Program.

5.4 ASME TASK GROUP ON RISK-BASED INSPECTION GUIDELINES

The first meeting of the ASME Task Group on Risk-Based Inspection Guidelines was held in Washington, D.C. on February 18, 1988. F. A. Simonen and B. F. Gore were in attendance to represent PNL's interests from the standpoint of the NRC-funded NDE Reliability Program. A trip report was prepared and submitted to the NRC program monitor.

Chairman Balkey emphasized his efforts to recruit task group members that represent several industries, including nuclear power, industrial insurance, civil engineering structures, aircraft, offshore oil, and petrochemical processing. While risk-based efforts in all these industries will be documented by the Task Group, our initial indication is that the nuclear power industry does not lag other industries in applications of PRA methods to safety and inspection concerns.

The meeting agenda began with a series of self introductions, and each member described his relevant knowledge and experience along with his perspective of priorities for the task group. Balkey then presented his draft work statement for the Task Group, and updated the membership on his efforts to secure funding to help support costs of travel and staff time. The meeting concluded with a workshop session that refined the work statement and schedule for the Task Group.

The second meeting of the group was tentatively scheduled for early June 1988. At the conclusion of the current reporting period, efforts to obtain funding were not yet final, but formal proposals to NRC and EPRI had been submitted and were being processed by these organizations.

5.5 DEVELOPMENT OF A COMPREHENSIVE PROBABILISTIC APPROACH

A "road map" document to outline a comprehensive probabilistic approach for the development of improved inspection requirements was drafted during this reporting period. This document provides a flow chart and the associated methodologies that can relate inspection requirements in a quantitative manner to desired improvements in systems safety.

The concept behind the proposed approach can be expressed in terms of three probabilistic parameters as follows:

$$(1 - P_{ISI}) * P_{failure} < P_{acceptable} \tag{5.1}$$

where $P_{acceptable}$ = Acceptable failure probability for a weld based on considerations of safety goals such as core melt frequency, public risk, and occupational exposure.

$P_{failure}$ = Baseline failure probability for the weld given that no inservice inspection is performed.

P_{ISI} = Probability of detecting degradation in the weld before failure occurs. Given that detection is successful, it is implied that the repair or mitigation of this degradation is 100% effective.

The document reviews the models and data that are now available or will be needed to put this concept into practice. Also, the assumptions and limitations of current probabilistic methods are addressed. The following sources of data and computational methods have been identified for use in quantification of the three parameters of the model:

Acceptable Failure Probability -
- NRC Safety Goals
- Probabilistic Risk Assessment

Baseline Failure Probability -

- Historical Data on Reliability
- Plant-Specific Operating Data
- Probabilistic Fracture Mechanics
- Engineering Evaluations and Tests
- Expert Judgement

Probability of Detection -

- Round Robin Inspection Data
- Trends from Field Inspections
- Crack Growth Rate Data/Calculations
- Sampling Plan Models/Calculations

The report will outline the research activities needed to support the probabilistic approach, including the pilot calculations begun during this reporting period. Later activities will demonstrate the probabilistic methods in greater depth and detail through plant-specific studies. The ultimate goal will be to derive generic-type requirements for incorporation into Codes and regulatory requirements.

5.6 DATA BASE ON PLANT OPERATING HISTORIES

This activity responds to a recommendation made during a March 1987 PNL/NRC workshop. The recommendation was to search data bases and industry records for information on component failures and repairs, and also findings of component inspections. During FY88, we are establishing where such information can be found, estimating the effort to retrieve and interpret the resulting data, and determining the potential usefulness of the data as the basis for setting priorities for future inspection requirements.

Contacts with utilities have indicated that suitable records are maintained at plant sites, and that these records could provide much useful information. However, the costs of on-site visits to obtain this information is beyond the scope of the NDE Reliability Program.

Discussions with NRC staff have revealed two potentially useful computerized data bases; namely, Licensing Event Reports (LER) and an industry-maintained data base available through the Nuclear Power Plant Reliability System (NPRDS). Being oriented to components, PNL was advised by NRC staff that the NPRDS data base would report more of the types of information of interest to ASME Section XI inspections. Accordingly, a trial search of the NPRDS data was performed through a request to the NRC staff. Data from this search was received towards the end of the reporting period, and review of these data from the standpoint of usefulness will be covered in the next semi-annual report.

5.7 OCONEE-3 PILOT STUDY

In this study we are exploiting information from an existing PRA for the Oconee-3 plant. The objective is to demonstrate the feasibility of using such results for establishing inspection priorities for pressure boundary systems and components. In the first half of FY88, several alternative methods (importance parameters) for ranking the safety importance of systems were proposed, and Table 5.1 gives a preliminary ranking of the Oconee-3 piping systems. The following information was used to generate Table 5.1:

- The EPRI report on the Oconee-3 PRA (NSAC 60) was used to evaluate the consequences of piping system failures.
- A report prepared by INEL (NUREG/CR-4407, Pipe Break Frequency Estimation for Nuclear Power Plants) was used to estimate failure probabilities for the different piping systems.

TABLE 5.1. Rankings of Systems and Components for Inspection Priority as Based on Risk Considerations for Oconee-3

System[a]	Weld Inspection Importance Rank	Weld Inspection Importance Value	Birnbaum Importance Rank	Birnbaum Importance Value
Low-Pressure Injection (LPI)[b]	1	(3.1E-04)	2	(1.5E-02)
High-Pressure Injection (HPI)	2	(2.7E-04)	5	(5.4E-03)
Emergency Feedwater (EFW)	3	(3.8E-05)	3	(1.5E-02)
Service Water (SWS)	4	(1.9E-05)	4	(7.7E-03)
Reactor Coolant (RCS)	5	(9.0E-06)	6	(3.6E-03)
Steam Generators (SGs)	6	(6.5E-06)	9	(1.5E-04)
Reactor Pressure Vessel (RPV)	7	(5.0E-06)	1	(1.0)
Power Conversion (PCS)[c]	8	(4.3E-06)	8	(2.1E-04)
Standby Shutdown Facility (SSF)	9	(1.7E-06)	7	(6.9E-04)
Instrument Air (IA)	10	(5.0E-08)	10	(1.5E-05)

(a) Only systems covered by ASME Section XI on ISI are listed.
(b) Under normal conditions, the most frequently used function of the LPI system is decay-heat removal (DHR) after a shutdown.
(c) The PCS system consists of the following: main feedwater, main steam, condensate, condenser circulating water, and vacuum systems.

One of the important parameters in Table 5.1 is the well-known Birnbaum Importance parameter, which assumes that the given system fails and then calculates the consequences relative to core melt. There is no consideration of the differences in failure probabilities of the systems. The second parameter (Weld Inspection Importance) was newly derived under this PNL program. This parameter introduces individual estimates of failure probabilities for each system. The calculation involves weighting the Birnbaum parameter in accordance with the estimated failure probabilities. The resulting rankings approximate those of the well-known Fussel-Vesely importance, but with the focus being solely on pipe break probabilities.

It is interesting to note (from Table 5.1) that except for the Reactor Pressure Vessel (low rupture probability) and the Steam Generators (high rupture probability), the remaining systems have relatively the same rank for both the Weld Inspection Importance and the Birnbaum Importance Measures. The

Low-Pressure Injection, High-Pressure Injection, and Emergency Feedwater systems are ranked highest due to their higher pipe break probabilities and their important functions to prevent the core from being uncovered following a transient or accident.

The rankings of Table 5.1 are the first step in the pilot study, and thus the relative rankings indicate inspection priorities only on a systems basis. One can view these rankings as roughly parallel to the approach of ASME Section XI which uses Class 1, 2, and 3 designations to prioritize inspections. The final report on the pilot study will compare the rankings of the probabilistic approach with the actual Class 1, 2, and 3 designations for the piping systems of Oconee-3.

5.8 FUTURE WORK

In the next step of the pilot study, the emergency feedwater system will be subjected to a more detailed evaluation. The results will establish priorities for inspecting the individual welds in this system, based both on estimates of failure probabilities for individual welds and on the consequences of rupture at different locations in emergency feedwater systems.

The Oconee-3 pilot study will be completed during FY88, and a report will be prepared by September 1988. These results will only show relative priorities for inspecting the different systems and components. However, the successful conclusion of the pilot study will show the way to further probabilistic calculations that will address inspection requirements on a more quantitative level. In these future calculations, the requirements will be stated in terms of risk-based goals. Subsequently, the long-term goal of generic requirements for ASME Section XI will be developed in a systematic manner by performing a number of plant-specific studies as the foundation. Trends from these studies will determine the nature and extent to which generalizations of inspection requirements are meaningful, and will indicate the possible role of plant-specific evaluations.

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The Evaluation and Improvement of NDE Reliability for Inservice Inspection of Light Water Reactors (NDE Reliability) Program at the Pacific Northwest Laboratory was established by the Nuclear Regulatory Commission to determine the reliability of current inservice inspection (ISI) techniques and to develop recommendations that will ensure a suitably high inspection reliability. The objectives of this program include determining the reliability of ISI performed on the primary systems of commercial light-water reactors (LWRs); using probabilistic fracture mechanics analysis to determine the impact of NDE unreliability on system safety; and evaluating reliability improvements that can be achieved with improved and advanced technology. A final objective is to formulate recommended revisions to ASME Code and Regulatory requirements, based on material properties, service conditions, and NDE capabilities and uncertainties. The program scope is limited to ISI of the primary systems including the piping, vessel, and other inspected components. This is a progress report covering the programmatic work from October 1987 through March 1988.

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