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Technical Basis for Substituting Ultrasonic Testing for Radiographic Testing for New, Repaired, and Replacement Welds for ASME Section XI, Division 1, Stainless Steel Piping

2017 TECHNICAL REPORT

Technical Basis for Substituting Ultrasonic Testing for Radiographic Testing for New, Repaired, and Replacement Welds for ASME Section XI, Division 1, Stainless Steel Piping

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Final Report, June 2017

EPRI Project Manager
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ABSTRACT

This report will serve as the technical basis to support the use of ultrasonic testing (UT) for the volumetric examination of new, repaired, and replaced welds when required by construction codes or owner's requirements of welds in austenitic stainless steel piping systems. It will be used as background information for a revision to the existing, Board-approved American Society of Mechanical Engineers (ASME) Section XI Code Case N-831, "Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe, Section XI, Division 1" to include austenitic stainless steel piping welds.

The technical basis is the result of a project that designed and fabricated austenitic stainless steel piping weld specimens. The specimens contain typical welding defects such as slag, incomplete penetration, lack of fusion, and so on. The defects were designed so that their sizes were either acceptable or rejectable in accordance with the 2015 edition of ASME Section XI acceptance criteria in Tables IWB-3514-1 and IWC-3514-1. For the defects that were designed to be acceptable, their sizes were not less than 50% of the allowable flaw sizes in accordance with the Section XI acceptance criteria. The specimens were then subjected to UT examinations to determine the detectability of the defects and the ability to size the defects within the acceptance criteria (root mean square error values) that currently exist in Code Case N-831.

This report provides an introduction and background regarding the benefits of using UT instead of radiographic testing (RT) during the support of repair and replacement activities. It also includes sections regarding the piping weld specimen and flaw designs, brief descriptions of the UT techniques and the results of the UT examinations, and appendices that document detailed information from the UT examinations. In addition, this report provides a detailed, step-by-step explanation about flaw evaluations performed in conjunction with Section XI, Table IWB-3514-1; a side-by-side comparison of the existing Code Case N-831 to a proposed Code Case N-831-1, which is currently under development; and a reproduction (with the authors' permission) of the white paper, "Effectiveness of Substituting Ultrasonic Testing for Radiographic Testing for Repair/Replacement of Carbon Steel (N-831)," that was used as background information to support the existing Code Case N-831.

Keywords

Austenitic stainless steel piping welds
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PRIMARY AUDIENCE: Nondestructive examination personnel, ISI program owners

SECONDARY AUDIENCE: Engineering and maintenance program personnel

KEY RESEARCH QUESTION

Can ultrasonic testing (UT) be used instead of radiographic testing (RT) when volumetric examinations are required for new, repaired, and replacement welds in austenitic stainless steel piping systems in accordance with ASME Section XI? Currently, when a volumetric examination is required by the applicable construction code or owner's requirements, it typically requires the use of RT. Using RT during operations or Section XI repair and replacement activities can create some safety hazards, as well as affecting work in adjacent areas that can result in outage schedule impact; in some cases, an entire building may become an exclusion zone, causing the loss of one or two shifts of outage impact. This is avoidable by using UT in lieu of RT for the necessary volumetric examinations for acceptance.

RESEARCH OVERVIEW

The project team designed, fabricated, and UT examined austenitic stainless steel piping weld specimens containing welding and fabrication-type defects. The primary purpose of the experiments was to determine whether all the defects could be detected by applying single-side access examination techniques. By performing the UT experiments, examiners learned much information about the techniques that are needed to volumetrically examine full weld volumes in austenitic stainless steel piping welds.

KEY FINDINGS

- UT examination was able to detect all the fabrication and welding defects presented in both near-sided and far-sided locations of the weld.
- All flaws were also successfully sized using conventional UT examinations.
- Using the results of the UT examinations, this technical basis will be used to support a revision to ASME Section XI Code Case N-831, "Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe, Section XI, Division 1," which will be Code Case N-831-1, to include austenitic stainless steel piping welds.

EXECUTIVE SUMMARY

WHY THIS MATTERS

Having the opportunity to substitute UT for RT for the acceptance volumetric examination when needed during outage situations will reduce safety and radiological hazards for many plant workers, reduce the outage impact of performing RT, and thereby potentially save significant outage impact.

HOW TO APPLY RESULTS

The results of this project form this technical basis document. This technical basis will be used to support a revision to the existing Code Case, Board-approved for use, to expand N 831 to include new, repaired, and replaced austenitic stainless steel piping welds.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

INTRODUCTION

1.1 Objective

The objective of this report is to provide the technical basis for substituting ultrasonic testing (UT) for radiographic testing (RT) when performing required volumetric examinations of austenitic stainless steel piping welds. It is also intended to support the use of Section XI preservice inspection (PSI) volumetric acceptance criteria for repairs and replacements.

Currently, when austenitic stainless steel piping welds at operating nuclear power plants require repair or replacement, a volumetric examination may be required by the applicable construction code or owner's requirements. For piping weld repairs or replacements done in accordance with Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, the specific examination currently required for acceptance is RT.

This requirement presents several problems that can have a significant impact on outage schedules, on-line repairs, and radiation exposure concerns at operating plants. In many cases, one or more shifts of outage schedule are impacted when areas of the affected building (or sometimes the entire building) become exclusion zones due to RT examination activities in which an open source is used for the exposures. At the same time, there is the risk for RT technicians and plant personnel to be accidentally exposed to additional occupational radiation dose.

Another potential problem is that codes such as ASME Section III, "Rules for Construction of Nuclear Facility Components," require repairs of flaw indications such as cracks, lack of fusion, and so on, regardless of their sizes. These rules are sufficiently conservative to exclude structurally significant flaws, but they also exclude benign indications that do not affect the structural integrity of the welds. This approach has resulted in repairs of minor flaws. The problem with this approach is that when localized repairs are performed, high residual stresses may result. These stresses may cause the affected area to be more susceptible to stress corrosion cracking during the service life of the weld [1].

Because "operating experience has shown a high level of reliability, with service failures rarely being attributed to fabrication flaws," a more prudent approach is to evaluate any flaws found during the initial examination of repaired or replacement welds using evaluation methods such as those found in ASME Section XI, IWB and IWC. These provide a conservative approach to evaluate flaws that may be considered benign, as opposed to initiating a localized repair that can be more detrimental to the weld than leaving an acceptable flaw in the weld as is [1].

Alternatively, UT could be used to meet the volumetric examination requirements. Using UT would minimize the impact on other outage activities created by the use of RT.

Another advantage of using UT instead of RT is that RT may miss planar flaws such as cracks due to orientation; cracks oriented greater than 10° from parallel to the radiation source will probably not be seen on the resulting image. Properly identifying the length and through-wall dimension of these planar flaws is important because they can be significantly detrimental to the service life of a weld. UT is capable of detecting planar flaws (cracks) such as these.

This report provides a technical basis for proposed Code Case N-831-1, which is a revision to the existing Code Case N-831, “Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe, Section XI, Division 1.” Code Case N-831 allows the use of UT in lieu of RT when required by the construction code or owner’s requirements during Section XI repairs or replacements. This report is the technical basis to allow N-831, which is currently limited to ferritic steel piping welds, to also be applicable to austenitic stainless steel piping welds.

To do this, the project team designed and fabricated stainless steel piping specimens with welding defects, scanned the specimens using encoded UT as part of the application of the Electric Power Research Institute (EPRI) Quality Assurance (QA) program, and compared the UT results to the as-built documentation.

This report provides detailed information regarding the design and fabrication of the specimens, information about the UT techniques and equipment used to examine the specimens, and the results of the UT examinations. In addition, the appendices provide information about flaw evaluations using Section XI, Table IWB-3514-1, along with example evaluations, a side-by-side comparison of Code Case N-831 (for ferritic pipe only) and proposed Code Case N-831-1 (revision to N-831 to included austenitic stainless steel pipe), and a copy of the white paper that was used as background material to support Code Case N-831 for ferritic pipe.

1.2 Background

The repair or replacement of nuclear power plant piping is governed by the rules of applicable construction codes and owner’s requirements. Depending on several factors, the pressure boundary welds often require RT. The objective of this volumetric examination is to ensure high levels of structural integrity by detecting fabrication flaws induced during the welding process. If fabrication flaws determined from the RT images exceed the acceptance criteria specified in the construction code (such as ASME Section III or ANSI B31.1) or owner’s requirements, repair and reexamination of the weld is required to ensure that the final weld is free of unacceptable fabrication flaws [2].

“The requirements in the construction codes are referred to as a *workmanship standard* because they are not based on detailed structural integrity or fracture mechanics evaluations” [1, 2]. The construction codes are sufficiently conservative to exclude flaw indications that may contribute to a pressure-retaining boundary failure.

However, this conservative approach also excludes more benign fabrication flaw indications, resulting in piping welds being repaired unnecessarily and causing other undesirable conditions. When localized repairs are performed, high residual stresses may result. These stresses may cause the affected area to be more susceptible to stress corrosion cracking during the service life of the weld. “Because small flaws are inherent even to high-quality welding processes, flaw-free welds are not a realistic goal. Operating experience has shown a high level of reliability, with service failures rarely being attributed to fabrication flaws” [1].

Using UT in conjunction with a conservative acceptance standard such as ASME Section XI, IWB-3400 or IWC-3400, has two benefits. First, it eliminates costly repairs that in some cases eliminate benign flaws but at the same time leave the weld and repair areas susceptible to cracking later in the service life of the weld. Second, it ensures a necessary margin of safety for the weld being placed into service.

To do this, the UT examinations must be capable of reliably detecting and sizing flaws within the weld volume where fabrication defects will occur. An Appendix VIII qualified UT examination would not be appropriate to meet the construction code or owner's examination requirements of a new weld, which would include examination of the entire thickness of the weld but no adjacent base material [3]. Therefore, to justify the use of ASME Section XI UT examination to fulfill the examination requirements of the construction code and owner's requirements, it is prudent and conservative to require that any UT process (that is, procedure, equipment, and personnel) used for such a purpose should require qualification by performance demonstration. Such an approach would be in line with Code Case N-831 for use of UT in lieu of RT examination of ferritic piping welds [4].

This technical basis document is the result of studies performed on stainless steel piping weld specimens that were designed and fabricated to contain typical fabrication flaws. These flaws were designed to be of both acceptable and unacceptable sizes and locations, using ASME Section XI, Table IWB-3514-1, as the evaluation standard.

This report is organized in a somewhat chronological order based on the tasks that were part of the overall project, as follows:

- Section 2, Specimen Design, provides information on specimen thickness selection, specimen materials and welding, flaw design, and the approach taken to determine the sizes and locations of flaws that would be both acceptable and unacceptable in accordance with ASME Section XI, Table IWB-3514-1.
- Section 3, Ultrasonic Test Techniques, is a general description of the UT fingerprinting process performed after the specimens were fabricated, including an overall review of the results.
- Section 4, Ultrasonic Test Results, is a general description of the UT results compared to flaw as-built dimensions.
- Section 5, Summary and Conclusions, broadly describes the results of UT studies and results for the stainless steel piping specimens designed and fabricated for this project, along with conclusions regarding the benefits of using UT in lieu of RT for the volumetric examination acceptance of new, repaired, or replaced welds in stainless steel piping systems.
- Section 6, References, contains a list of literature that was reviewed and used during this project.
- Appendix A, Results of Ultrasonic Test Fingerprinting, provides a more detailed discussion regarding the UT fingerprinting processes used on the stainless steel piping specimens.
- Appendix B, Flaw Evaluations Using Section XI, Table IWB-3514-1, provides a detailed, step-by-step explanation of how the flaws for the stainless steel piping specimens were designed to ensure a reasonable population of acceptable and unacceptable flaw sizes and

locations. It includes a description of how the acceptance standards of IWB-3514 were used in conjunction with the flaw characterization figures (IWA-3300) to design flaws of both acceptable and rejectable sizes.

- Appendix C, Side-by-Side Comparison Table of Code Case N-831 and Proposed Code Case N-831-1, lists each item in the existing Code Case ferritic welds along with a description of possible changes needed to incorporate austenitic stainless steel welds into N-831, resulting in N-831-1.
- Appendix D, White Paper: Effectiveness of Substituting Ultrasonic Testing for Radiographic Testing for Repair/Replacement of Carbon Steel (N-831), is the background material file posted at the ASME C&S Connect website (https://cstools.asme.org) associated with Record Number 12-2244 (reproduced with authors' permission).

1.3 Conversion Factors

Table 1-1 provides conversion factors for units of measure used in this report.

Table 1-1
Conversion factors used in this report

Parameter	English to Standard International
Length	1 ft = 0.305 m 1 in. = 2.54 cm

2
SPECIMEN DESIGN

Because of the lack of available austenitic stainless steel piping specimens with fabrication-type flaws suitable for this project, specimen design and fabrication was required. This provided an opportunity to receive input from EPRI personnel experienced with administering performance demonstration (PD) activities, welding specialists, and utility members with experience in weld repairs and replacements. By doing this, the project was able to maximize the effectiveness and efficiency of the specimen and flaw selection and design processes. Several meetings and discussions were held early on in the project to determine the following needs:

- Pipe sizes and schedules
- Inside diameter (ID) geometric conditions
- Outside diameter (OD) surface conditions
- Welding processes
- Fabrication flaw types and orientations
- Flaw distribution (that is, a range of flaw sizes compared to the acceptance standards in Tables IWB-3514-1 and IWC-3514-1)
- Appropriate UT techniques

Note: All the specimens for this project were designed and fabricated in accordance with the EPRI QA Program and the QA requirements of the EPRI PD Program. In addition, all the specimens remain secure and blind, in accordance with the security protocols of these programs.

2.1 Pipe Sizes and Schedules

After some discussion with EPRI colleagues experienced in welding and plant designs, along with several of the project advisors, it was postulated that the need to replace austenitic stainless steel piping welds in operating plants might occur under the following conditions:

- An ID, surface-connected, service-induced crack was found of an unacceptable size that required removal rather than the weld overlay repair option
- Piping system design modification such that portions of a piping were replaced, resulting in new welds being installed
- Removal or replacement of a flange, valve, or other component
- Other embedded flaws requiring repair or replacement

In most cases, the upper diameter size would be less than or equal to a pressurizer surge line configuration (18 in. diameter, Schedule 160). However, to ensure that the full thickness and diameter ranges were adequate, the maximum size pipe chosen was 24-in. diameter Schedule 160 (2.344 in. nominal thickness).

For the lower end of the range, 4-in. diameter was chosen because the ASME Section XI Code category for piping (Category BJ, Pressure-Retaining Welds in Piping, Item B9.10) would apply, which is 4-in. diameter or larger.

Table 2-1 is a summary of the specimen sizes fabricated for this project.

Table 2-1
Summary of specimen sizes, lengths, and thicknesses

Nominal Pipe Size (in.)	Specimen Length (in.)	Nominal Thickness (in.)
4	18	0.237
4	18	0.486
6	18	0.651
8	18	0.814
12	24	1.169
24	24	2.343

2.2 Materials and Welding

The specimens were made from 304 wrought, austenitic stainless steel pipe material. This is a commonly used material for stainless steel piping systems in operating nuclear power plants and was a suitable material for this project. Two types of weld configurations were used for the specimens:

- Single bevel with a 30° bevel angle for specimens less than 0.75-in. in thickness (see Figure 2-1)
- Single bevel with an initial 30° bevel angle up to 0.75 in. from the ID, continuing with a 20° bevel angle up to the specimen's OD (see Figure 2-2)

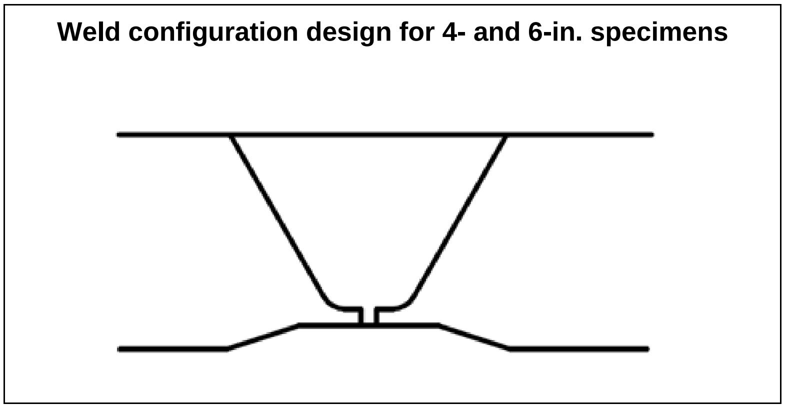
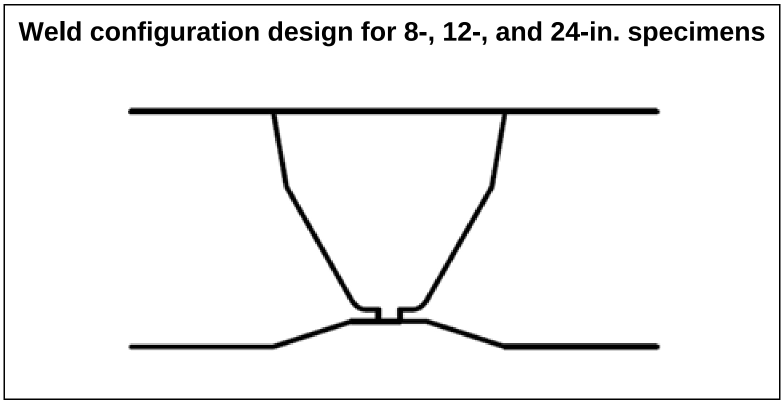


Figure 2-1
End preparation for 4- and 6-in. specimens



Weld configuration design for 8-, 12-, and 24-in. specimens

Figure 2-2
End preparation for 8-, 12-, and 24-in. specimens

For the welding and welding materials, the manual gas tungsten arc welding process was used for welding the root and hot pass portions of the welds. The remainder of the weldments were completed using the shielded metal arc weld process. The filler material was 308/308L.

2.3 Geometric Conditions

Inside Diameter

To simulate expected field weld conditions, different ID geometric and defect conditions were designed and built into the fabricated specimens. These included various root and counterbore conditions, as well as unacceptable defects such as incomplete penetration.

Outside Diameter

For new, repaired, or replaced welds, the volumetric examination for acceptance requirements includes the entire weld volume. To achieve the examination of this weld volume, the specimens for this project were fabricated with a final OD surface condition of flat and flush.

Note: A *flush* surface condition is defined as a weld with the weld crown removed so that the adjoining base materials and weld lie on the same plane.

2.4 Flaw Types

To be thorough and have sufficient data to support the technical basis, common subsurface and surface fabrications flaw types such as incomplete penetration, slag, porosity, interbead, and sidewall lack of fusion were included in the specimens and were placed in various locations throughout the weld volume.

In addition, consideration was given to flaw orientation. EPRI welding engineers provided input into the type and orientation of flaws to be included in the specimens. Due to the nature of the welding processes (that is, the direction of welding), only circumferential flaws were included in the design and fabrication of the specimens.

2.5 Flaw Distribution

After discussion with industry personnel experienced in PD processes and testing, as well as with ASME Code committee members, it was decided that an adequate flaw distribution of 60% rejectable sized flaws and 40% acceptable sized flaws would be adequate for the purposes of this project. (**Note:** The terms *rejectable* and *acceptable* refer to flaw sizes and locations compared to the acceptance standards published in ASME Section XI, Tables IWB-3514-1 and IWC-3514-1.)

For acceptable sized flaws, consideration was given to PD criteria in ASME Code Case N-831 that would allow for UT to be performed on new, repaired, or replaced welds in lieu of RT. For the purposes of N-831-1, the qualification of procedures, equipment, and personnel by PD will also be required. A failure to qualify these based on missed detections of extremely small flaws (of acceptable size) would not be a desirable end state. Therefore, flaws smaller than 50% of the allowable flaw size, as defined in IWB-3500 and IWC-3500, were not included in the specimens designed and fabricated for this project.

Flaw distribution not only addresses flaw sizes (that is, rejectable versus acceptable sizes) but also addresses flaw locations. For this project, consideration was given to distributing the available flaw population in three zones throughout the weld thicknesses. The categories established were based on one-third of the nominal pipe wall thicknesses (see Figure 2-3):

- Near OD (outer one-third of the nominal pipe wall thickness)
- Middle (middle one-third of the nominal pipe wall thickness)
- Near ID (inner one-third of the nominal pipe wall thickness)

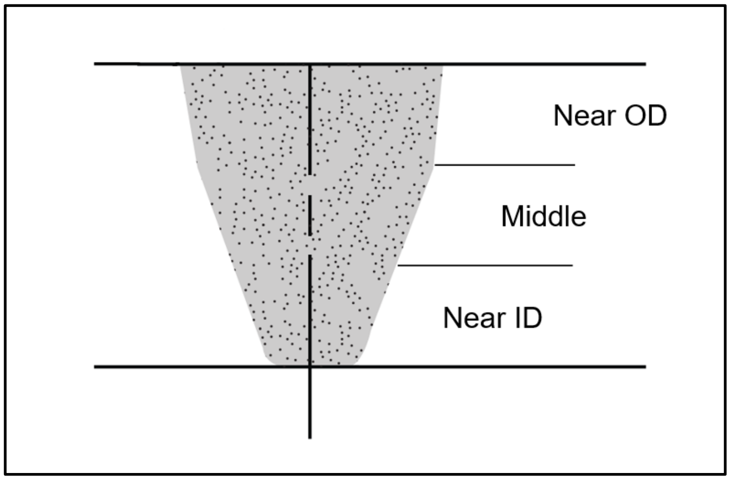


Figure 2-3
Weld profile showing through-wall distribution zones

Consideration was also given to the longitudinal (that is, side to side) distribution of the flaws. Thus the flaws were distributed as follows:

- Within the weld
- On the far side of the weld
- On the near side of the weld

Although the term *within the weld* is self-explanatory, the terms *far side* and *near side* are sometimes difficult to describe because they are relative terms based on UT examination search unit position and flaw position at the time of examination. One simplified way to describe this is pictorially (see Figures 2-4 and 2-5).

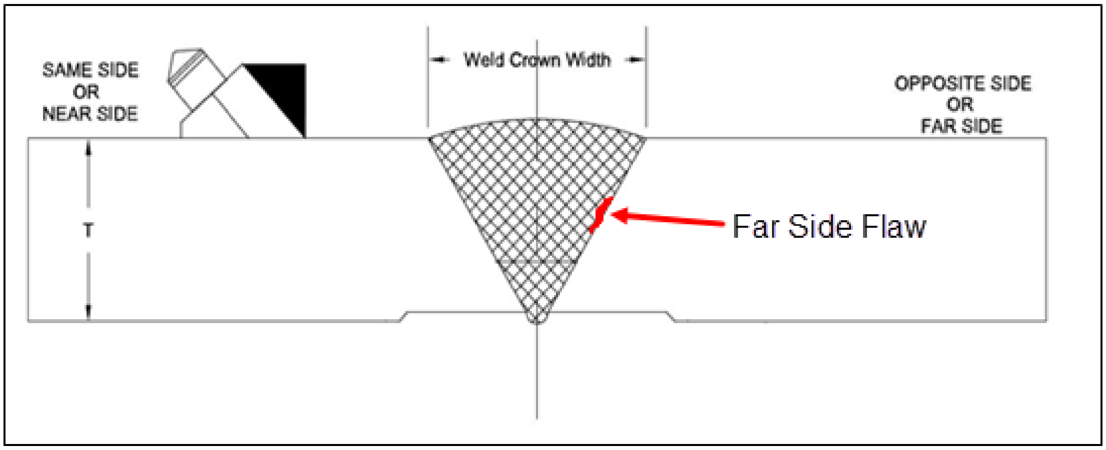


Figure 2-4
Illustration of a far-side flaw

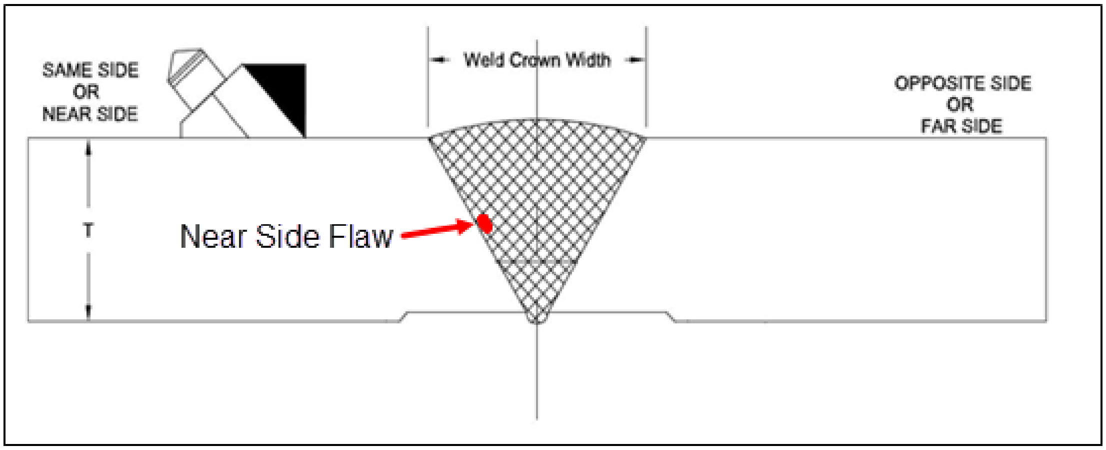


Figure 2-5
Illustration of a near-side flaw

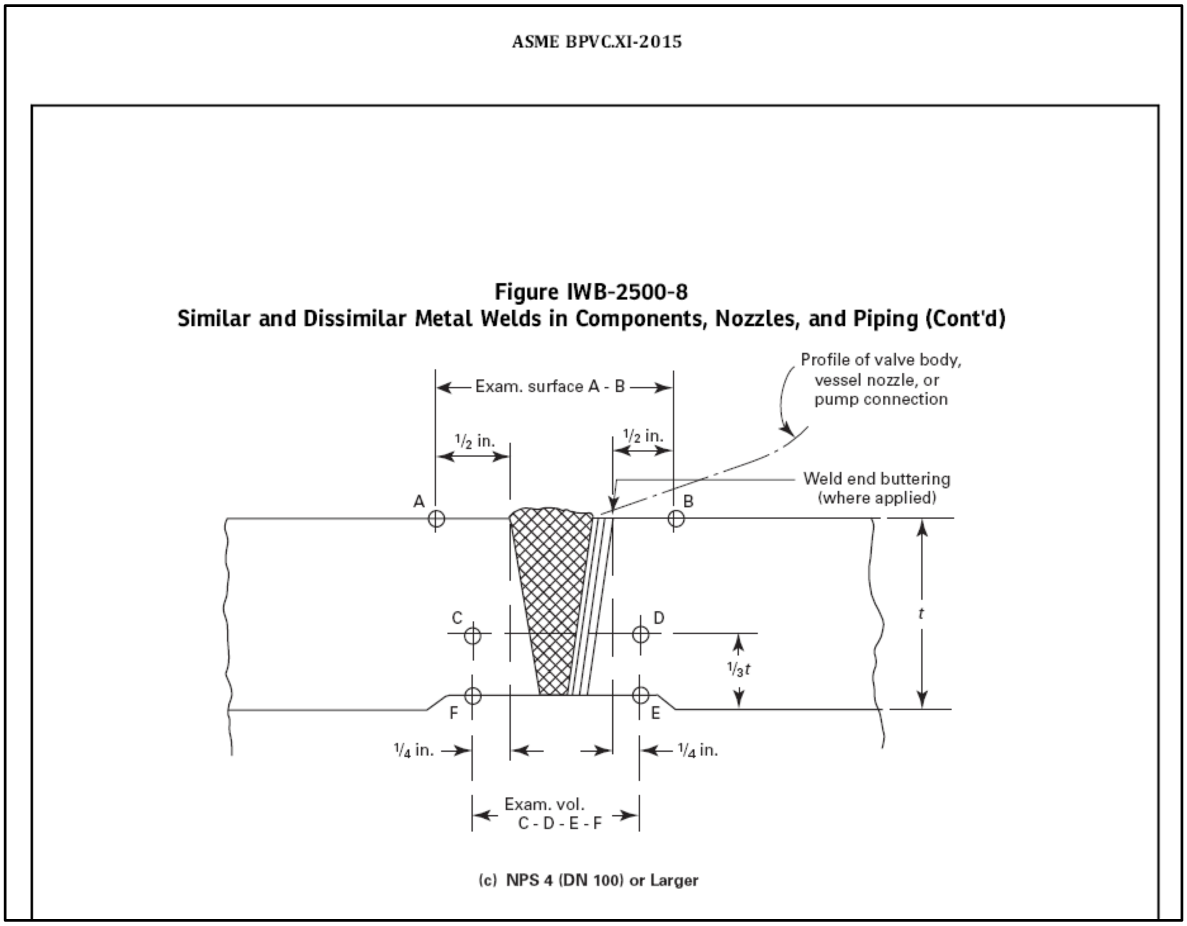
In total, 13 pipe specimens were fabricated containing approximately 40 flaws. Each specimen was scanned as a single-sided examination configuration so that the total population of flaws could be considered to be a total of approximately 80 flaws.

3

ULTRASONIC TESTING TECHNIQUES

The UT techniques for the examination of the specimens for this project were chosen using the ASME Section XI, Appendix VIII, Performance Demonstration Initiative (PDI) generic procedures PDI-UT-2 and PDI-UT-3 for general guidance. The demonstrated procedures have a long history of proven performance and are accepted throughout most of the nuclear industry. These procedures use manual, conventional UT techniques. They were adapted for use with an encoded, automated UT system. Conventional UT was chosen over phased array UT because conventional UT is considered more conservative than the technologically advanced phased array UT.

Due to the nature of the examination volume for new, repaired, or replaced welds, certain modifications to the generic procedures were necessary. For example, the PDI demonstrated procedures are focused on the ASME Section XI, ISI examination volume of interest, which is the lower one-third thickness of the weld plus some of the adjacent base material. The volume is depicted in Figure 3-1.



ASME BPVC.XI-2015

Figure IWB-2500-8
Similar and Dissimilar Metal Welds in Components, Nozzles, and Piping (Cont'd)

(c) NPS 4 (DN 100) or Larger

Figure 3-1
Examination volume for preservice and in-service inspection volumetric examinations (volume C-D-E-F)

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To meet the requirements of construction codes or owner's requirements, the entire weld volume must be examined. To do this, the scanning surface must be unobstructed to allow UT scanning over the weld and adjacent areas. This also enhances the UT capability of detecting flaws using angle beams "as well as allowing zero-degree data to be collected for assisting flaw characterization" [8].

Removing weld crowns and having an unobstructed scanning surface also allows for the UT examinations to be performed using the first leg of the sound beam (that is, the sound beam does not have to bounce to obtain full examination coverage). However, if there is a need to use the second leg of the sound beam for coverage, having an unobstructed scanning surface enhances the ability to perform a full-vee examination.

Due to concerns about coarse grain structures of austenitic stainless steel welds, the UT techniques for examination of the specimens included refracted longitudinal examinations in addition to shear wave examinations. The team followed the guidance of procedure PDI-UT-2 regarding the use of refracted longitudinal search units, which states the following [5]:

> 6.8.2 d) When any portion of the examination accessibility is limited to a single side in material greater than 0.50″ (inches) thick (nominal wall thickness), a longitudinal search unit that provides adequate coverage on the far side of the weld shall be used in addition to the techniques defined in 6.7.1 for the detection and length sizing of flaws on the far side of the weld.

Note: Although all the specimens are straight pipes without weld crowns, each specimen was examined as though only single-side access was available. Therefore, the examination of each specimen required multiple scans from each side of the weld (that is, scans from the downstream side only and scans from the upstream side only).

For clarity, paragraph 6.7.1 is also reproduced here:

> 6.7.1 The examination angle shall be the lowest angle that provides coverage of the required examination volume from each side of the weld.
>
> a) The primary search unit shall have a nominal angle of 45°.
>
> b) A nominal 60° search unit shall be used in addition to the 45° for examination when geometric conditions prohibit full coverage with the 45° search unit.
>
> c) A nominal 70° search unit shall be used in addition to the 60° for examination when geometric conditions prohibit full coverage with the 45°and 60° search units.
>
> **Note: The higher angle(s) described above need only be used to examine the volume not covered by the lower angles.**

Generally, the examination volume to meet construction codes and owners’ requirements is the full weld volume. Therefore, the time-base ranges for the shear wave examination techniques were lengthened to encompass the full weld volumes using a full-vee technique.

Another consideration for the choices of UT techniques was the dendritic structure of the austenitic stainless steel welds. A combination of shear and longitudinal wave modes are prudent when examining the entire thickness of these welds. To perform these examinations effectively, it is necessary to have flat, unobstructed scanning surfaces.

Note: For the purposes of this report, the terms *flat* and *flush* are synonymous. A *flush* surface condition is defined as a weld with the weld crown removed so that the adjoining base materials and weld lie on the same plane [4].

Due to concerns about coarse grain structures of austenitic stainless steel welds, the UT techniques for examination of the specimens included refracted longitudinal examinations in addition to shear wave examinations. The team followed the guidance of procedure PDI-UT-2 regarding the use of refracted longitudinal search units, which states the following [5]:

> 6.8.2 d) When any portion of the examination accessibility is limited to a single side in material greater than 0.50″ (inches) thick (nominal wall thickness), a longitudinal search unit that provides adequate coverage on the far side of the weld shall be used in addition to the techniques defined in 6.7.1 for the detection and length sizing of flaws on the far side of the weld.

Note: Although all the specimens are straight pipes without weld crowns, each specimen was examined as though only single-side access was available. Therefore, the examination of each specimen required multiple scans from each side of the weld (that is, scans from the downstream side only and scans from the upstream side only).

For clarity, paragraph 6.7.1 is also reproduced here:

> 6.7.1 The examination angle shall be the lowest angle that provides coverage of the required examination volume from each side of the weld.
>
> a) The primary search unit shall have a nominal angle of 45°.
>
> b) A nominal 60° search unit shall be used in addition to the 45° for examination when geometric conditions prohibit full coverage with the 45° search unit.
>
> c) A nominal 70° search unit shall be used in addition to the 60° for examination when geometric conditions prohibit full coverage with the 45°and 60° search units.
>
> **Note: The higher angle(s) described above need only be used to examine the volume not covered by the lower angles.**

Generally, the examination volume to meet construction codes and owners' requirements is the full weld volume. Therefore, the time-base ranges for the shear wave examination techniques were lengthened to encompass the full weld volumes using a full-vee technique.

Another consideration for the choices of UT techniques was the dendritic structure of the austenitic stainless steel welds. A combination of shear and longitudinal wave modes are prudent when examining the entire thickness of these welds. To perform these examinations effectively, it is necessary to have flat, unobstructed scanning surfaces.

Note: For the purposes of this report, the terms *flat* and *flush* are synonymous. A *flush* surface condition is defined as a weld with the weld crown removed so that the adjoining base materials and weld lie on the same plane [4].

In addition, the UT techniques were required to address the most likely examination configuration—a single-sided, limited scanning situation. It is anticipated that new or replaced welds in stainless steel piping systems in operating plants will result in a pipe-to-component configuration. This is an example of a single-sided, limited scanning situation. To effectively ensure a high-quality examination of the far side of an austenitic stainless steel weld with nominal thickness greater than approximately 0.5 in., refracted longitudinal wave mode examinations are required by such demonstrated procedures as PDI-UT-2. Figures 3-2 and 3-3 illustrate half-vee and full-vee sound paths needed for single-sided examinations.

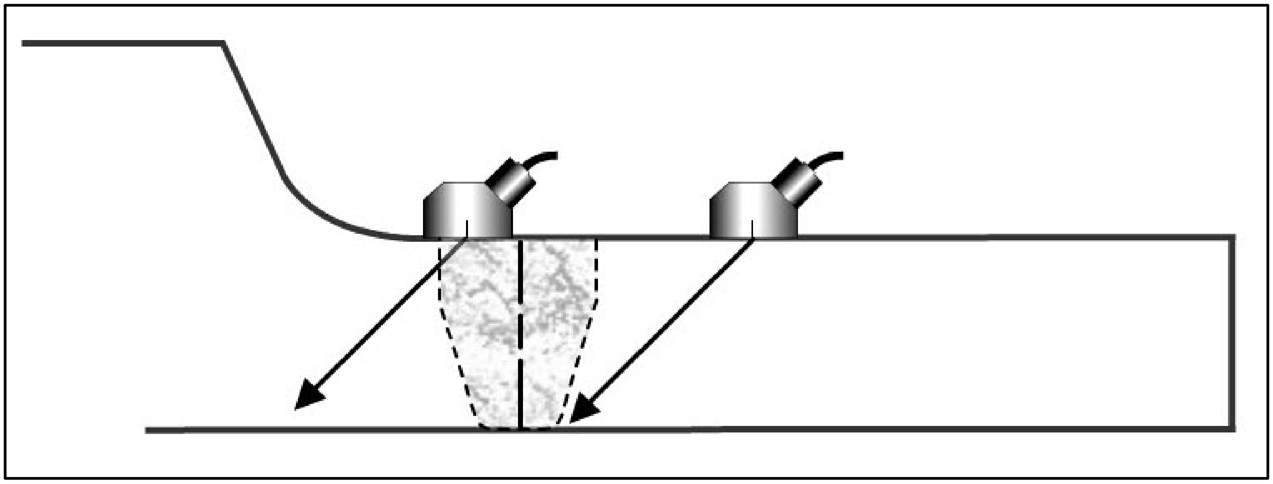

Figure 3-2
Half-vee sound path

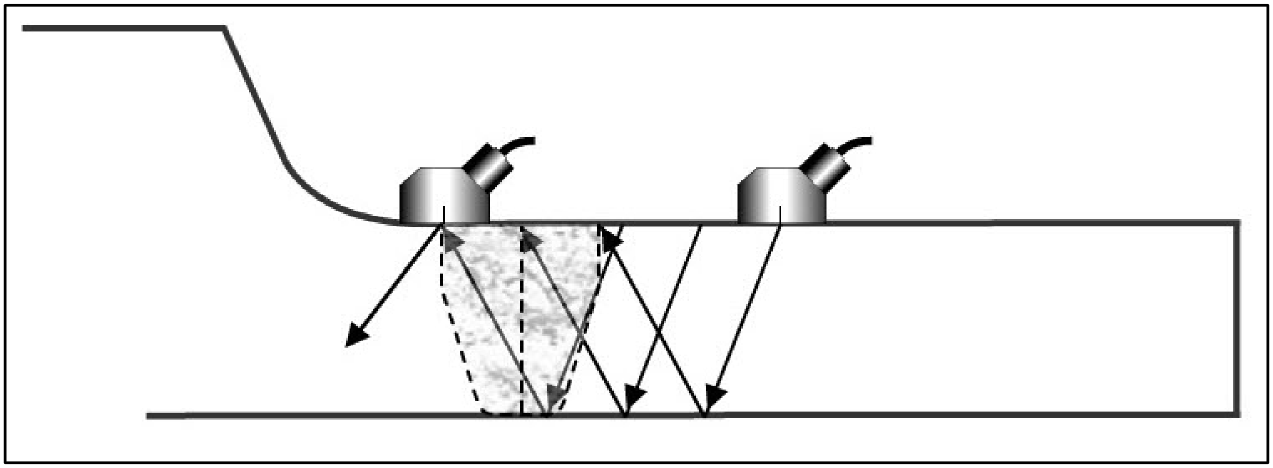

Figure 3-3
Full-vee sound path

Finally, encoded UT was chosen over non-encoded UT for better data and information retention and the ability to analyze data off-line. Encoded UT is a preferred method for reasons such as repeatability of examinations, better imaging, and presentation of examination results. Table 3-1 summarizes the examinations performed on each of the specimens based on diameter and thickness.

Table 3-1
Conventional search units' angles, frequencies, and wave modes used for scanning specimens

Nominal Pipe Size (in.)	Nominal Thickness (in.)	Examination Angle (°)	Examination Frequency (MHz)	Wave Mode
4	0.237	0	2.0 and 4.0	Longitudinal
4	0.237	45, 60, and 70	2.25 and 5.0	Shear
4	0.486	0	2.0 and 4.0	Longitudinal
4	0.486	45, 60, and 70	2.25 and 5.0	Shear
6	0.651	0	2.0 and 4.0	Longitudinal
6	0.651	45, 60, and 70	2.0	Longitudinal
6	0.651	45, 60, and 70	2.25	Shear
8	0.814	0	2.0 and 4.0	Longitudinal
8	0.814	45, 60, and 70	2.0	Longitudinal
8	0.814	45, 60, and 70	2.25	Shear
12	1.169	0	2.0 and 4.0	Longitudinal
12	1.169	45, 60, and 70	2.0	Longitudinal
12	1.169	45, 60, and 70	2.25	Shear
24	2.343	0	2.0 and 4.0	Longitudinal
24	2.343	45 and 60	1.5	Longitudinal
24	2.343	70	2.0	Longitudinal
24	2.343	45, 60, and 70	2.25	Shear

With regard to the focusing of the refracted longitudinal search units, consideration must be given to the examination volume of interest—namely, the entire volume of the weld. Therefore, these refracted longitudinal search units will need to be focused at different depths or half paths. A method of doing this is to target three different zones, as depicted in Figure 2-3, or near OD (outer one-third of the nominal pipe wall thickness), middle (middle one-third of the nominal pipe wall thickness), and near ID (inner one-third of the nominal pipe wall thickness). This methodology should be effective for both detection and sizing examinations and generally follows the guidance of PDI-UT-3, which states the following:

> 6.7.2 Search units should be focused within 25 percent of the qualitatively estimated flaw tip depth.

Although this statement is specifically targeted at through-wall sizing of ID-connected cracks, it is also effective for performing detection scans on welds in which the entire volume of the weld is the volume of interest (coverage).

For calibrations, the first step was to establish a linear screen time base. Because all the specimens were considered to be limited to single-side access, and to allow for pipe manufacturer deviations from exactly nominal thicknesses, the time-base ranges used were established so that they did not exceed approximately three times the weld thicknesses.

After the time bases were established, the calibration type used for the UT fingerprinting of the specimens was true depth on side-drilled holes up to sample weld thickness in reference blocks such as those depicted in Figures 3-4 through 3-6.

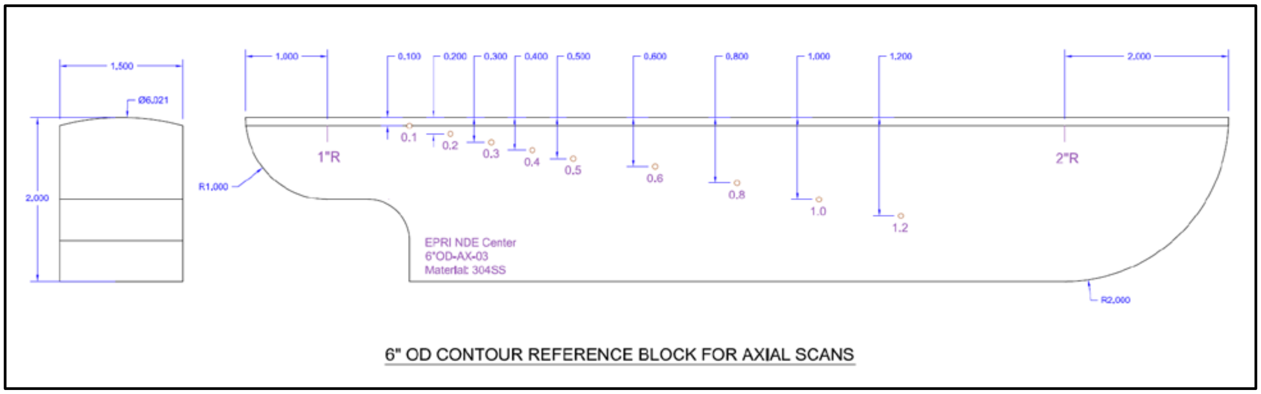

Figure 3-4
Stainless steel reference block, 6-in. outside diameter EPRI AX-03

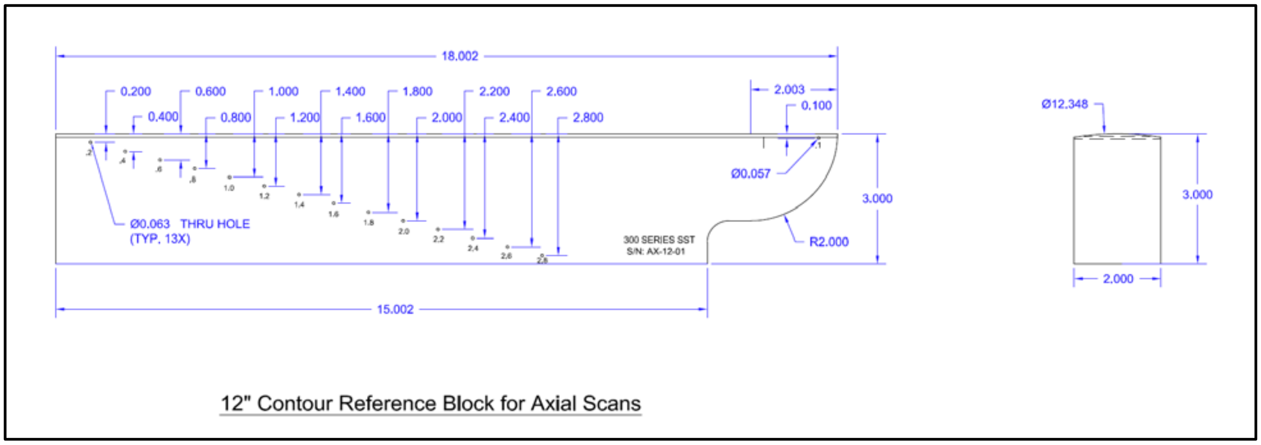

Figure 3-5
Stainless steel reference block, 12-in. outside diameter EPRI AX-01

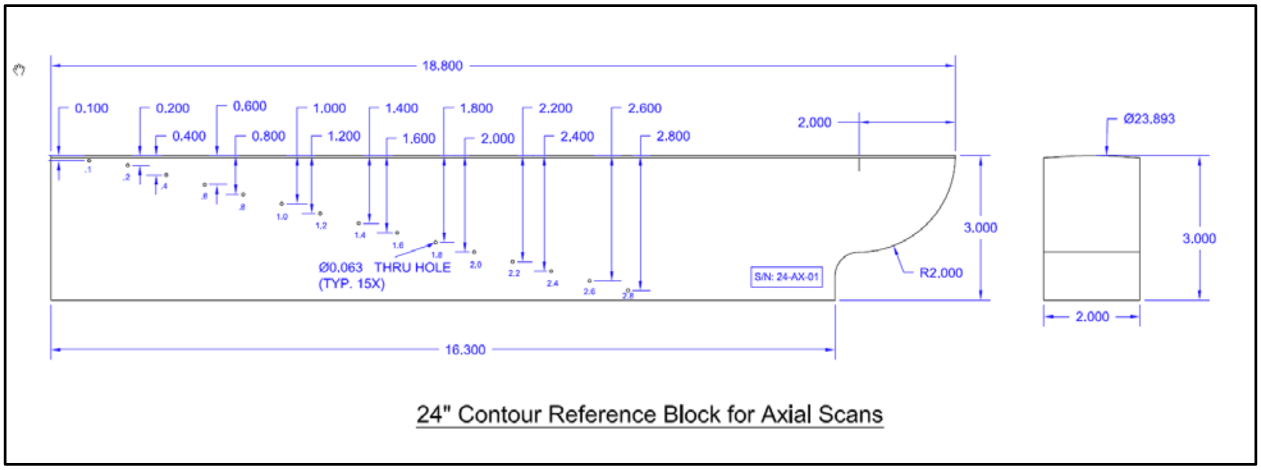

Figure 3-6
Stainless steel reference block, 24-in. outside diameter EPRI AX-01

Calibrations using refracted longitudinal search units should be performed at approximately the deepest part of the zones for which they will be used—namely, the following (see Figure 2-3):

- Near OD (outer one-third of the nominal pipe wall thickness)
- Middle (middle one-third of the nominal pipe wall thickness)
- Near ID (inner one-third of the nominal pipe wall thickness)

Other calibration requirements performed were as follows:

- Verification of search unit exit points and beam angle measurements
- Establishment of reference sensitivity using appropriate side-drilled holes
- Periodic calibration verifications, as needed

3.1 Description of Ultrasonic Test Equipment

The encoded UT system used for data collection included a fully automated scanning system using a Zetec DynaRay Lite UT instrument and an R/D Tech MCDU-02 motor control drive unit. The software used for the encoded examinations was UltraVision 3.2. The UT search units used are listed in Table 3-2.

Table 3-2
Conventional search units used for scanning specimens

Manufacturer	Model	Frequency (MHz)	Mode	Size	Angle (°)	Focusing (mm)
GEIT	MSEK2	2	Long.	11/2 mm	0	N/A
GEIT	MSEK4	4	Long.	11/2 mm	0	N/A
GEIT	SC2486	5	Shear	0.25 in.	45, 60, 70	N/A
GEIT	SB1302	2.25	Shear	0.25 in.	45, 60, 70	N/A
GEIT	SI0516	2.25	Shear	0.375 in.	45, 60, 70	N/A
GEIT	SE1057	2.25	Shear	0.5 in.	45, 60, 70	N/A
RTD	TRL	2	Long.	2(10 × 18) mm	45, 60, 70	Half path, 30, 38, 33
RTD	TRL	2	Long.	2(10 × 18) mm	45, 60, 70	Half path, 32, 39, 30
RTD	TRL	1.5	Long.	2(15 × 25) mm	45, 60	Half path, 40, 40, 52
RTD	TRL	1.5	Long.	2(15 × 25) mm	45, 60	Half path, 65, 75, 90

Notes:

Calibration type: True depth using side-drilled holes in reference blocks up to the weld specimen thickness.

Reference blocks: 6-in. OD EPRI AX-03 (see Figure 3-4)
EPRI flat block NDEC-6
EPRI flat block NDEC-8
12-in. OD EPRI AX-01 (see Figure 3-5)
24-in. OD EPRI AX-01 (see Figure 3-6)

Cabling: 12-ft RG-174 with no intermediate connectors

Scan speeds Not to exceed 3 in. per second on either axis

Time bases: Not to exceed approximately three times the weld thickness

Scan pattern: Unidirectional raster

Data resolution: 0.040-in. data taking

Examination sensitivity: Hard gain setup to avoid saturation of signals with an additional 12 dB channel

3.2 Description of Ultrasonic Test Data Analysis

The analysis of the encoded UT data was performed using UltraVision software, version 3.2. The detection and length sizing of the flaws was performed using the standard techniques typically used when performing receipt inspections and UT fingerprinting of specimens fabricated for the EPRI PDI Program.

Through-wall sizing was performed using the absolute arrival time technique as described in the PDI generic procedure PDI-UT-3. Software gates in the UltraVision software were manipulated to enhance the flaw imaging for the through-wall sizing tasks as well as the detection and length sizing analysis.

UT fingerprinting is defined as the process used to validate that specimens fabricated are provided by the manufacturer as fit for purpose. This process involves performing nondestructive evaluation (NDE) on the specimens provided and comparing the NDE results to the as-built information provided by the manufacturer. EPRI follows internal procedures to perform the UT fingerprinting process, which allow for a comprehensive set of examinations to be performed. For most specimens, generic ultrasonic procedures exist to provide the baseline for the inspection parameters used in the fingerprinting process. In some cases, generic procedures do not exist; in these cases, industry best practices are used to inform the technique selection process.

The UT fingerprinting process does not limit the examination to these techniques and allows for supplementary techniques to be used to ensure that a comprehensive examination of the specimen and all intended and unintended defects can be fully characterized. The UT fingerprinting process is not used to determine specimen truth. The physical dimensions provided by the manufacturer from the as-built dimensions taken during fabrication are considered to be the specimen and flaw truth information. The UT fingerprinting process is undertaken to determine that a specimen is fit for purpose and that no conditions exist within the specimen that would be detrimental to the final purpose of the specimen, meaning that no unintended defects are present near intended flaws that would inhibit the detection or characterization of the intended flaws.

4

ULTRASONIC TESTING RESULTS

Using the PDI generic procedures (PDI-UT-2 and PDI-UT-3) for guidance, with certain modifications such as the focusing of refracted longitudinal search units, the UT fingerprinting processes were successful in detecting and sizing all the intended fabrication-type flaws within the austenitic stainless steel specimens. Some of the actual UT data are presented in this report to show the effectiveness of the UT techniques used and the confidence with which the flaws can be identified and characterized (see Appendix A). In addition, all flaws were length sized and through-wall sized within the acceptance criteria of Code Case N-831, and all the specimens fabricated for this project are considered fit for purpose.

The data resulting from the UT fingerprinting and the detection, length sizing, and through-wall sizing data analyses were summarized using the standard root mean square error calculations for both length sizing and through-wall sizing, as follows:

$$\mathrm{RMS} = \left[\frac{\sum_{i=1}^{n} \left(m_i - t_i\right)^2}{n} \right]^{1/2}$$

Where:

m_i is the measured flaw size

n is the number of flaws measured

t_i is the true flaw size

The results are presented in the following tables and were compiled in different ways to show not only the overall performance but also specific performances, as follows:

- All flaws, summary of length sizing and through-wall sizing results (Table 4-1)
- All flaws presented as far-side flaws (Table 4-2)
- All flaws presented as near-side flaws (Table 4-3)
- All flaws presented as far-side flaws in 6-in. diameter and smaller specimens (Table 4-4)
- All flaws presented as near-side flaws in 6-in. diameter and smaller specimens (Table 4-5)
- All flaws presented as far-side flaws in specimens greater than 6-in. diameter (Table 4-6)
- All flaws presented as near-side flaws in specimens greater than 6-in. diameter (Table 4-7)

Table 4-1
All flaws: summary of length sizing and through-wall sizing results

Category	Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
All flaws	0.422	0.032

Tables 4-2 through 4-7 present the conventional, encoded UT fingerprinting results compared to the as-built flaw dimensions. These results are grouped by specimen size and flaw locations.

Table 4-2
All flaws presented as far-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.274	0.050

Table 4-3
All flaws presented as near-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.340	0.048

Table 4-4
Flaws in 4-in. and 6-in. specimens presented as far-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.172	0.022

Table 4-5
Flaws in 4-in. and 6-in. specimens presented as near-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.130	0.038

Table 4-6
Flaws in 8-in. through 24-in. specimens presented as far-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.313	0.060

Table 4-7
Flaws in 8-in. through 24-in. specimens presented as near-side flaws

Overall Length Sizing RMS (in.)	Overall Through-Wall Sizing RMS (in.)
0.412	0.053

These results were compared to the acceptance criteria for length sizing and through-wall sizing currently in Code Case N-831 and were found to be acceptable (see Table 4-8). Code Case N-831 states the following:

> (i) To be qualified for flaw length sizing, the RMS error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.25 in. (6 mm) for NPS 6 (DN150) and smaller, and 0.75 in. (18 mm) for larger than NPS 6 (DN150).
>
> (ii) To be qualified for flaw through-wall height sizing, the RMS error of the flaw through-wall heights estimated by ultrasonics, as compared with the true through-wall heights, shall not exceed 0.125 in. (3 mm) [4].

Table 4-8
Acceptance criteria from ASME Section XI, Code Case N-831

Length Sizing RMS for NPS 6 and Smaller (in.)	Length Sizing RMS for Larger than NPS 6 (in.)	Through-Wall Sizing RMS (in.)
0.25	0.75	0.125

Appendix A provides a sample of results for some of the specimens. Not all the specimen data and information can be provided because the specimens remain secure and blind in accordance with the EPRI QA Program and the security and QA requirements of the PDI Demonstration and Fabrication Programs.

5

SUMMARY AND CONCLUSIONS

This report provides background and supporting data related to using UT in lieu of RT for new, repaired, or replaced welds in operating nuclear power plants' austenitic stainless steel piping systems as the volumetric examination for acceptance. Presently, when austenitic stainless steel piping welds are repaired or replaced, Section XI leads back to the construction codes or owner's requirements. In most cases, these codes and requirements call for the use of RT as the volumetric examination for acceptance.

There is sufficient basis to use UT for the volumetric examination during repairs or replacements along with a flaw evaluation process such as that found in ASME Section XI, IWB and IWC.

When performed during refueling and maintenance outages, RT can have real and potentially undesired effects such as the following:

- Downtime. Typically, RT requires the establishment of high-radiation area boundaries (that is, exclusion zones) that only the radiographers may enter. These exclusion zones must be secured against unauthorized entry and may require exclusion of all personnel other than radiographers from the entire reactor building, turbine building, and so on.
- Outage schedules. The exclusion zones can cause significant impact on outage schedules.
- Occupational doses. RT can increase the risk of personnel exposures to occupational dose from the RT sources, not only to the radiographers but also to plant and contractor personnel unrelated to the RT activities.
- Missed flaws. RT increases the likelihood of missing certain types of flaws, such as cracking.

Other advantages of using UT instead of RT (along with a flaw evaluation methodology) exist in addition to the economics of having to evacuate areas or buildings for one or two shifts while RT is performed. One example is having the opportunity to use Section XI type acceptance criteria to avoid unneeded repairs of benign flaws. In many cases, localized repairs such as these are more detrimental to the life of a weld than leaving small, acceptable size fabrication defects in place.

Another example for supporting UT instead of RT is the ability of UT to detect and size planar flaws on a three-dimensional basis. The use of UT provides the ability to find these types of flaws that would be highly detrimental to the service life of a weld.

Several Code Cases may be used as precedents supporting the use of UT in lieu of RT. Among them are the following:

- Code Case N-831, Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe Section XI, Division 1
- Code Case N-818, Use of NDE and Fracture Mechanics for Acceptance of Full Penetration Butt Welds in Lieu of Weld Repair, Class 1 and 2, Section III, Division 1
- Code Case N-659, Use of Ultrasonic Examination in Lieu of Radiography for Weld Examination Section III, Division 1; Section III, Division 3

In addition, other codes and standards outside the nuclear industry have already accepted the use of UT in lieu of RT, such as ASME/ANSI B31.1, Power Piping, and other parts of the ASME Code, such as Section I, Rules for Construction of Power Boilers, and Section VIII, Rules for Construction of Pressure Vessels.

Using the existing precedence along with the UT results of this technical basis provides sufficient bases to support a revised Code Case N-831-1, Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic and Austenitic Pipe Section XI, Division 1, that could allow the use of UT (particularly encoded UT) in lieu of RT.

6
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1. *Proceedings of the ASME 2001 Pressure Vessels and Piping Division Conference, PVP2011, July 17–21, 2011, Baltimore, Maryland, USA.* PVP2011-57675, Proposed ASME Section III Code Case—Reduction of NDE Weld Repairs.
2. *Technical Advanced Nuclear Technology: Reduction of American Society of Mechanical Engineers III Weld Fabrication Repairs—Fitness for Purpose*. EPRI, Palo Alto, CA: 2010. 1021181.
3. J. Spanner and K. Hacker, “Effectiveness of Substituting Ultrasonic Testing for Radiographic Testing for Repair/Replacement of Carbon Steel (N-831).” Technical Basis White Paper.
4. ASME Section XI, Code Case N-831, “Ultrasonic Examination in Lieu of Radiography for Welds in Ferritic Pipe Section XI, Division 1.”
5. Performance Demonstration Initiative, Procedure Number PDI-UT-2, latest revision: *Generic Procedure for the Ultrasonic Examination of Austenitic Pipe Welds.*
6. Performance Demonstration Initiative, Procedure Number PDI-UT-3, latest revision: *Generic Procedure for the Ultrasonic Through-Wall Sizing in Pipe Welds.*
7. Section XI, *ASME Boiler and Pressure Vessel Code Rules for Inservice Inspection of Nuclear Power Plant Components,* American Society of Mechanical Engineers, 2015 Edition.
8. T. L. Moran, M. Prowant, C. A. Nove, A. F. Pardini, S. L. Crawford, A. D. Cinson, and M. T. Anderson (2015). *Applying Ultrasonic Testing in Lieu of Radiography for Volumetric Examination of Carbon Steel Piping.* NUREG/CR-7204; PNNL-24232.
9. T. L. Moran, P. Ramuhalli, A. F. Pardini, M. T. Anderson, and S. R. Doctor (2010). *Replacement of Radiography with Ultrasonics for the Nondestructive Inspection of Welds – Evaluation of Technical Gaps – An Interim Report.* PNNL-19086.

A

RESULTS OF ULTRASONIC TESTING FINGERPRINTING

This appendix presents comparisons of weld indication information—such as flaw characteristics, sizes, and locations—between as-built and UT examination data for some of the specimens that were fabricated for this project. Not all the specimen data and information can be provided because the specimens remain secure and blind in accordance with the EPRI QA Program and the security and QA requirements of the PDI Demonstration and Fabrication Programs.

Table A-1
A 4-in. diameter specimen

	Flaw Number	Flaw Type	Flaw Location	Start, X1 (Degree)	Stop, X2 (Degree)	Length (Inch)	Z1 (Inch)	Z2 (Inch)	Through Wall Extent, H (Inch)
As-built	1	Slag	Sub-surface	296.3	343.5	1.833	0.097	0.147	0.050
70°S 2.25MHz LKDN	1	Volumetric	Sub-surface	306.0	343.0	1.438	0.101	0.134	0.033

Flaw A-1-1

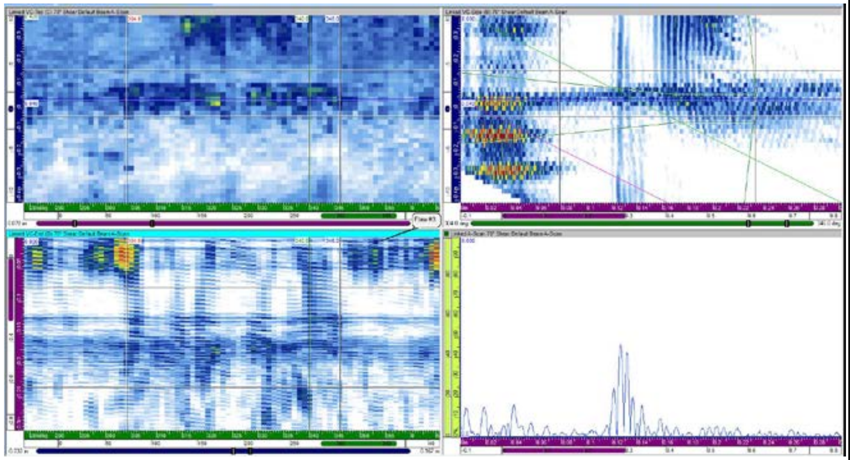
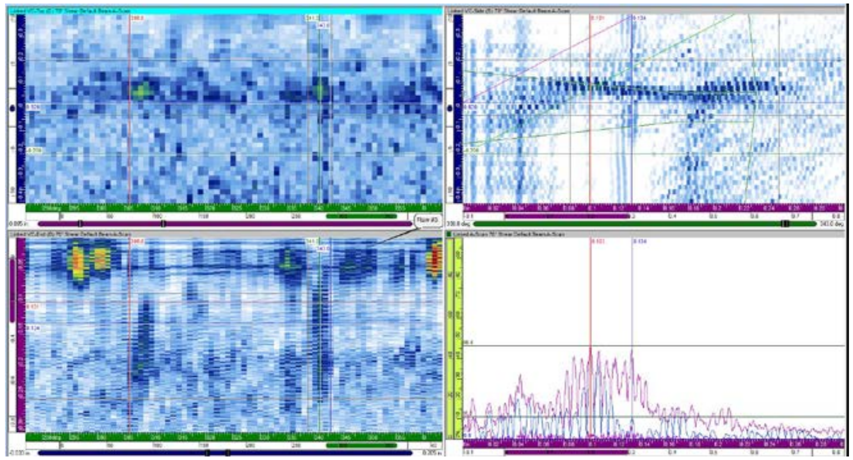
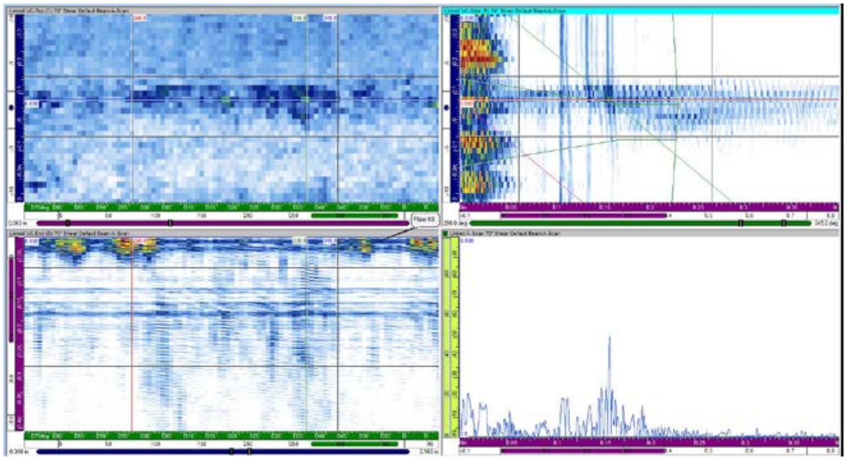
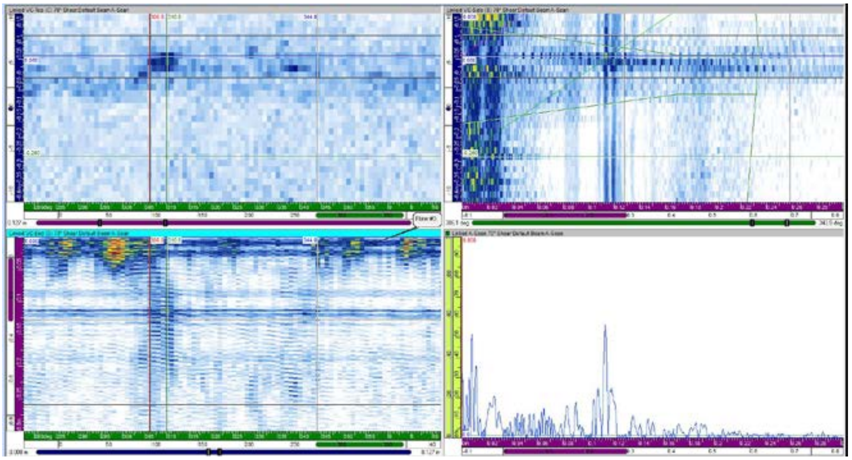
LKUP - 2.25MHz Probe - 70° Shear Wave	LKDN - 2.25MHz Probe - 70° Shear Wave
	
LKUP - 5.0MHz Probe - 70° Shear Wave	LKDN - 5.0MHz Probe - 70° Shear Wave
	

Figure A-1
A 4-in. diameter specimen—flaw A-1-1: angle beam data

Flaw A-1-1

4MHz - 0°Longitudinal Wave

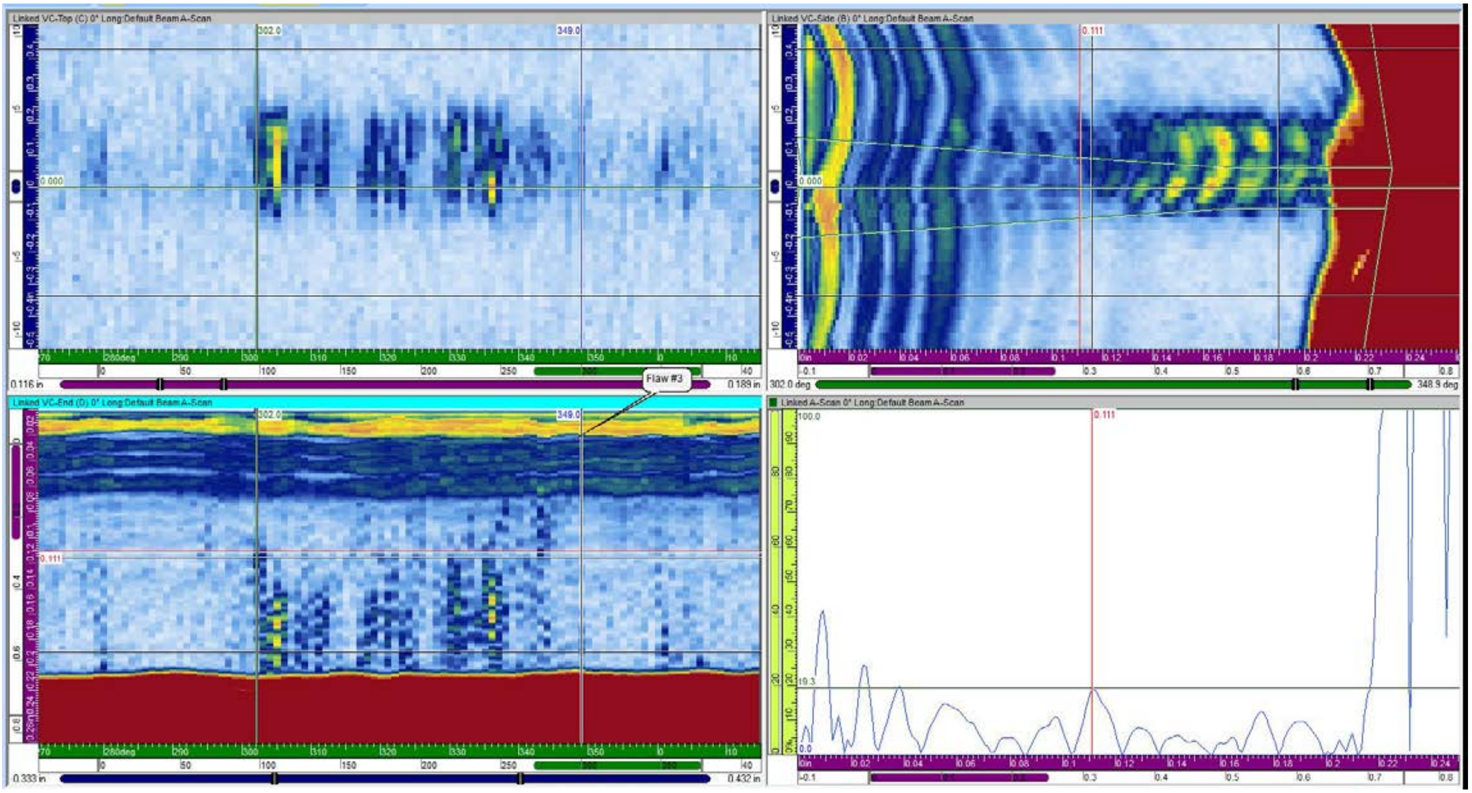


Figure A-2
A 4-in. diameter specimen—flaw A-1-1: 0° beam data

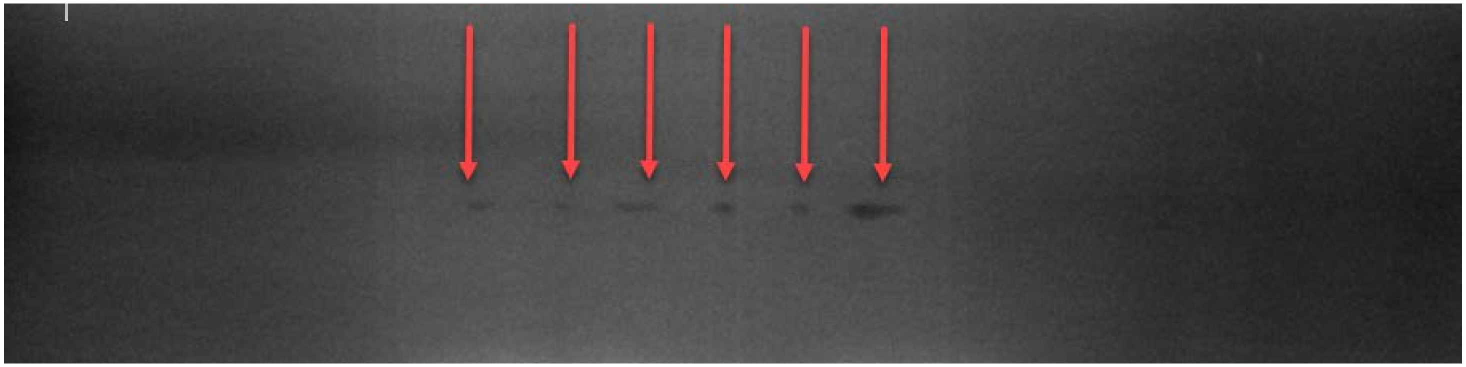


Figure A-3
A 4-in. diameter specimen—flaw A-1-1: radiography film (image contrast and brightness enhanced for presentation)

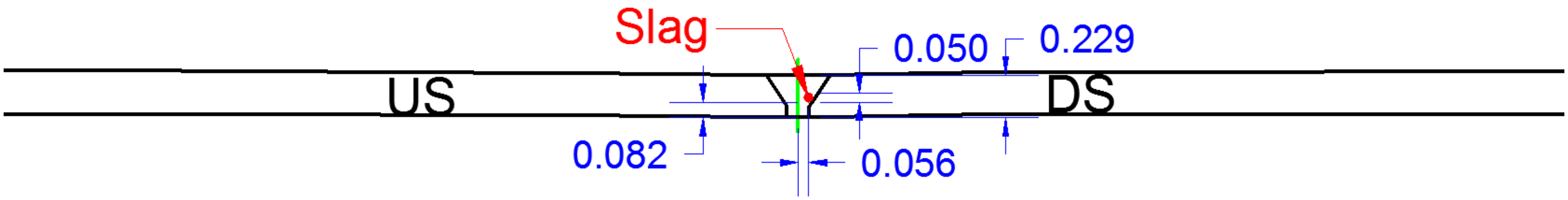


Figure A-4
A 4-in. diameter specimen—flaw A-1-1: computer-aided design drawing

Table A-2
A 6-in. diameter specimen

	6 Inch OD Specimen								
	Flaw Number	**Flaw Type**	**Flaw Location**	**Start, X1 (Degree)**	**Stop, X2 (Degree)**	**Length (Inch)**	**Z1 (Inch)**	**Z2 (Inch)**	**Through Wall Extent, H (Inch)**
As-built	1	Slag	Sub-surface	108.6	197.2	5.078	0.242	0.334	0.092
60°S 2.25MHz LKUP	1	Volumetric	Sub-surface	111.0	201.0	5.158	0.240	0.311	0.071
As-built	2	Interbead -LOF	Sub-surface	2.0	27.9	1.479	0.177	0.266	0.089
60°L 2.0MHz LKUP	2	Quasi -Laminar	Sub-surface	6.0	30.0	1.376	0.198	0.341	0.143

Flaw A-2-1

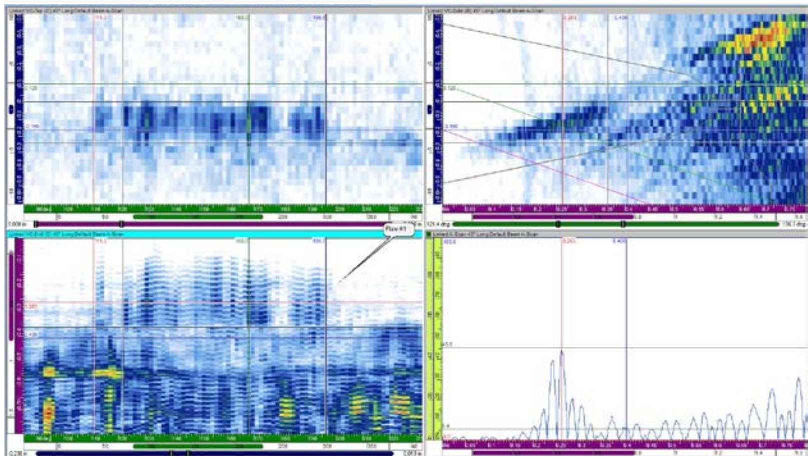
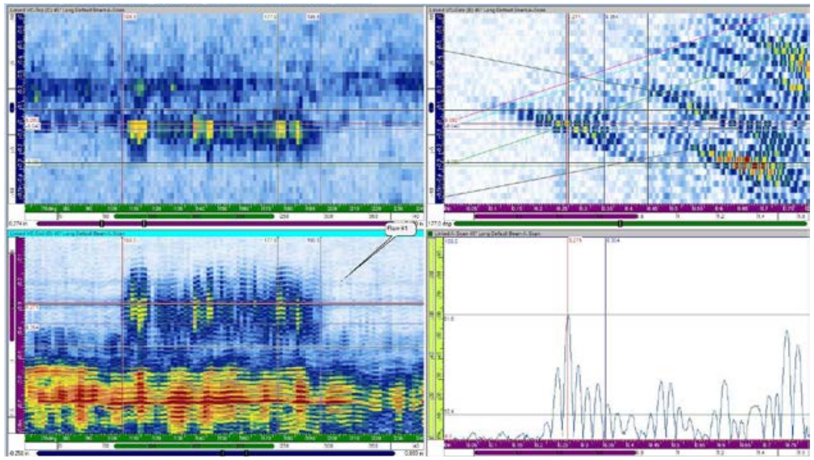
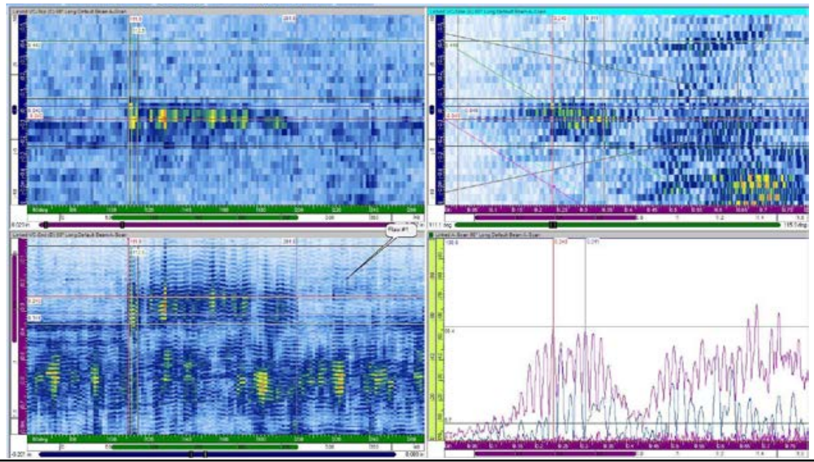
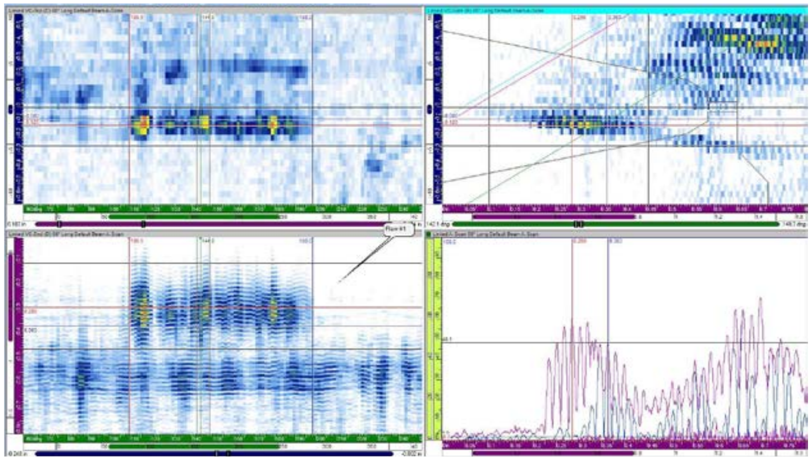
LKUP - 2.0MHz Probe - 45° Longitudinal Wave	LKDN - 2.0MHz Probe - 45° Longitudinal Wave
	
LKUP - 2.0MHz Probe - 60° Longitudinal Wave	LKDN - 2.0MHz Probe - 60° Longitudinal Wave
	

Figure A-5
A 6-in. diameter specimen—flaw A-2-1: angle beam data

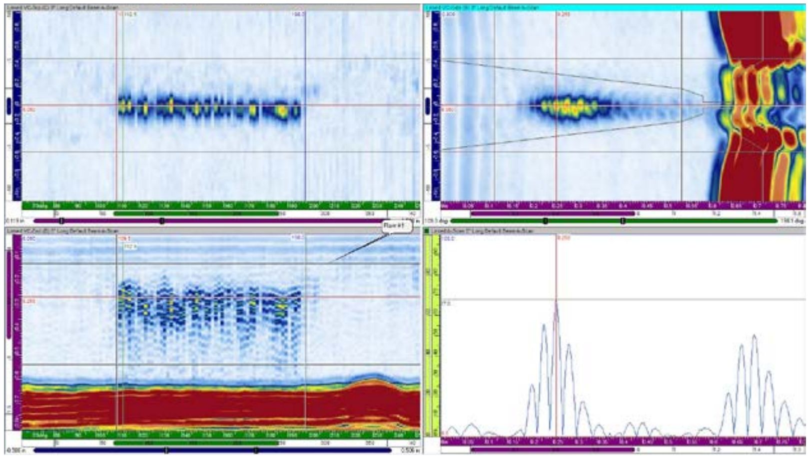
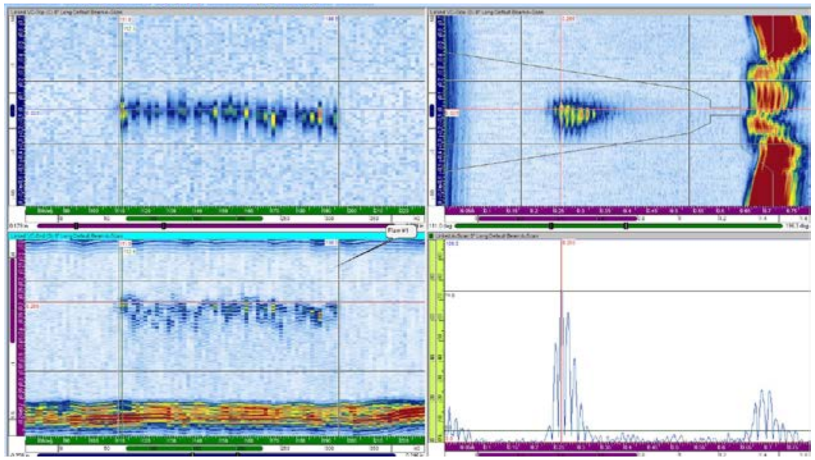
<table>
<tr><th colspan="2">Flaw A-2-1</th></tr>
<tr><td>2MHz - 0° Longitudinal Wave</td><td>4MHz - 0°Longitudinal Wave</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure A-6
A 6-in. diameter specimen—flaw A-2-1: 0° beam data

Figure A-7
A 6-in. diameter specimen—flaw A-2-1: radiography film (image contrast and brightness enhanced for presentation)

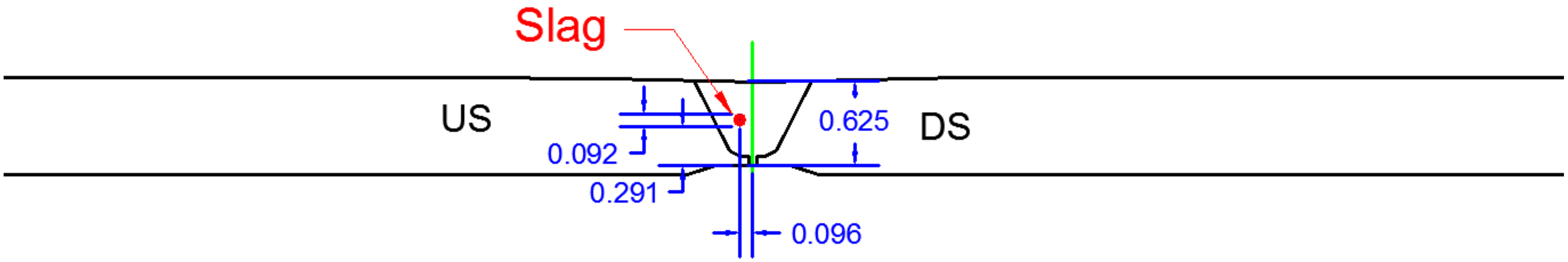


Figure A-8
A 6-in. diameter specimen—flaw A-2-1: computer-aided design drawing

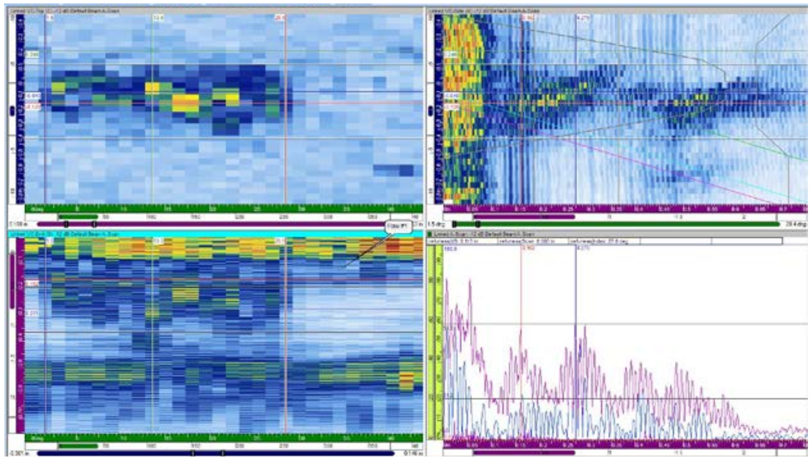
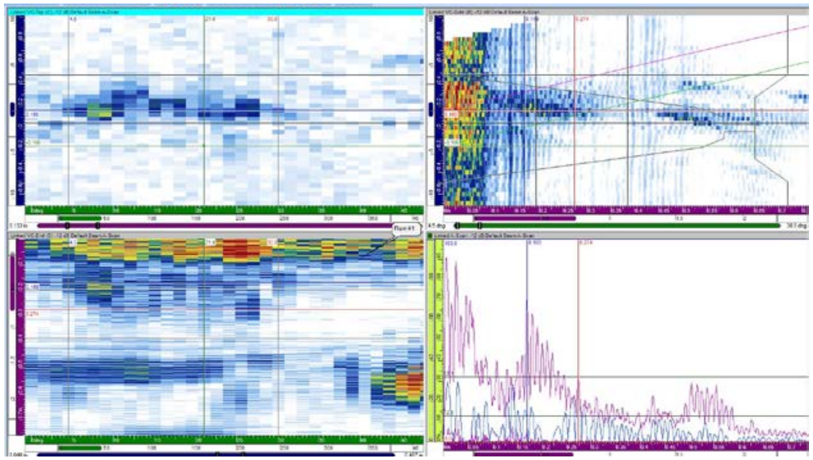
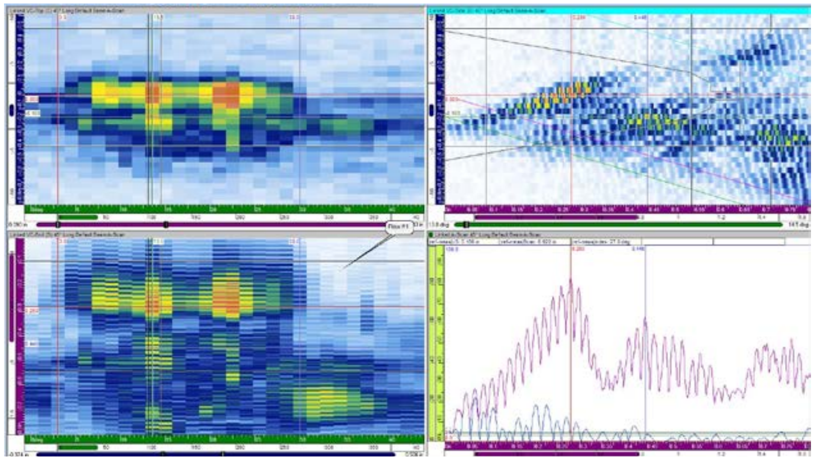
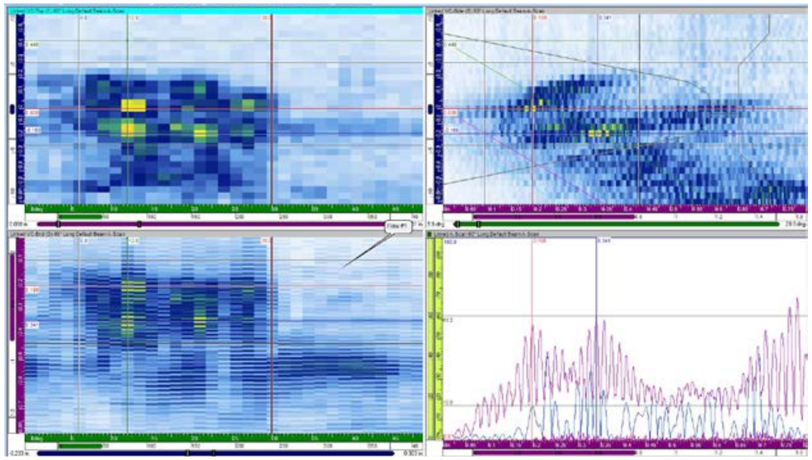
<table>
<tr><th colspan="2">Flaw A-2-2</th></tr>
<tr><td>LKUP - 2.25MHz Probe - 45° Shear Wave</td><td>LKDN - 2.25MHz Probe - 45° Shear Wave</td></tr>
<tr><td></td><td></td></tr>
<tr><td>LKUP - 2.0MHz Probe - 45° Longitudinal Wave</td><td>LKUP - 2.0MHz Probe - 60° Longitudinal Wave</td></tr>
<tr><td></td><td></td></tr>
</table>

Figure A-9
A 6-in. diameter specimen—flaw A-2-2: angle beam data

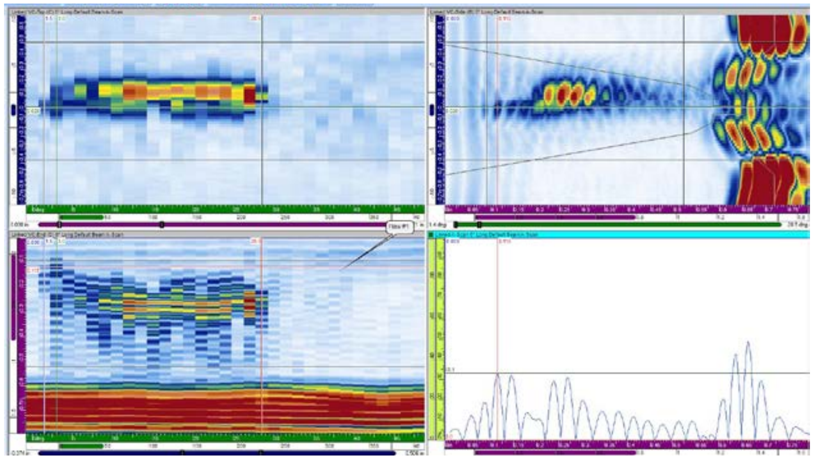
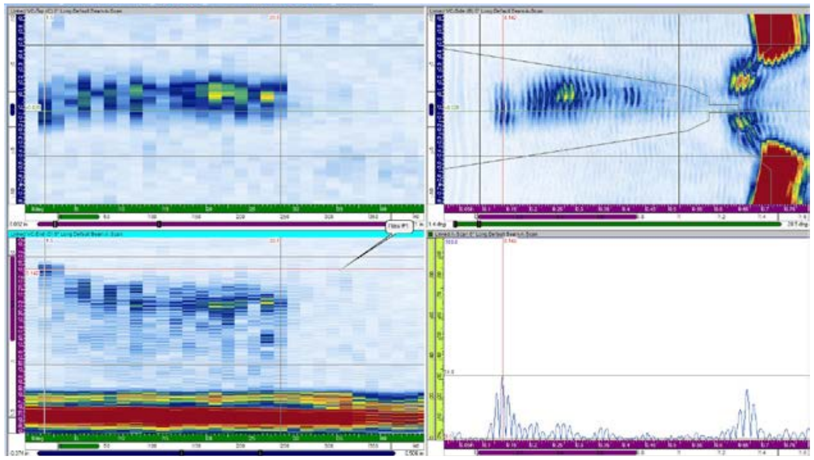
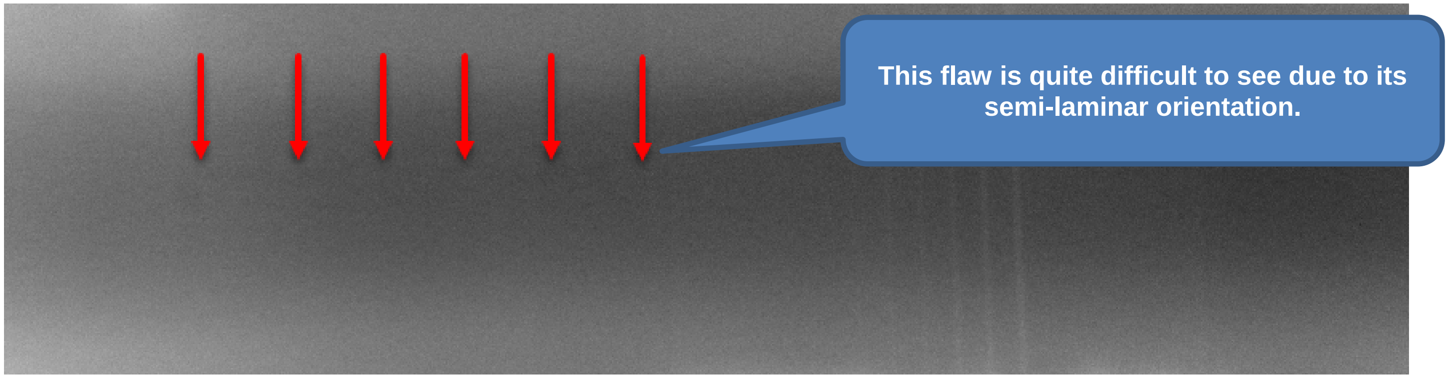
Flaw A-2-2	
2MHz - 0° Longitudinal Wave	4MHz - 0°Longitudinal Wave
	

Figure A-10
A 6-in. diameter specimen—flaw A-2-2: 0° beam data



This flaw is quite difficult to see due to its semi-laminar orientation.

Figure A-11
A 6-in. diameter specimen—flaw A-2-2: radiography film (image contrast and brightness enhanced for presentation)

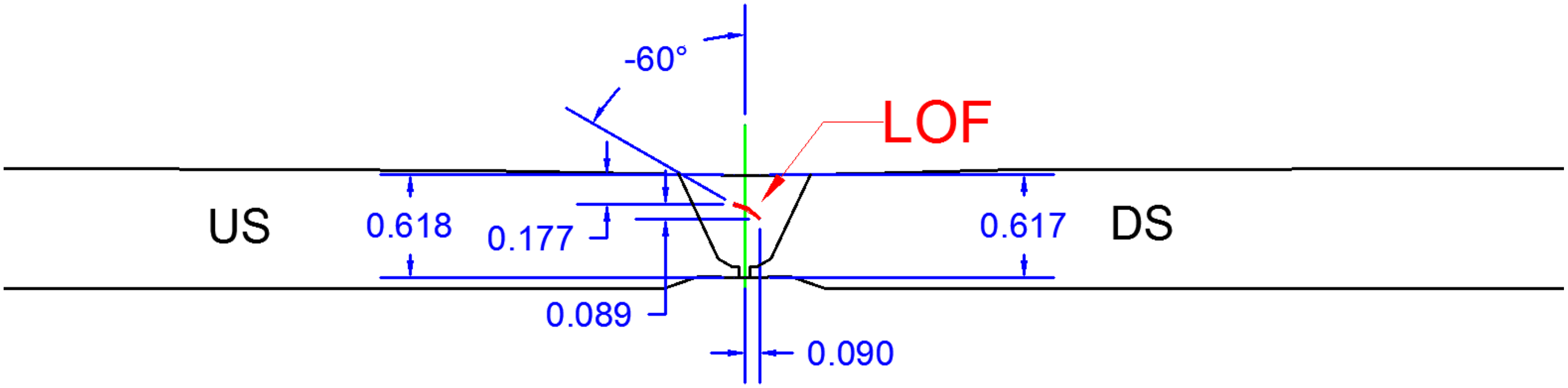


Figure A-12
A 6-in. diameter specimen—flaw A-2-2: computer-aided design drawing

Table A-3
An 8-in. diameter specimen

	8 Inch OD Specimen								
	Flaw Number	**Flaw Type**	**Flaw Location**	**Start, X1 (Degree)**	**Stop, X2 (Degree)**	**Length (Inch)**	**Z1 (Inch)**	**Z2 (Inch)**	**Through Wall Extent, H (Inch)**
As-built	1	SWLOF	Sub-surface	196.5	221.5	1.848	0.192	0.455	0.263
70°L 2.0 MHz LKUP	1	Planar	Sub-surface	196.3	221.3	1.863	0.188	0.414	0.226

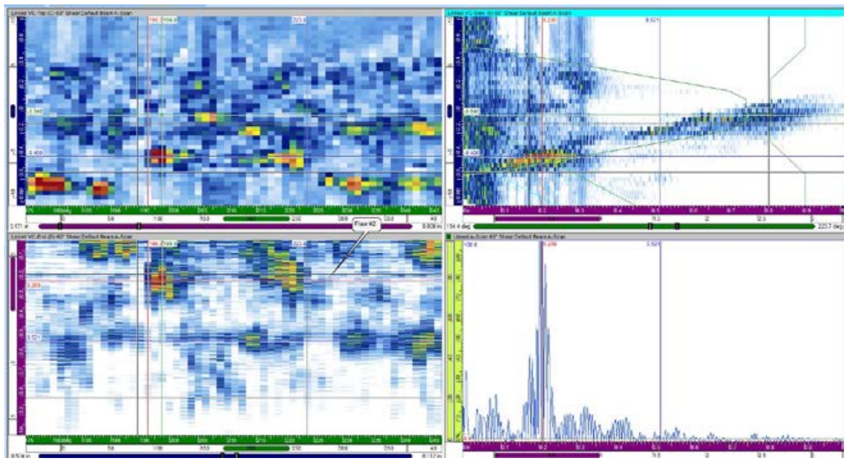
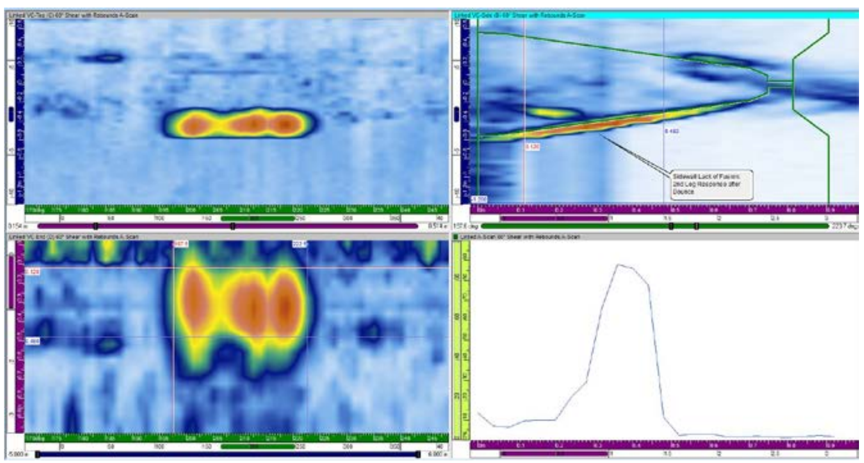
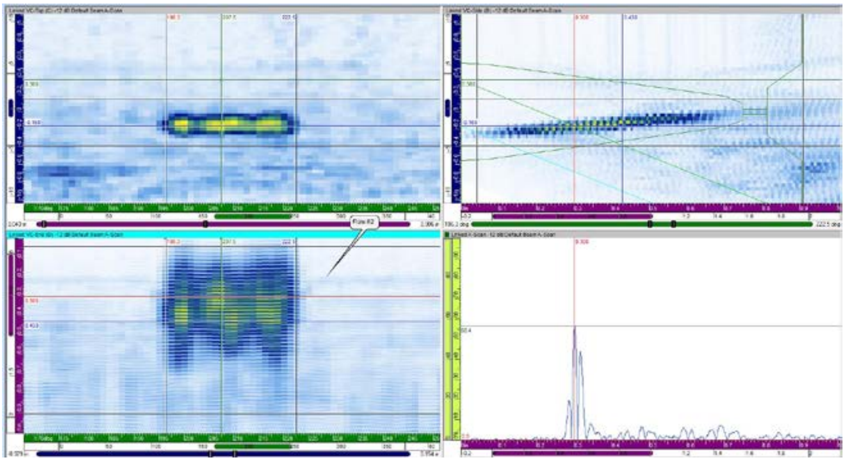
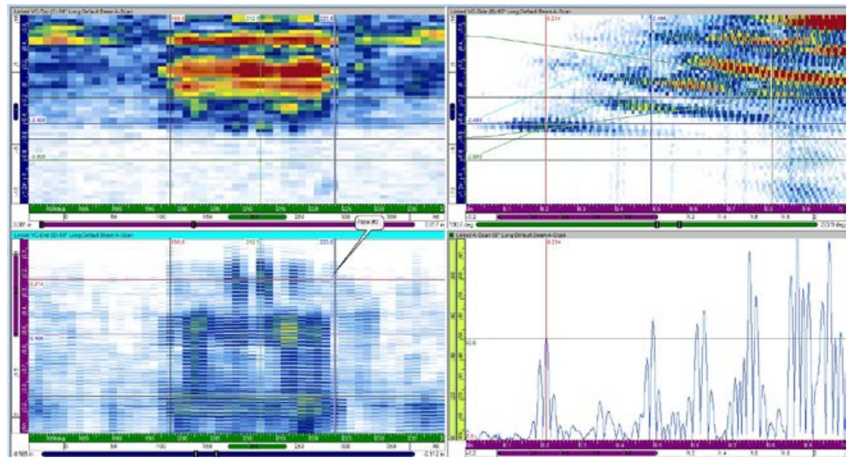
<table>
<tr><th colspan="2">Flaw A-3-1</th></tr>
<tr><td>LKUP - 2.25MHz Probe - 60° Shear Wave</td><td>LKDN - 2.25MHz Probe - 60° Shear Wave - 2nd Leg Response after Rebound</td></tr>
<tr><td> </td><td> </td></tr>
<tr><td>LKUP - 2.0MHz Probe - 60° Longitudinal Wave</td><td>LKDN - 2.0MHz Probe - 60° Longitudinal Wave</td></tr>
<tr><td> </td><td> </td></tr>
</table>

Figure A-13
An 8-in. diameter specimen—flaw A-3-1: angle beam data

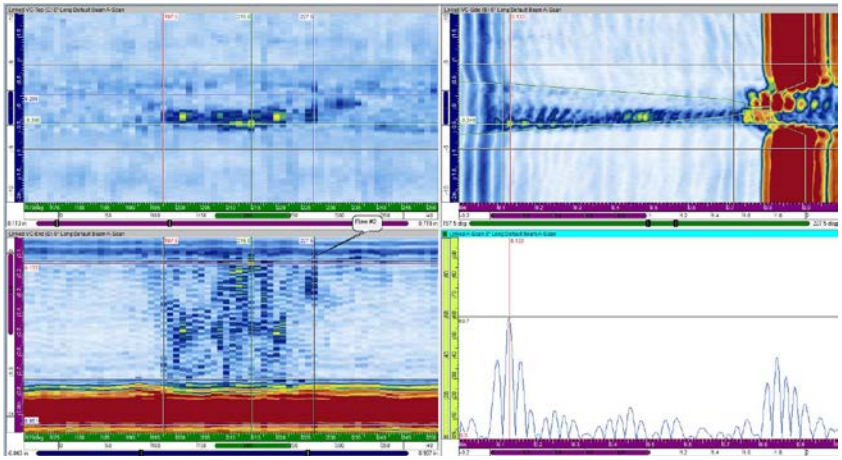
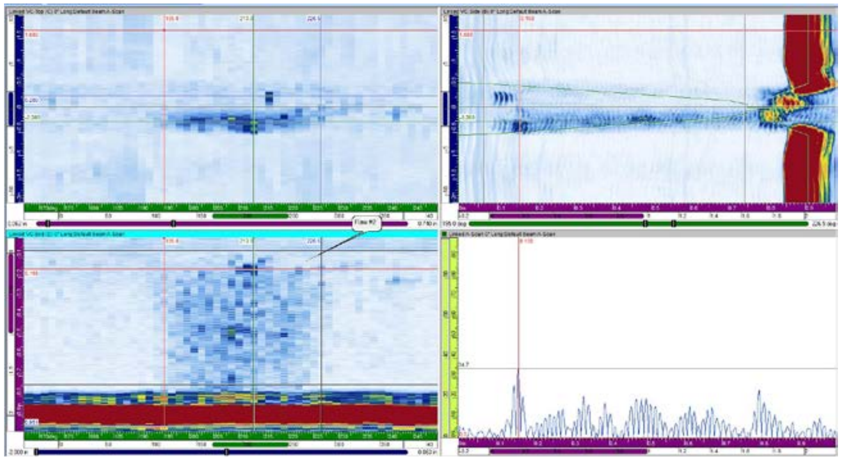
Flaw A-3-1	
2MHz - 0° Longitudinal Wave	4MHz - 0°Longitudinal Wave
	

Figure A-14
An 8-in. diameter specimen—flaw A-3-1: 0° beam data

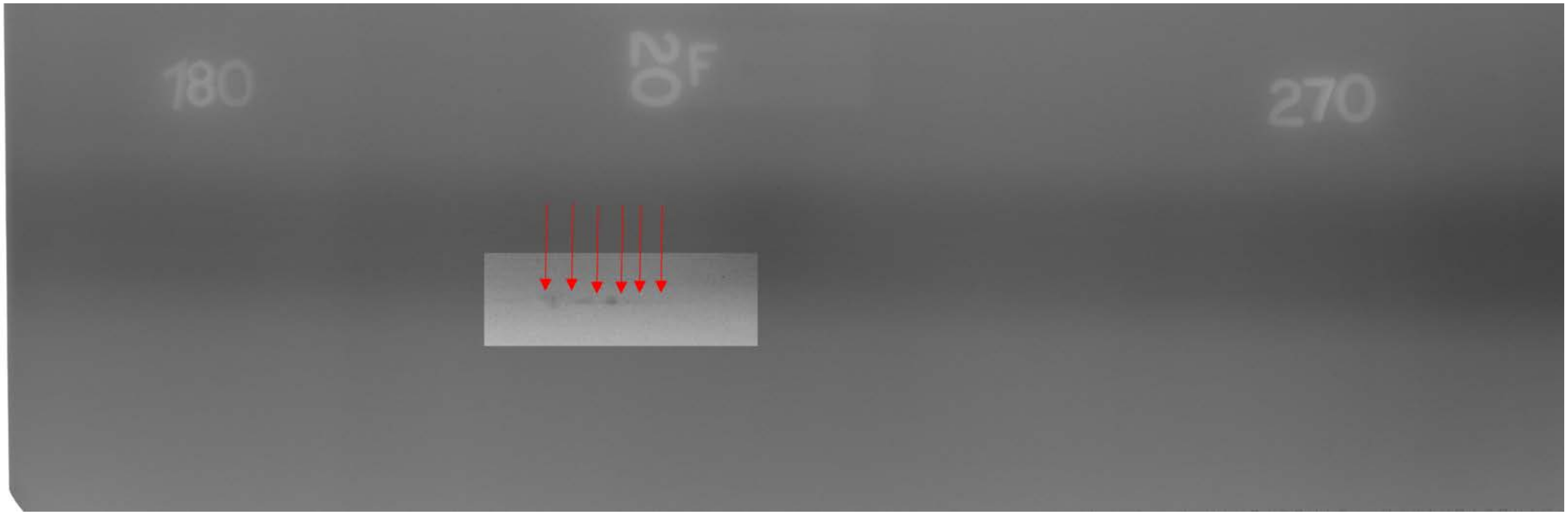


Figure A-15
An 8-in. diameter specimen—flaw A-3-1: radiography film (image contrast and brightness enhanced for presentation)

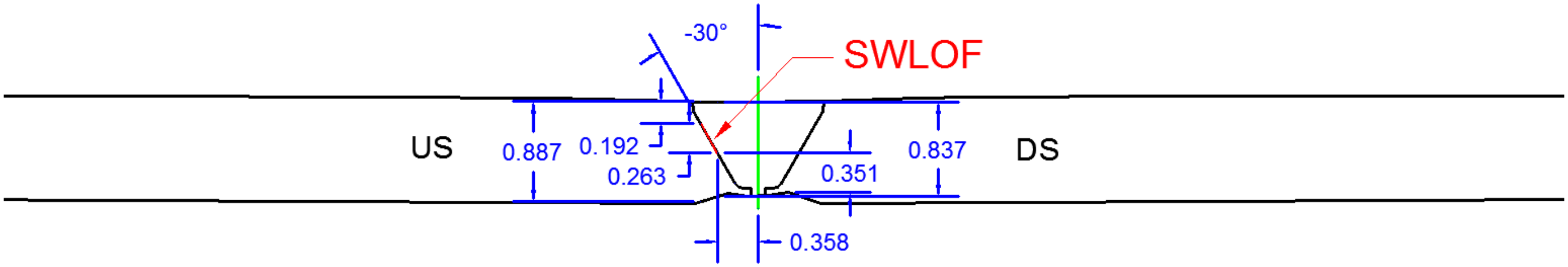


Figure A-16
An 8-in. diameter specimen—flaw A-3-1: computer-aided design drawing

Table A-4
A 12-in. diameter specimen

	12 Inch OD Specimen								
	Flaw Number	**Flaw Type**	**Flaw Location**	**Start, X1 (Degree)**	**Stop, X2 (Degree)**	**Length (Inch)**	**Z1 (Inch)**	**Z2 (Inch)**	**Through Wall Extent, H (Inch)**
As-built	1	SWLOF	Sub-surface	11.2	24.9	1.506	0.175	0.457	0.282
70°L 1.5MHz LKUP	1	Planar	Sub-surface	9.9	26.1	1.780	0.138	0.437	0.299
As-built	2	Cluster Porosity	Sub-surface	248.2	259.9	1.283	0.174	0.280	0.106
45°L 1.5MHz LKDN	2	Volumetric	Sub-surface	244.8	260.0	1.671	0.774	0.890	0.116

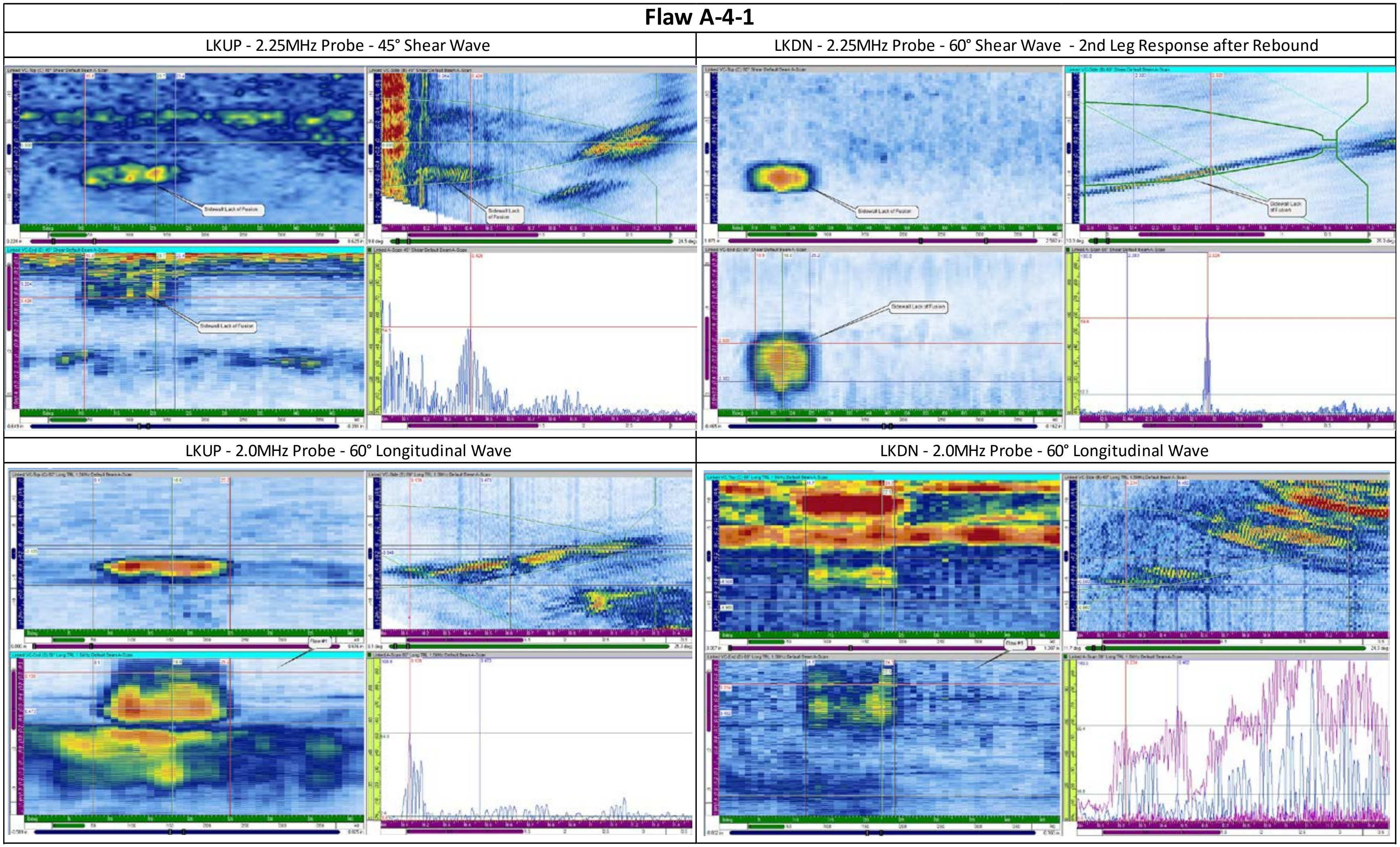


Figure A-17
A 12-in. diameter specimen—flaw A-4-1: angle beam data

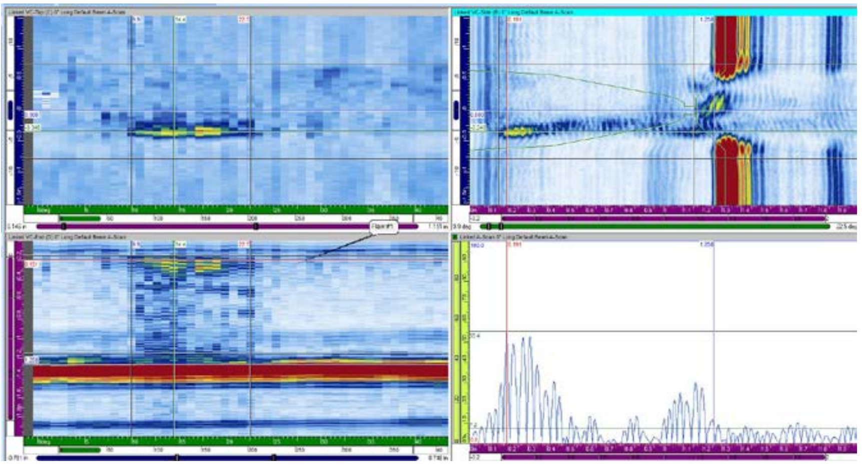
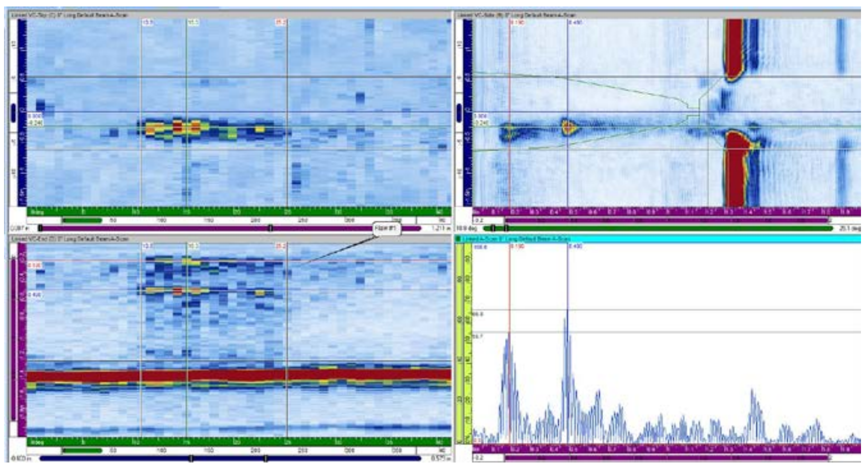
Flaw A-4-1	
2MHz - 0° Longitudinal Wave	4MHz - 0°Longitudinal Wave
	

Figure A-18
A 12-in. diameter specimen—flaw A-4-1: 0° beam data

Figure A-19
A 12-in. diameter specimen—flaw A-4-1: radiography film (image contrast and brightness enhanced for presentation)

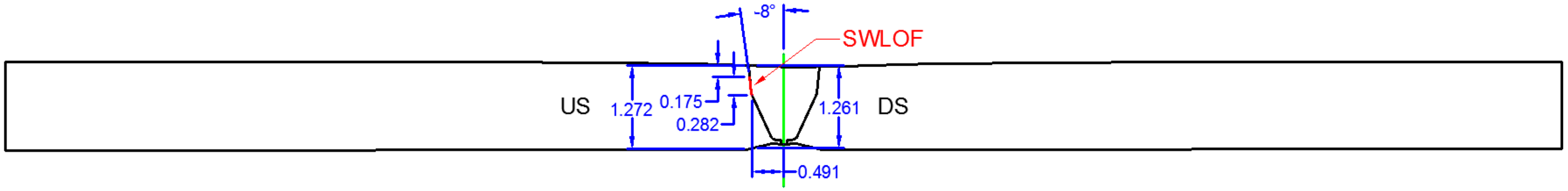


Figure A-20
A 12-in. diameter specimen—flaw A-4-1: computer-aided design drawing

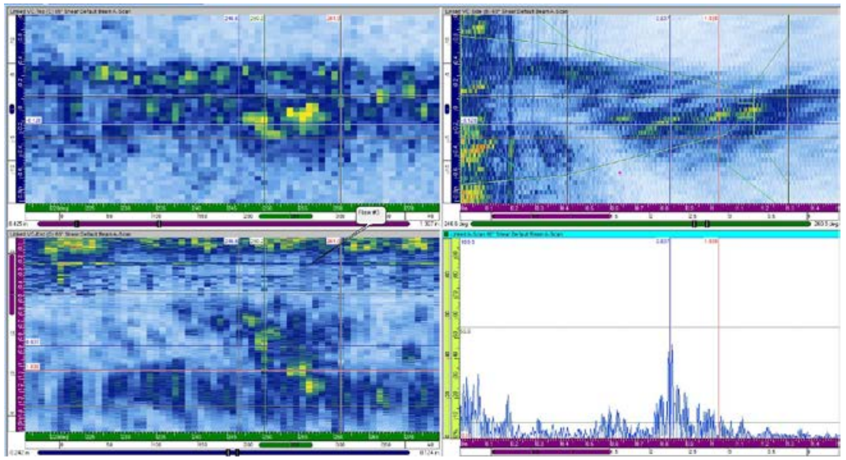
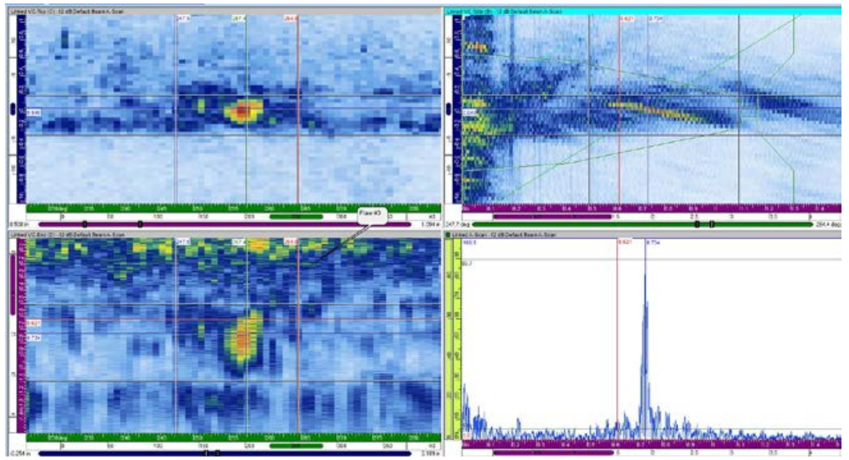
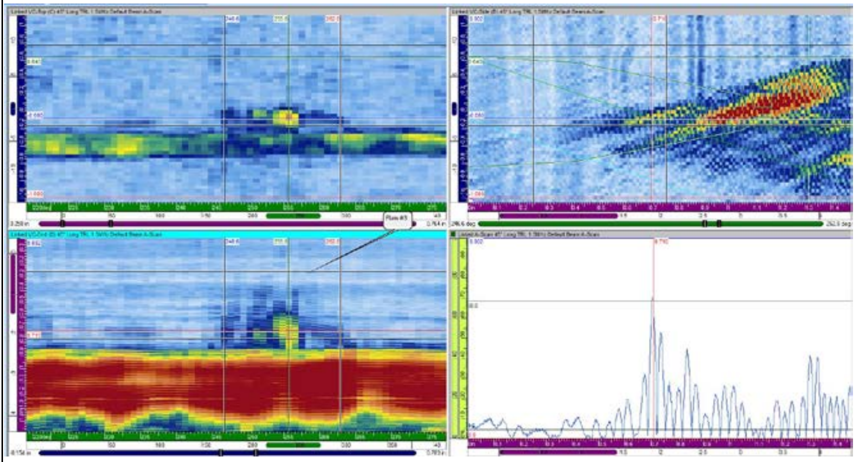
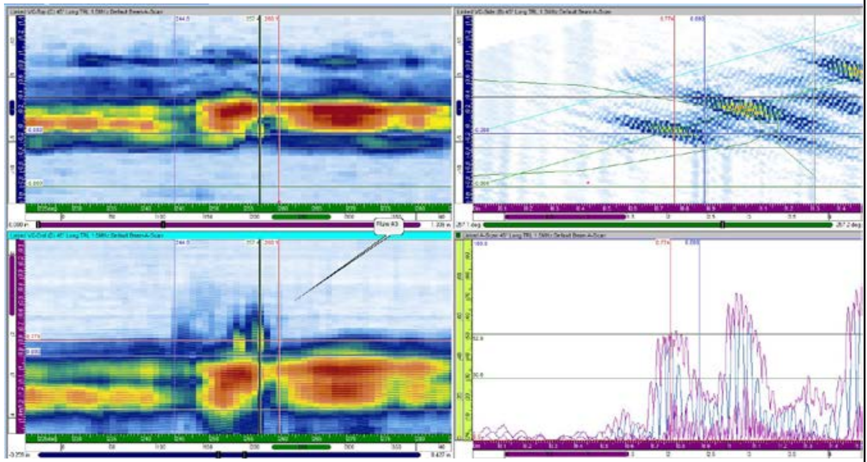
Flaw A-4-2	
LKUP - 2.25MHz Probe - 60° Shear Wave	LKDN - 2.25MHz Probe - 60° Shear Wave
	
LKUP - 1.5MHz Probe - 45° Longitudinal Wave	LKDN - 1.5MHz Probe - 45° Longitudinal Wave
	

Figure A-21
A 12-in. diameter specimen—flaw A-4-2: angle beam data

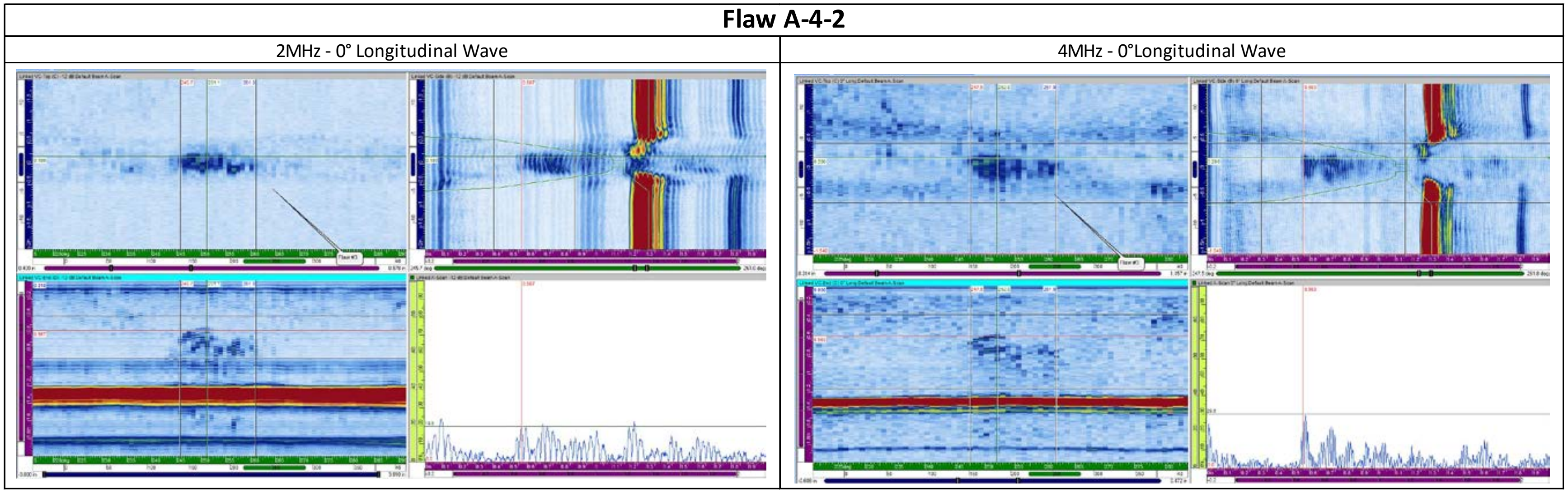


Figure A-22
A 12-in. diameter specimen—flaw A-4-2: 0° beam data

Figure A-23
A 12-in. diameter specimen—flaw A-4-2: radiography film (image contrast and brightness enhanced for presentation)

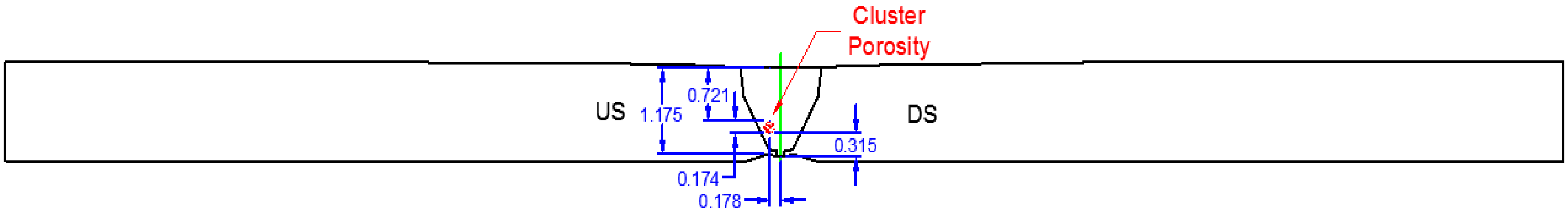


Figure A-24
A 12-in. diameter specimen—flaw A-4-2: computer-aided design drawing

Table A-5
A 24-in. diameter specimen

	24 Inch OD Specimen								
	Flaw Number	**Flaw Type**	**Flaw Location**	**Start, X1 (Degree)**	**Stop, X2 (Degree)**	**Length (Inch)**	**Z1 (Inch)**	**Z2 (Inch)**	**Through Wall Extent, H (Inch)**
As-built	1	OD Toe Crack	Surface	304.8	311.5	1.417	N/A	2.065	0.180
60°S 2.25MHz LKUP	1	Planar	Surface	304.0	311.0	1.467	N/A	2.055	0.190

Flaw A-5-1

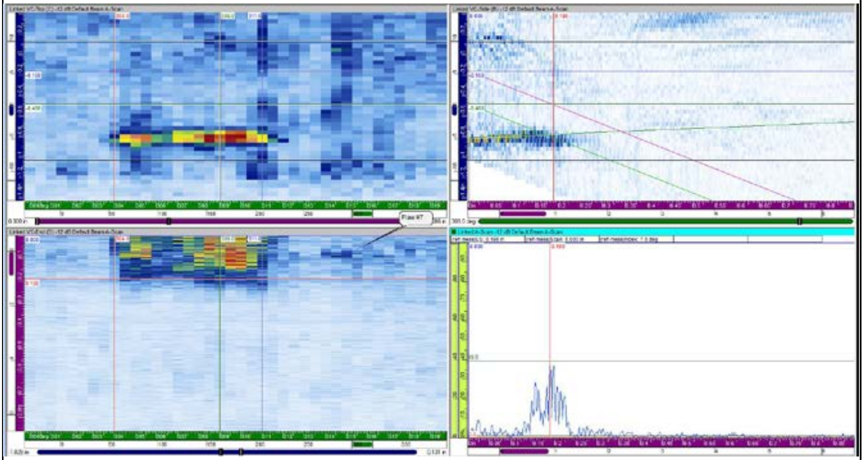
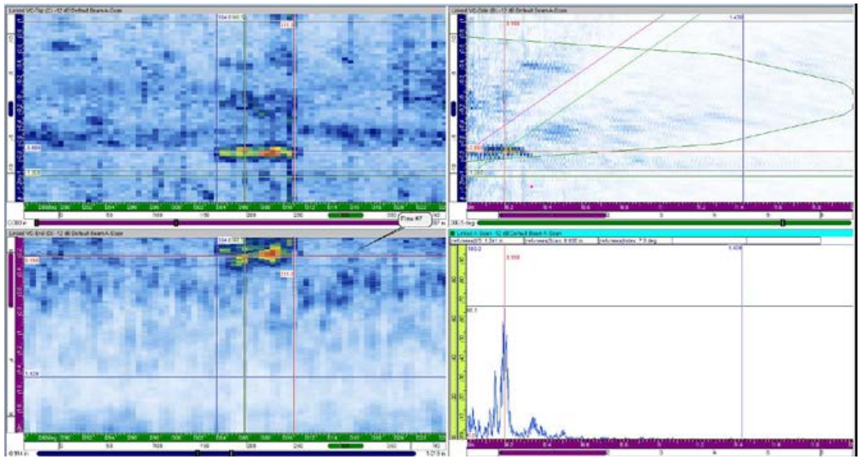
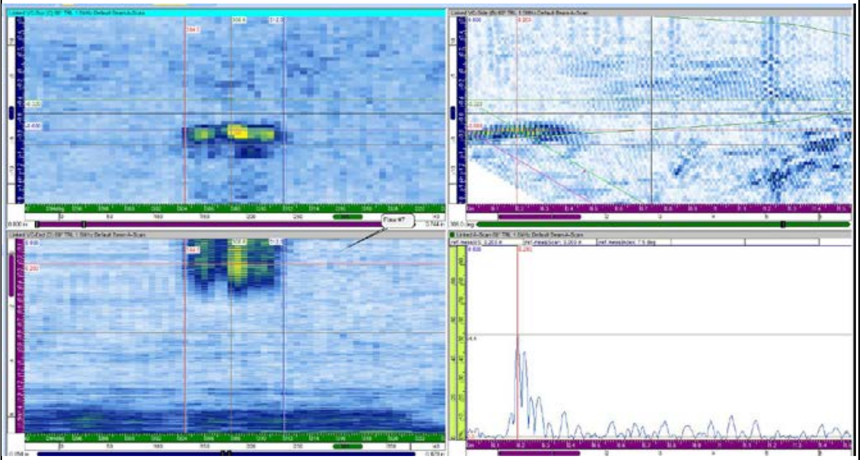
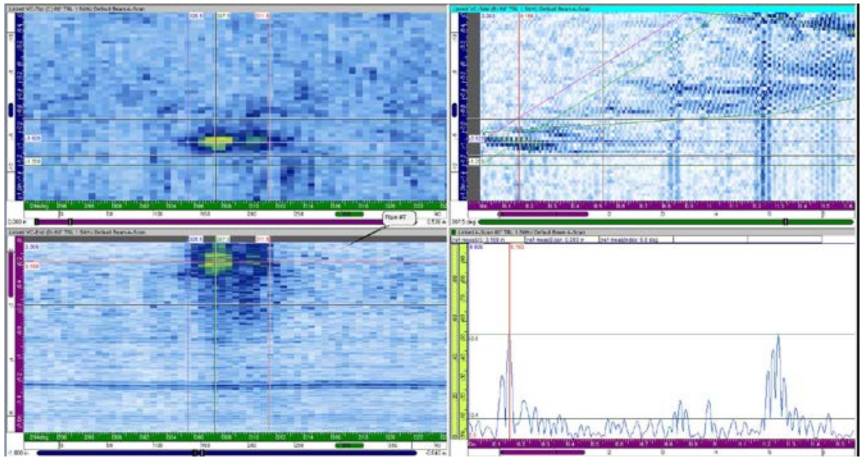
LKUP - 2.0MHz Probe - 60° Shear Wave	LKDN - 2.25MHz Probe - 60° Shear Wave
	
LKUP - 2.0MHz Probe - 60° Longitudinal Wave	LKDN - 2.0MHz Probe - 60° Longitudinal Wave
	

Figure A-25
A 24-in. diameter specimen—flaw A-5-1: angle beam data

Flaw A-5-1

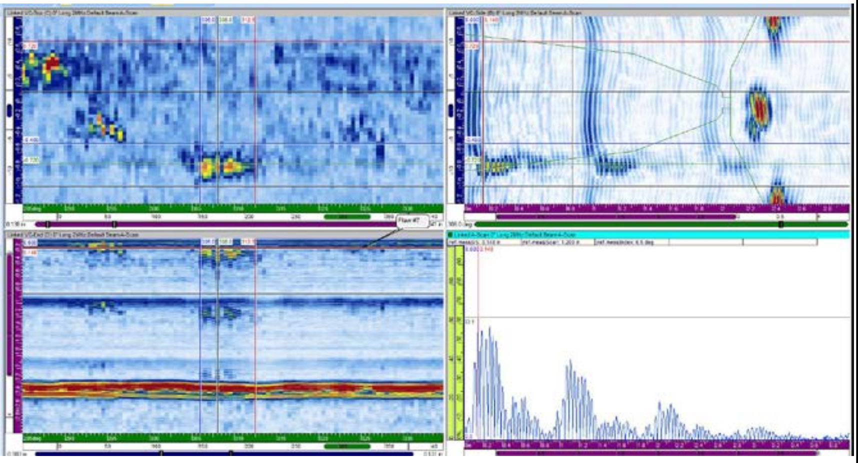
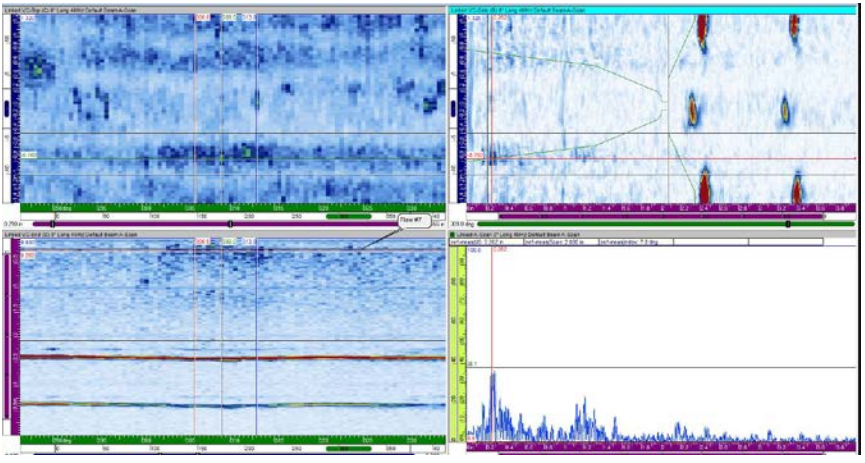
2MHz - 0° Longitudinal Wave	4MHz - 0°Longitudinal Wave
	

Figure A-26
A 24-in. diameter specimen—flaw A-5-1: 0° beam data

Figure A-27
A 24-in. diameter specimen—flaw A-5-1: radiography film (image contrast and brightness enhanced for presentation)

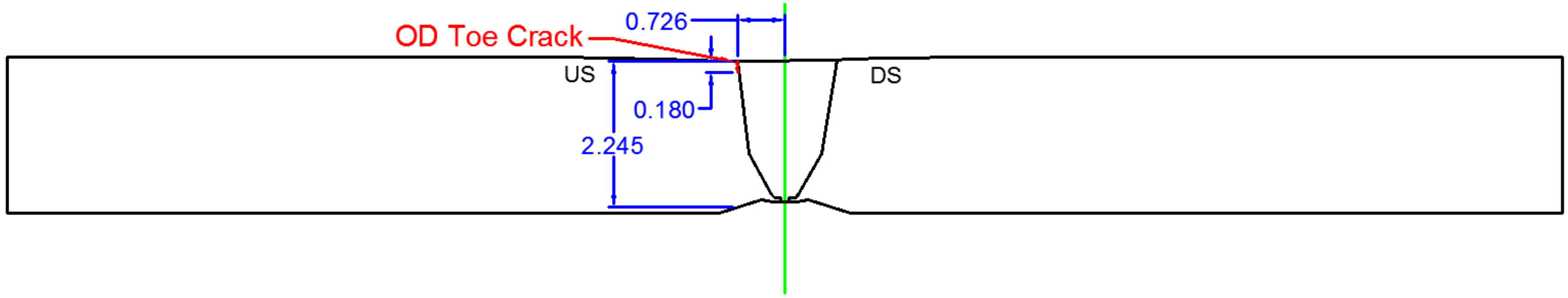


Figure A-28
A 24-in. diameter specimen—flaw A-5-1: computer-aided design drawing

B

FLAW EVALUATIONS USING SECTION XI, TABLE IWB 3514-1

This appendix provides detailed information about how flaws can be evaluated after they are detected and sized. It first describes some general rationale and how the acceptance standards of IWB-3514 were used in conjunction with the flaw characterization figures (IWA-3300) to design both acceptable and rejectable flaws. It then describes the step-by-step process for evaluating two hypothetical flaws; they are good exercises for those who infrequently perform evaluations according to the Table IWB-3514-1 acceptance standards.

As part of the flaw design process, a determination of the threshold for when subsurface, planar flaws become rejectable in accordance with the criteria of Section XI, Table IWB-3514-1 for austenitic stainless steel piping welds was needed. It has been postulated that subsurface flaws should appear after the root of a weld was installed. Therefore, the separation distance (*S* or ligament distance) from the nearest surface to the top or bottom of a flaw is an important dimension for starting the flaw evaluation process (see Figure B-1).

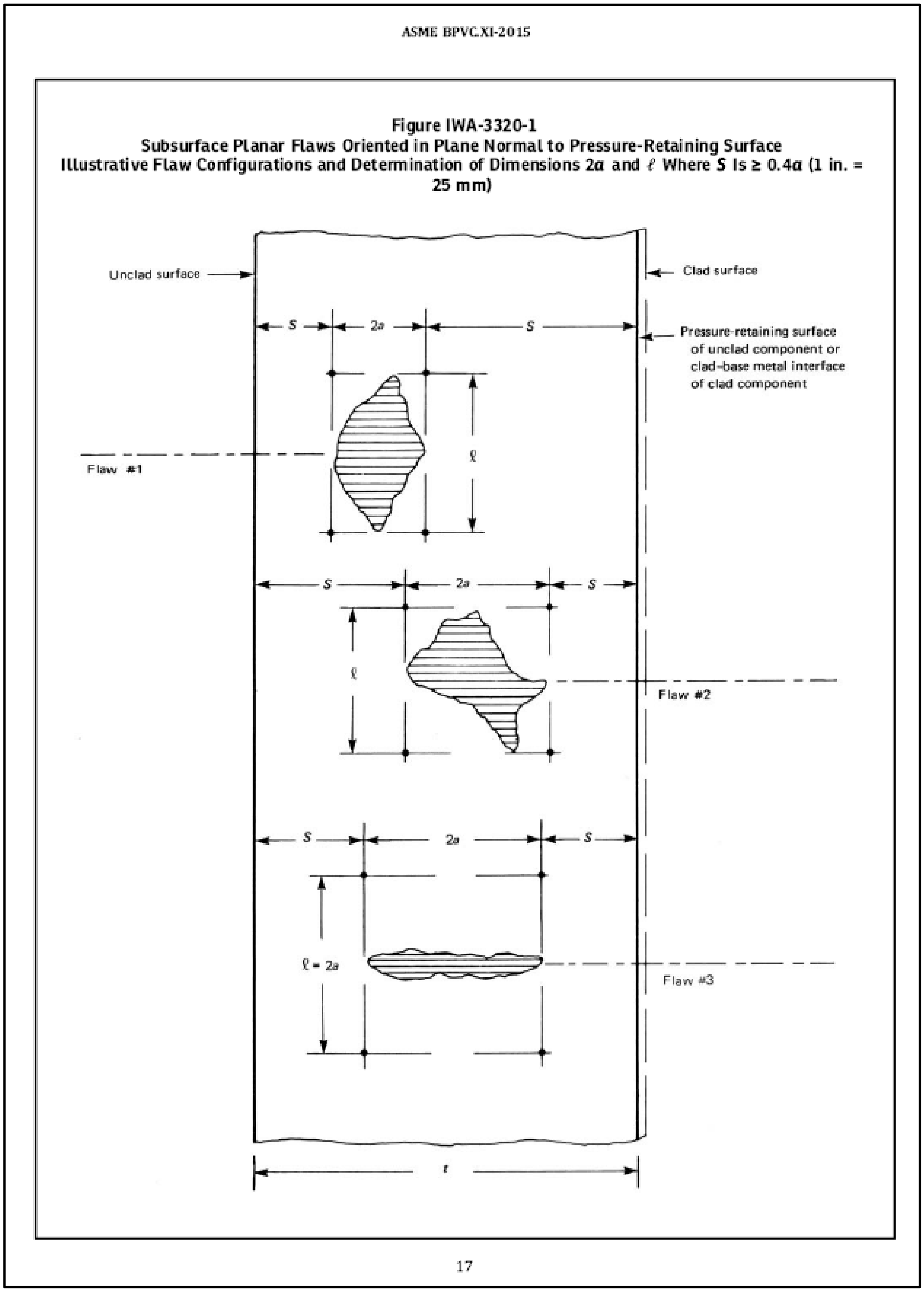
To determine a flaw's threshold, tools were developed to efficiently perform the calculations, the acceptance or rejection determination, and the required linear interpolations allowed by the Section XI acceptance standard tables.

After the tools were developed to perform this evaluation efficiently, the next step was to implement an iterative process to determine flaw sizes and locations to achieve a good mix of acceptable and rejectable sized flaws. Flaws smaller than 50% of the allowable flaw size (at the threshold of being unacceptable as defined in IWB-3500 and IWC-3500) were not included as detection flaws in the specimens that were designed and fabricated for this project. The basis for this was that pass–fail criteria for performance demonstrations (PDs) that will be part of Code Case N-831-1 should not be based on a procedure or personnel not detecting very small, acceptable sized flaws.

To use Table IWB-3514-1 to determine flaw acceptability, several data points must first be collected:

- $2a$: A flaw's through-wall dimension (see Figure B-1)
- S dimension: A flaw's ligament dimension to the nearest surface
- Is $S \geq 0.4a$? Determination of a flaw's S dimension requires the flaw to be evaluated as a surface or subsurface flaw (if $S \geq 0.4a$, the flaw is considered a subsurface flaw)
- ℓ: A flaw's length dimension
- t: The weld or component thickness
- Y: a calculated value

$Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.



ASME BPVC.XI-2015

Figure IWA-3320-1
Subsurface Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations and Determination of Dimensions $2a$ and ℓ Where S Is ≥ $0.4a$ (1 in. = 25 mm)

17

Figure B-1
Section XI, 2015 edition, Figure IWA-3320-1

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After these data points are collected, a flaw’s acceptability can be determined. (The following subsections provide step-by-step examples of flaw evaluations according to Table IWB-3514-1.)

After the tools needed to efficiently perform the iterative process of flaw acceptability determinations were developed, hand calculations were performed for various flaws for a variety of sizes, lengths, and material thicknesses. In addition, hand calculations yielded additional information that was used for spreadsheets for set cases in which the dimensions $2a$, l, S, and t were held constant.

Additional spreadsheets were then developed in which the $2a$ dimension was varied while the l and S dimensions remained constant. After these spreadsheets were verified, additional tables were added so that the material thickness dimension (t) could be varied while holding the l and S dimensions constant. This allowed for much more flexibility for determining the acceptability of proposed flaws for the fabricated specimens.

After the spreadsheets were functionally verified, the final step was to apply the schema to a single spreadsheet that was loaded with the nominal dimensions of the proposed specimens, as follows:

- 4-in., Schedule 80
- 6-in., Schedule 160
- 8-in., Schedule 160
- 12-in., Schedule 160
- 18-in., Schedule 160
- 24-in., Schedule 160

From there, flaw dimensions $2a$, l, and S were varied so that approximately half of the flaws were unacceptable and approximately half were of acceptable sizes, but not smaller than 50% of the allowable flaw size, as defined in IWB-3500 and IWC-3500.

After appropriate sizes were established, the S dimension was varied so that there was a good mix of flaws in three zones of through-wall location distribution. The categories established were based on one-third of the nominal pipe wall thicknesses, as follows (see Figure B-2):

- Near OD (outer one-third of the nominal pipe wall thickness)
- Middle (middle one-third of the nominal pipe wall thickness)
- Near ID (inner one-third of the nominal pipe wall thickness)

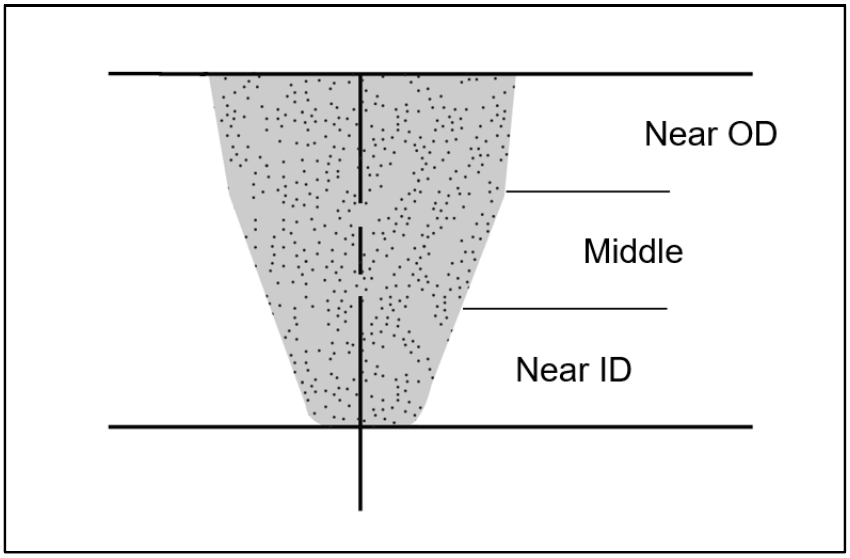


Figure B-2
Weld profile showing through-wall distribution zones

Finally, a count was performed to verify the distributions (approximately one-third each for through-wall location for the three zones and the mix of acceptable and unacceptable sized flaws). After flaw sizes and distributions were peer-checked and reviewed, design drawings were developed, and the specimens were fabricated

The following subsection present flaw evaluation exercises to determine when flaws of different sizes, locations, and pipe wall thicknesses would go beyond the acceptable threshold. An additional aspect of the exercise was to determine flaw sizes and locations in different pipe wall thicknesses that were at or near the 50% acceptable threshold.

The following examples demonstrate sample calculations and evaluations for postulated flaws.

B.1 Example 1

Evaluate a flaw using the following information and ASME Section XI, Table IWB-3514-1:

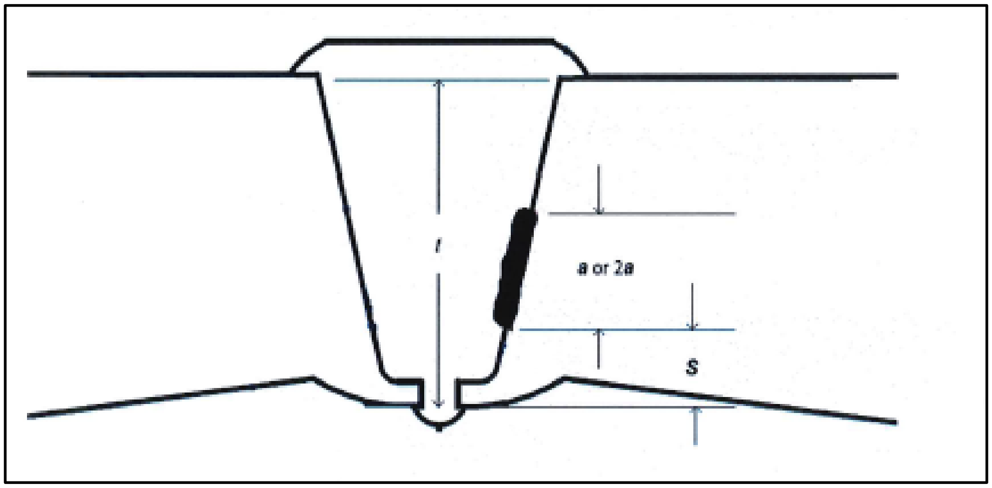
L = flaw length = 2.0 in.

t = pipe wall thickness = 1.0 in.

Flaw through-wall dimension (size) = 0.25 in.

S = separation distance from the nearest surface to the top or bottom of the flaw = 0.15 in.

Based on the data collected during UT examination, determine whether this flaw is acceptable or rejectable using Table IWB-3514-1.



Note: Sketch is not to scale; for illustrative purposes only.

B.1.1 Step 1

Determine whether this flaw will be evaluated as a surface or subsurface flaw, according to Figure IWA-3320-1:

ASME BPVC.XI-2015

Figure IWA-3320-1
Subsurface Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations and Determination of Dimensions $2a$ and ℓ Where S Is ≥ $0.4a$ (1 in. = 25 mm)

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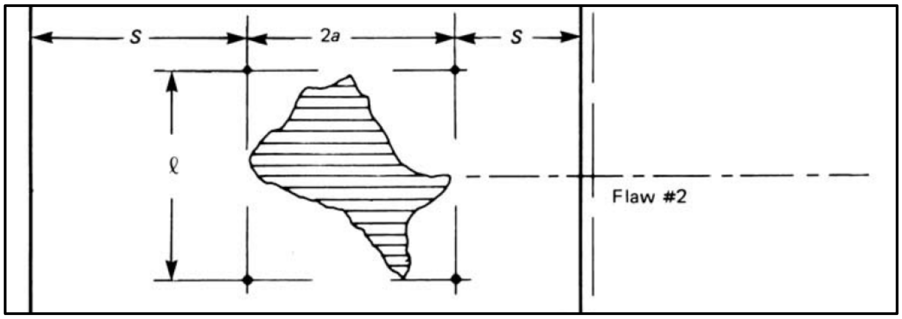
A determination must be made as to whether this flaw is considered surface or subsurface. If $S \geq 0.4a$, this flaw is considered a subsurface flaw.

But, what is a?

From Flaw #2 in Figure IWA-3320-1, it appears that the through-wall dimension (in this case, 0.25 in.) is $2a$.



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$$\boldsymbol{a} = \frac{through\ wall\ dimension}{2}$$

$$\boldsymbol{a} = \frac{0.25}{2}$$

$$\boldsymbol{a} = 0.125\ inch$$

And:

$$0.4\boldsymbol{a} = (0.4) * (0.125) = 0.05$$

Is **S** $\geq$ 0.4***a***?

Is 0.15 $\geq$ 0.05?

Yes. Therefore, this flaw will be evaluated as a subsurface flaw using an ***a*** dimension of 0.125 in.

B.1.2 Step 2

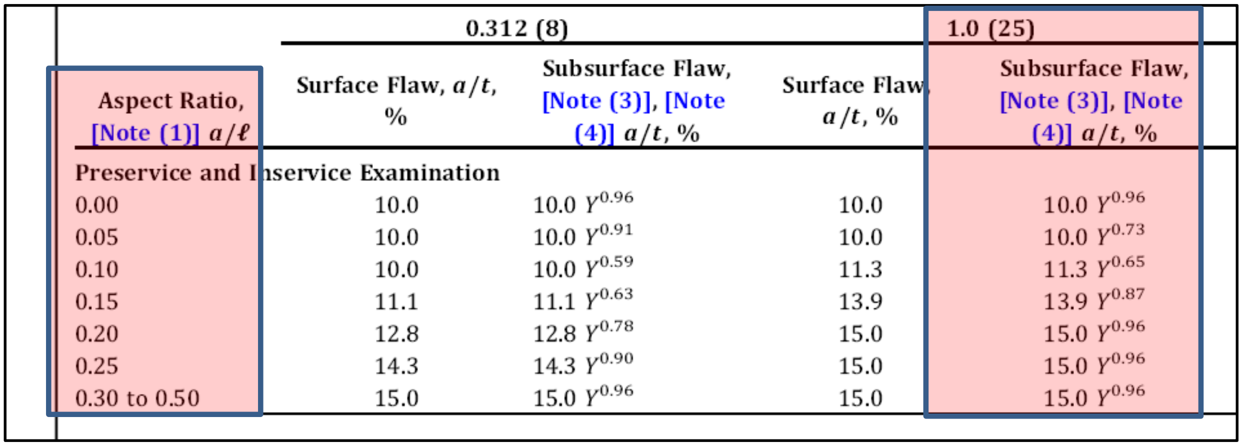
From Table IWB-3514-1, it appears that additional information is needed.

Calculate ***a*/L** to determine the aspect ratio to be used for the evaluation.

$$Aspect\ Ratio\ \left(\frac{a}{\mathrm{L}}\right) = \frac{0.125}{2.0} = 0.0625$$

The table shows that linear interpolation is required.

Table IWB-3514-1



	0.312 (8)		1.0 (25)	
Aspect Ratio, [Note (1)] a/ℓ	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
Preservice and Inservice Examination				
0.00	10.0	10.0 $Y^{0.96}$	10.0	10.0 $Y^{0.96}$
0.05	10.0	10.0 $Y^{0.91}$	10.0	10.0 $Y^{0.73}$
0.10	10.0	10.0 $Y^{0.59}$	11.3	11.3 $Y^{0.65}$
0.15	11.1	11.1 $Y^{0.63}$	13.9	13.9 $Y^{0.87}$
0.20	12.8	12.8 $Y^{0.78}$	15.0	15.0 $Y^{0.96}$
0.25	14.3	14.3 $Y^{0.90}$	15.0	15.0 $Y^{0.96}$
0.30 to 0.50	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$

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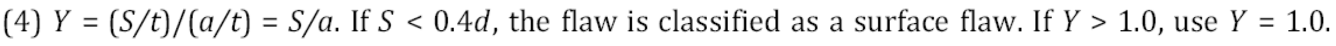
But first, determine Y.

B.1.3 Step 3

From Note 4 of Table IWB-3514-1:



(4) $Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

$$\boldsymbol{Y} = \frac{\boldsymbol{S}}{\boldsymbol{a}} = \frac{0.15}{0.125} = 1.2$$

Because $\boldsymbol{Y} > 1.0$, use $\boldsymbol{Y} = 1.0$

B.1.4 Step 4

Perform the linear interpolation: For an aspect ratio of 0.0625, determine the correct allowable ***a/t%*** value.

From Table IWB-3514-1, in the column for subsurface flaws for a thickness of 1.0 in., the following table can be used to determine the appropriate ***a/t%*** value:

Aspect Ratio (a/l)	a/t% Allowable
0.05	10.0 $Y^{0.73}$
0.0625	X
0.1	11.3 $Y^{0.65}$

Because Note 4 of Table IWB-3514-1 indicates that Y can be set to $Y = 1.0$, this table reduces to the following:

Aspect Ratio (a/l)	a/t% Allowable
0.05	10.0
0.0625	X
0.1	11.3

Begin linear interpolation.

$$\frac{(0.0625 - 0.05)}{(0.1 - 0.05)} = \frac{(X - 10.0)}{(11.3 - 10.0)}$$

Solve for X:

$$(X - 10.0) = \frac{(11.3 - 10.0) * (0.0625 - 0.05)}{(0.1 - 0.05)}$$

$$(X - 10.0) = 0.325$$

And:

$$X = 10.325$$

Therefore, a flaw’s a/t% ratio must be less than 10.325% (or 10.3% when rounded) for it to be acceptable.

B.1.5 Step 5

Determine acceptability. The flaw in this example has an *a/t%* value of the following:

$$\frac{a}{t}\% = \frac{0.125}{1.0} * 100\%$$

$$\frac{a}{t}\% = 12.5\%$$

Comparing this 12.5% value to the interpolated value of 10.3%, it is clear that this flaw is unacceptable.

B.2 Example 2

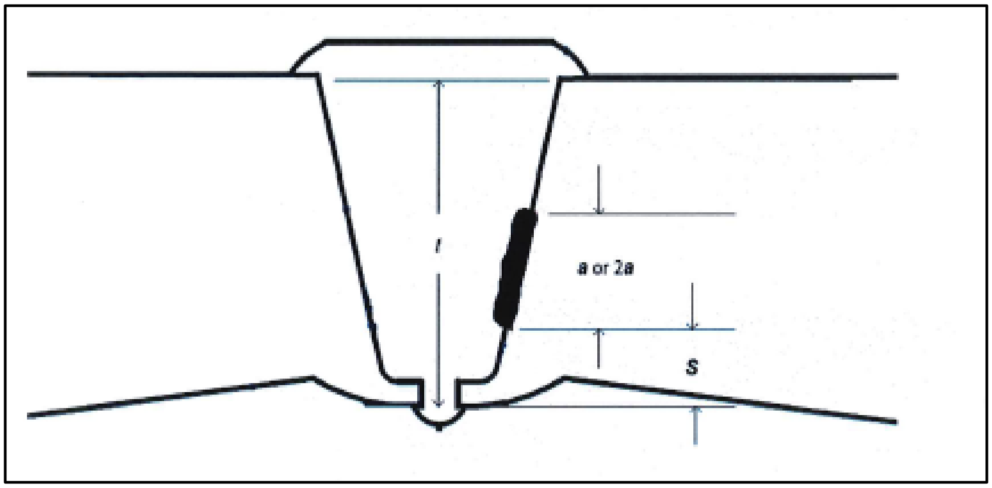
Evaluate a flaw using the following information and ASME Section XI, Table IWB-3514-1:

L = flaw length = 1.0 in.

t = pipe wall thickness = 1.5 in.

Flaw through-wall dimension (size) = 0.15 in.

S = separation distance from the nearest surface to the top or bottom of the flaw = 0.15 in.

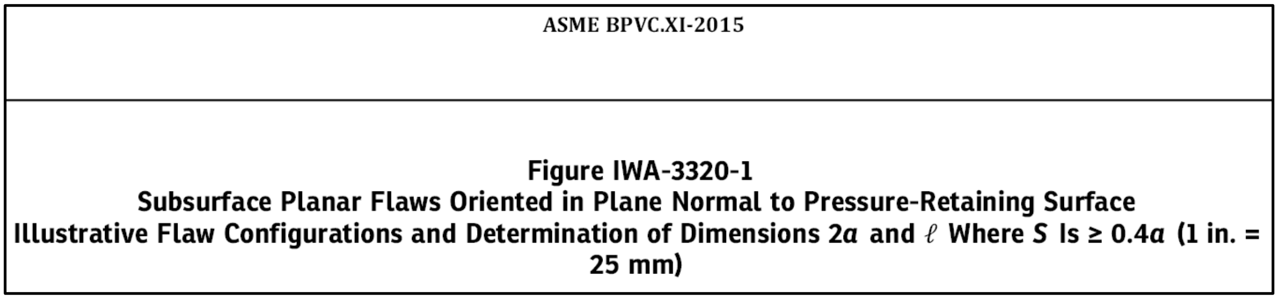


Note: Sketch is not to scale. Illustrative purposes only.

Based on the data collected during UT examination, determine whether this flaw is acceptable or rejectable using Table IWB-3514-1.

B.2.1 Step 1

Determine whether this flaw will be evaluated as a surface or subsurface flaw, according to Figure IWA-3320-1:



ASME BPVC.XI-2015

Figure IWA-3320-1
Subsurface Planar Flaws Oriented in Plane Normal to Pressure-Retaining Surface
Illustrative Flaw Configurations and Determination of Dimensions 2*a* and ℓ Where *S* Is ≥ 0.4*a* (1 in. = 25 mm)

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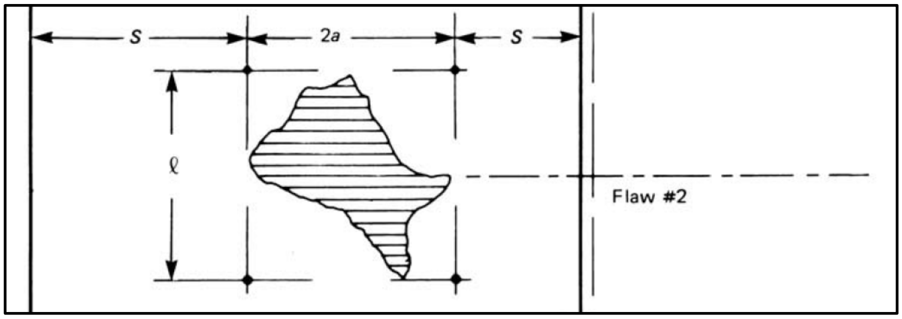
A determination must be made as to whether this flaw is considered surface or subsurface. If **S** ≥ 0.4***a***, this flaw is considered a subsurface flaw.

But, what is ***a*?**

From Flaw #2 in Figure IWA-3320-1, it appears that the through-wall dimension (in this case, 0.15 in.) is ***2a***.



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$$\boldsymbol{a} = \frac{through\ wall\ dimension}{2}$$

$$\boldsymbol{a} = \frac{0.15}{2}$$

$$\boldsymbol{a} = 0.075\ inch$$

And:

$$0.4\boldsymbol{a} = (0.4) * (0.075) = 0.03$$

Is **S** $\geq$ 0.4***a***?

Is 0.15 $\geq$ 0.03?

Yes. Therefore, this flaw will be evaluated as a subsurface flaw using an ***a*** dimension of 0.125 in.

B.2.2 Step 2

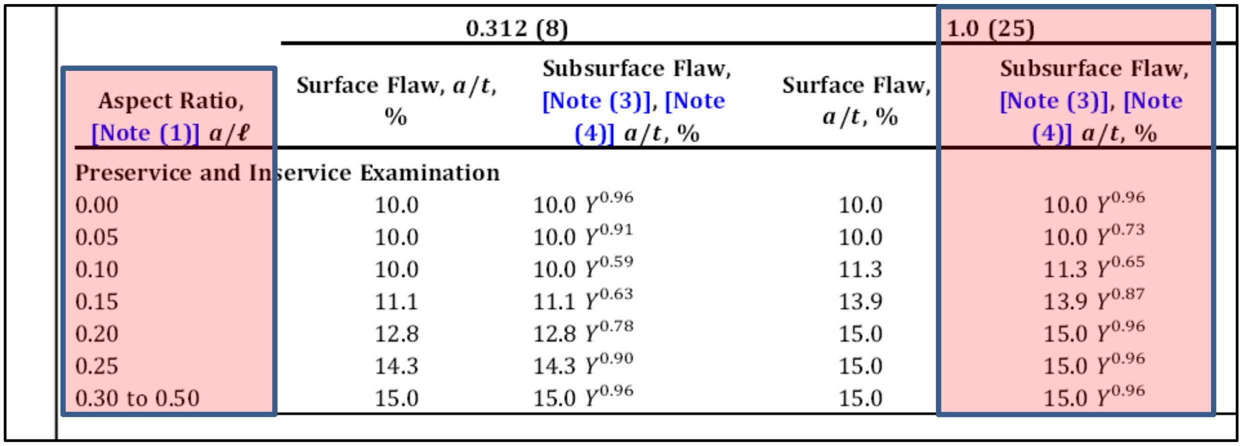
From Table IWB-3514-1, it appears that additional information is needed.

Calculate ***a*/ L** to determine the aspect ratio to be used for the evaluation.

$$Aspect\ Ratio\ \left(\frac{a}{\mathrm{L}}\right) = \frac{0.075}{1.0} = 0.075$$

The table shows that linear interpolation is required.

Table IWB-3514-1



	0.312 (8)			1.0 (25)
Aspect Ratio, [Note (1)] a/ℓ	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %	Surface Flaw, a/t, %	Subsurface Flaw, [Note (3)], [Note (4)] a/t, %
Preservice and Inservice Examination				
0.00	10.0	10.0 $Y^{0.96}$	10.0	10.0 $Y^{0.96}$
0.05	10.0	10.0 $Y^{0.91}$	10.0	10.0 $Y^{0.73}$
0.10	10.0	10.0 $Y^{0.59}$	11.3	11.3 $Y^{0.65}$
0.15	11.1	11.1 $Y^{0.63}$	13.9	13.9 $Y^{0.87}$
0.20	12.8	12.8 $Y^{0.78}$	15.0	15.0 $Y^{0.96}$
0.25	14.3	14.3 $Y^{0.90}$	15.0	15.0 $Y^{0.96}$
0.30 to 0.50	15.0	15.0 $Y^{0.96}$	15.0	15.0 $Y^{0.96}$

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But first, determine Y.

B.2.3 Step 3

From Note 4 of Table IWB-3514-1:

(4) $Y = (S/t)/(a/t) = S/a$. If $S < 0.4d$, the flaw is classified as a surface flaw. If $Y > 1.0$, use $Y = 1.0$.

$$\boldsymbol{Y} = \frac{\boldsymbol{S}}{\boldsymbol{a}} = \frac{0.15}{0.075} = 2.0$$

Because $\boldsymbol{Y} > 1.0$, use $\boldsymbol{Y} = 1.0$

B.2.4 Step 4

Perform the linear interpolation: For an aspect ratio of 0.075, determine the correct allowable **a**/***t%*** value.

From Table IWB-3514-1, in the column for subsurface flaws for a thickness of 1.0 in., the following table can be used to determine the appropriate ***a/t%*** value:

Aspect Ratio (a/l)	a/t% Allowable
0.05	10.0 $Y^{0.73}$
0.075	X
0.1	11.3 $Y^{0.65}$

Because Note 4 of Table IWB-3514-1 indicates that Y can be set to $Y = 1.0$, this table reduces to the following:

Aspect Ratio (a/l)	**a/t% Allowable**
0.05	10.0
0.075	X
0.1	11.3

Begin linear interpolation:

$$\frac{(0.075 - 0.05)}{(0.1 - 0.05)} = \frac{(X - 10.0)}{(11.3 - 10.0)}$$

Solve for X:

$$(X - 10.0) = \frac{(11.3 - 10.0) * (0.075 - 0.05)}{(0.1 - 0.05)}$$

$$(X - 10.0) = 0.65$$

And:

$$X = 10.65$$

Therefore, a flaw's a/t% ratio must be less than 10.65% (or 10.7% when rounded) for it to be acceptable.

B.2.5 Step 5

Determine acceptability. The flaw in this example has an *a/t%* value of the following:

$$\frac{a}{t}\% = \frac{0.075}{1.5} * 100\%$$

$$\frac{a}{t}\% = 5.0\%$$

Comparing this 5.0% value to the interpolated value of 10.7%, it is clear that this flaw is acceptable.

However, because this flaw is smaller than 50% of the allowable flaw size according to Table IWB-3514-1, it is not a good candidate for a PD and procedure qualification because, if it were missed, there would be an impact on the grading and final evaluation of a procedure's performance.

C

SIDE-BY-SIDE COMPARISON TABLE OF CODE CASE N-831 AND PROPOSED CODE CASE N-831-1

Existing Language in N-831	**Will the Stainless Steel Project Need this Item Modified?**
1) Use of this Case is limited to welds made as part of a repair/replacement activity and is subject to review by the Authorized Inspection Agency.	No. Stainless steel (SS) will not affect this.
2) The welds to be examined shall be conditioned such that transducers properly couple with the scanning surface with no more than a 1/32 in. (0.8 mm) gap between the search unit and the scanning surface.	No. The surface condition will be defined in procedures that were qualified by performance demonstration.
3) Ultrasonic examination shall be performed using equipment, procedures, and personnel qualified by performance demonstration as described in this Case.	No. This is standard wording.
4) The examination volume shall include 100% of the weld volume and the weld-to-base-metal interface.	No. The same volume was interrogated during fingerprinting of the specimens.
a) Angle beam examination of the complete examination volume for fabrication flaws oriented parallel to the weld joint shall be performed.	No. Angle beam exams were performed during the fingerprinting of the specimens.
b) Angle beam examination for fabrication flaws oriented transverse to the weld joint shall be performed to the extent practical. Scan restrictions that limit complete coverage shall be documented.	No. For the field examinations, this is probably needed. Flaws transverse to the weld joints were not included in the specimen set.
c) A supplemental straight beam examination shall be performed on the volume of base metal through which the angle beams will travel, to locate any reflectors that can limit the ability of the angle beam to examine the weld. Detected reflectors that may limit the angle beam examination shall be recorded and evaluated for impact on examination coverage. The straight beam examination procedure, or the straight beam portion of the procedure, is required to be qualified in accordance with Section V, Article 4	No. Straight beam exams were performed during the fingerprinting of the specimens.
5) All detected flaws from (4)(a) and (4)(b) above shall be considered planar flaws and shall be compared to the preservice acceptance standards for volumetric examination in accordance with IWB-3000, IWC-3000, or IWD-3000, as applicable. Analytical evaluation for acceptance of flaws in accordance with IWB-3600, IWC-3600, or IWD-3600 is permitted for flaws that exceed the applicable acceptance standards and are confirmed by surface or volumetric examination to be non-surface-connected.	No. This item will not affect or be affected by the SS specimens. (Note: For Code editions after 2010, the same table is used for both PSI and ISI flaws.)

Existing Language in N-831	Will the Stainless Steel Project Need this Item Modified?
6) Flaws exceeding the applicable acceptance standards, and analytical evaluation has not been performed for acceptance, shall be reduced to an acceptable size or removed and repaired, and the location of the repair shall be reexamined using the same ultrasonic examination procedure that detected the flaw.	No. This item will not affect or be affected by the SS specimens.
7) The ultrasonic examination shall be performed using encoded ultrasonic examination technology that produces an electronic record of the ultrasonic responses indexed to the probe position, permitting off-line analysis of images built from the combined data. Where component configuration does not allow for effective examination for transverse flaws (e.g., pipe-to-valve, tapered weld transition, weld shrinkage), use of non-encoded ultrasonic examination technology may be used for transverse flaws. The basis for the non-encoded examination shall be documented.	No. This item will not affect or be affected by the SS specimens. (Note: The SS specimens were examined using encoded, conventional UT and no circumferential scans for axial flaws were performed.)
8) A written ultrasonic examination procedure qualified by performance demonstration shall be used. The qualification shall be applicable to the scope of the procedure, e.g., flaw detection or sizing (length or through-wall height), encoded or non-encoded, single- or dual-side access. The procedure shall:	No. This item will not affect or be affected by the SS specimens.
a) Contain a statement of scope that specifically defines the limits of procedure applicability (e.g., minimum and maximum thickness, minimum and maximum diameter, scanning access);	No. This item will not affect or be affected by the SS specimens.
b) Specify which parameters are considered essential variables, and a single value, a range of values or criteria for selecting each of the essential variables;	No. This item will not affect or be affected by the SS specimens.
c) List the examination equipment, including manufacturer and model or series;	No. This item will not affect or be affected by the SS specimens.
d) Define the scanning requirements, such as beam angles, scan patterns, beam direction, maximum scan speed, extent of scanning, and access;	No. This item will not affect or be affected by the SS specimens.

Existing Language in N-831	Will the Stainless Steel Project Need this Item Modified?
e) Contain a description of the calibration method (that is, actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination);	No. This item will not affect or be affected by the SS specimens.
f) Describe the method and criteria for discrimination of indications (e.g., geometric indications versus indications of flaws and surface versus subsurface indications); and	No. This item will not affect or be affected by the SS specimens.
g) Describe the surface preparation requirements.	No. This item will not affect or be affected by the SS specimens. (Note: the SS specimens were all fabricated to be smooth and flat. No specimens were in the as-welded condition.)
9) Performance demonstration specimens shall conform to the following requirements.	No. This item will not affect or be affected by the SS specimens.
a) The specimens shall be fabricated from ferritic material with the same inside surface cladding process, if applicable, with the following exceptions.	Yes. This item will need to be edited to incorporate SS material. Also, the cladding statement will not pertain to SS welds or materials.
i. Demonstration with shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes.	No. This item will not affect or be affected by the SS specimens.
ii. Demonstration with a multiple-wire or strip-clad process is considered equivalent but is not transferable to SMAW type cladding processes.	No. This item will not affect or be affected by the SS specimens.
b) The demonstration specimens shall contain a weld representative of the joint to be ultrasonically examined, including the same welding processes.	No. This item will not affect or be affected by the SS specimens.

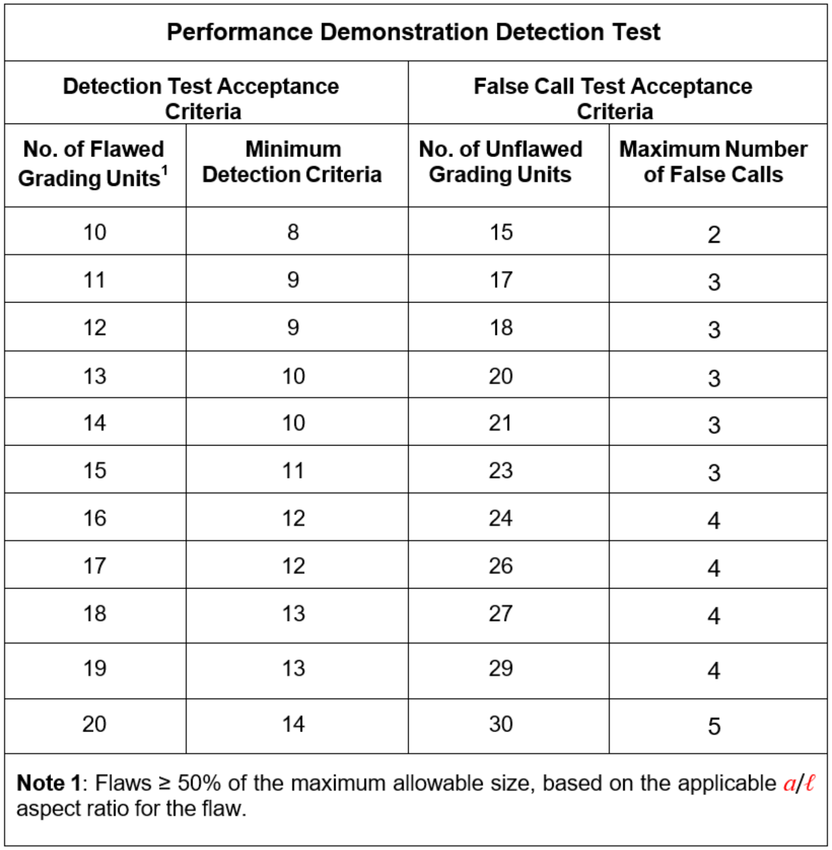
Existing Language in N-831	Will the Stainless Steel Project Need this Item Modified?
c) The demonstration set shall include specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 0.5 in. (13 mm) less than the maximum thickness for which the examination procedure is applicable. The demonstration set shall include the minimum, within ½ of the nominal outside diameter, and maximum pipe diameters for which the examination procedure is applicable. If the procedure is applicable to piping of 24 in. (600 mm) O.D. or larger, the specimen set must include at least one specimen 24 in. (600 mm) O.D. or larger but need not include the maximum diameter.	No. This item will not affect or be affected by the SS specimens.
d) The demonstration specimen scanning and weld surfaces shall be representative of the surfaces to be examined.	No. This item will not affect or be affected by the SS specimens.
e) The demonstration specimen set shall include geometric conditions that require discrimination from flaws (e.g., counterbore, weld root conditions, weld crowns) and limited scanning surface conditions for single-side access, when applicable.	No. This item will not affect or be affected by the SS specimens.
f) The demonstration specimens shall include both planar and volumetric fabrication flaws (e.g., lack of fusion, crack, incomplete penetration, slag inclusions) representative welding process or processes of the welds to be examined. The flaws shall be distributed throughout the examination volume.	No. This item will not affect or be affected by the SS specimens.
g) Specimens shall be divided into flawed and unflawed grading units.	No. This item will not affect or be affected by the SS specimens.
i. Flawed grading units shall be the actual flaw length, plus a minimum of 0.25 in. (6 mm) on each end of the flaw. Unflawed grading units shall be at least 1 in. (25 mm).	No. This item will not affect or be affected by the SS specimens.
ii. The number of unflawed grading units shall be at least 1-1/2 times the number of flawed grading units.	No. This item will not affect or be affected by the SS specimens.

Existing Language in N-831	**Will the Stainless Steel Project Need this Item Modified?**
h) Demonstration specimen set flaw distribution shall be as follows:	No. This item will not affect or be affected by the SS specimens.
i. For thickness greater than 0.50 in. (13mm); at least 20% of the flaws shall be distributed in the outer third of the specimen wall thickness, at least 20% of the flaws shall be distributed in the middle third of the specimen wall thickness, and at least 40% of the flaws shall be distributed in the inner third of the specimen wall thickness. For thickness 0.50 in. (13 mm) and less, at least 20% of the flaws shall be distributed in the outer half of the specimen wall thickness, and at least 40% of the flaws shall be distributed in the inner half of the specimen wall thickness.	No. This item will not affect or be affected by the SS specimens.
ii. At least 30% of the flaws shall be classified as surface planar flaws in accordance with IWA-3310. At least 40% of the flaws shall be classified as subsurface planar flaws in accordance with IWA-3320.	No. This item will not affect or be affected by the SS specimens.
iii. At least 50% of the flaws shall be planar flaws, such as lack of fusion, incomplete penetration, or cracks. At least 20% of the flaws shall be volumetric flaws, such as slag inclusions.	No. This item will not affect or be affected by the SS specimens.
iv. The flaw through-wall heights shall be based on the applicable acceptance standards for volumetric examination in accordance with IWB-3400, IWC-3400, or IWD-3000, as applicable. At least 30% of the flaws shall be classified as acceptable planar flaws, with the smallest flaws being at least 50% of the maximum allowable size based on the applicable a/ℓ aspect ratio for the flaw. Additional smaller flaws may be included in the specimens to assist in establishing a detection threshold, but shall not be counted as a missed detection if not detected. At least 30% of the flaws shall be classified as unacceptable in accordance with the applicable acceptance standards. Welding fabrication flaws are typically confined to a height of a single weld pass. Flaw through-wall height distribution shall range from approximately one to four weld pass thicknesses, based on the welding process used.	No. This item will not affect or be affected by the SS specimens.

Existing Language in N-831	Will the Stainless Steel Project Need this Item Modified?
v. If applicable, at least two flaws, but no more than 30% of the flaws, shall be oriented perpendicular to the weld fusion line, and the remaining flaws shall be circumferentially oriented.	No. This item will not affect or be affected by the SS specimens.
vi. For demonstration of single-side access capabilities, at least 30% of the flaws shall be located on the far side of the weld centerline and at least 30% of the planar flaws shall be located on the near side of the weld centerline. The remaining flaws shall be distributed on either side of the weld.	No. This item will not affect or be affected by the SS specimens.
10) Ultrasonic examination procedures shall be qualified by performance demonstration in accordance with the following requirements.	No. This item will not affect or be affected by the SS specimens.
a) The procedure shall be demonstrated using either a blind or a non-blind demonstration.	No. This item will not affect or be affected by the SS specimens.
b) The non-blind performance demonstration is used to assist in optimizing the examination procedure. When applying the non-blind performance demonstration process, personnel have access to limited knowledge of specimen flaw information during the demonstration process. The non-blind performance demonstration process consists of an initial demonstration without any flaw information, an assessment of the results, and feedback of the performance provided to the qualifying candidate. After an assessment of the initial demonstration results, limited flaw information may be shared with the candidate, as part of the feedback process, to assist in enhancing the examination procedure to improve the procedure performance. To maintain the integrity of the specimens for blind personnel demonstrations, only generalities of the flaw information may be provided to the candidate. Procedure modifications or enhancements made to the procedure, based on the feedback process, shall be applied to all applicable specimens, based on the scope of the changes.	No. This item will not affect or be affected by the SS specimens.
c) Objective evidence of a flaw’s detection, length, and through-wall height sizing, in accordance with the procedure requirements, shall be provided to the organization administering the performance demonstration.	No. This item will not affect or be affected by the SS specimens.

Existing Language in N-831	**Will the Stainless Steel Project Need this Item Modified?**
d) The procedure demonstration specimen set shall be representative of the procedure scope and limitations (e.g., thickness range, diameter range, material, access, surface condition).	No. This item will not affect or be affected by the SS specimens.
e) The demonstration set shall include specimens to represent the minimum and maximum diameter and thickness covered by the procedure. If the procedure spans a range of diameters and thicknesses, additional specimens shall be included in the set to demonstrate the effectiveness of the procedure throughout the entire range.	No. This item will not affect or be affected by the SS specimens.
f) The procedure demonstration specimen set shall include at least 30 flaws and shall meet the requirements of (9) above.	No. This item will not affect or be affected by the SS specimens.
g) Procedure performance demonstration acceptance criteria	No. This item will not affect or be affected by the SS specimens.
i. To be qualified for flaw detection, all flaws in the demonstration set that are not less than 50% of the maximum allowable size, based on the applicable a/ℓ aspect ratio for the flaw, shall be detected. In addition, when performing blind procedure demonstrations, no more than 20% of the non-flawed grading units may contain a false call. Any non-flaw condition (e.g., geometry) reported as a flaw shall be considered a false call.	No. This item will not affect or be affected by the SS specimens.
ii. To be qualified for flaw length sizing, the root mean square (RMS) error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.25 in. (6 mm) for NPS 6 (DN150) and smaller, and 0.75 in. (18 mm) for larger than NPS 6 (DN150).	No. This item will not affect or be affected by the SS specimens.
iii. To be qualified for flaw through-wall height sizing, the RMS error of the flaw through-wall heights estimated by ultrasonics, as compared with the true through-wall heights, shall not exceed 0.125 in. (3 mm).	No. This item will not affect or be affected by the SS specimens.

Existing Language in N-831	**Will the Stainless Steel Project Need this Item Modified?**
iv. RMS error shall be calculated as follows: $RMS = \left[\frac{\sum_{n}^{i=1} \left(m_i - t_i \right)^2}{n} \right]^{1/2}$ Where m_i = measured flaw size n = number of flaws measured t_i = true flaw size	No. This item will not affect or be affected by the SS specimens.
h) Essential variables may be changed during successive personnel performance demonstrations. Each examiner need not demonstrate qualification over the entire range of every essential variable.	No. This item will not affect or be affected by the SS specimens.
11) Ultrasonic examination personnel shall be qualified in accordance with IWA-2300. In addition, examination personnel shall demonstrate their capability to detect and size flaws by performance demonstration, using the qualified procedure, in accordance with the following requirements.	No. This item will not affect or be affected by the SS specimens.
a) The personnel performance demonstration shall be conducted in a blind fashion (flaw information is not provided).	No. This item will not affect or be affected by the SS specimens.
i. The demonstration specimen set shall contain at least 10 flaws and shall meet the flaw distribution requirements of (9)(h) above, with the exception of (9)(h)(v). When applicable, at least one flaw, but no more than 20% of the flaws, shall be oriented perpendicular to the weld fusion line, and the remaining flaws shall be circumferentially oriented.	No. This item will not affect or be affected by the SS specimens.
b) Personnel performance demonstration acceptance criteria:	No. This item will not affect or be affected by the SS specimens.

<table>
<tr><th>Existing Language in N-831</th><th>Will the Stainless Steel Project Need this Item Modified?</th></tr>
<tr><td>i. To be qualified for flaw detection, personnel performance demonstration shall meet the requirements of the following table for both detection and false calls. Any non-flaw condition (e.g., geometry) reported as a flaw shall be considered a false call.</td><td></td></tr>
<tr><td>

<table>
<tr><th colspan="4">Performance Demonstration Detection Test</th></tr>
<tr><th colspan="2">Detection Test Acceptance Criteria</th><th colspan="2">False Call Test Acceptance Criteria</th></tr>
<tr><th>No. of Flawed Grading Units[1]</th><th>Minimum Detection Criteria</th><th>No. of Unflawed Grading Units</th><th>Maximum Number of False Calls</th></tr>
<tr><td>10</td><td>8</td><td>15</td><td>2</td></tr>
<tr><td>11</td><td>9</td><td>17</td><td>3</td></tr>
<tr><td>12</td><td>9</td><td>18</td><td>3</td></tr>
<tr><td>13</td><td>10</td><td>20</td><td>3</td></tr>
<tr><td>14</td><td>10</td><td>21</td><td>3</td></tr>
<tr><td>15</td><td>11</td><td>23</td><td>3</td></tr>
<tr><td>16</td><td>12</td><td>24</td><td>4</td></tr>
<tr><td>17</td><td>12</td><td>26</td><td>4</td></tr>
<tr><td>18</td><td>13</td><td>27</td><td>4</td></tr>
<tr><td>19</td><td>13</td><td>29</td><td>4</td></tr>
<tr><td>20</td><td>14</td><td>30</td><td>5</td></tr>
<tr><td colspan="4">Note 1: Flaws ≥ 50% of the maximum allowable size, based on the applicable a/ℓ aspect ratio for the flaw.</td></tr>
</table>
</td><td>No. This item will not affect or be affected by the SS specimens.</td></tr>
</table>

Existing Language in N-831	**Will the Stainless Steel Project Need this Item Modified?**
ii. To be qualified for flaw length sizing, the RMS error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.25 in. (6 mm) for NPS 6 (DN150) and smaller, and 0.75 in. (18 mm) for larger than NPS 6 (DN150).	No. This item will not affect or be affected by the SS specimens.
iii. To be qualified for flaw through-wall height sizing, the RMS error of the flaw through-wall heights estimated by ultrasonics, as compared with the true through-wall heights, shall not exceed 0.125 in. (3 mm).	No. This item will not affect or be affected by the SS specimens.
12) The Owner is responsible for reviewing the procedure and demonstration results to validate that the ranges of the essential variables in the procedure were included in the demonstration.	No. This item will not affect or be affected by the SS specimens.
13) Documentation of the qualifications of procedures and personnel shall be maintained by the Owner. Documentation shall include identification of personnel, NDE procedures, equipment and specimens used during qualification, and results of the performance demonstration.	No. This item will not affect or be affected by the SS specimens.

Applicability: 1995 Edition with the 1996 Addenda through the 2015 Edition

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WHITE PAPER: EFFECTIVENESS OF SUBSTITUTING ULTRASONIC TESTING FOR RADIOGRAPHIC TESTING FOR REPAIR/REPLACEMENT OF CARBON STEEL (N-831)

Due to changes in the ASME records retention policy, this appendix was added to preserve the white paper that accompanied the Board-approved ASME Section XI Code Case N-831. Because this white paper is considered background information, the new records retention policy at ASME and the C & S Connect website allows the document to be purged after a limited time.

At the time this report was written, it was uncertain how and when the new policies of ASME and C & S Connect would affect the white paper, so out of an abundance of caution, the decision was made to reproduce the white paper in this report (with the authors' permission).

Effectiveness of Substituting Ultrasonic Testing for Radiographic Testing for Repair/Replacement of Carbon Steel (N-831)

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Kevin Hacker, Dominion, Glen Allen, VA

Abstract

This paper provides a technical basis for Code Case N-831. Proposed Code Case N-831 will allow the user to substitute ultrasonic (UT) examinations for radiographic (RT) examinations when performing repair and replacement activities in ferritic piping, provided the ultrasonic process (personnel, procedures and equipment) are qualified by performance demonstration.

Introduction

Ultrasonic examinations are usually performed when volumetric inservice inspections (ISI) are required, and radiography is usually performed when repair/replacement activity or construction volumetric examinations are required. It would be extremely beneficial to utilities if repair/replacement welds could be examined with UT. The American Society of Mechanical Engineers (ASME) Code does not provide the necessary detailed requirements to allow utilities to easily substitute one volumetric method for the other but has published three non-nuclear Code cases and three nuclear code cases (N-691, N-713 and N-818) . The United States Nuclear Regulatory Commission (USNRC) has included a limitation in 10CFR 50.55a [1] on the use of alternative examination techniques for repair/replacement activities. A task group was formed by Section XI that includes members from Subgroup NDE and Subgroup Repair/Replacement Activities to address the limitation. Members of the USNRC staff have expressed support for the industry to develop a performance-based approach for using alternative examination methods and techniques.

Background

Major differences between the initial acceptance examination of a new weld and the ISI examination of that weld is the need to detect different types of flaws and to examine a different volume of material. For pipe welds the inner one third of the weld and adjacent base material is examined during Section XI ISI examinations. The construction codes generally require examination of the entire thickness of the weld but no adjacent base material. This impacts the selection of search units and UT procedures. The objective of examining a new weld during fabrication or repair/replacement activities is to detect flaws introduced into the weld volume by improper welding practices. During an inservice examination, it is assumed that the weld was acceptable when originally installed and that flaws detected during inservice examination are service induced and initiated during operation, unless proven otherwise. Typical fabrication flaws include lack of fusion, incomplete penetration, inclusions, porosity, concavity, and cracking. RT is ideally suited for detection of volumetric flaws (inclusions, porosity, and concavity) but is only capable of detecting planar flaws if the radiation beam is favorably aligned with the plane of the flaw. On the other hand, inservice flaws are typically cracks or wall thinning and they are better suited for detection, and their dimensions accurately measured, by UT [11]. Previous studies have shown that UT is capable of detecting the volumetric flaws that

RT detected except for the smallest flaws, typically in the range of .0625 to .15 in. (1.5 to 4 mm) in diameter [7, 11]. These flaws are considered acceptable when applying ASME construction codes acceptance criteria. A large population of welds in power plants can only be examined from one side because the pipes are welded to fittings, vessels, pumps or valves. It is necessary to demonstrate the one-sided examination capability to increase the usefulness of performing UT in lieu of RT in the field because RT does not have this limitation, in general.

Ultrasonic testing is usually performed in a power plant during ISI because RT requires that a high-radiation area be established to prevent radiation exposure to personnel. This precludes personnel from entering the high-radiation area and restricts the outage work in the surrounding areas. In addition, the use of RT includes a risk of accidental exposure to personnel.

The technical basis underlying the requirements of ASME Code Case N-831, is provided in the following table. A dual-column layout of each requirement is reproduced verbatim in the left-hand column. The right-hand column presents the rationale for the requirement. In the tables, gray highlighting has been used to make it easier for the reader to correlate the associated information in the two columns.

Code Case Requirement	Technical Basis and Rationale for Requirement
(1) Use of this Case is limited to welds made as part of a repair/replacement activity and is subject to review by the Authorized Inspection Agency.	
(2) The welds to be examined shall be conditioned such that transducers properly couple with the scanning surface with no more than a 1/32 in. (0.8 mm) gap between the search unit and the scanning surface.	This requirement ensures adequate surface conditions to maintain proper search unit coupling. This refers to the surface that is required to be scanned by the search unit to obtain the examination coverage. This requirement incorporates the surface conditions from Section XI, Non-Mandatory Appendix D.
(3) Ultrasonic examination shall be performed using equipment, procedures, and personnel qualified by performance demonstration as described in this Case.	ASME Section XI, Appendix VIII has shown that the use of performance demonstrations for procedure, personnel and equipment is an effective method to demonstrate the effectiveness of the UT examination systems (procedure, personnel and equipment).
(4) The examination volume shall include 100% of the weld volume and the weld-to-base-metal interface.	This reflects the construction Code examination volume for the acceptance examination, which includes the full thickness of the weld. This is different than the Section XI, PSI/ISI examination volume, which is the inner 1/3 of the weld thickness and includes some volume of adjacent base material.
(a) Angle beam examination of the complete examination volume for fabrication flaws oriented parallel to the weld joint shall be performed.	(a) Examination for circumferential fabrication flaws, oriented parallel to the weld joint, is required.

Code Case Requirement	Technical Basis and Rationale for Requirement
(b) Angle beam examination for fabrication flaws oriented transverse to the weld joint shall be performed to the extent practical. Scan restrictions that limit complete coverage shall be documented.	(b) Examination for fabrication flaws oriented transverse to the weld axis is time consuming and in some cases, based on joint configuration, limits the amount of coverage obtained. Encoded examination scans for transverse flaws is typically about 70% of the examination time, due to the type of scanning required and the small index values between scan lines. It is more difficult to perform automated scanning in the circumferential direction and maintain good contact between the search unit and the examination surface, especially when examining small diameter piping. In addition, many of the weld configurations during R&R activities may limit full coverage of the required examination volume for transverse flaws due to weld transitions/ tapers, or weld shrinkage between the components being welded. The construction Code does not provide provisions for obtaining less than 100% coverage as Section XI does. When it is not possible to obtain complete coverage with the encoded examination equipment, non-encoded examination using procedures qualified to this Code Case will generally increase the examination coverage. Therefore, this Case will allow the use of non-encoded examination for transverse flaws, when the configuration limits the effectiveness of an encoded examination, to supplement the encoded examination for circumferential flaw to obtain the most coverage. The likelihood of transverse flaws occurring in ferritic piping welds is very low and structurally insignificant. Many of the repair or replacement welds are pipe to fitting configurations where access to examine the full examination volume is limited, especially with encoded scan devices. Obtaining complete coverage for axial flaws in these types of configurations is rarely possible. Due to the unlikelihood of transverse flaws occurring 100% coverage for the examination of transverse flaws is not required. The examination for transverse flaws shall be performed to the extent practical.
(c) A supplemental straight beam examination shall be performed on the volume of base metal through which the angle beams will travel to locate any reflectors that can limit the ability of the angle beam to examine the weld. Detected reflectors that may limit the angle beam examination shall be recorded and evaluated for impact on examination coverage. The straight beam examination procedure, or the straight beam portion of the procedure, is required to be qualified in accordance with Section V, Article 4.	(c) To ensure effective examination coverage is being obtained, a supplemental straight beam examination of the volume of base material through which the angle beams will travel to locate any reflectors that can limit the ability of the angle beam to examine the weld. This is a good practice to ensure there are no limiting conditions that prevent full coverage of the required examination volume. If indications are detected during this examination, they are recorded and evaluated to determine their impact on obtaining the necessary coverage. Standard Section V, Article 4 straight beam examinations techniques are capable of performing the function of these supplemental examinations and don’t require qualification in accordance with the requirements of this case.

Code Case Requirement	Technical Basis and Rationale for Requirement
(5) All detected flaws i from (4)(a) and (4)(b) above shall be considered planar flaws and shall be compared to the preservice acceptance standards for volumetric examination in accordance with IWB-3000, IWC-3000, or IWD-3000, as applicable. Preservice acceptance standards shall be applied. Analytical evaluation for acceptance of flaws in accordance with IWB-3600, IWC-3600, or IWD-3600 is permitted.	It is difficult to reliably differentiate between planar flaws (lack of fusion, lack of penetration, cracks, etc.) and volumetric flaws (inclusions, porosity, etc.). Assuming all detected fabrication flaws are planar is a conservative approach. Comparison to the preservice acceptance standards and the application of the analytical evaluation eliminates repairs of insignificant fabrication flaws that have no impact on the service of the component.
(6) Flaws exceeding the applicable acceptance standards, and analytical evaluation has not been performed for acceptance, shall be reduced to an acceptable size or removed and repaired, and the location of the repair shall be reexamined using the same ultrasonic examination procedure that detected the flaw.	Adopted the wording of IWA-4000 requirements.
(7) The ultrasonic examination shall be performed using encoded ultrasonic examination technology that produces an electronic record of the ultrasonic responses indexed to the probe position, permitting off-line analysis of images built from the combined data. Where component configuration does not allow for effective examination for transverse flaws, (e.g. pipe-to-valve, tapered weld transition, weld shrinkage) use of non-encoded ultrasonic examination technology may be used. The basis for the non-encoded examination shall be documented.	The use of encoded UT technology allows data analysis by additional qualified examiners and permits future examination results to be compared to original UT examination results. This process also provides a permanent record of the examination data. Non-encoded examination for transverse flaws is permitted to maximize the examination coverage. The procedure and personnel are required to be qualified by performance demonstration in accordance with this Case.

Code Case Requirement	Technical Basis and Rationale for Requirement
(8) A written ultrasonic examination procedure qualified by performance demonstration shall be used. The qualification shall be applicable to the scope of the procedure, e.g., flaw detection or sizing (length or through-wall height), encoded or non-encoded, single- or dual-side access. The procedure shall: (a) contain a statement of scope that specifically defines the limits of procedure applicability (e.g. minimum and maximum thickness, minimum and maximum diameter, scanning access); (b) specify which parameters are considered essential variables, and a single value, a range of values or criteria for selecting each of the essential variables. (c) list the examination equipment, including manufacturer and model or series; (d) define the scanning requirements, such as beam angles, scan patterns, beam direction, maximum scan speed, extent of scanning, and access; (e) contain a description of the calibration method (i.e., actions required to ensure that the sensitivity and accuracy of the signal amplitude and time outputs of the examination system, whether displayed, recorded, or automatically processed, are repeated from examination to examination); (f) describe the method and criteria for discrimination of indications (e.g., geometric indications versus indications of flaws and surface versus subsurface indications); and (g) describe the surface preparation requirements.	These requirements for procedure content are based on other sections of the Code, such as Section V and Section XI Appendix VIII. These requirements specify the basic input into ultrasonic procedures that are to be qualified to this Code Case and provide sufficient detail to ensure controlled, repeatable and reliable examinations.

Code Case Requirement	Technical Basis and Rationale for Requirement
(9) Performance demonstration specimens shall conform to the following requirements.	Requirements (a)-(f) are based Appendix VIII requirements except that the specimens contain fabrication-type flaws and the flaws are distributed throughout the weld volume instead of the inner 1/3. These are the types of flaws associated with the welding process and the flaws of interest for the examinations performed. Welding related fabrication flaws can occur throughout the weld volume.
(a) The specimens shall be fabricated from ferritic material with the same inside surface cladding process, if applicable, with the following exceptions. (i) Demonstration with shielded metal arc weld (SMAW) single-wire cladding is transferable to multiple-wire or strip-clad processes; (ii) Demonstration with a multiple-wire or strip-clad process is considered equivalent but is not transferable to SMAW type cladding processes.	(a) SMAW is the most challenging surface finish that can adversely impact an examination. If an examination can be performed on SMAW, then it can easily deal with other cladding processes because they produce much smoother surfaces. This requirement is based on Section XI Appendix VIII requirements.
(b) The demonstration specimens shall contain a weld representative of the joint to be ultrasonically examined, including the same welding processes	(b) The type of fabrication flaws introduced into a weld is directly related to the welding process. It is important for the procedure and personnel to demonstrate their ability to detect and size the type of flaws applicable to the weld being examined.
(c) The demonstration set shall include specimens not thicker than 0.1 in. (2.5 mm) more than the minimum thickness, nor thinner than 0.5 in. (13 mm) less than the maximum thickness for which the examination procedure is applicable. The demonstration set shall include the minimum, within ½ of the nominal outside diameter, and maximum pipe diameters for which the examination procedure is applicable. If the procedure is applicable to piping of 24 in. (600 mm) O.D. or larger, the specimen set must include at least one specimen 24 in. (600 mm) O.D. or larger but need not include the maximum diameter.	(c) Because examination procedures typically cover a range of pipe diameters and wall thicknesses, this guidance explains the allowable tolerance for thickness and diameter based on the specimen sizes used for the demonstration.
(d) The demonstration specimen scanning and weld surfaces shall be representative of the surfaces to be examined.	(d) To ensure that the field surface condition is capable of being effectively examined with the examination procedure, demonstration are required to be performed with specimens representative of the surface to be examined.

Code Case Requirement	Technical Basis and Rationale for Requirement
(e) The demonstration specimen set shall include geometric conditions that require discrimination from flaws (e.g., counterbore, weld root conditions, weld crowns) and limited scanning surface conditions for single-side access, when applicable.	(e) Surface conditions and geometrical conditions are potential major limitations adversely impacting examination effectiveness; thus, these conditions must be part of the sample set in order to have assurance that they do not impact the examination.
(f) The demonstration specimens shall include both planar and volumetric fabrication flaws (e.g., lack of fusion, crack, incomplete penetration, slag inclusions) representative welding process or processes of the welds to be examined. The flaws shall be distributed throughout the examination volume.	(f) Welding fabrication flaws can be either planar or volumetric type flaws and are directly related to the welding process being applied. These types of flaws can occur throughout the weld volume. Requiring the demonstration specimen flaws to be typical for the welding process being applied and distributed throughout the examination volume ensures the demonstrated procedure and personnel are capable of detecting and sizing the flaws of interest. Lack of fusion flaws will be more prevalent in welds then cracks welding flaws. The ultrasonic response from lack of fusion flaws is similar to transgranular cracking. Lacks of fusion as well as other non-crack fabrication flaws are contained within a one weld layer thickness, whereas a crack would most likely be larger in height. For these reasons the distribution of planar flaws can include more lack of fusion flaws than cracks.
(g) Specimens shall be divided into flawed and unflawed grading units. (i) Flawed grading units shall be the actual flaw length, plus a minimum of 0.25 in. (6 mm) on each end of the flaw. Unflawed grading units shall be at least 1 in. (25 mm). (ii) The number of unflawed grading units shall be at least 1-1⁄2 times the number of flawed grading units.	(g) Grading units were selected to simplify the grading process and make it objective. The spacing between grading units helps ensure that there is no cross contamination from one grading unit to another because of their proximity. Grading units are not marked on the test specimen so that an examiner does not know how many are in a particular specimen or where they are located. The size of the grading unit was a compromise to maintain an objective demonstration and minimize the cost of the mockups. This amount of unflawed grading units is based on Appendix VIII Supplement 10 demonstration test requirements and provides sufficient unflawed area to effectively demonstrate the procedures capabilities.
(h) Demonstration specimen set flaw distribution shall be as follows:	Generally, the requirements for the number or percentage of flaw types and locations are a minimum amount and rounding is not an issue. However, when necessary rounding-off shall be performed to the requirements of ASTM Recommended Practice E-29.

Code Case Requirement	Technical Basis and Rationale for Requirement
(i) For thickness greater than 0.50 in. (13mm); at least 20% of the flaws shall be distributed in the outer third of the specimen wall thickness, at least 20% of the flaws shall be distributed in the middle third of the specimen wall thickness and at least 40% of the flaws shall be distributed in the inner third of the specimen wall thickness. For thickness 0.50 in. (13mm) and less, at least 20% of the flaws shall be distributed in the outer half of the specimen wall thickness and at least 40% of the flaws shall be distributed in the inner half of the specimen wall thickness.	(i) This requirement provides a distribution of the flaws within the volume of the material based on the significance of the flaw in relation to the surface. These distributions will fully address the scope of the procedure for detection and sizing of indications throughout the thickness of the weld.
(ii) At least 30% of the flaws shall be classified as surface planar flaws in accordance with IWA-3310. At least 40% of the flaws shall be classified as subsurface planar flaws in accordance with IWA-3320.	(ii) This requirement provides a distribution of the flaws based on their classification as surface or subsurface flaws. The majority of flaws within the weld volume are usually subsurface flaws. Subsurface planar flaws do not produce a high amplitude corner trap response, as the surface-connected flaws, and are usually more difficult to detect. These distributions will fully address the scope of the procedure for detection and sizing of indications throughout the thickness of the weld, with an emphasis on the more difficult to detect and size.
(iii) At least 50% of the flaws shall be planar flaws, such as lack of fusion, incomplete penetration, or cracks. At least 20% of the flaws shall be volumetric flaws, such as slag inclusions.	(iii) This requirement provides a distribution of flaws based on flaw type, planar or volumetric. Volumetric flaws are usually easier to detect, as they are detected over a large range of angles. These types of flaws are typically lower amplitude than planar flaws and may be detected from either side of the weld with similar responses. Planar flaws are generally more difficult to detect, especially when being examined with single-side access. Due to the difficulty in detecting planar type flaws, this requirement is biased towards the planar flaws to effectively demonstrate the procedure capabilities.

Code Case Requirement	Technical Basis and Rationale for Requirement
(iv) The flaw through-wall heights shall be based on the applicable acceptance standards for volumetric examination in accordance with IWB-3400, IWC-3400, or IWD-3000, as applicable. At least 30% of the flaws shall be classified as acceptable planar flaws, with the smallest flaws being at least 50% of the maximum allowable size based on the applicable a/ℓ aspect ratio for the flaw. Additional smaller flaws may be included in the specimens to assist in establishing a detection threshold, but shall not be counted as a missed detection if not detected. At least 30% of the flaws shall be classified as unacceptable in accordance with the applicable acceptance standards. Welding fabrication flaws are typically confined to a height of a single weld pass. Flaw through-wall height distribution shall range from approximately one to four weld pass thicknesses, based on the welding process used.	(iv) Including acceptable and unacceptable flaw sizes will test the procedure's ability to discriminate between these flaws. Most fabrication flaws are the height of a weld pass but it is possible to have, for example slag, stacked near each other in adjacent weld passes so it is reasonable to include deeper flaws in the test set. These flaw sizes demonstrate that the techniques are capable of detecting and sizing flaws near the accept/reject boundary. Many scenarios for flaw sizes have been evaluated using the IWB-3514 acceptance table and 50% of the maximum allowable flaw size is reasonable to ensure detection sensitivity that unacceptable flaws are detected.
(v) If applicable, at least two flaws but no more than 30% of the flaws shall be oriented perpendicular to the weld fusion line and the remaining flaws shall be circumferentially oriented.	(v) When using the weave welding technique, the mockup needs to include transverse flaws to demonstrate the procedure capabilities for transverse flaws.
(vi) For demonstration of single-side access capabilities, at least 30% of the flaws shall be located on the far side of the weld centerline and at least 30% of the planar flaws shall be located on the near side of the weld centerline. The remaining flaws shall be distributed on either side of the weld.	(vi) Volumetric flaw placement for single-side access capability demonstrations are not as critical as planar flaws. Volumetric type flaws are typically detectable from either side of the weld and with various beam angles. Planar flaws located on the near side of the weld are usually more difficult to detect than those located on the far side of the weld, due to the flaw orientation. These percentages have been selected to test the effectiveness of single-side examinations and avoid testmanship. Procedure qualification requires detection of all flaws of interest in the specimen set. Personnel qualification for flaw detection requires at least 80% detection of the flaws of interest. The requirement to have at least 30% of the planar flaws located on the near side of the weld ensures a successful examiner is capable of detecting flaws positioned in the most difficult locations for single-side access examinations. PNNL 19086 (5.2.2) [10] states that single-sided UT can be used with ferritic materials.

Code Case Requirement	Technical Basis and Rationale for Requirement
(10) Ultrasonic examination procedures shall be qualified by performance demonstration in accordance with the following requirements.	
(a) The procedure shall be demonstrated using either a blind or a non-blind demonstration.	(a) Feedback provided during the course of non-blind procedure qualifications has proven to be effective in enhancing examination procedures. The requirement to provide objective evidence during the data analysis process ensures that the procedure requirements are properly applied and are effective. This process provides an optimized procedure for the examiner to implement during the “blind” personnel test, which is another validation of the procedure’s capabilities.
(b) The non-blind performance demonstration is used to assist in optimizing the examination procedure. When applying the non-blind performance demonstration process, personnel have access to limited knowledge of specimen flaw information during the demonstration process. The non-blind performance demonstration process consists of an initial demonstration without any flaw information, an assessment of the results and feedback of the performance provided to the qualifying candidate. After an assessment of the initial demonstration results, limited flaw information may be shared with the candidate, as part of the feedback process, to assist in enhancing the examination procedure to improve the procedure performance. To maintain the integrity of the specimens for blind personnel demonstrations, only generalities of the flaw information may be provide to the candidate. Procedure modifications or enhancements made to the procedure, based on the feedback process, shall be applied to all applicable specimens based on the scope of the changes.	(b) This three-part process of implementing non-blind demonstrations ensure an objective assessment of the procedures capability without jeopardizing the integrity of the specimens, thus eliminating the need for multiple specimen sets for procedure and personnel demonstrations. This provides the ability to provide constructive feedback for procedure enhancement to improve the procedure performance.

Code Case Requirement	Technical Basis and Rationale for Requirement
(c) Objective evidence of a flaw's detection, length and through-wall height sizing, in accordance with the procedure requirements, shall be provided to the organization administering the performance demonstration.	(c) The requirement to provide objective evidence, of the calls made for flaw detection and sizing, provides a true assessment of the procedure guidance and capabilities. The need to provide objective evidence also identifies procedure weaknesses and areas that need further enhancements.
(d) The procedure demonstration specimen set shall be representative of the procedure scope and limitations (e.g., thickness range, diameter range, material, access, surface condition).	(d) The need to have a demonstration specimen set representative of the procedure scope and limitations ensures the successfully demonstrated procedure is capable of performing its intended function.
(e) The demonstration set shall include specimens to represent the minimum and maximum diameter and thickness covered by the procedure. If the procedure spans a range of diameters and thicknesses, additional specimens shall be included in the set to demonstrate the effectiveness of the procedure throughout the entire range.	(e) Because examination procedures cover a range of pipe diameters and wall thicknesses, this guidance ensures that the procedure/equipment and personnel are tested for the full range covered by the procedure scope. As a minimum, the demonstration set shall include specimens to represent the minimum and maximum diameter and thickness covered by the procedure. In addition, when the procedure spans a range of diameters and thicknesses, additional specimens shall be included in the set to demonstrate the effectiveness of the procedure throughout the entire range. For example, an examination procedure covers a range of diameters from 6″ to 28″. The procedure calls for a change in search unit size and frequency at the 12″, 18″ and 24″ diameters. To effectively demonstrate this procedure throughout the entire range of diameters, as a minimum, specimen with diameters of 6″, 12″, 18″ and 24″ would need to be included in the demonstration test set.
(f) The procedure demonstration specimen set shall include at least 30 flaws and shall meet the requirements of (9) above.	(f) The procedure demonstration specimen includes a minimum number of flaws equivalent to three personnel tests. This increases the robustness of the equipment and procedure qualification because all the flaws have to be detected by the procedure and equipment. This requirement to contain a minimum number of flaws equivalent to three personnel tests should lead to a higher pass rate for personnel. Relief requests and EPRI studies [7] for UT in lieu of RT have shown this to be an acceptable number of flaws for the procedure demonstration.
(g) Procedure performance demonstration acceptance criteria	

Code Case Requirement	Technical Basis and Rationale for Requirement
(i) To be qualified for flaw detection, all flaws in the demonstration set that are not less than 50% of the maximum allowable size, based on the applicable *a*/*ℓ* aspect ratio for the flaw, shall be detected. In addition, when performing blind procedure demonstrations, no more than 20% of the non-flawed grading units may contain a false call. Any non-flaw condition (e.g., geometry) reported as a flaw shall be considered a false call.	(i) The detection threshold of 50% of the maximum allowable flaw size, based on the applicable a/l aspect ratio for the flaw, ensures the procedure is capable of detecting the flaws of interest, i.e. unacceptable flaws. The use of a minimum threshold also ensures that the procedure is not overly sensitive, resulting in the detection of very small, insignificant flaws that would also result in an increase in the false call rate.
(ii) To be qualified for flaw length sizing, the root mean square (RMS) error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.25 in. (6 mm) for NPS 6 (DN150) and smaller, and 0.75 in. (18 mm) for larger than NPS 6 (DN150).	(ii) The RMSE criteria for smaller piping was reduced because of the smaller circumference. The Canadian UT in lieu of RT program [6] used a smaller RMSE length sizing criteria for their small diameter piping and has shown that this reduced length sizing RMSE is appropriate for the smaller diameter piping.
(iii) To be qualified for flaw through-wall height sizing, the RMS error of the flaw through-wall heights estimated by ultrasonics, as compared with the true through-wall heights, shall not exceed 0.125 in. (3 mm).	(iii) The RMS error criteria for through-wall height sizing has been adopted from Appendix VIII acceptance criteria.
(iv) RMS error shall be calculated as follows: $RMS = \left[\frac{\sum_{i-1}^{n} (m_i - t_i)^2}{n} \right]^{1/2}$ Where m_i = measured flaw size n = number of flaws measured t_i = true flaw size	(iv) Root mean square (RMS) error is a standard statistical measurement that was adopted into Appendix VIII and has been effectively used to evaluate flaw sizing performance. Prior to procedure or personnel qualification demonstrations, the flaw truth needs to be established. The flaw true size is generally determined by the fabricator of the specimens and experience has shown that most of the flaws meet the specifications when confirmed by an ultrasonic examination. When the as-built dimensions don't match the UT measured size, RT has shown to be effective for confirming the actual flaw length for flaws detectable with RT. The true flaw length can be derived from the UT and RT results. RT triangulation or UT can be used to determine the through-wall height if the size provided by the specimen manufacturer is questionable

Code Case Requirement	Technical Basis and Rationale for Requirement
(h) Essential variables may be changed during successive personnel performance demonstrations. Each examiner need not demonstrate qualification over the entire range of every essential variable.	(h) This process for changing essential variables follows the requirements of Appendix VIII, VIII-3130.
(11) Ultrasonic examination personnel shall be qualified in accordance with IWA-2300. In addition, examination personnel shall demonstrate their capability to detect and size flaws by performance demonstration using the qualified procedure in accordance with the following requirements:	This statement establishes the minimum qualification requirements the examiner must have prior to attempting the performance demonstration. Personnel performance demonstration are intended to assure that examination personnel are capable of performing to the specified requirements of the qualified procedure and to reach the desired conclusions regarding detection and sizing. Generally, examination personnel that perform encoded ultrasonic data analysis maintain a higher skill level for UT examination than the non-encoded examiner. This is mainly due to the knowledge required to operate the encoded system, understand the examination parameters, and interpret the data. In addition, the required performance demonstration of this Case using small fabrication flaws ensures highly skilled examiners in order to successfully pass the required testing for both encoded and non-encoded examiners. It should be noted that the examination for fabrication flaws is different than ISI flaws, mainly due to the flaw type, flaw size, examination volume, and examination techniques.
(a) The personnel performance demonstration shall be conducted in a blind fashion (flaw information is not provided). (i) The demonstration specimen set shall contain at least 10 flaws and shall meet the flaw distribution requirements of (9)(h) above, with the exception of (9)(h)(v). When applicable, at least one flaw but no more than 20% of the flaws shall be oriented perpendicular to the weld fusion line, and the remaining flaws shall be circumferentially oriented.	The personnel performance demonstration is conducted in a blind fashion where the examiner has no knowledge of the number, type, and/or location of flaws. When a blind personnel performance demonstration is performed, the examination procedure must be very detailed to allow an independent evaluator to reach the same interpretation. The following provides an example of a single-side access examination applying the minimum flaw distribution of (9)(h): (9)(h)(i) at least two flaws positioned within the outer 1/3t, two flaws positioned within the middle 1/3t, four flaws within the inner 1/3t. (9)(h)(ii) at least three surface planar flaws and four subsurface planar flaws. (9)(h)(iii) at least five planar type flaws (lack of fusion, incomplete penetration, cracks, etc.) and at least two volumetric type flaws (inclusions). (9)(h)(iv) at least three acceptable and three unacceptable flaws. (9)(h)(v) at least one and no more than two axial oriented flaw(s). (9)(h)(vi) at least three planar flaws on the near side of the weld centerline and at least three flaws (planar and/or volumetric) on the far side of the weld centerline.

<table>
<tr><th>Code Case Requirement</th><th>Technical Basis and Rationale for Requirement</th></tr>
<tr><td></td><td>See the following table for an example of these requirements, applied to a single diameter and thickness scenario, in a table format to better understand the flaw distribution.
<table>
<tr><th>Criteria</th><th>(9)(h)(i)</th><th>(9)(h)(ii)</th><th>(9)(h)(iii)</th><th>(9)(h)(iv)</th><th>(9)(h)(v)</th><th>(9)(h)(vi)</th></tr>
<tr><th>Flaw #</th><th>Region1/3t</th><th>Surface or Subsurface</th><th>Flaw Type</th><th>Acceptance</th><th>Flaw Orientation</th><th>Near or Far Side</th></tr>
<tr><td>1</td><td>Outer</td><td>Surface</td><td>Crack</td><td>Unacceptable</td><td>Circumferential</td><td>Near</td></tr>
<tr><td>2</td><td>Outer</td><td>Surface</td><td>LOF</td><td>Unacceptable</td><td>Circumferential</td><td>Near</td></tr>
<tr><td>3</td><td>Middle</td><td>Subsurface</td><td>LOF</td><td>Acceptable</td><td>Circumferential</td><td>Far</td></tr>
<tr><td>4</td><td>Middle</td><td>Subsurface</td><td>Slag</td><td>Acceptable</td><td>Circumferential</td><td>Far</td></tr>
<tr><td>5</td><td>Inner</td><td>Subsurface</td><td>LOF</td><td>Acceptable</td><td>Circumferential</td><td>Near</td></tr>
<tr><td>6</td><td>Inner</td><td>Subsurface</td><td>Slag</td><td>Acceptable</td><td>Circumferential</td><td>Far</td></tr>
<tr><td>7</td><td>Inner</td><td>Surface</td><td>LOF</td><td>Unacceptable</td><td>Circumferential</td><td>Near</td></tr>
<tr><td>8</td><td>Inner</td><td>Surface</td><td>IP</td><td>Unacceptable</td><td>Circumferential</td><td>Centerline</td></tr>
<tr><td>9</td><td>Middle</td><td>Subsurface</td><td>LOF</td><td>Acceptable</td><td>Axial</td><td>N/A</td></tr>
<tr><td>10</td><td>Outer</td><td>Subsurface</td><td>LOF</td><td>Acceptable</td><td>Circumferential</td><td>Far</td></tr>
<tr><td colspan="7">Note: Flaw 10 is added to meet the requirement to have at least 10 flaws in accordance with paragraph (11)(a)(i).</td></tr>
</table>
</td></tr>
<tr><td></td><td>To reduce testmanship, the remaining flaws may be selected from the requirements of (9)(h)(i) through (iv) and (vi).
This guidance is provided with some vagueness to ensure the testing remains blind.
The initial procedure qualification provides a very detailed and robust examination procedure. With the flaw distributions of (11)(a)(i) and the 80% flaw detection requirement of (11)(b)(i), it is highly unlikely that a candidate that lacks the required skills would pass this test.</td></tr>
</table>

<table>
<tr><th>Code Case Requirement</th><th>Technical Basis and Rationale for Requirement</th></tr>
<tr><td>(b) Personnel performance demonstration acceptance criteria:</td><td></td></tr>
<tr><td>(i) To be qualified for flaw detection, personnel performance demonstration shall meet the requirements of the following table for both detection and false calls. Any non-flaw condition (e.g., geometry) reported as a flaw shall be considered a false call.
<table>
<tr><th colspan="4">Performance Demonstration Detection Test Acceptance Criteria</th></tr>
<tr><th colspan="2">Detection Test Acceptance Criteria</th><th colspan="2">False Call Test Acceptance Criteria</th></tr>
<tr><th>No. of Flawed Grading Units[1]</th><th>Minimum Detection Criteria</th><th>No. of Unflawed Grading Units</th><th>Maximum Number of False Calls</th></tr>
<tr><td>10</td><td>8</td><td>15</td><td>2</td></tr>
<tr><td>11</td><td>9</td><td>17</td><td>3</td></tr>
<tr><td>12</td><td>9</td><td>18</td><td>3</td></tr>
<tr><td>13</td><td>10</td><td>20</td><td>3</td></tr>
<tr><td>14</td><td>10</td><td>21</td><td>3</td></tr>
<tr><td>15</td><td>11</td><td>23</td><td>3</td></tr>
<tr><td>16</td><td>12</td><td>24</td><td>4</td></tr>
<tr><td>17</td><td>12</td><td>26</td><td>4</td></tr>
<tr><td>18</td><td>13</td><td>27</td><td>4</td></tr>
<tr><td>19</td><td>13</td><td>29</td><td>4</td></tr>
<tr><td>20</td><td>14</td><td>30</td><td>5</td></tr>
<tr><td colspan="4">Note 1: Flaws ≥ 50% of the maximum allowable size, based on the applicable a/l aspect ratio for the flaw.</td></tr>
</table>
</td><td>(i) The performance demonstration for personnel detection process consists of two separate tests. A test that measures detection capability and a test that measures false calls. This acceptance criteria screens the examiners to ensure that the examination population that passed have the desired performance. This is consistent with existing approved code position which is based on a high pass rate for those with a probability of detection (POD) > 0.8 and false call probability (FCP) of < 20% and low pass rate for examiners with a POD of < 0.6 and FCP > 20%.</td></tr>
</table>

Code Case Requirement	Technical Basis and Rationale for Requirement
(ii) To be qualified for flaw length sizing, the RMS error of the flaw lengths estimated by ultrasonics, as compared with the true lengths, shall not exceed 0.25 in. (6 mm) for NPS 6 (DN150) and smaller, and 0.75 in. (18 mm) for larger than NPS 6 (DN150).	(ii) The length sizing acceptance criteria for personnel demonstrations are the same as the procedure criteria.
(iii) To be qualified for flaw through-wall height sizing, the RMS error of the flaw through-wall heights estimated by ultrasonics, as compared with the true through-wall heights, shall not exceed 0.125 in. (3 mm).	(iii) The through-wall height sizing acceptance criteria for personnel demonstrations are the same as the procedure criteria.
(12) The Owner is responsible for reviewing the procedure and demonstration results to validate that the ranges of the essential variables in the procedure were included in the demonstration.	
(13) Documentation of the qualifications of procedures and personnel shall be maintained by the Owner. Documentation shall include identification of personnel, NDE procedures, and equipment and specimens used during qualification, and results of the performance demonstration.	Documentation is required so that programs can be audited and third parties can confirm that the procedures, personnel, and equipment had successfully passed the demonstration as well as serving as a means to verify that UT was being performed according to what was qualified.

Field Implementation

One non-US utility recently implemented a large program substituting ultrasonic examination for radiographic examination. As required by their regulatory authority, the program was based on the intent of Appendix VIII and a modification of Code Case N-659 requirements. The project qualified a phased array UT technique for examination of feeder tube installation welds as an alternate to the customary use of RT. The objective of the work was to refurbish/re-construct Pressurized Heavy Water Reactor (PHWR) reactor core and primary system "feeder" piping from fuel channel ends to main system loop headers. This included replacement of 380 carbon steel feeder pipes at each end of reactor. Five pipe sizes (1.5, 2.0, 2.5, 3.0, 3.5 NPS) were supplied in prefabricated pipe subassembly segments. Field installation involved two butt welds per pipe that resulted in 1520 new welds total. If RT examination methods were employed approximately 7000 shots would have been required to obtain full weld volume coverage. It was estimated that the exclusion zone requirements would have halted all other work on the reactor face for approximately 1500 hours. The associated dose to RT technicians becomes substantial, not including the dose from the reactor vault environment. It was decided to develop a phased array UT (PAUT) procedure to examine the welds and qualify it to ASME. The technical specification for PAUT was based on N659-2 and the intent of the Section XI Appendix VIII requirements, but augmented and modified to better reflect the application as a construction code examination for smaller pipe sizes. The major enhancements to the Code requirements included:

- Three specimen sets consisting of seven welds created (using all five diameters and thicknesses), each set containing 15 flaws
- Procedure demonstration (non-blind) used all 15 flawed pipe samples (45 specimen flaws) and was required to detect 100% of the flaws (from one side)
- Personnel demonstration was a "pure" blind test for detection, false calls, length sizing and flaw characterization. The grading units were .64 in. (16 mm) in length.
- All flaws included in the specimen sets were flaws that would be considered relevant to the construction type flaws; lack of fusion, porosity, cracks, incomplete penetration, ID/OD connected and subsurface flaws
- The weld crowns were not ground
- The procedure was successfully qualified by performance demonstration to the enhanced requirements. Three NDE technicians were successfully qualified in "blind" test process. Flaw length sizing error was decreased to an RMSE of 0.25″ (6.4 mm) (from 0.75″ (19 mm) from Appendix VIII).

Use of the qualified procedure and technicians were being implemented during the time of the presentation. This project highlighted a benefit of UT. That is the near real-time feedback provided to the welders resulted in improved welding and more acceptable welds. By not using RT the other outage work could be completed without interruption.

Benefits

There are several benefits in performing UT in lieu of RT. These include:

1. UT avoids schedule impacts on other outage work. Radiography requires the establishment of high-radiation area boundaries (exclusion zones) that only the radiographers with dosimeters can enter. The exclusion zone must be secured against unauthorized entry, and may require exclusion of all personnel other than radiographers from the entire reactor building. This impacts other outage work within the area, affecting the outage length.
2. UT eliminates the safety concern of personnel exposure to radiation from the radiography source.
3. UT allows examination and repair activities to be closely coordinated, allowing almost immediate feedback to welders performing repairs. RT typically requires a delay of several hours to a full shift or more to obtain examination results.

Utilities have estimated the potential cost savings if UT is used to examine repair/replacement welds instead of RT. Estimated benefits are listed below for repair/replacement activities during one outage at three different nuclear power stations:

- $5 million for Class 2 piping and containment equipment hatch
- $750 thousand for steam generator replacement
- $200 thousand for feedwater and valve replacement

It is difficult to compare the costs of the methods themselves due to the variety of conditions and geometries, but typically radiography and manual UT cost approximately the same, and automated UT is more expensive. However, RT ultimately has additional costs associated with additional personnel radiation dose concerns inherent with RT, plus the schedule impact on other work scheduled in the exclusion area during radiography examinations.

Conclusions

The results of this study and others cited in the literature search support the use of UT in lieu of RT for repair/replacement activities. This is particularly true for the planar flaws that are also more detrimental to the intended service of the component than volumetric flaws. When accessible, examinations should be performed from both sides of the weld, but studies have shown that acceptable performance can also be achieved with single-sided examinations for ferritic welds. Procedures previously qualified to Appendix VIII can be modified to encompass the entire examination volume and record volumetric and subsurface flaws in addition to the inner surface breaking cracks. The UT procedures can use pulse echo, phased array or TOFD techniques. Automated UT results in reproducible images that can be used to compare the integrity of welds before and after going into service. The personnel need to be qualified in a blind fashion. Non-blind procedure qualifications may be performed. The benefits for a utility to perform UT in lieu of RT can be significant. The major impact is that the other outage activities can be performed without the interruptions caused by the high-radiation areas necessary for RT. The potential radiation safety hazards associated RT also make UT the more desirable method.

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