

Nondestructive Evaluation: Improving NDE Examiner Proficiency

1015150



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Technical Update, November 2007

EPRI Project Manager

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PRODUCT DESCRIPTION

The Nuclear Regulatory Commission (NRC) has been concerned for several years that ultrasonic examiners are not maintaining their proficiency during the three-year requalification period required for detection of the intergranular stress corrosion cracking (IGSCC) flaw mechanism. The NRC may recommend more frequent and more stringent testing requirements if the level of proficiency does not improve as judged by candidate pass rates for austenitic qualification (with IGSCC). Phase One of this project provided a statistical analysis of IGSCC pass rates through the Performance Demonstration Initiative (PDI) and focused on both initial IGSCC qualifications and requalifications performed between 1999 and 2006. Phase One also produced an improvement strategy in the form of a training session presented immediately before the qualification examination. This update describes the development and implementation of this strategy for improving the pass rates of PDI IGSCC requalifications and, by extension, ultrasonic examiner proficiency. If successful, the proposed program could reduce requalification testing requirements. Successful results could discourage the NRC from adding new requalification and proficiency examination requirements and could also provide a measure of justification for using a performance-based approach for nondestructive evaluation (NDE) personnel certification.

Results and Findings

From experience, we have learned that specific, hands-on training can significantly improve the performance of examiners during qualification and requalification examinations. The higher pass rate of the test group as compared to the control group shows that the structured, hands-on training was effective and should be considered a prerequisite for IGSCC requalification. The success of the hands-on training session as preparation for the PDI austenitic (with IGSCC) requalification examination should be offered to other experienced candidates who have had difficulty with the exam, especially the IGSCC portion, or those who would simply like a review immediately before the exam. Candidate feedback from the session indicated that the training had value and should be incorporated into the PDI Program. It is also recommended that the PDI Steering Committee should consider employing specific hands-on training for candidates who will attempt to take the dissimilar metal (DM) weld qualification tests.

Challenges and Objectives

The strategy-based training session was designed to be thorough but very specific to the task of detecting and length sizing ISGCC and austenitic thermal and fatigue flaws. The session was designed around each individual transducer and its application to the overall detection strategy. The session was planned for a five-day week to cover the basic information on the first day via PowerPoint slides and interactive classroom instruction with demonstrations of detection techniques. Extensive individual practice and feedback on selected samples was planned for the second day of the session, with the practice practical beginning late in the afternoon and continuing into the third day. The last part of the third day was devoted to practice practical feedback and questions. The actual PDI requalification session occupied the fourth and fifth days of the session.

The classroom training instruction presented information thought to be critical to IGSCC detection and included a short review of the history and causes of IGSCC, optimum application of the 45-, 60-, and 70-degree shear wave and refracted longitudinal wave transducers, and detection and length sizing strategies. This training material is presented in Appendix A of this report. Each application module discussed selecting the proper transducer, calibration, scan pattern and sensitivity, problem areas, and signal discrimination. Flowcharts detailing the detection strategy and process were included for IGSCC and austenitic detection, axial and circumferential flaws, and single- and dual-sided access.

Applications, Value, and Use

Requalification examinations for IGSCC ultrasonic testing (UT) examiners have documented poor examiner performance, with pass rates averaging 57%. The NRC has questioned whether examiners have maintained their proficiency over the three-year requalification period and may recommend more frequent and more stringent testing requirements. The NRC is also questioning why there are no requalification requirements for DM weld UT examiners. An alternative to stringent requalification requirements is to provide annual practice or training as part of a performance-based qualification approach. In 2006, Phase One of this project evaluated the past performance of UT candidates who participated in the PDI Program and developed a strategy to improve the pass rates. Phase Two of this project will develop and implement the suggested strategy of specific, hands-on training and evaluate the effectiveness of the improvement strategy by studying the impact on a sample of UT examiners.

Approach

A training/proficiency session plan was developed based on lessons learned and this project's previous evaluation of the PDI qualification database. Two groups of previously qualified candidates were evaluated during a PDI demonstration. One of the groups received this newly developed training/proficiency program. Their performance was evaluated, on an individual candidate level, considering areas such as experience, training, and past performance. The results of this test group were compared to the results of a control group that did not participate in this program.

Keywords

Intergranular stress corrosion cracking (IGSCC)
Personnel recertification
Qualification
Ultrasonic examination
Performance Demonstration Initiative (PDI)
NDE skills

ABSTRACT

The Nuclear Regulatory Commission (NRC) has been concerned for several years that ultrasonic examiners are not maintaining their proficiency during the three-year requalification period required for detection of the intergranular stress corrosion cracking (IGSCC) flaw mechanism. The NRC may recommend more frequent and more stringent testing requirements if the level of proficiency does not improve as judged by candidate pass rates for austenitic qualification (with IGSCC). Phase One of this project provided a statistical analysis of IGSCC pass rates through the Performance Demonstration Initiative (PDI) and focused on both initial IGSCC qualifications and requalifications performed between 1999 and 2006. Phase One also produced an improvement strategy in the form of a training session presented immediately before the qualification examination. This update describes the development and implementation of this strategy for improving the pass rates of PDI IGSCC requalifications and, by extension, ultrasonic examiner proficiency. If successful, the proposed program could reduce requalification testing requirements. Successful results could discourage the NRC from adding new requalification and proficiency examination requirements and could also provide a measure of justification for using a performance-based approach for nondestructive evaluation (NDE) personnel certification.

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INTRODUCTION

Requalification examinations for intergranular stress corrosion cracking (IGSCC) ultrasonic testing (UT) examiners have documented poor examiner performance, with pass rates averaging 57%. The Nuclear Regulatory Commission (NRC) has questioned whether examiners have maintained their proficiency over the three-year requalification period and may recommend more frequent and more stringent testing requirements. The NRC is also questioning why there are no requalification requirements for dissimilar metal (DM) weld UT examiners. An alternative to stringent requalification requirements is to provide annual practice or training as part of a performance-based qualification approach. In 2006, Phase One of this project evaluated the past performance of UT candidates who participated in the Performance Demonstration Initiative (PDI) Program and developed a strategy to improve the pass rates. Phase Two of this project will develop and implement the suggested strategy of specific, hands-on training and evaluate the effectiveness of the improvement strategy by studying the impact on a sample of UT examiners.

Transferring Essential Skills

Personnel are commonly qualified for technical tasks by completing a specified amount of on-the-job training (OJT). However, exposure to training and job experience does not necessarily lead to job proficiency. Prior research involving 32 candidates (two groups) for qualification in the PDI Program revealed no positive correlation between the number of years of nondestructive evaluation (NDE), ultrasonic, or piping examination experience and ultrasonic examination performance. Results such as these are not puzzling if one recognizes that unstructured training and job experience may or may not include the key factors that are essential for learning—measurement and feedback of performance results. Admittedly, it is difficult to measure performance and provide feedback while on the job—actual flaws may be rarely encountered—and timely, accurate measurement and feedback may be difficult, even in laboratory-type training settings. Therefore, it is important to look to new technologies as avenues for incorporating key learning factors into the skill development process and to focus on these factors in structuring both training and on-the-job experience. Personnel learn at different speeds, and a performance-based training program would likely decrease training time while improving retention [1].

A Structured Approach to NDE Skills Development

The development and implementation of a structured approach to NDE skills development will be evaluated by comparing the results of a test group to those of another group that did not receive the training. The most effective combination of teaching techniques will be implemented. Human performance studies have shown the importance of including certain strategies in training, such as immediate feedback. Although they are more costly and time consuming to develop, computer-based interactive materials can be employed for entry-level and also more advanced knowledge-based training. Virtual systems can be used in developing skills in the

cognitive aspects of NDE tasks—those that require reasoning, interpretation, application of knowledge, and the development and testing of hypotheses. Practical aspects of NDE tasks can be learned and practiced in the actual job environment. The objective is to structure the skills-development experience in a manner that applies the available technology and resources to produce better qualified NDE personnel in less time. Recognizing that individuals learn at different rates, an important aspect of the structured approach will be to accommodate individual differences. Adequate proficiency testing will be required in the process so that an individual can move from one level of performance to the next when ready, but only when ready. This objective-oriented approach to training has been adopted by the Accreditation Board of Engineering and Technology (ABET) [1].

Past Performance of NDE Personnel

Utility management responsible for in-service inspections has become concerned with the decrease in quantity, quality, and knowledge of the NDE workforce. This is evidenced by the numerous attempts necessary to successfully pass the UT performance tests required by the nuclear industry since May 2000. Prior to that date, UT examiners were required to pass a demonstration program that included service-removed pipe sections containing IGSCC. In general, the pass rate for IGSCC detection on the first attempt was between 19% and 34%; this rate increased to 27% and 70% after multiple attempts. These data are based on 27 classes with 182 candidates held from September 1985 until July 1987. In 2001, the IGSCC-qualified personnel were still required to pass the IGSCC demonstration test every three years. The pass rate was approximately 50% on the first attempt and increased to approximately 75% after multiple attempts.

Performance Demonstration Initiative Program

The PDI is an organization composed of all U.S. nuclear utilities that was formed to provide an efficient, cost-effective, and technically sound implementation of Appendix VIII performance demonstration requirements. It consists of an executive committee, a steering committee, and working groups. The PDI is responsible for preparing the test protocol, documenting the budget and schedule, providing the interface between the NRC and the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, and providing technical, financial, and administrative oversight. The EPRI NDE Center is the Performance Demonstration Administrator (PDA) for the program. Under the guidance of the PDI, the PDA collects and disperses supplemental funding, provides technical and legal support, and administers the plan provided by the PDI. This includes specimen design, sample fabrication, qualification testing, and maintaining registries. The PDA also performs other support activities such as participation in the Nuclear Procurement Issues Committee (NUPIC) and EPRI internal quality assurance (QA) audits, coordinating Authorized Nuclear Inservice Inspectors' (ANII's) involvement in the PDI Program, and maintaining generic procedures for manual ultrasonic examinations.

The PDI Program was formed in 1991 and began administering qualifications in 1994. In 1996, the PDI Program was accepted by the NRC as an acceptable method of meeting the requirements of ASME Section XI, Appendix VIII. The PDI Program has continued to maintain a high level of industry utilization and has administered approximately 550 IGSCC qualifications to domestic and foreign participants since its commencement. The PDI Qualification Laboratory is shown in Figure 1-1.



Figure 1-1
PDI Qualification Laboratory

Administration of Qualification Examinations

The PDI Program administers qualifications related to the ultrasonic inspections of piping components, bolting components, and reactor pressure vessel (RPV) welds. This report focuses only on IGSCC qualifications of piping components. These qualifications are performed in accordance with the requirements of ASME Section XI, Appendix VIII. The performance of these qualifications requires piping specimens containing known defects. The PDI Program maintains a sample inventory containing hundreds of such specimens. These specimens are typically pipe sections joined by butt welds and contain either service-induced or man-made flaws. Prior to being incorporated into the PDI sample inventory, these specimens undergo an extremely thorough evaluation performed in accordance with the EPRI QA Program. As part of this evaluation, the samples are ultrasonically inspected to identify and characterize intentional and unintentional flaws. If the results of this evaluation process determine that the sample is acceptable for use, it can be used for qualification testing purposes.

The ASME Code defines the criteria for creating qualification test sets. These criteria include items such as number of flaws, flaw height distribution, required amounts of flawed and unflawed material, and acceptance criteria for grading qualification test results. The ASME Code describes how the weld length of a sample will be divided into flawed and unflawed grading units. These grading units make up the building blocks of the test sets. In essence, the individual test samples and their grading units become pieces of a puzzle that when correctly combined create test sets that meet these requirements. The PDI Program additionally evaluates the difficulty of the samples and factors this into test set design with the intent of creating uniform levels of difficulty among the test sets.

All of the sample and test set information is contained within databases maintained by the PDI Program. The databases serve several functions, including composing and validating the test sets and the actual grading of candidate qualification attempts. As part of the grading functionality of the databases, the sample truth information is compared to the examination results reported by the candidates. The pass or fail grade is determined by comparing these values, and information is permanently stored in the databases. This permanent record of candidate results versus sample truth information and the resulting pass/fail grade was extracted and used as the basis of this project.

Strategy-Based Training for NDE

EPRI has evaluated a strategy-based approach to training and qualifying operators in the application of NDE techniques. Specifically, the program involved training and qualifying operators to detect IGSCC in pipe welds. Overall, EPRI's strategy-based training, which focuses on using a specified NDE fault detection strategy combined with a systems approach to training, has proved more effective than conventional approaches to NDE training.

With the guidance of an advisory panel of instructors and ultrasonic inspection specialists, a strategy-based approach to NDE training was developed, implemented, and evaluated. The IGSCC detection course was revised to incorporate the concepts of strategy-based training into the instructional sequence, content, and practice sessions. Strategy-based training encompassed the following five concepts:

1. Providing training within the framework of a specified fault detection strategy
2. Limiting instruction to the specific knowledge and skills required to apply the strategy
3. Employing performance aids to support the strategy
4. Using progressive part-task training
5. Providing extensive, detailed, and timely feedback at each stage of strategy development

The impact of strategy-based training was determined through the collection and analysis of operator qualifying rates, measures of IGSCC detection performance, and subjective ratings made by course participants. During a seven-year baseline, the operator qualification rate averaged only 34.4%. Qualification was performance based, depending primarily on passing a practical performance test. After the implementation of strategy-based training, the qualification rate increased to 54.9%. In addition, operators who received strategy-based training rated the training effectiveness higher.

Because of the complex nature of the task, the detection of IGSCC in pipe welds is very difficult. The results of this work suggest that strategy-based training is more effective than conventional training approaches. Previous attempts to increase the effectiveness of conventional training, including increasing the course length from five to eight days, had no impact on the relatively low, but stable, qualification rate. On the basis of the results of this study, EPRI can confidently recommend a strategy-based approach for training and qualifying operators in the application of NDE techniques [2].

2

OVERVIEW OF PASS RATES

The statistics presented here are based on IGSCC qualifications attempted through the PDI Program since 1999. Initial qualification attempts refer to candidates who had not previously been qualified for the IGSCC flow mechanism. Requalification attempts refer to individuals who had previously obtained an IGSCC qualification and needed to requalify due to the three-year requalification requirement.

Overall Success Rate

According to the 2006 progress report, there have been a total of 541 IGSCC qualification attempts since 1999. Of these attempts, 236 have been initial qualifications and 305 have been requalifications. The data presented here represent simply the number of attempts and are intended as a high-level summary of IGSCC pass rates. A more detailed look into the components that make up this overview is provided in subsequent sections of this report. Figure 2-1 represents the overall pass/fail rate of both initial and requalification attempts.

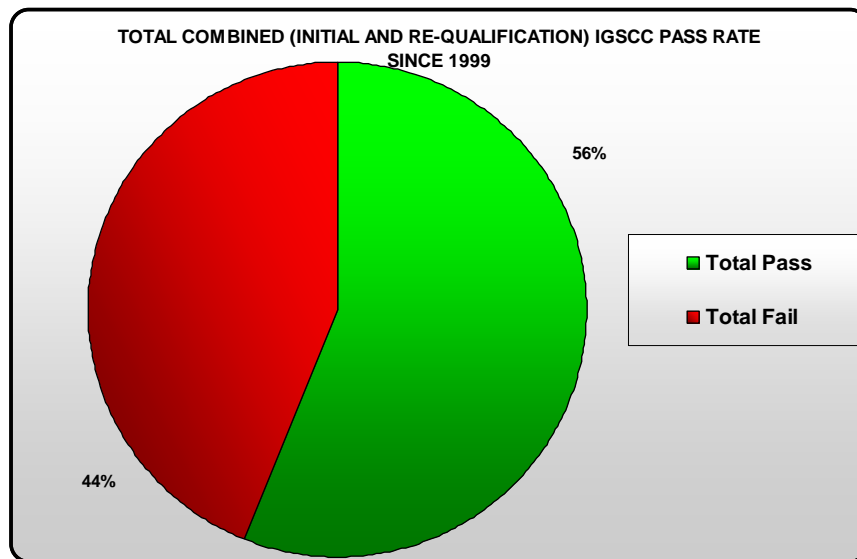


Figure 2-1
Overall IGSCC Pass/Fail Rates

When considering these data, it is important to consider the number of individuals attempting qualification. As the data indicate, the number of candidates attempting qualification per year is somewhat cyclic. However, in most years the number of candidates seeking requalification is greater than those seeking an initial qualification. Figure 2-2 illustrates this number per year and compares the number of candidates attempting initial qualification to those attempting requalification.

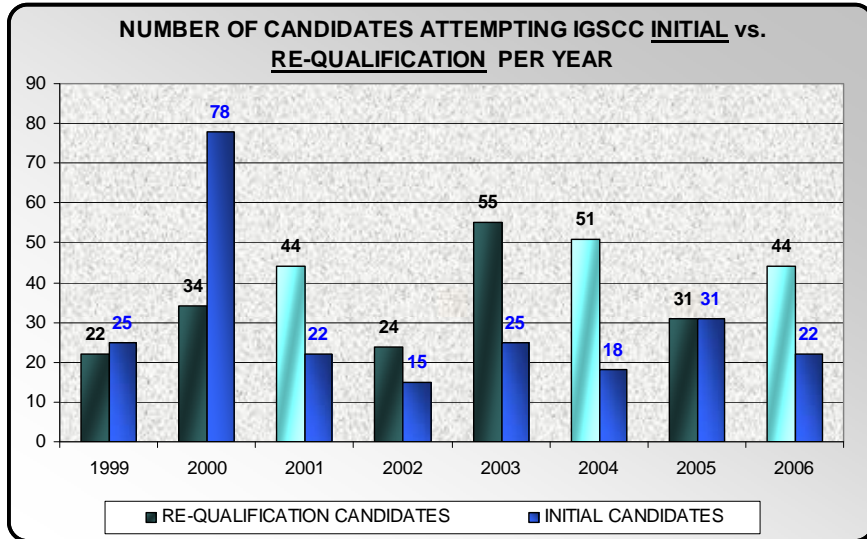


Figure 2-2
Number of Candidates Attempting Qualification per Year

Figure 2-3 compares initial and requalification pass rates per year. Again, the data are cyclic in nature. It is worth noting that there appears to be approximately a three-year wavelength in the trend. If this trend was related only to requalifications, it could be surmised that the talent level of the individuals seeking requalification could be an explanation. However, due to initial qualification attempts generally following the same trend, it would appear that other factors may be influencing the overall pass rates.

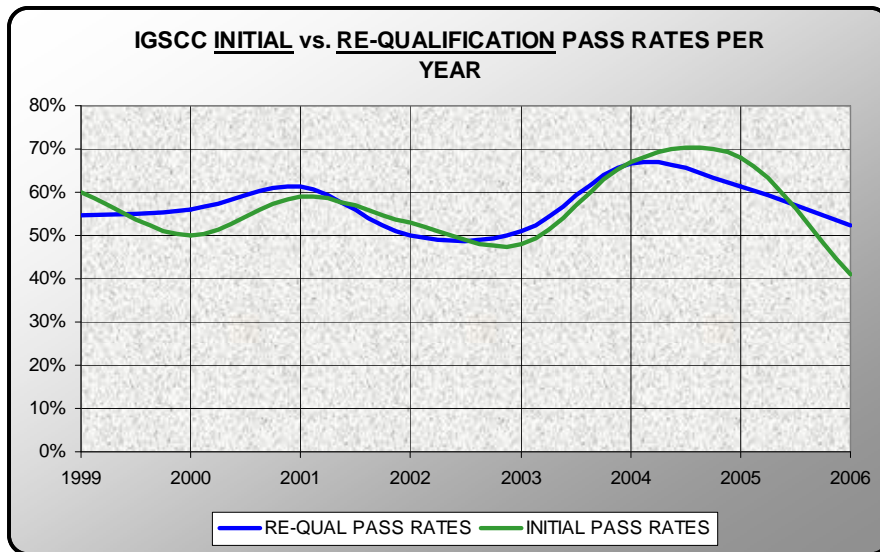


Figure 2-3
Initial Versus Requalification Pass Rates per Year

Overall IGSCC Pass Rates

Although pass rates seem to have a cyclic nature, the overall IGSCC pass rates for both initial qualifications and requalifications appear to fluctuate between approximately 50% and 60% from year to year, as shown in Figure 2-4.

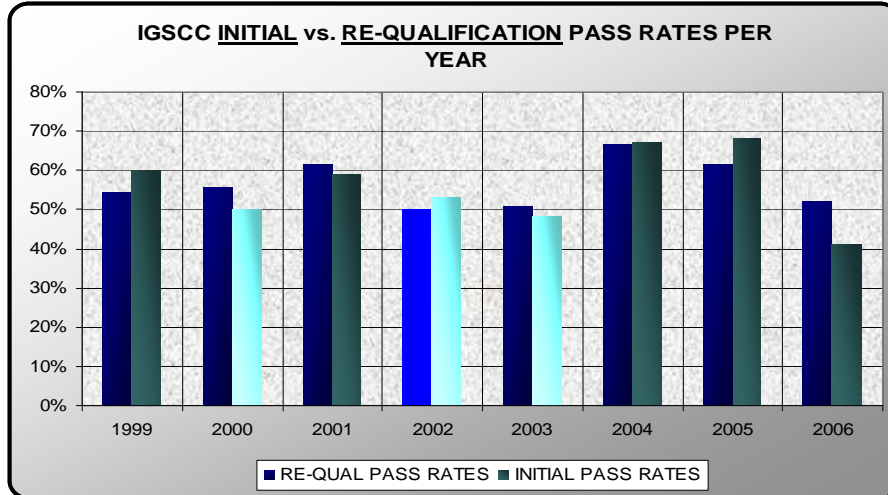


Figure 2-4
Overall IGSCC Pass Rate

3

DEVELOPMENT OF HANDS-ON TRAINING/ PROFICIENCY SESSION

The hands-on training session developed in conjunction with this project applied the lessons learned and used selected materials from the previously offered IGSCC training class and the guided practice program developed by the PDI. The strengths of the old eight-day training program for IGSCC included its reliance on intensive instructor-candidate individual practice and feedback to teach the basic flaw detection and length sizing strategy principles. Additionally, two practice practical examinations that simulated test conditions and grading were conducted that offered intensive individual candidate feedback. The practice practical also offered an opportunity to evaluate each candidate's in-progress proficiency.

The main training program weaknesses were determined to be the presentation of excessive unnecessary background information unrelated to the practical exam and the level of difficulty and poor exam correlation of the practice and practice practical samples. Guided practice for PDI exams consisted of an experienced instructor reviewing the test protocol and generic procedures and offered very little instructor assistance for the candidates. The new training session had to address the different grading criteria and strict procedure adherence that is an inherent part of the PDI examination and include the detection strategies for PDI austenitic samples that are now paired with IGSCC detection for an austenitic qualification. Single-sided access requiring the use of refracted longitudinal wave transducers also had to be addressed for the new training session.

The strategy-based training session was designed to be thorough but very specific to the task of detecting and length sizing ISGCC and austenitic thermal and fatigue flaws. The session was designed around each individual transducer and its application to the overall detection strategy. The session was planned for a five-day week to cover the basic information on the first day through PowerPoint slides and interactive classroom instruction, including demonstrations of detection techniques. Extensive individual practice and feedback on selected samples were planned for the second day of the session, with a practice practical beginning late in the afternoon and continuing into the third day. The last part of the third day was devoted to practice practical feedback and questions. The actual PDI requalification session occupied the fourth and fifth days of the session.

The classroom training instruction presented information thought to be critical to IGSCC detection and included a short review of the history and causes of IGSCC, optimum application of the 45-, 60-, and 70-degree shear wave and refracted longitudinal wave transducers, and detection and length sizing strategy. The classroom training materials are presented in Appendix A. Each application module discussed selecting the proper transducer, calibration, scan pattern and sensitivity, problem areas, and signal discrimination. Flowcharts detailing the detection strategy and process were included for IGSCC and austenitic detection, axial and circumferential flaws, and single- and dual-sided access.

4

PASS RATE EVALUATION

A training/proficiency session plan was developed based on lessons learned and this project's previous evaluation of the PDI qualification database. Two groups of previously qualified candidates were evaluated during a PDI demonstration. One of the groups received this newly developed training/proficiency program. Their performance was evaluated, on an individual candidate level, considering areas such as experience, training, and past performance. The results of this test group were then compared to the results of a control group that did not participate in this program.

The control group that did not receive the training session or a guided practice session (only for IGSCC initial qualifications) consisted of six ultrasonic testing examiners who attempted IGSCC requalification during the 2007 summer session. These examiners are considered experienced (over 10 years of in-service ultrasonic testing) and had passed and failed the exam several times previously. Two of the six passed detection and length sizing on the first attempt (33%), two more passed on the second attempt, and the final two passed on their third attempt.

The test group that received the training also consisted of six IGSCC requalification candidates who, as a group, were very experienced. Five of the six were participants in the original IGSCC program and have held certifications for many years. As with the control group, five of the six were employed by vendors and one was a member utility employee. Each candidate had previously passed and failed the PDI IGSCC austenitic examination. The training session was held at the EPRI NDE Center in late August 2007, and the qualification examination was given the last two days of the five-day session. Four of the six candidates passed the detection exam and also qualified for length sizing (66%). Of the two remaining candidates who failed the exam, one was very close to passing and the other did poorly, as predicted by the practice practical results. Neither of the candidates who failed attempted a second try. One of the candidates who passed detection and length sizing had never passed length sizing during any of his successful attempts at qualification. The results of these evaluations are summarized in Figure 4-1.

Pass Rates After Training

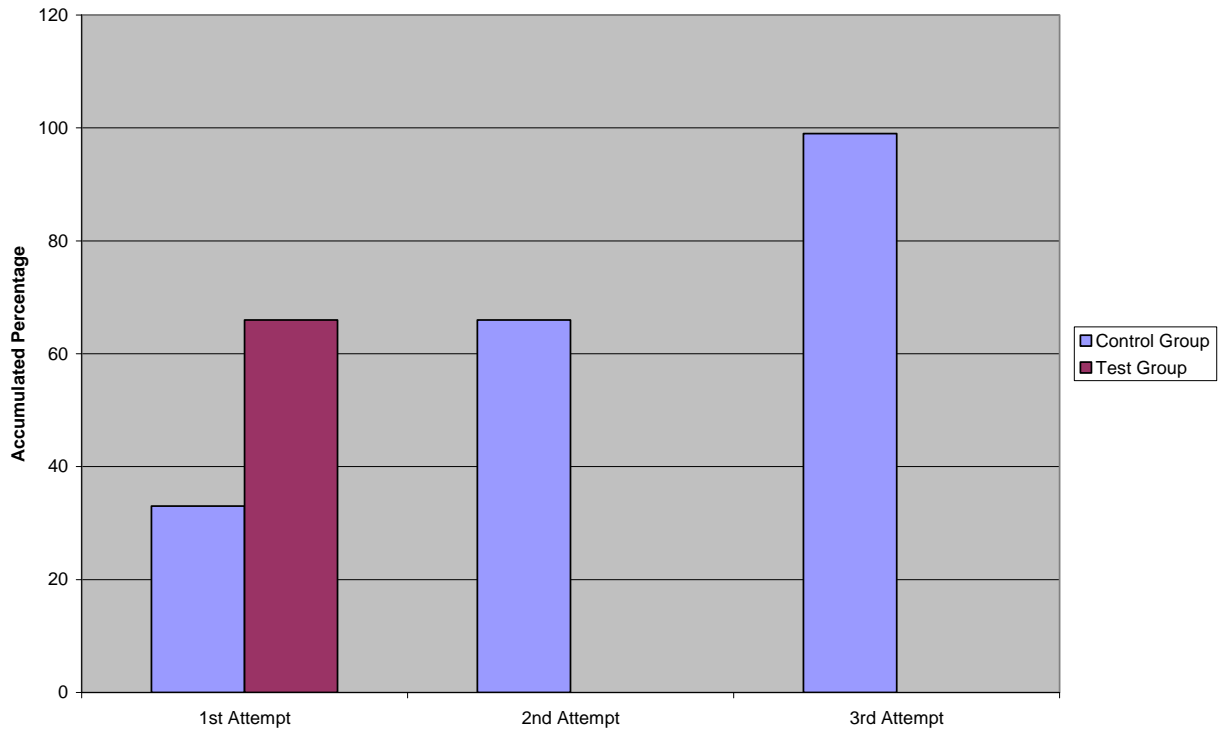


Figure 4-1
Pass Rate for the Groups

5

SUMMARY

From experience, we have learned that specific, hands-on training can significantly improve the performance of examiners during qualification and requalification examinations. The higher pass rate of the test group compared to the control group shows that the structured, hands-on training was effective and should be a prerequisite to IGSCC requalification. It is also recommended that the PDI Steering Committee consider employing specific, hands-on training for candidates planning to take the DM weld qualification tests.

The Next Step

The success of the hands-on training session as preparation for the PDI austenitic (with IGSCC) requalification examination shows that it should be offered to other experienced candidates who have had difficulty with the exam, especially the IGSCC portion, or would simply like a review immediately prior to the exam. Candidate feedback from the session indicated that the training had value and should be incorporated into the PDI Program.

6

REFERENCES

1. *Improve PDI Pass Rates Progress Report*. EPRI, Palo Alto, CA: 2007. 1013546.
2. *Strategy-Based Training for Nondestructive Evaluation*. EPRI, Palo Alto, CA: 2005. TR-103245.

A

POWERPOINT SLIDES FOR HANDS-ON TRAINING

Background on IGSCC

Its Growth and History

- Objectives
 - Identify and describe the three factors contributing to IGSCC
 - Briefly explain effects of alloying content, material diameter, and thickness on IGSCC



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COMPETENCY AREA
PDI

MODULE
1

PAGE
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• Introduction

– IGSCC

- InterGranular Stress Corrosion Cracking
 - Attacks the heat affected zone (HAZ) of austenitic stainless steel



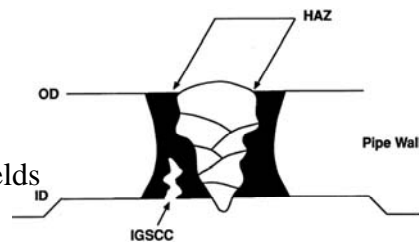
– IGSCC has received attention



- Persistence
- Economic impact
- Safety considerations

– IGSCC in stainless steel pipe welds

- Cracking phenomenon
 - Cracks propagate in a branch-like manner along the material grain boundaries
 - The length of the individual flaw branches is, in general, proportional to the material grain size



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COMPETENCY AREA
PDI

MODULE
1

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• IGSCC – What Is It?

– Contributing Factors

- IGSCC in the HAZ of an SS weld depends on three factors

- Material sensitization

- Welding

- **Tensile stress**

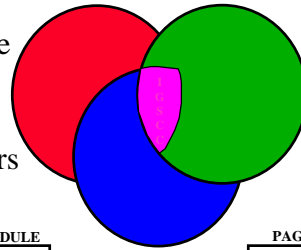
- Residual

- Environment

- Water chemistry



- The extent of the presence of any one of these factors of IGSCC to occur depends on the extent or intensity of coincidence with the other two factors



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COMPETENCY AREA

PDI

MODULE

1

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• Material Sensitization

- Sensitization of austenitic SS can result

- Manufacturing processes
- Subsequent welding



- Sensitization may occur in SS piping weld HAZ

- High-temperature sensitization

- Occurs when austenitic stainless steel is heated between 900° and 1600° F
- Can exist even prior to welding because of improper mill treatments

- Low-temperature sensitization

- Low-temperature sensitization can occur in an austenitic SS weld HAZ because of extended thermal exposure of partially sensitized SS

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COMPETENCY AREA

PDI

MODULE

1

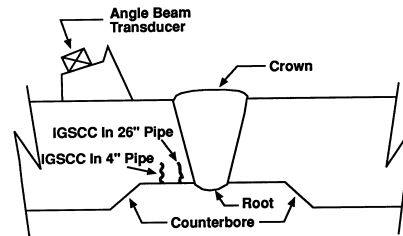
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- Tensile Stress

- IGSCC appears to initiate as a film rupture process which is related to a stress/strain factor

- Stress/strain factor may result
 - Local surface strains of dynamic loads
 - Residual welding stresses
 - Thermal stresses



- Environmental Factors

- IGSCC is an electrochemically-controlled process
 - Proportions of dissolved oxygen in the reactor water and temperature are fundamental for crack initiation and growth

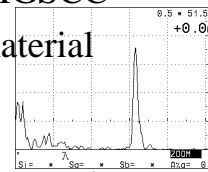
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- Ultrasonic Characteristics

- Similarities and differences exist in the echo-dynamic properties of notches, fatigue cracks, and IGSCC

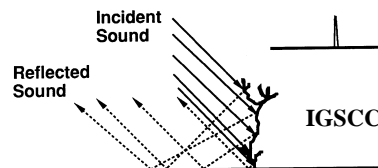
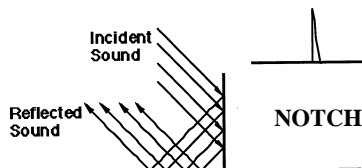
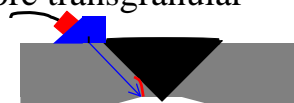
- IGSCC follows the grain boundaries of material

- Much more difficult to detect and size
 - Signal from crack tip is more difficult to find



- Notches and fatigue cracks are more transgranular

- Across the grain boundary
- Easier to detect and size



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- **Summary**

- Occurs in austenitic SS

- Three factors must exist

- Sensitization
 - Stress
 - Environment

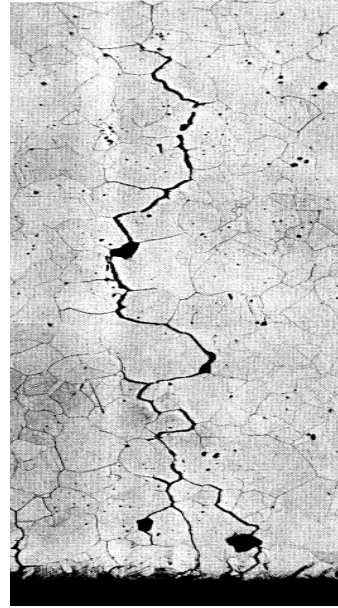
- IGSCC

- Follows the grain boundaries of material
 - Much more difficult to detect and size

- Very tight crack

- Lower Frequencies

- Better penetration
 - Less scatter of energy



EDITION

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Apply the 45° Technique

- Objectives
 - Understand grain structure and how it can impact the sound wave
 - Identify the most effective search unit frequency and bandwidth
 - Select the appropriate search unit size
 - Select the most effective wave mode and search unit type
 - Calibrate the sweep length
 - Set the minimum scanning sensitivity
 - Identify scanning methods used to detect axial and circumferential flaws
 - Identify ways to overcome search difficulties including access to problem areas and identification of beam redirection
 - Distinguish the various signals and determine the source (counterbore, root, or IGSCC)



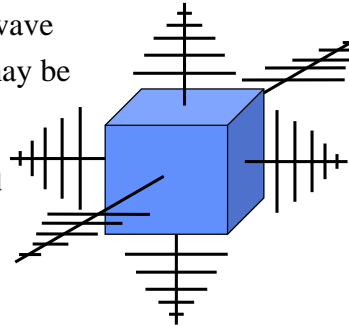
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- Weld Metals
 - Can have severe grain size problems for UT
 - Can grow dendrites from the face of a crystal
 - Dendritic structures in the weld
 - Redirect the sound wave
 - Change the velocity of the sound wave
 - Dual longitudinal focused probe may be used to examine the weld volume
 - May require a probe focused for the thickness of material being examined



EDITION
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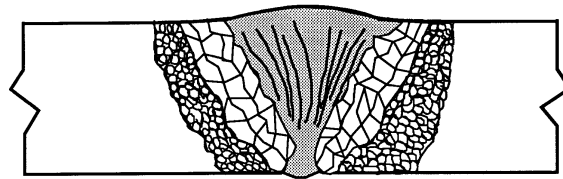
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- **Material Structure Disturbances**

- **Grain**

- Size and orientation in weld metal is different than in parent metal
 - Differences influence testability
 - Varying grain sizes tend to scatter sonic energy in an unpredictable fashion
 - Example of grains producing three different velocities for the sound wave moving through a weld



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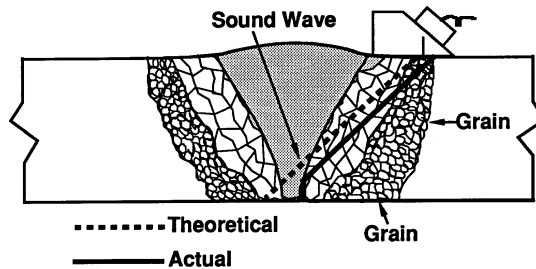
COMPETENCY AREA
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- **Grain size and orientation**

- Example of theoretical vs. actual sound path through a weld with varying grain sizes and orientations
 - Such circumstances would have considerable effect upon examination for IGSCC



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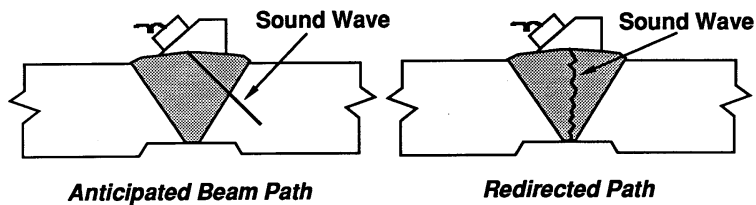
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– Austenitic welds or cladding

- Check for redirection
 - Rotate probe
 - Use another angle
- Use longitudinal waves
 - Scattering of sound is reduced



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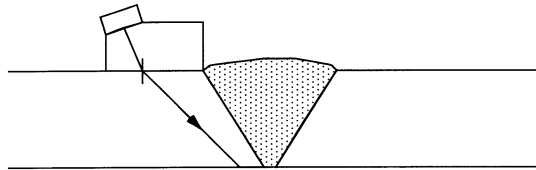
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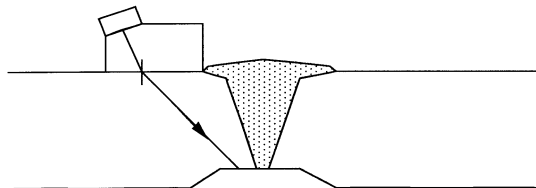
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• Overcome Limitations

- Problem areas
- Wedge with large index point setback distance



- Wide weld crown



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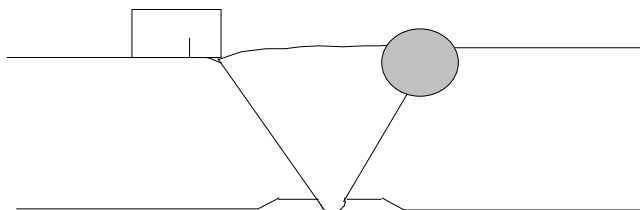
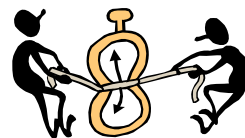
COMPETENCY AREA
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- Access limitations

- OD geometry limits access
 - Hoop shrinkage
 - Weld crown
 - Combination of both



- Solutions

- Search unit sizes
- Set back distances
- Wedge angles
- Calibration ranges

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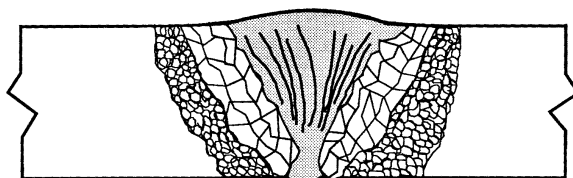
COMPETENCY AREA
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- Check for beam redirection

- Check on beam redirection
 - Method 1
 - Rotate the search unit 180° on the weld crown
 - Method 2
 - Change the angle of the search unit wedge
 - *If the ID signal remains at essentially the same location, then the beam is probably redirected*



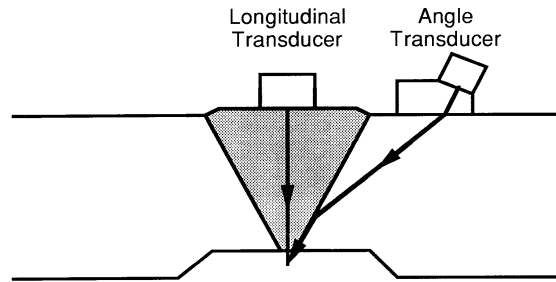
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- Verify metal path distance
 - Effect of differences in grain sizes and orientation
 - Verify plot of metal path distance



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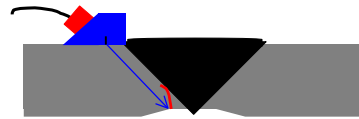
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• Set-Up and Calibration

- Transducer frequency for **initial** detection
 - 1.5 megahertz (MHz) for IGSCC
 - 2.25 MHz may be used for confirmation
 - 2.25 or 1.5 megahertz (MHz) for non-IGSCC
- Search unit diameters
 - 3/8-inch and 1/2-inch
- Sweep length of 1 V-path
 - Calibrate your sweep
 - For example, 306 (12-inch OD, T=.688") set up a 2-inch sweep
 - Use range and place ID notch at 5 screen divisions and 80-90% FSH
 - 308. IGSCC sample, place ID at 7 screen divisions
 - Better screen resolution
- Scanning sensitivity
 - 5-20% ID roll
 - Typically around 10%



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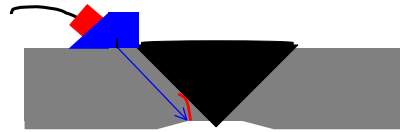
MODULE
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- Search for flaws

- Coverage

- Weld
- Heat affected zone (HAZ)
- Half the thickness of the base metal
 - ASME code requires the lower 1/3



- Maximum reflection

- Sound beam perpendicular to the axis of the reflector
 - Not necessarily perpendicular to the weld centerline

- Scanning speed:

- 3 inches per second or less



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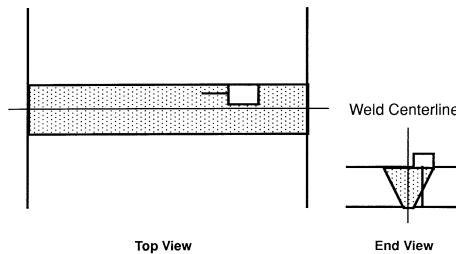
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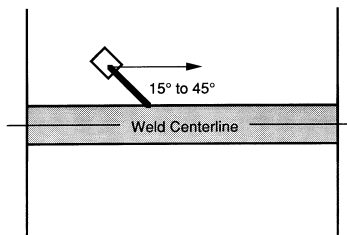
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- Scanning technique to detect axial flaws

- Technique 1



- Technique 2



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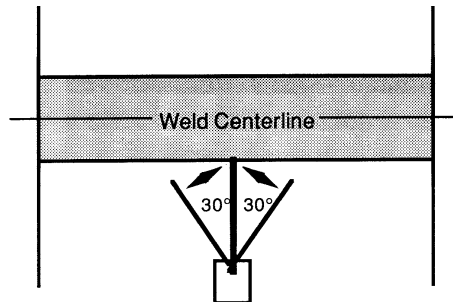
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– Scan to detect circumferential flaws

- Obtain a “signature” of the weld
 - Slide the search unit, along the weld toe, perpendicular to the weld centerline the entire length
- Use the raster scan
 - Oscillation improves probability of detection



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• Length Estimation

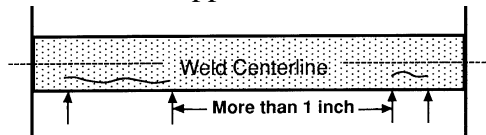
– Circumferential Fatigue Crack

- Ends of circumferential cracks are where signal amplitude drops to 20% FSH (once flaw was peaked at 80% FSH) and does not reappear within one-inch

– Note: Far side flaws are taken into the baseline noise

– Circumferential IGSCC

- Ends of circumferential IGSCC are where signal amplitude drops into the baseline noise (once flaw was peaked at 80% FSH) and does not reappear within one-inch



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- Characterizing signals (Fatigue Cracks, IGSCC and Geometry)

- Some considerations

- Signal amplitude alone is not a reliable basis for identifying IGSCC
- Counterbore signals easily mistaken for IGSCC
 - Fast rise time
 - Appears before the root
 - Location



- IGSCC/Cracks can be identified from answers to the following questions about signal characteristics

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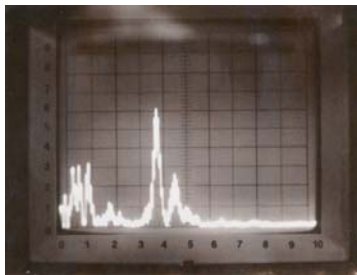
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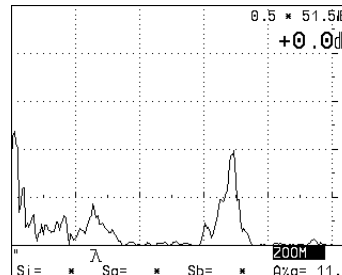
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- Question 1

- How many signals are detected?
 - If two or three signals appear on the display, then one of the signals is probably from IGSCC/crack



IGSCC signal with root



Root signal

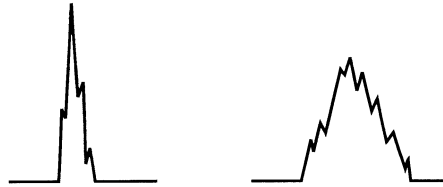
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- Baseline position shifts during parallel scan?
 - *If a signal appears to shift position along the baseline during parallel scans, then it is probably IGSCC/Fatigue crack*
 - Geometry (counterbore, root) typically maintain the same position along the sweep
- Fast rise time?
 - *If a signal has a fast rise time, then it is probably either IGSCC/ Fatigue crack or counterbore*



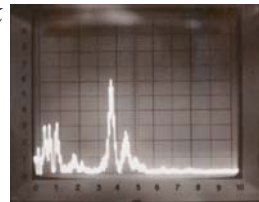
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IGSCC and Counterbore
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Weld Root
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- Maintains amplitude with skew?
 - *If a signal maintains amplitude with skewing of the search unit, then it is probably IGSCC/Fatigue crack*
- Baseline position shifts during perpendicular scan?
 - *If the signal position shifts along the baseline during perpendicular scans, then it is probably IGSCC/Fatigue Crack*
- Close to the weld root?
 - *If the reflector is not located in the HAZ close to the weld root, then it is not IGSCC/Fatigue Crack*
 - Example: For 308 Samples - close is within 15 millimeters of the weld centerline



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- Can the indication be seen through the weld?
 - *Confirmation may be available from the other side of the weld*
 - Difficult if the flaw is shallow (small height) or sample is thick ($\geq 1.5''$)
 - IGSCC may be difficult to see from the opposite side
 - Shallow flaws
 - Highly attentive material
- Can the indication be confirmed with a higher angle?
 - *If the signal can be confirmed with higher angles, while maintaining substantial amplitude, then it is probably a crack*
 - Caution: Counterbore may be seen with a 45 and 60 degree, however the amplitude should be less with a 60-degree
- Does the indication have any through-wall depth?
 - Composite search units may show a tip signal associated with the corner trap signal

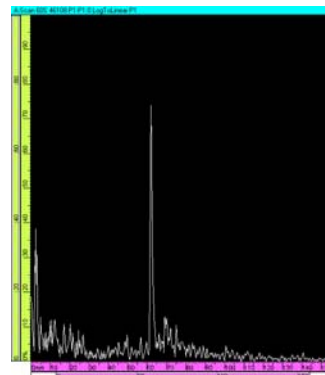
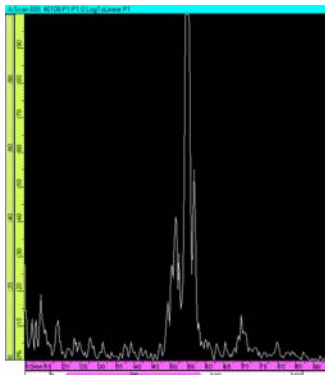
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- Does the signal have multiple point reflecting surfaces?
 - Cracks are usually faceted which results in multiple points of reflection
 - Counterbore typically has a single point reflecting surface
 - Machined surface



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Apply 60°/70° Shear Wave Technique

- Objectives

- Identify the appropriate search unit size
- Calibrate the sweep length
- Set the scanning sensitivity
- Search for cracks using scanning techniques
- Discriminate cracks from counterbore and root



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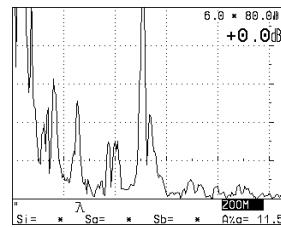
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Apply the 60°/70° Shear Wave Technique

- Verify cracks and discriminate cracks from geometric reflectors
 - Root
 - Counterbore
- Set-up and calibration
 - Similar to that required for application of the 45° technique
 - Appropriate search unit (follow procedure)
 - Frequency of 1.5 MHz or 2.25 MHz
 - Diameter of 3/8 inch or 1/2 inch
 - Single-element type
 - Sweep length at 1 V-path
 - Minimum scanning sensitivity
 - 5-20% baseline roll
 - 10% roll works well



60° Shear: IGSCC with root

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• Search for Cracks

- Repeat the scanning pattern used for the 45° technique
- Identify Signals from Cracks
 - Like characteristics of signals obtained by the 60° and 70° technique are similar to those obtained by the 45° technique
 - Appears with other signals
 - Baseline position shifts during parallel scan
 - Has fast rise time
 - Maintains amplitude with skew
 - Baseline position shifts during perpendicular scan
 - Close to the weld root
 - *If a reflector exhibits these signal characteristics with both the 60° and 70° techniques, then it is most likely a crack*



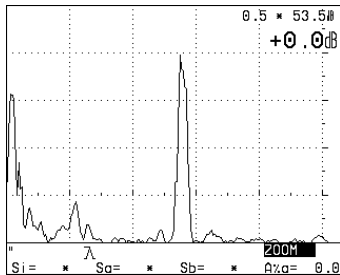
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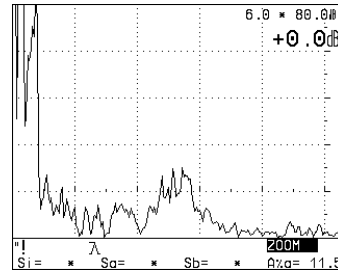
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- Discriminate cracks from counterbore
 - If the amplitude of the 60° signal is significantly lower than the amplitude of the 45° signal, then the signal is probably from counterbore rather than a crack



45° from counterbore



60° from counterbore

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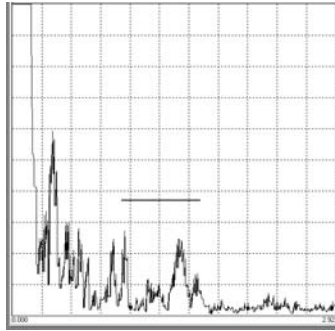
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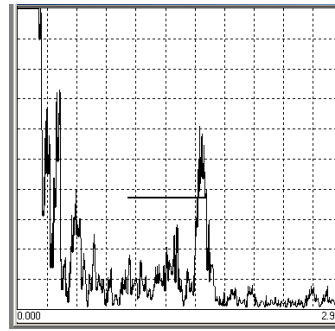
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– Discriminate cracks from root

- If the amplitude of the 60° signal is significantly higher than the amplitude of the 45° signal, then the signal is probably from root rather than a crack
 - Verify location



45° Shear from root



60° Shear from root

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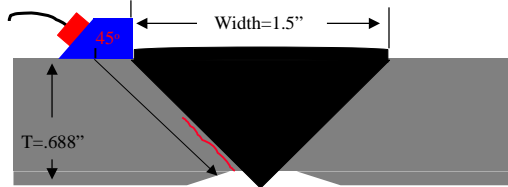
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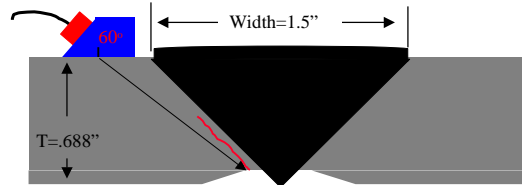
– Using Higher Angles (60°/70°)

- Wide weld crowns may prevent the 45° from reaching the crack
 - Sample 306/X is .688" thick with a 1.5" wide weld crown



- Use the 60° to provide better coverage

- Confirm with the 70°



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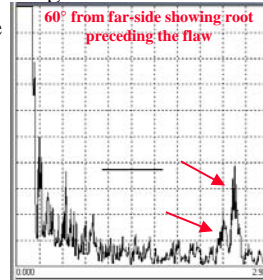
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– Using Higher Angles (60°/70°)

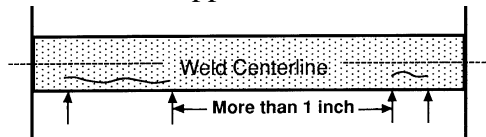
- Single-side Access
 - T > 0.500", procedure requires an RL
 - Covered in another module
 - Note: Use shear waves for supplemental information when scanning for far-side flaws
 - Identify suspect areas
 - Look for the root signal to precede the flaw signal
 - Apply the RL to the far-side to characterize
 - Detection and length sizing
 - T ≤ 0.500", procedure requires a 2.25MHz, 70° shear wave
 - Austenitic materials



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• Length Estimation (same as 45°)

- Circumferential Fatigue Crack
 - Ends of circumferential cracks are where signal amplitude drops to 20% FSH (once flaw was peaked at 80% FSH) and does not reappear within one-inch
 - Note: Far side flaws are taken into the baseline noise
- Circumferential IGSCC
 - Ends of circumferential IGSCC are where signal amplitude drops into the baseline noise (once flaw was peaked at 80% FSH) and does not reappear within one-inch



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- **Summary**

- Calibration is similar to the 45° shear wave
 - Follow the procedure
 - Frequency and size
 - Sweep and scanning sensitivity
- Use higher angles when access is limited
 - Wide weld crown
 - Far-side flaws
- Use higher angles for confirmation
 - Circumferential and axial flaws
- Utilize your higher angles
 - Should be part of the “plan”
 - Plan the work, work the plan



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Apply RL Technique

- **Objectives**

- Identify the basic characteristics of Refracted Longitudinal (RL) wave transducers
- Identify RL transducer applications
- Select the appropriate RL transducer
- Perform calibration of an RL transducer
- Identify scanning methods used to detect far side circumferential flaws
- Distinguish between geometry and flaw responses



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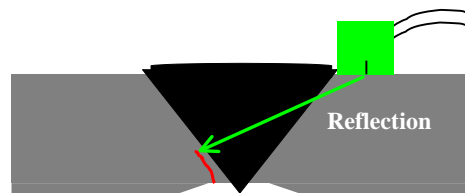
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- **RL Basics**

- Longitudinal waves penetrate dendritic weld metal better and produce more reliable results through weld metal than shear waves.
- RL transducers are described in terms of element size and shape, frequency, beam angle, focal length, and roof angle.
- RL transducers are reverse engineered to provide the ideal combination of variables for a particular application.



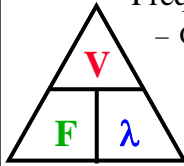
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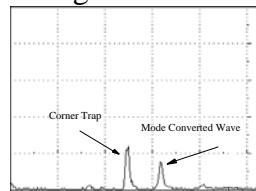
– Variables to consider



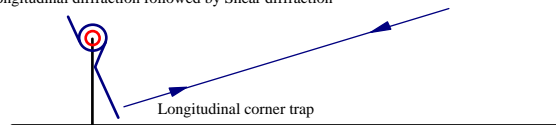
- Frequency
 - Good performance is achieved using lower frequencies for detection
 - The longitudinal wave length is greater than that of S-waves
 - L-waves are less sensitive to weld and base metal grain structures
 - In respect to shear waves
- Elements
 - Dual-element units are preferred for near-surface resolution and to avoid strong internal wedge reflections
 - Single-element units may be used but require unusual wedge configurations
- Contact area
 - Width should be narrow to allow adequate coupling of both elements
 - Length should be short for coupling in case of diametrical weld shrinkage and/or excessive grinding

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- RL transducers have a shear wave component
 - Typically half the longitudinal angle
- Challenges with RL Transducers
 - Miscalibration using the shear wave component
 - Maintaining intimate surface contact with large transducers



Longitudinal diffraction followed by Shear diffraction

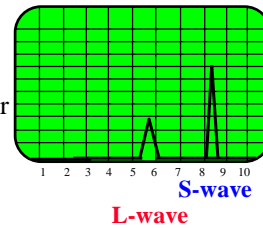
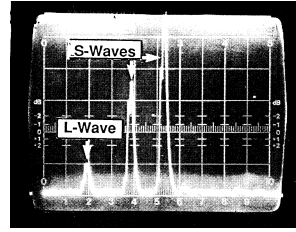


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- Application Considerations

- Accompanying S-wave

- Exists with the refracted L-waves
 - For high-angle L-waves in steel
 - The S-wave angle is about 30°
 - The S-wave will produce high amplitude signals from reflectors on the inside surface of the pipe
 - The S-wave signals appear later in time than the L-wave signals of interest
 - The shear component is not used
 - The operator must be familiar with its behavior so that the shear signals can be ignored



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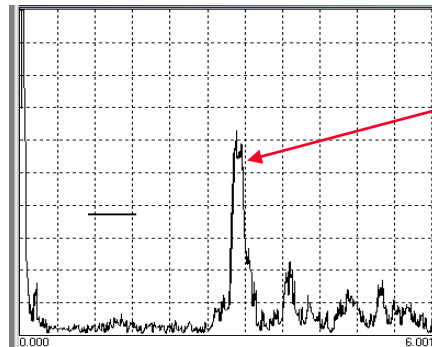
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- RL Transducer Application

- “Best effort” detection and length sizing of far side circumferential flaws for single side exams
 - Supplemental technique for confirmation and discrimination of shear wave data from either side of the weld



Refracted Longitudinal
Wave from Far Side
IGSCC

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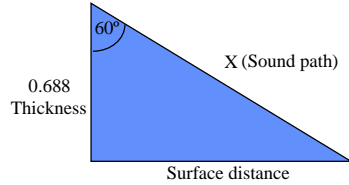
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• **Selecting RL Transducers for Middle Thickness Category Austenitic Pipe Samples**

- Transducer type: dual
- Transducer bandwidth: >30 %
- Element shape: square or rectangular
- Transducer frequency
 - IGSCC - 1.0 to 2.25 MHz
 - Non-IGSCC - 1.0 – 5.0 MHz
- Transducer size (maximum)
 - >4" to 12" diameter: 10 x 14 mm
 - >12" to 24" pipe diameter: 16 x 25 mm
 - >24" diameter: 26 x 51 mm
- Nominal angles: 60 or 70 degrees (use lowest angle with coverage)
- Focal length: ¼-inch beyond the sound path at ID
 - For example, Sample 306 is 0.688 thick, so a 60-degree RL will need a FS of 45mm



$$\cos 60^\circ = .688"/X$$

Solve for X

Hint: If using a 60° RL then divide T by .5 (cos 60), next multiply the result by 25.4 (mm) to get FS. Finally add ¼" (6mm).

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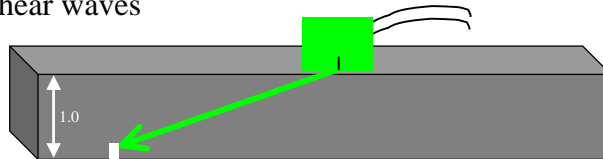
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• **Calibration of RL Transducers**

- Set up a linear time base appropriate to the sample thickness on an austenitic reference block with known reflector distance
 - Rompas or IIW
- Set the longitudinal response from the ID notch on the appropriate calibration block at 5 screen divisions.
 - Set the ID notch reflection at 80% FSH
 - This will be reference level
- Position the transducer near the edge of sample and observe the wave train to distinguish the relative arrival positions of the longitudinal and shear waves



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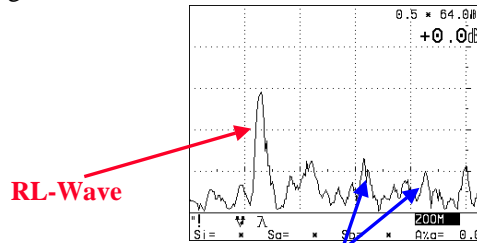
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• Examination Sensitivity with RL Transducers

- Establish examination sensitivity on the component to be examined by adjusting the gain level until the signal response from the ID surface (roll) is 5-20% FSH.
 - If the ID surface is not easily discernable when using higher angles, exam sensitivity may be set using the average baseline noise level in lieu of the ID roll.
 - The examination sensitivity gain level may be less than the reference sensitivity level with angles greater than 55%



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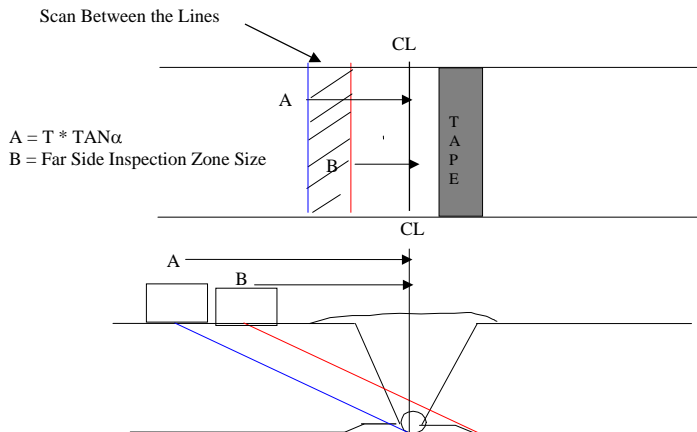
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Noise

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– Scanning Technique for Far Side Circ Flaws

- Same as shear wave technique with 45/60/70 degree angles
- Raster scan with +/- 30% oscillation



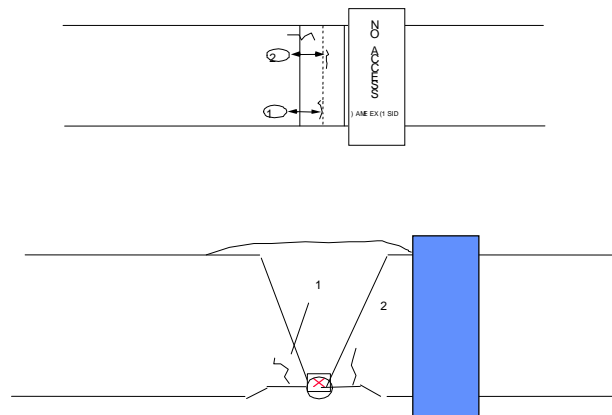
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– Single side exams



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– Key Factors

- Get the same side exam done with the dual side technique.
 - Know what the same side looks like.
- Know the coverage necessary for the far side of the weld.
- **Understand what is happening to the sound**
 - A majority of the sound is consumed by the weld
 - Maybe all with shear wave
 - Increase gain as required (primarily on austenitic)
 - The greatest flaw response may be from upper regions of the flaw
 - Don't forget how thick these samples are
 - Expect attenuation and reflection at the interfaces
- Slow down the scanning speed.
- Be sure you can repeat your results
- **USE LOTS OF COUPLANT**

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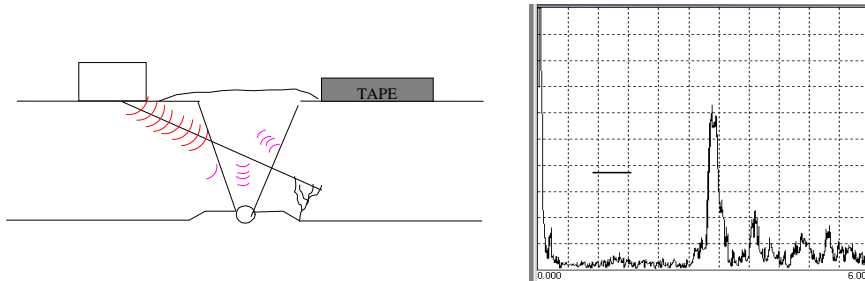
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– Identify signals from the flaws

- Use similar discrimination that was used with shear waves
 - For example; high amplitude, fast rise time, shift in baseline position during parallel scans, maintains amplitude with skew, located close to weld root on far side of weld
 - Signal amplitude alone is not a reliable basis for identifying flaws
 - Geometry signals easily mistaken for flaws



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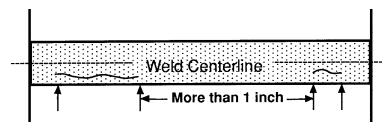
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– Identify Signals from Geometry

- Location of reflector consistent with geometry
- Does not maintain amplitude with skew
- Higher angles tend to produce lower amplitude responses from geometry relative to flaw indications

– Length Estimation of Circumferential Flaws on the Far Side for Single Sided Exams

- Use lowest transducer angle for length sizing
- Ends of circumferential flaws are where signal amplitude drops into the baseline noise (at reference gain) and does not reappear within one-inch



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- **Summary**

- **Refracted Longitudinal Wave**

- Less sensitive to weld dendritics
 - Usually gives a good signal-to-noise ratio
 - Requires special search units and calibration blocks
 - The S-wave component generates large signals that must be ignored
 - As-welded weld crowns will impede access
 - Hoop shrinkage may prevent adequate coupling
 - Possibility a noise signal may be misinterpreted as being a flaw
 - Redirected, mode converted, etc.



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Detection and Length Sizing Strategy

- **Objectives:**

- Develop a detailed strategy for the detection and length sizing of IGSCC and non-IGSCC cracks
- Identify strategies for specimens with dual or single side access.
- Identify challenging aspects of the practical exam.



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- **PDI Program Requirements**

- **Grading Requirements**

- Number of flaws and amount of unflawed material is very defined
- Missed detection's and overcalls are based upon the test type and size
 - Very little margin for error
 - Guessing does not work
 - Solid UT skills and a consistent process works!



- **Mandatory Procedure Adherence**

- Demonstration means you will prove (show to monitors) the detection and sizing of all flaws and techniques used

- **Leading Causes of Failure**

- False calls
- No confirmation
- Not following procedure and process
- Trying to find the 5% flaw



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– Keys to Success

- Procedure adherence
 - Feedback cannot be given if you don't use the procedures or processes
 - Consistency - Consistency - Consistency
- Preparation
 - Equipment (prep wedges, know angles, capabilities of search units, etc.)
 - Know the procedure and processes
 - Practice (don't waste practice time on paperwork, simple samples, etc.)
- Believe in yourself – and the procedures
- The test is not easy - the test is not hard



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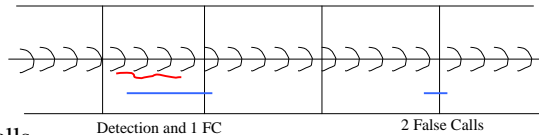
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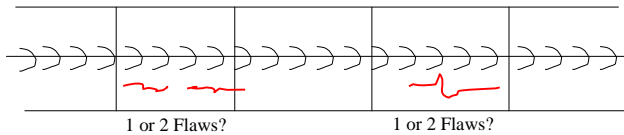
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– Detection Sample Test Design

- Samples are divided into grading units
 - Grading units consist of at **least 3"** of weld length
 - May be longer and are randomly distributed
 - Grading units are either flawed or unflawed
 - Some areas within samples are considered blanks
 - Neither flawed nor unflawed



- False Calls



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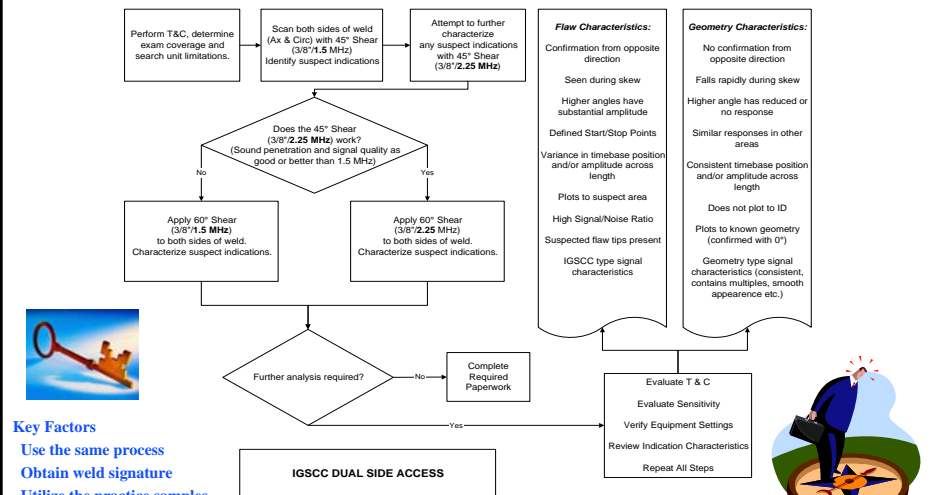
• IGSCC Exam Samples

- Contain IGSCC
- Field-Removed samples
 - As-welded
 - As-found surface condition
- Most flaws have a good S/N ratio
 - 1.5 MHz sees all flaws
 - 2.25 MHz may see some flaws better than 1.5 MHz
 - Higher angles limited due to attenuation and configuration
- Opposite direction confirmation is **not** always there
- Wedge preparation is very important (front and corners)
 - Get as close to the root as possible
- Call what you see – don't create anything – false calls hurt
- Use the practice samples to your advantage
- RL's are difficult



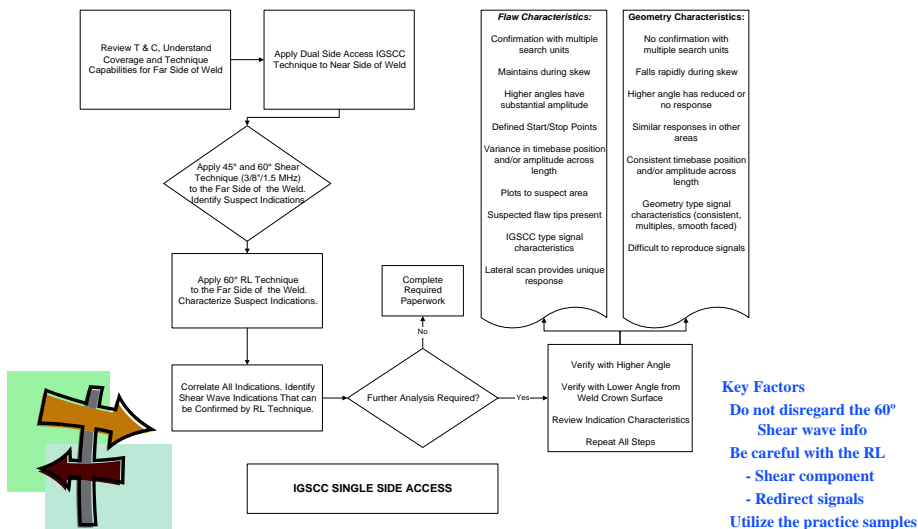
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• IGSCC Detection Process – Dual Side Access



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• IGSCC Detection Process – Single Side Access



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• Fatigue Cracks Exam

- Thermal and mechanical fatigue cracks
- Man-made samples
- Controlled welding environment
- Consistent surface condition
- Most flaws have excellent S/N ratio
- Most flaws have confirmation from opposite direction
 - Also with higher angles



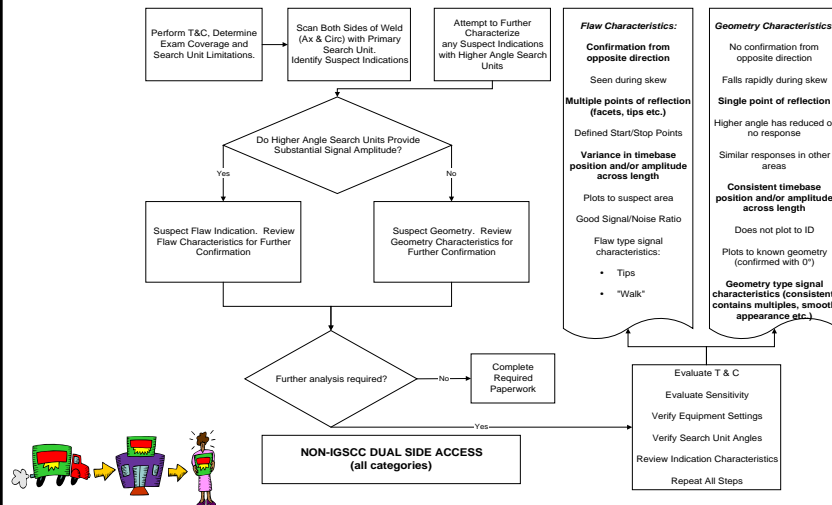
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• Non-IGSCC Process – Dual Sided Access



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• Non-IGSCC Process

- Practice Flaw Confirmation Techniques
 - Can indication be seen through the weld from the opposite direction?
 - Can indication be confirmed with higher angle?
 - Does the indication have a single or multiple point reflecting surface?
 - Does the indication vary in amplitude and time base position ?
 - Does the indication have thru-wall depth? Can it be depth sized?
 - Confirmation should be available from both sides of weld unless the flaw is shallow or sample is thick (> 1.50") stainless steel
- Practice Geometry Discrimination Techniques
 - Can indication be seen through the weld from the opposite direction?
 - Can indication be confirmed with higher angle? (substantial amplitude)
 - Does the indication have a single or multiple point reflecting surface?
 - Does the indication vary in amplitude and time base position?
 - Is the signal dynamics (walk) consistent throughout its length?

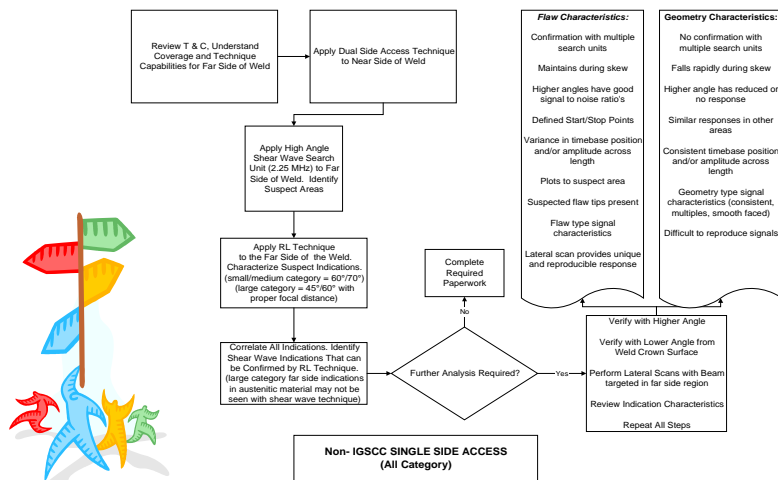
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• Non IGSCC Process – Single Side Access



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• Single Side Exam Process

- Be certain flaw is on opposite side
 - Does the flaw plot correctly to the opposite side with all angles?
 - Can benchmark reflectors be seen before flaw (root, weld interface, etc)?
 - Can it be seen with higher frequency? (i.e., 5 MHz)
- Focus entirely on the opposite side with multiple angles if possible
 - Raster and lateral scan
 - Observe significant amplitude variance
 - Be certain the signal is repeatable
- Do not forget your circ scans

Key Factors:

- Eliminate same side geometry
- Target the far side
- Look for background changes in far side area
- Use multiple angles/frequencies



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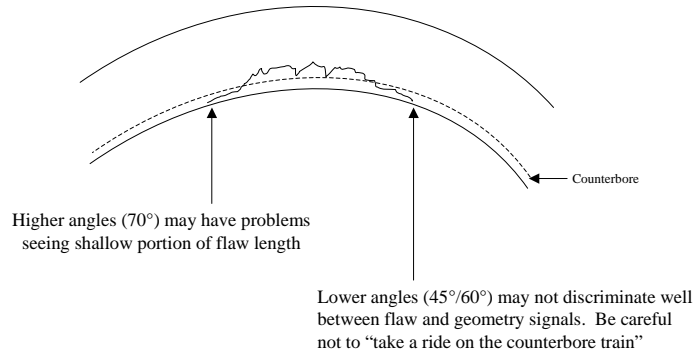
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– Typical flaw profile – End View



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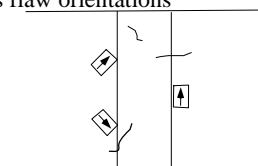
• Scanning Times for Non-IGSCC

– Axial Scans (for circumferential flaws)

- 20 minutes per side of weld
- If you take too much time doing axial scans you are digging!!!
 - Don't try and find the 5% flaw!
- Discriminate the geometry
- Increase the angle
- Verify with multiple angles

– Circumferential Scans (for axial flaws)

- 10 to 20 minutes per side of weld
 - Multiple skew angles are needed to see the various flaw orientations
 - Depends on weld condition and sample type
 - Slower scan speeds
- Less if no interference
 - Prep wedges
- More if additional angles are required
- Scan on the weld if smooth or flush



0°, 15°, 30° and 45° Skews

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• Practical Exam Tips

- Start with "Low Hanging Fruit"
 - Fatigue cracks and dual side exams
 - Duplicated samples (learn from other sample)
- Utilize the practice samples during the test
 - Geometry will change – flaw response will not
- **Do Not Dig – False calls Hurt**
- Remember the Fundamentals
 - Detection Process
 - Procedure requirements
- Remember "Murphy's Law"
 - Unflawed Samples
 - Equipment Failures
- Turn in the samples when you are 100% certain
 - Review your paperwork
 - Stay confident



- Equipment
- Ultrasonics



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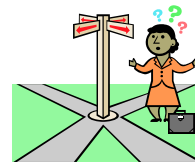
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• Decisions

- About the presence, location, and length of IGSCC in the pipe weld are reached after all information from the examination has been obtained and assessed
- Decision making errors
 - Early decisions
 - Disregard of information
 - *If an early decision is reached and/or conflicting information is disregarded, then an examination is not likely to be successful*
 - *IGSCC will be missed or will be falsely reported*



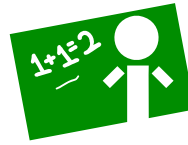
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- Decision-making process
 - Confirm IGSCC/Fatigue Crack
 - Verified by other techniques
 - 60 degree
 - 70 degree
 - Consistent with the geometry of the weld profile
 - Decide on questionable indications
 - Conduct additional testing
 - Apply knowledge through if-then logic
 - Utilize worksheets
 - Record the final decisions regarding locations of IGSCC or fatigue cracks



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