Chockie Group International, Inc.

Future Directions

for the Inspection of CASS

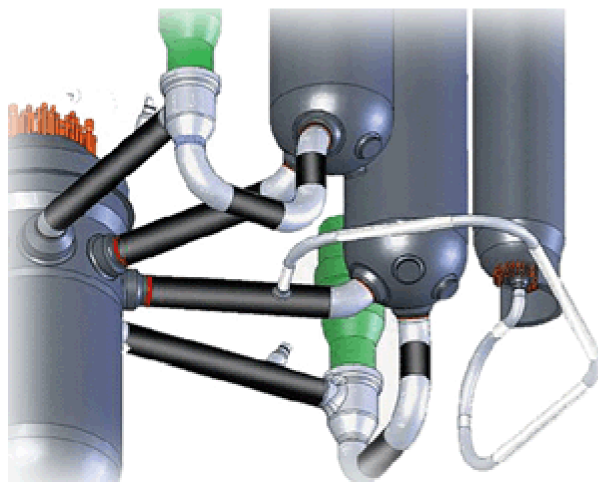
Summary Report

3rd International Workshop on the Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

January 28 - 29, 2011
Seattle, WA

The Challenge

Cast austenitic stainless steel (CASS) is used in the primary coolant piping system in pressurized water reactors (PWRs) in the United States, Japan, Sweden, France, and other countries. The attributes that make CASS a good candidate for the primary piping system significantly hamper the ability to effectively detect, locate, and size flaws within the material.



The service loads on PWR primary coolant piping are relatively low and even severely aged CASS is considered capable of tolerating major flaws. However, there is increasing pressure to continue to improve the inspection systems and to ensure the integrity of aging CASS piping systems.

The First and Second Workshops

The first international workshop was held in San Diego in 2006. The second workshop was held in Seattle in 2009. These workshops resulted in the establishment of several important initiatives including critical flaw evaluation and international cooperative inspection research programs. In recent years there has been advances in inspection techniques, critical flaw evaluation, transducer and signal processing development, and ASME Code actions. There has also been increasing pressure to address the inspection of CASS by regulatory bodies due to such concerns as the inspection of mitigated Alloy 82/182 welds to CASS components.

The Third Workshop

The two-day workshop was held at the Bell Harbor Conference Center in Seattle, Washington, on January 28 -29, 2011. The purpose was to bring together interested parties to review the current state-of-the-art in the inspection and analysis of CASS material and to identify opportunities for coordinated actions to manage aging CASS piping.

There were thirty-two participants from eight countries -- Finland, Sweden, Belgium, France, Canada, Japan, South Korea, and the United States. They represented utilities, vendors, regulators, inspection companies, and research organizations. A list of the participants is provided on pages 15 through 18.

Workshop Objectives

- Build upon the results of the previous workshops
- Review the current state-of-the-art in the inspection of CASS piping
- Determine what are the “gaps” and what can be done to fill the “gaps”
- Establish the foundations for cooperative improvement initiatives

Workshop Agenda

The workshop was structured to:

- Inform the participants of recent CASS-related activities and programs
- Facilitate discussions concerning the direction of future research

The majority of the first day was devoted to a review of CASS inspection and analyses programs. During the morning there were a number of brief presentations. The afternoon session focussed on flaw tolerance analysis and recent advancements in inspection capabilities.

The second day was spent discussing the current situation and the need for both near-term and long-range initiatives. The opportunity for open discussions was an important aspect of the workshop. A list of proposed discussion topics (shown on the right) was provided at the beginning of the workshop. Over the two days many of these topics were addressed to one degree or another.

Georges Bedzikain, from Georges Bezdikian Consulting Co.

Takayoshi Tsuruta from MHI

Proposed Discussion Topics

Inspection Strategies
- Inspection from ID/OD using UT & ET

Inspectability Issues
- < 2-inch versus > 2-inch CASS material

Sound Field Characterization & Modelling

Macrostructure Characterization
- In-situ characterization

Critical Flaw Size
- Influencing factors

Signal Processing
- Criteria for signal evaluation

Vintage CASS Material
- Casting processes & variables
- Availability & reproductions

Flaw Fabrication Issues for Mock-ups

New Plant CASS Material
- Plant configuration issues

The Presentations

The participants provided a wealth of information in their slide presentations. The presenters gave an overview of their recent and planned CASS-related activities. Unfortunately, due to time limitations it was not possible for each presenter to cover their material to the degree they may have desired. However, copies of all the presentation slides are included in the are available in the Attachment to this summary report and on the Workshop CD.

Presentations were made by:

- EPRI
- US Nuclear Regulatory Commission
- The Pacific Northwest National Laboratory
- Structural Integrity Associates
- Georges Bezdikian Consulting Co.
- LABORELEC
- RTQP Ringhals AB
- AREVA NP Uddcomb AB
- Trueflaw
- Zetec
- Japan Nuclear Energy Safety Organization
- Korea Institute of Nuclear Safety

Additional presentation material was provided by LMT, Inc., WesDyne, Southern Nuclear, and the Institute of Nuclear System Safety, Inc. (INSS)[1]. A list of all twenty-two presentation sets is provided on pages 13 - 14.

Copies of the presentation are included on the Workshop CD. The CD can be obtained by contacting Alan Chockie at chockie@chockiegroup.com or +1 (206) 367-1908.

[1] Dr. Yasuo Kurozumi from INSS in Japan was not able to attend the workshop. However he provided an set of slides on recent CASS activities at INSS.

Inspection Requirements

CASS material used in PWR primary piping systems has had an incident-free service record for almost 40 years. CASS was selected for these installations based on such factors as its relative cost, corrosion resistance, and ease of welding. As Tim Griesbach from Structural Integrity pointed out, it is also known to be very ductile, flaw tolerant, and resistant to stress corrosion cracking.

However, CASS material is difficult to inspect using UT and is susceptible to thermal aging embrittlement. Robert Hardies from the NRC reminded the group that CASS components are in safety significant locations in reactor pressure boundary. Continued operation may present issues with age/thermal related degradation. Inspection is used for defense-in-depth and to discover if degradation mechanisms are occurring that were not considered in the design. He reinforced the points that:

- NDE is part of the NRC's defense-in-depth approach to regulating
- There are currently no qualified NDE techniques for CASS
- There are thermal embrittlement concerns with the aging CASS material
- The NRC must ensure the structural integrity of the plant systems and components

Iikka Virkkunen and Aaron Diaz from Trueflaw and PNNL

Tim Griesbach, Kazunoba Sakamoto, and Claes Sandelin from Structural Integrity, JNES, and Ringhals

In the United States (US) the inservice inspection (ISI) requirements for piping systems are found in Title 10 of the US Code of Federal Regulations, Part 50, Section 50.55 (10 CFR §50.55a). However, the Federal Regulations do not spell out the detailed ISI requirements. Rather they invoke Section XI of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for inservice inspection requirements.

ASME CASS ISI Requirements

The ASME ISI qualification requirements are found in Appendix VIII. Ronnie Swain from EPRI noted that Supplement 9 of Appendix VIII (which concerns CASS inspections) has been "in course of preparation" since 1989. Until the qualification requirements are developed the plants must follow the requirements found in Section XI, Appendix III.

Appendix III contains prescriptive requirements for performing non-qualified ultrasonic examination (UT) of vessel and piping welds. The Appendix III techniques are amplitude based techniques and are not considered the best available UT methods for successful CASS exams.

In 1997 the Section XI Task Group on Austenitic Stainless Steel Inspections was established to resolve the issues concerning CASS inspections and to propose Code actions to complete Appendix VIII Supplement 9. Mr. Swain, the Chair of the Task Group, pointed out that before Supplement 9 qualification requirements can be established, a reliable UT method has to be developed for detection and sizing of flaws within CASS. Also, the critical flaw sizes for CASS components must be determined to allow realistic qualification rules to be written.

Recently the Task Group has initiated two significant actions:

- Code Case for inspection of CASS piping welds less than 2-inches in wall thickness
- Appendix III supplemental requirements for UT exams of CASS piping welds

The draft Code Case is based on the work of PNNL on 1.6-inch thick CASS pressurizer surge line material from a cancelled US plant. The Code Case would create an "add-on" to a Supplement 10 qualification for UT of dissimilar metal welds – allowing the same techniques to apply to thinner CASS weldments. Mr. Swain stated that in order to validate the intent of this Code Case EPRI and PNNL are currently performing additional UT experiments on other vintage CASS piping material obtained from operating US plant calibration standards.

The Appendix III supplemental requirements will call for specific equipment and exam parameters that have been shown to provide the best and most reliable exam results currently available for CASS material. The Appendix III rules will serve as interim "best practice" requirements for CASS inspections while the Appendix VIII requirements are being developed.

During the discussions it was mentioned that one concern with the Appendix III supplemental requirements is how to ensure the appropriate level of detail is specified. How detailed will the requirements need to be?

As can be noted in the numerous presentations at the Workshop, there has been increasing research and development work related to the inspection of CASS. The following are brief summaries of recently completed, ongoing, and planned projects -- in the US, Belgium, Japan, Korea, and Sweden. More information can be found in the associated presentations provided in the Attachment to this summary report.

EPRI CASS Activities

In recent years EPRI has initiated a number of CASS-related research programs. Doug Kull of EPRI briefly reviewed the NDE Center's recently completed, ongoing, and planned CASS projects.

The five completed projects are:

- Flaw tolerance evaluation of thermally aged CASS (Deterministic Approach)
- Probabilistic model for the reliability of thermally aged CASS (Phase I)
- Use of thermography for NDE of CASS
- Guidelines for the inspectability of new components (including CASS)
- Low frequency UT for weld overlays on CASS base material

The four ongoing projects are:

- Flaw fabrication in CASS components
- Acquisition and analysis of CASS material
- Inspection results on CASS < 2-inches thick
- Evaluation of Inside Surface Examination Techniques for CASS

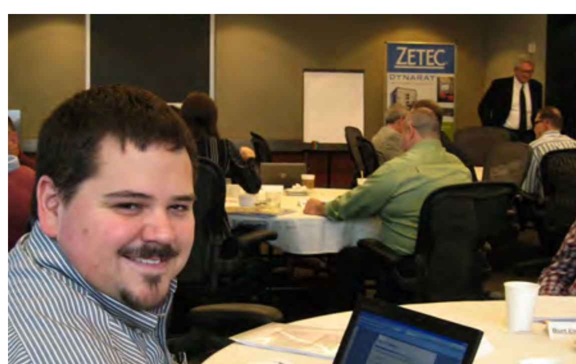
The two new EPRI CASS projects are:

- Signal processing advancements for CASS UT examinations
- Probabilistic model for the reliability of thermally aged CASS (Phase II)

Doug provided information on the objectives, methods, and results of all the CASS projects in his presentation (see Attachment Presentation #4).

EPRI, in association with the Ringhals plant in Sweden, conducted a study concerning the feasibility of performing UT exams on statically cast stainless steel valve material (see Presentation #10). The three EDM notches in the valve mock-up were detected using a 500 kHz UT phased array probe. However, Claes Sandelin and Mark Dennis indicated that although the results demonstrate a gradual improvement in the ability to inspect statically cast CASS material, two items should be considered for potential enhancements:

- Fixed angle low frequency (~500 kHz) conventional rather than phased-array UT probes
- Large low frequency (~500 kHz) immersion probes or flexible array probes



Doug Kull from EPRI

PNNL CASS Activities

The Pacific Northwest National Laboratory has been actively involved for many years in conducting CASS UT studies for the US NRC. As reviewed by Aaron Diaz the current PNNL work includes (Presentation #6):

- Phase array UT confirmatory research
    - < 2-inch and > 2-inch wall thicknesses in CASS components
    - Obtaining vintage CASS material
    - Effects of flaw fabrication methods on signal responses
- Evaluating methods for in-situ CASS microstructure characterization
- Assessing casting parameters and their impact on CASS microstructures
- Evaluating UT phased-array signal processing methodologies
- Assessing phased-array UT and eddy current exams on the ID
- Sound field propagation in CASS
    - Sound field mapping through CASS microstructures
    - Corner trap signal response and dropout from CASS samples
    - Theoretical modeling of sound field propagation through CASS microstructures and austenitic welds
- Collaborative research with IRSN/ CEA in France -- including validation of CIVA modeling results and phased-array UT characterization of Manoir specimens

Detailed reviews of PNNL projects on UT phased-array evaluations of both thick-wall (>2-inches) and thin-wall (<2-inches) CASS piping were presented by Traci Moran and Tony Cinson (Presentations #7 and #8).

Traci Moran and Tony Cinson from PNNL

CASS Activities in Belgium

Laborelec (LBE) in Belgium has been involved in the inspection of nozzles to CASS primary piping welds. Ms Moussebois of Laborelec stated that the first trials in 2005 did not produce good results due to geometry issues and UT low permeability. Follow-on efforts with a full-scale mock-up are focussing on the detection of circumferential flaws in the ASME zone. A collaborative project with CEA in France is evaluation a low frequency 2D-matrix phased-array UT probe that is adjustable to the CASS piping surface. (Presentation #13)

Other current LBE efforts include:

- A modeling project with CIVA to support the design and identification of mechanical and ultrasonic maximum stress zones and beam distortion modelling
- A feasibility study for the dedicated scanner

CASS Activities in Japan

The Japan Nuclear Energy Safety Organization (JNES) began a 5-year NDE CASS research program in 2009. To date preliminary UT data and visualization image of ultrasound propagation has been obtained. The visualization technique revealed the beam propagation such as skew due to the coarse grained and acoustically anisotropic crystal structures. JNES plans to build upon this effort with the following programs:

- Applying the visualization technique to various CASS samples
- Conducting mathematical analysis and developing simulation models to gain a better understanding of the phenomena
- Obtaining more UT performance data
- Destructively verifying the true flaw size to comprehend the inspection capability

JNES has indicated that they would like to encourage international cooperation on these programs.

The Institute for Nuclear System Safety (INSS) in Japan has been involved in the evaluation and development of CASS inspection techniques for many years. As summarized by Dr. Kurozumi in his presentation material (Presentation #22) recent exams using the INSS automated UT system detected all the defects in the CASS (CF-8M) mock-ups with good signal to noise ration. Although depth sizing remains a challenge, the INSS system was able to depth size fatigue cracks >14% through-wall. Length sizing performance was “good” and can be improved with optimized probes. INSS continues to refine their system and has used it for on-site verification exams at 8 plants in Japan since 1999.

Zetec Hosted Reception

Zetec Hosted Reception

CASS Activities in Korea

With respect to international CASS research, Mr. Hong of the Korea Institute of Nuclear Safety (KINS) discussed the Regional Cooperative Project-2 (RCOP-2). This multi-national program involved utility, vendor, and regulatory organizations from Korea, Japan, and China. The objective was to evaluate NDE reliability through NDE round robin inspections of CASS piping. The three-year program began in early 2007 and was completed in early 2010.

It has been concluded that low frequency phased-array probes provide the best results when inspecting CASS material. According to Mr. Hong statistical analysis of the data is ongoing.

CASS Activities in Sweden

The Ringhals power plant in Sweden has been actively assessing CASS inspection techniques for many years. As note previously the Ringhals plant, in association with EPRI, recently conducted a study concerning the feasibility of performing UT exams on statically cast stainless steel valve material (see Presentation #10).

Ringhals also evaluated the effectiveness of an interesting nonlinear NDE technique on detect cracks in CASS material (Presentation #11). The "fingerprint" technique is based on the fact that a crack behavior is nonlinear.

The frequency spectrums are used in the calculation of damage level. Tests were made of the damage level before and after the implementation of the crack into a CASS valve body. It was shown that it is possible to detect cracks in statically cast CASS material using this technique. However, Mr. Sandelin indicated that additional research is needed.

CASS Aging Management at EDF

Georges Bezdikian was the project manager at Électricité de France (EDF) for CASS life management from 1993 to 2007. He is now retired from EDF with his own consulting company. His presentation provided the group with a detailed understanding of the rationale, activities, and results of the 14-year CASS aging management program at EDF (Attachment Presentation #9).

In the 1980's EDF identified thermal aging of CASS and the decrease in the toughness as a potential safety issue. A multi-year R&D program was initiated. Mr. Bezdikian stated that the ability to demonstrate and justify the integrity of the CASS material is dependent on three factors:

- In-Service inspection and flaw characterization
- Aging impacts on the metallurgical and toughness characteristics
- Assessment of the mechanical integrity

The objectives of the program was to assess the integrity of the CASS elbows during all loading conditions over 40-years of operation. The first step was to perform ISI of all sensitive CASS elbows (using gamma radiography and PT) to characterize the fabrication flaws. The second step was to define the acceptance criteria through metallurgical analyses.
Special tools for use "on-site" were developed to measure the decrease in toughness of the elbows over time. Mr. Bezdikian explained that these measurement tools were based on the "thermal electric power" and the application of the Seebeck effect.

The EDF integrity assessment of CASS components has relied on a number of engineering and R&D studies. These included:

- Development of prediction formulas
- Tests on large-sized elbows containing analytical notches

Dinner at the World Trade Center

- Tests on mock-ups with casting defects
- Development of numerical analysis tools for elbow calculations
- Mechanical analyses of CASS components to operate within safety margins under all loading conditions

EDF concluded that all the elbows were acceptable for 40-years of operation and on-going actions for 60 years. However, based on a cost-benefit analysis of the ISI requirements over time it was concluded that it would be best to replace the CASS elbows whenever the steam generators were replaced. Therefore, as a preventive cost-effective measure, EDF has replaced a number of CASS elbows in recent years.

CASS Flaw Tolerance

Tim Griesbach and David Harris of Structural Integrity reviewed the results of recently completed projects for EPRI related to the flaw tolerance of CASS material (see Presentations #17 and # 18).

The objectives of the studies were to:

- Provide a methodology for developing acceptable flaw sizes for the inspection CASS piping the flaw tolerance approach
- Establish a reasonable acceptable flaw size[2] that the inspection technology should be capable of detecting
- Develop a Code methodology for managing aging of CASS materials
- Define the role of inspections for demonstrating piping integrity

2 Acceptable flaw size is defined as the initial flaw size from inspection such that the allowable flaw size will not be reached during operation (includes consideration of potential flaw growth)

Tim Griesbach, David Harris, and Doug Kull

Tim pointed out that in order to improve the evaluation of the CASS piping the following is required:

- Plant-specific design and materials information
- Characterization of material toughness using correlations with chemistry or by measuring delta ferrite
- Screening and categorization of the risk significance of components and locations using risk-based methods
- Using probabilistic fracture mechanics methods to address conditional probability of failure instead of safety factor
- Using the best-available inspection techniques selectively to verify the absence of flaws greater than the maximum allowable flaw size

The reliability of the CASS piping can be characterized by using either a deterministic or probabilistic fracture mechanics analysis. A previous study for EPRI has sown that the deterministic analysis approach results in acceptable flaw sizes that would be difficult, if not impossible, to reliably detect in CASS material. The probabilistic fracture mechanics (PFM) model that Structural Integrity is developing will allow:

- Defining the inputs as probability functions and explicitly characterize mean values and uncertainties
- Changes in properties (such as toughness and strength) can be estimated directly from experimental data
- Setting a safety goal (such as a conditional probability < 10-6/reactor-year) as a failure criteria consistent with other safety issues (such as Pressurized Thermal Shock)
- Results of PFM analysis can be used to evaluate essential variables, determine sensitivity to changes and uncertainties, consider options to manage the issue, and propose flaw acceptance standards for CASS piping

Zetec Hosted Reception

David Harris provided a detailed review of the PFM model (Presentation #18). He noted that the key to his presentation is summarized on slide 13 and in the highlighted figure entitled, “Critical Crack Size at Selected Probabilities”, at the bottom of the slide.

The conclusions from the preliminary model development indicate that the probability of failure in CF8M CASS material is quite low unless the cracks is very large. However there are a number of issues with the model. These include:

- Statistical fits to data is not always good
- Contrary to expectations the preliminary results indicate that tolerable crack sizes (at a given probability) are larger for aged material than non-aged material
- There is insufficient data available to define correlation of strength and toughness

David noted that the reliability of the PFM model has not been exercised. This will be undertaken in the Phase II follow-on project. The Phase II work will involve:

- Developing an improved technical basis
- Performing more detailed analyses
- Preparing a proposed Code change for flaw acceptance standards in CASS piping

Both Mr. Griesbach and Mr. Harris emphasized the need for additional data on the relationship between material toughness and strength. Information is also needed on the probability of detection and the initial flaw size distribution.

The participants wanted to know if the PFM model was “ready for use”? Tim stated that the development of the model was complete but it they needed more data to refine the model and reduce the uncertainties. A major benefit of the model is the ability to perform “what-if” analyses while working to gather better data.

Bob Hardies of the NRC “highly recommended” that the PFM CASS model should be integrated into the xLPR program (materials fracture analysis code) that the NRC and EPRI are developing. Greg Selby from EPRI stated that he would make the contact the appropriate person at EPRI to ensure coordination and integration takes place.

Mr. Hardies reminded the group of the NRC's defense-in-depth philosophy. In order to address potentially unknown issues one will need to implement safety actions or inspections that are not based on probability of failure.

Concerning the need for more data to improve the PFM analyses, Georges Bezdikian suggested that the Material Aging Institute might be a valuable resource. Other participants also said they would provide Tim with possible sources of thermal and mechanical load data. Although specific load data may be considered proprietary and therefore very difficult to obtain, Tim felt that generic load and cycle data could be useful to help bound the issue.

Tim believes that a risk informed approach to the determination of CASS inspections would be very beneficial in supporting each plant to focus on where and how to inspect the CASS piping at their plant. He proposed a program to pilot test the risk informed approach at one or more plants. Several of the utility representatives indicated that this might be of interest to them.

The Next Steps

At the end of the presentation and discussion sessions the group was asked to identify the key next steps. The group identified a number of issues that the "next" development activities will need to address. These issues fall into three basic categories:

- Material Characteristics
- Flaw Characteristics
- Inspection Systems

Material Characteristics

- How does centrifugally versus statically cast processes affect UT?
- Is grain structure the main driver for UT permeability?
- How does chemical composition affect UT (CF8, CF8M, CF8A)?
- What are the differences between centrifugally and statically cast CASS material?
- What are the differences between new materials versus vintage materials?
- What are the surface condition requirements for weld inspection?
- What are the influencing casting parameters on the microstructure?
- What casting requirements should be established for new plants?
- Cleanliness of manufacturing process (population of internal voids)?
- What is the affect of thickness -- is < or > 2-inch wall thickness the correct cut-off?
- How to determine the sound field in CASS?
- What is the affect of material aging on UT permeability?

Flaw Characteristics

- What is the critical flaw size for each existing component type?
- What morphology or type of flaw are we trying to find?
- What is the affect of flaw orientation (axial versus circumferential versus off-axis)?
- How does delectability of base material flaws differ from flaw wholly contained in the weld material?
- What flaw manufacturing type is best

for representing base material flaws and best for weld flaws or best for heat affected zone flaw?

<u>Inspection System</u>

- Probe characteristics needed (angles, resolution, aperture characteristics, number of elements, importance of skewing, element size, materials, mode of propagation)?
- What is the most effective scan approach for UT -- in combination with ET from ID?
- What are beam simulation requirements that should be used to develop a cast UT inspection system?
- What is important pertaining to wedge design/materials?

Acknowledgments

We wish to recognize the support, encouragement, and assistance of the following organizations in making the Workshop a success:

- Zetec — for their encouragement and their sponsorship of the Friday evening reception
- Structural Integrity Associates
- Japan Nuclear Energy Safety Organization
- The US Nuclear Regulatory Commission
- EPRI
- The Pacific Northwest National Laboratory
- The Bell Harbor Conference Center
- The Westin Hotel (the Workshop's host hotel)

We also wish to thank the presenters and participants for a very informative and productive two days.

Bell Harbor Conference Center

Presentations

The following presentations are included on the Workshop CD:

1. Workshop Welcome: Agenda/Participants

    (Alan Chockie - Chockie Group International, Inc.)
2. Cast Stainless Steel Inspection: An Overview of ASME Section XI Activity

    (Ronnie Swain - EPRI Performance Demonstration Program)
3. EPRI - Performance Demonstration Program

    (Ronnie Swain - EPRI Performance Demonstration Program)
4. Summary of CASS NDE Activities

    (Doug Kull - EPRI)
5. Regulatory Issues Related to the Examination of Cast Austenitic Stainless Steel

    (Robert Hardies - US Nuclear Regulatory Commission)
6. Summary Overview of CASS NDE Activities at PNNL

    (MT Anderson, AA Diaz, SL Crawford, AD Cinson, TL Moran, P Ramuhalli and MS Prowant - Pacific Northwest National Laboratory)
7. Ultrasonic Phased Array Evaluation of Thick-wall Cast Austenitic Stainless Steel (CASS) Piping

    (MT Anderson, AA Diaz, SL Crawford, AD Cinson, TL Moran, P Ramuhalli and MS Prowant - Pacific Northwest National Laboratory)
8. Ultrasonic Phased Array Evaluation of Thin-wall Cast Austenitic Stainless Steel (CASS) Piping

    (MT Anderson, AA Diaz, SL Crawford, AD Cinson, TL Moran and MS Prowant - Pacific Northwest National Laboratory)
9. Lifetime, In-Service Inspection, Aging Management of Cast Duplex Stainless Steel Components on Reactor Coolant Primary Circuit

    (Georges Bezdikian - Georges Bezdikian Consulting Co.)
10. Cast Stainless Ultrasonic Examination Feasibility Study for Ringhals

    (Claes Sandelin - RTQP Ringhals AB & Mark Dennis - EPRI)
11. Nonlinear Nondestructive Testing: Fingerprint of Cast Stainless Steel Examination of Rods Submerged in Water

    (Claes Sandelin - RTQP Ringhals AB)
12. Short Presentation AREVA Uddcomb AB Testblocks

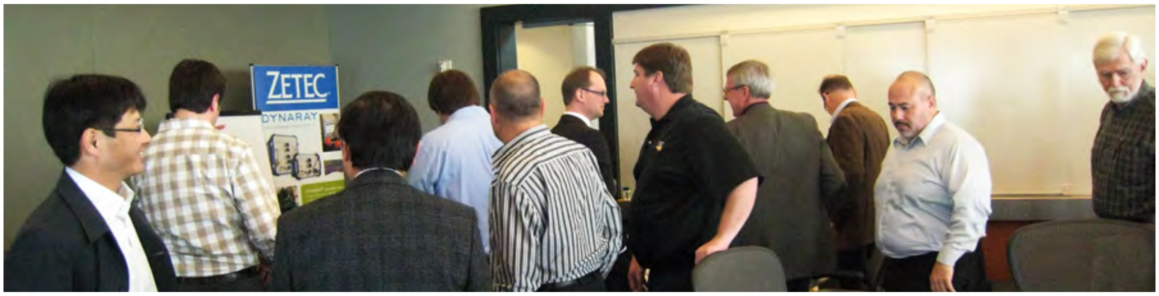
    (Per Arne Bjurling - AREVA Uddcomb AB)
13. Study on the Ultrasonic Inspection for CASS

    (Kazunobu Sakamoto - Japan Nuclear Energy Safety Organization)
14. Laborelec NDT Activities

    (Dominique Moussebois - LABORELEC)

15. Current Status of CASS Work in KINS (Round Robin Test of RCOP-2)
    (Jin-Ki Hong - Korea Institute of Nuclear Safety)
16. Trueflaw: Cracking CASS
    (Iikka Virkkunen - Trueflaw)
17. Flaw Tolerance Evaluation of Thermally Aged Cast Austenitic Stainless Steel Piping
    (Timothy J. Griesbach - Structural Integrity Associates, Inc.)
18. Probabilistic Model of Reliability of Cast Austenitic Stainless Piping
    (Tim Griesbach, David Harris, Merric Qian and Danen Heath - Structural Integrity Associates, Inc.)
19. LMT CASS Activities
    (Jeff Devers - LMT, Inc.)
20. Southern Company
    (Danny Cordes - Southern Nuclear)
21. WesDyne International Activities Associated with the Inspection of Cast Austenitic Stainless Steel Pipe Welds
    (Rick Rishel - WesDyne International)
22. Recent Ultrasonic Research and Development Activities and Results for CAST Stainless Steel in INSS
    (Yasuo Kurozumi - Institute of Nuclear Safety Systems, Inc.)

Too Much Information!



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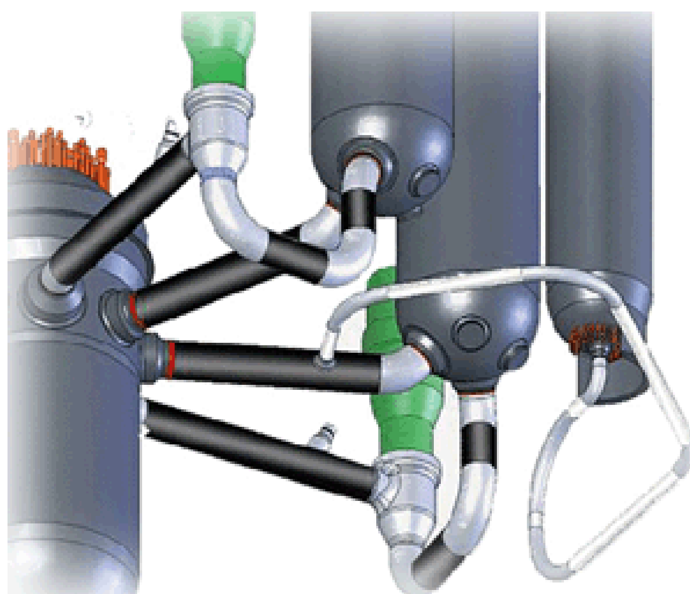
Chockie Group International, Inc.

3rd International Workshop

Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

Summary Report Attachments:

Workshop Presentations



January 28 - 29, 2011
Bell Harbor Conference Center
Seattle, Washington

Summary Report - Workshop Attachments

3rd International Workshop on the Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

January 28 - 29, 2011
Seattle, WA

The Workshop

The two-day workshop was held at the Bell Harbor Conference Center in Seattle, Washington, on January 28 -29, 2011. The purpose was to bring together interested parties to review the current state-of-the-art in the inspection and analysis of CASS material and to identify opportunities for coordinated actions to manage aging CASS piping.

The Presentations

The Workshop participants provided a wealth of information in their slide presentations. The presenters gave an overview of their recent and planned CASS-related activities. Unfortunately, due to time limitations it was not possible for each presenter to cover their material to the degree they may have desired. However, copies of all the presentation slides are included in the this Attachment. Presentations were made by:

- EPRI
- US Nuclear Regulatory Commission
- The Pacific Northwest National Laboratory
- Structural Integrity Associates
- Georges Bezdikian Consulting Co.
- LABORELEC
- RTQP Ringhals AB
- AREVA NP Uddcomb AB
- Trueflaw
- Zetec
- Japan Nuclear Energy Safety Organization
- Korea Institute of Nuclear Safety

Additional presentation material was provided by LMT, Inc., WesDyne, Southern Nuclear, and the Institute of Nuclear System Safety, Inc. (INSS)[1].

Summary Report

For a copy of the Summary Report please contact

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[1] Dr. Yasuo Kurozumi from INSS in Japan was not able to attend the workshop. However he provided an set of slides on recent CASS activities at INSS.

Table of Contents

Click on the title to go to the presentation

[1] Dr. Kurozumi was not able to attend, however he provided a presentation on recent CASS activities at INSS

Chockie Group International, Inc.

3rd International Workshop

Future Directions for the
Inspection of Cast Austenitic Stainless Steel Piping

Chockie Group International, Inc.

3rd International Workshop

Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

Workshop Agenda

Friday - January 28

8:00	Continental Breakfast
9:00	Introductions & Review of Previous Workshops
9:30	ASME Section XI CASS Activities
9:45	EPRI CASS Programs
10:00	NRC - PNNL Programs
10:15	EDF CASS Program
10:30	Break (15 minutes)
10:45	Ringhals CASS Activities
11:00	JNES CASS Activities
11:15	LABORELEC Activities
11:30	KINS CASS Work
11:45	CASS Test Blocks
12:00	Lunch
1:00	Flaw Tolerance Analysis / Discussions
2:30	Break (15 minutes)
2:45	Inspection Developments / Discussions
4:30	Wrap-up

Saturday - January 29

8:00	Continental Breakfast
9:00	Group Discussions
10:30	Break (15 minutes)
10:45	Group Discussions
12:00	Lunch
1:00	Identify Future Actions / Potential International Cooperative Initiatives
2:30	Break (15 minutes)
2:45	Wrap-up
3:15	Workshop Conclusion

Chockie Group International, Inc.

3rd International Workshop

Future Directions for the

Inspection of Cast Austenitic Stainless Steel Piping

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Cast Stainless Steel Inspection An Overview of ASME Section XI Activity

January 2011

Ronnie Swain
Senior Project Manager
EPRI Performance Demonstration Program

Cast Austenitic Stainless Steel in Nuclear Power Plants

- Reactor Coolant System (Class 1)
- Static Cast Components
  - RCS Pipe Fittings (elbows)
  - Pump Casings
- Centrifugally Cast Components
  - RCS Pipe
- Safe-ends can be either static or centrifugally cast

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Evolution of CASS Inspection

- 1970 Edition
  - Earliest ASME Section XI rules required volumetric inspection of Class 1 piping welds.
  - No distinction made in material type or fabrication method.
- Mid-1970's
  - More detailed rules in 1974 and 1977 Editions and Addenda
  - Still no specific distinction made for material characteristics
  - Industry was beginning to recognize challenges concerning ultrasonic inspection of CASS material

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Evolution of CASS Inspection

- Development of Enhanced Techniques
  - Several inspection suppliers developed enhanced UT techniques to attempt to improve CASS inspection capability
    - Water column technique
    - Low frequency, dual element refracted L-wave
- Regulatory Action
  - IGSCC issues, primarily in BWR piping, led to actions to improve reliability of NDE processes used in ISI
  - Variety of regulatory processes in different regions
  - 1984: Proposed NRC rules led to creation of ASME Task Group to address NDE Performance Demonstration

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ASME Section XI Appendix VIII

- ASME formed Task Groups in early 1985
  - Appendix VII – Training and Qualification
  - Appendix VIII – Performance Demonstration
- 1989 – Appendix VIII Published
  - Included a Supplement for each type of inspection to be performed
  - Supplement 9 – Cast Austenitic Stainless Steel was "In Course of Preparation"
- 1990 – 1997
  - Performance Demonstration Initiative (PDI) was formed to implement the rules of Appendix VIII
  - Initial emphasis was on reactor vessel components and wrought austenitic and ferritic piping welds

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ASME Section XI Appendix VIII

- ASME formed Task Group on CASS Inspection in 1997
  - Charter is to resolve the issues concerning CASS inspection and propose Code actions to complete Appendix VIII Supplement 9
  - Before a Supplement 9 can be established for qualification of UT of cast stainless steel, a reliable UT method has to be developed for detection and sizing of flaws within this material
  - In addition, the critical flaw sizes for components comprised of this material must be established to allow realistic qualification rules to be written
  - It has also been discussed that Appendix VIII rules may have to be modified to handle qualification of UT techniques for CASS, or that these rules may have to reside in a different part of the Code.

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Recent ASME Code Activity on CASS

- 2009 – New Draft Code Case introduced to allow Appendix VIII, Supplement 10 techniques for examination of cast stainless piping welds less than 2 inches in wall thickness
  - Based on work performed by PNNL on vintage 1.6 inch thick cast pressurizer surge line material obtained from a cancelled U.S. power plant
  - The Code Case would create an "add-on" to a Supplement 10 qualification for UT of dissimilar metal welds – allowing the same techniques to apply to thinner cast stainless weldments
  - EPRI and PNNL are currently performing additional UT experiments on other vintage cast piping material obtained from operating U.S. power plant calibration standards in order to validate the intent of this Code Case

Recent ASME Code Activity on CASS

- While the Appendix VIII, Supplement 9 is "in course of preparation", Appendix VIII sends it's users to Section XI, Appendix III for examination of cast stainless steel piping components
  - This appendix contains prescriptive requirements for performing non-qualified ultrasonic examination of vessel and piping welds
  - The techniques currently described in Appendix III are amplitude based techniques and are not considered the best available UT methods for successful cast stainless steel examination
- Very recently, members of the Task Group on Cast Stainless Steel have begun drafting supplemental requirements for addition into Appendix III for UT examination of cast piping welds
  - Will call for specific equipment and examination parameters that have been shown to provide the best and most reliable examination results currently available for this type of material
  - These Appendix III rules will serve as interim "best practice" requirements for examination of CASS, while Appendix VIII requirements are "in course of preparation"

Other On-going Support Activities

- The NRC and the commercial nuclear power industry continue funding numerous cast stainless steel related research projects through PNNL and EPRI for advancing UT inspection technologies and flaw-making processes
  - The NRC and commercial utilities are also working on ways of sharing their research results, in hopes of better focusing the research and finding efficiencies
- The industry is also funding a multi-phased flaw evaluation project to determine what the critical flaw size (s) are for this material, in order to aid the development of realistic Appendix VIII UT qualification requirements

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Questions?

Together…Shaping the Future of Electricity

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Ronnie Swain

Senior Project Manager

EPRI - Performance Demonstration Program

Ronnie Swain
EPRI Performance Demonstration Program

- EPRI stands for Electric Power Research Institute – which is a research and development organization funded by all of the U.S. and many of the International commercial electric power utilities
- The Performance Demonstration Program exists within the Nuclear Power Sector of the EPRI organization – We develop, maintain and administer Performance Demonstration testing involving Ultrasonic Testing technologies on behalf of our member utilities.
  - ASME Section XI, Appendix VIII required qualifications (UT of piping and RPV components in nuclear plants)
  - 10 CFR 50.55a required UT qualifications (reactor head penetration examinations)

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Ronnie Swain
EPRI Performance Demonstration Program

- Currently there are no existing requirements for procedures, personnel and equipment to be qualified to ultrasonically inspect cast stainless steel materials
  - Those requirements are “in course of preparation” in the ASME Code

- My group at EPRI is working on advanced UT methods to improve examination of these materials
- We are also working on flaw making techniques to allow representative mockups to be constructed for future qualification testing
- I also represent EPRI at the ASME Code meetings, where I chair a Task Group on Cast Stainless Steel which is working to develop Code rules for examination of CASS.

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Summary of CASS NDE Activities

Doug Kull
Project Manager

3rd International Workshop on Future Directions for the Inspection of CASS Piping

01/29/2011

Contents

- Summary of EPRI NDE projects involving CASS material
  - Completed Projects (5)
  - Ongoing Projects (4)
  - New Projects (2)

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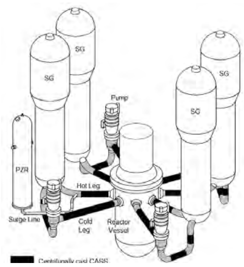
Completed Projects
Flaw Tolerance Evaluation of Thermally Aged CASS (Determinitistic Approach)

- Objective
  - Determine critical flaw size for CASS material throughout the industry
  - Develop suitable flaw acceptance criteria for ASME Sect.XI



- Method
  - Calculations based on fracture mechanics and flaw growth analysis
  - Using a range of material properties and operating conditions that encompass the industry
  - Include a safety margin that follows the current ASME methodology
- Results
  - Large variations in the essential variables were noted throughout the industry
  - Most likely not the appropriate solution for industry wide critical flaw size determination
  - Results published in Report 1019128

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Completed Projects
Probabilistic Model for the Reliability of Thermally Aged CASS (Phase I)

- Objective
  - Predict failure probability vs. time at temp with respect to ranges of critical flaw sizes
  - Bypasses the need for conservative bounding values
  - Used to predict thermal embrittlement
  - Results used to determine critical flaw sizes in CASS

- Method
  - Generate computer model similar to PRAISE Code for probabilistic evaluation of degraded piping
  - Estimate the distributions of random variables
  - Define and run example problem
- Results
  - The results of Phase 1 are currently being reviewed
  - A draft report has been generated and is expected to be published later in 2011

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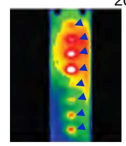
Completed Projects
Use of Thermography for NDE of CASS

- Objective
  - Crack detection independent of orientation
  - Insensitive to grain structure
  - Infrared camera measures temperature gradient



- Method
  - Tests performed from both ID and OD
  - Used both convection and induction heating sources
  - Record the temperature vs. time map (Thermogram)
  - Thermogram processed with various algorithms
- Results
  - Techniques used in this study were unsuccessful in detecting the notches
  - Additional testing is needed with larger specimens
  - Look into Vibrothermography as an alternative technology

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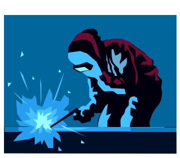
Completed Projects
Guidelines for the Inspectability of New Components (Including CASS)

- Objective
  - Provide guidelines for fabrication and design of new nuclear systems
  - Necessary steps for effective pre-service and in-service NDE
  - Prevent known problems that the existing nuclear fleet is experiencing
  - Provide a document that aids the newest generation of engineers in the development of nuclear components
- Method
  - Compile information pertaining to NDE problems and solutions experienced throughout the industry
  - Tap "aging resources" to prevent the loss of important knowledge



- Results
  - A large amount of information was obtained and documented
  - The 2010 report includes a section dedicated to CASS components
  - Results published in Report 1021160 (Considered a must read for 2011)

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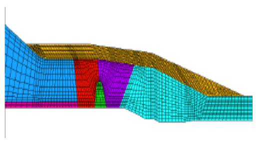
Completed Projects
Low Frequency UT for WOL on CASS Base Material

- Objective
  - Investigate the effectiveness of low frequency UT on WOL specimens with CASS base material
  - Compare low frequency UT techniques and traditional higher frequency techniques
  - Determine current limitations of CASS base material examinations through WOL material



- Method
  - Utilize mockups recently manufactured for the PDI WOL program
  - Mockups have a limited number of indications in the CASS base material that were intended for research only
  - Inspect the mockups with various low frequency instruments and search units
- Results
  - Improvement noted over standard higher frequency techniques
  - Some flaws could not be detected and others were difficult to fully characterize
  - Results from this study suggest that current low frequency techniques could result in an increased level of false calls
  - Results published in Report 1021145

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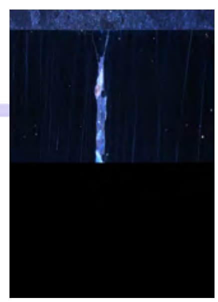
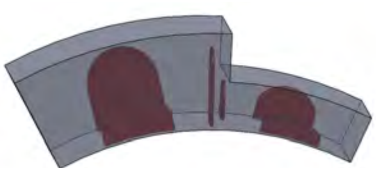
Ongoing Projects
Flaw Fabrication in CASS Components



- Objective
  - Supply the industry with an open set of flawed mockups that provide realistic NDE responses
  - Discover a way to implant flaws into CASS base material without disturbing the unique grain structure



- Method
  - Determine the limitations of current flaw making technology
  - Work with mockup manufactures to develop new flaw making techniques
  - Test flawed mockups with the latest NDE technology to determine if the response is realistic (no tell tale signs)
- Results
  - Recently took receipt of first trial flaw specimen and will subject it to UT in February 2011
  - Currently discussing alternative flaw fabrication techniques with domestic and international companies
  - If you have an idea we would like to hear it and possibly work with you on this project
  - Results to date are published in Report 1021146

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Ongoing Projects
Acquisition and Analysis of CASS Material

- Objective
  - Identify sources for non-contaminated vintage CASS material
  - Negotiate the purchase or donation of vintage CASS material
  - Identify a reliable source for additional material

- Method
  - Scour the earth for leads to sources for material
  - Work with foundries to manufacture new “old” material
  - Perform grain structure analysis on the material and catalog the results
- Results
  - Obtained four statically cast main loop elbows and a centrifugally cast surge line pipe from two US utilities
  - Recently took receipt of the first simulated vintage CASS material and awaiting results of the grain structure analysis
  - Results to date are published in Report 1021146

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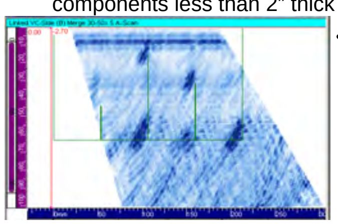
Ongoing Projects
Inspection Results on CASS Less than 2” Thick

- Objective
  - Determine if current NDE techniques are capable of reliably detecting and characterizing flaws in CASS material less than 2” thick
  - Aid in the development of a code case for the inspection of CASS components less than 2” thick



- Method
  - Obtain as many vintage CASS specimens as possible and expose them to currently qualified UT techniques
  - Perform and catalog the grain structure analysis for as many of the specimens as possible
  - Utilize both conventional and phased array UT techniques
  - For additional information expose the specimens to the latest low frequency UT available
- Results
  - Small reflectors (10% to 20%) are difficult to detect in some CASS material
  - Precise length and depth sizing is difficult and in some instances unobtainable
  - Some CASS material affects the UT propagation more than others (beam bending, attenuation, and reduced sensitivity)
  - This study included a very limited number of specimens and reflectors

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Ongoing Projects
Evaluation of Inside Surface Examination Techniques for CASS

- Objective
  - Evaluate and develop UT and ET techniques deployable from the ID surface of CASS components
  - Determine if ID connected flaws can be reliably detected from the inside surface of a CASS component

- Method
  - Investigate new technologies and procedures for ET techniques
  - Evaluate and possibly expand currently qualified ID UT inspection procedures
- Results
  - An inspection vendor is currently scanning the ID samples
  - Other vendors have expressed an interest in working on this project
  - Report will be published in 2011 describing the preliminary results of this project

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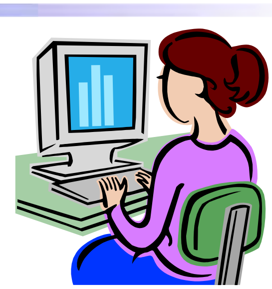
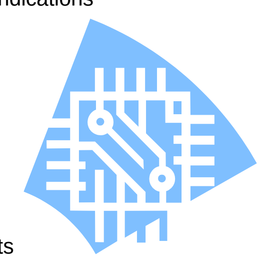
New Projects
Signal Processing Advancements for CASS UT Examinations



- Objective
  - Develop signal processing algorithms for more reliable flaw detection during UT inspections of CASS
  - Increase signal to noise ratio by eliminating some of the material noise while amplifying the signal response from indications



- Method
  - Develop the software and hardware necessary to perform the advanced signal processing
  - Test the signal processing routines on specimens with known reflectors
- Results
  - The results of this project will be published in an annual report

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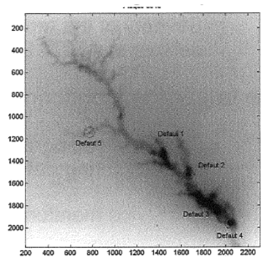
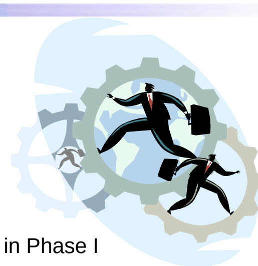
New Projects

Probabilistic Model for the Reliability of Thermally Aged CASS (Phase II)

- Objective
  - Develop final code for model
  - Develop detection probability and crack size distribution statistics





- Method
  - Refine model developed in Phase I
  - Document final input assumptions
  - Consider additional variable such as pore sharpening
  - Continue research on inspection capabilities
  - Characterize load inputs
- Results
  - The results of this project will be summarized in a report to be published in early 2012
  - Preliminary results will be published in the 2011 annual CASS Study report

Summary

EPRI has a lot going on!

"If I find 10,000 ways something wont work. I haven't failed. I am not discourage, because every wrong attempt discarded is another step forward." ~ Thomas Edison

The industry need to continue making small steps towards solving the inspection problems with CASS material

Together…Shaping the Future of Electricity

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

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UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Regulatory Issues Related to the Examination of Cast Austenitic Stainless Steel

3rd International Workshop on the Future Directions for the
Inspection of Cast Austenitic Stainless Steel Piping
January 28-29, 2011
Seattle, WA

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Regulatory Requirements

- General Design Criteria-32 “Inspection of reactor coolant pressure boundary.” Components which are part of the reactor coolant pressure boundary shall be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor pressure boundary pressure vessel.
- 10 CFR 50.55(a) incorporates ASME Code Section XI by reference. The Code requires inspection of welds adjacent to cast components.

2

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Background

- Inspection requirements exist for most components, even those with no known active degradation mechanism.
- For certain CASS components, inspection done on sampling basis to provide reasonable assurance of continued lack of degradation mechanism.
- Ability to inspect all piping components desired.

3

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Background

- CASS components are in safety significant locations in reactor pressure boundary.
- Though operational experience has not identified failures, continued operation may present issues with age/thermal related degradation.
- Inspection is used for defense-in-depth and to discover if degradation mechanisms are occurring that were not considered in the design.

4

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Regulatory Issues

- CASS components on one side of a weld interfere with the ability to inspect a weld resulting in coverage and quality issues.
- Single sided exam leads to lower robustness and potentially missed indications.
- Geometry on the accessible side can challenge coverage.

5

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Regulatory Issues

- For the CASS components themselves, inspections are required; however, the inspections do not provide useful information and, currently, cannot be qualified.
- Variety of components:
  - Piping, surge lines, pump bowls, safe ends
    - Single-sided and “no-sided” exams (where castings are on both sides of the weld).
  - Cast internal components
    - Not a requirement to inspect now; however, in license renewal arena, there are postulated degradation mechanisms related to thermal and radiation embrittlement which may lead to a need for inspection.

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Progress

- PNNL Program "Examination of CASS Pressurizer Surge Line Welds"
- Set of thermal fatigue cracks implanted into three CASS pressurizer surge-line pipe-to-elbow welds
  - Vintage CASS materials formed in the 1970's used
  - Material salvaged from Combustion Engineering designed units that were never brought into full operation
- State-of-the-art phased array inspection approaches are rapidly evolving and have enabled this PNNL program to demonstrate the capability to reliably detect and effectively characterize 10% - 50% through wall thermal fatigue cracks in cast austenitic stainless steel components where the wall thickness is less than 50 mm (2 in.)

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Summary

- Potential for new degradation mechanisms in CASS components could challenge structural integrity and functionality of the reactor coolant system.
- The inability to inspect CASS components challenges our ability to demonstrate the structural integrity of plants.
- NRC supports the approach to initially address ultrasonic examination of austenitic or dissimilar metal welds for which the ultrasonic beam must pass through CASS piping material 2" thick or less

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3rd International Workshop: Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping
January 28-29, 2011

Summary Overview of CASS NDE Activities at PNNL

MT Anderson, AA Diaz, SL Crawford, AD Cinson,
TL Moran, P Ramuhalli and MS Prowant

Pacific Northwest National Laboratory, Richland, WA USA

Work supported by the US NRC, RES Project JCN N6398
Wallace Norris, NRC Program Manager

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CASS Focus Areas

- PA-UT Confirmatory Research
  - < 2" and > 2" wall thicknesses in CASS components
  - Obtaining vintage materials for studies
  - Studying effects of flaw fabrication methods on signal responses
- Evaluating Methods for In-Situ Microstructure Characterization of CASS
- Assessing Casting Parameters and their Impact to CASS microstructures
- Evaluation of Ultrasonic Phased-Array Signal Processing Methodologies
- Assessment of PA-UT and EC Examinations on the ID
- Sound Field Propagation Assessments in CASS
  - Sound Field Mapping through CASS Microstructures
  - Corner Trap Signal Response and Dropout from CASS Samples
  - Theoretical Modeling of Sound Field Propagation through CASS Microstructures and Austenitic Welds
- IRSN/CEA Collaboration (France)
- NRC/EPRI MOU

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CASS Focus Areas

PA-UT Confirmatory Research

- Evaluating PA-UT detection, sizing and localization performance for < 2" and > 2" wall thicknesses in CASS components
  - Inspection parameters (range of angles, raster vs line, etc.)
  - Assessment of advanced PA probe designs
  - 500 kHz, 800 kHz, 1 MHz, 1.5 MHz and 2.0 MHz
  - Evaluating near- and far-side performance
  - Statically and Centrifugally Cast components
  - Effects of flaw fabrication methods/flaw type on signal responses
  - Various component configurations
    - PZR Surge lines, Nozzles, Elbows, Pipes, FSWOLs, etc.
  - Various microstructures
    - Purely columnar
    - Purely equiaxed
    - Mixed
    - Banded and Layered
  - Alternative techniques
    - Delta technique, TOF Diffraction, Siamese Imaging

3

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CASS Focus Areas

Evaluating Methods for In-Situ Microstructure Characterization of CASS

- Acoustic methods
  - L-wave and shear-wave velocity (ratio), attenuation (as a function of frequency), backscatter (as a function of frequency, angle and orientation), diffuse field measurements (diffusivity, dissipation and arrival time), shear-wave birefringence
- Electromagnetic methods
  - Multi-frequency eddy current and delta ferrite measurements
- Advanced compositional methods
  - X-ray fluorescence (XRF)
- Advanced imaging methods
  - Scanning electron microscopy (SEM) and Electron Backscatter Diffraction (EBSD)

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CASS Focus Areas

Assessing Casting Parameters and their Impact to CASS microstructures

- Understand the Fundamentals of CASS Casting Parameters and Their Effect on Grain Structure
- Document Foundry Casting Procedures Used for LWR CASS Piping
- Document and Collate CASS Grain Structures Associated with LWR Piping
- Develop a Strategy to Relate CASS Piping Grain Structure to Casting Parameters

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CASS Focus Areas

Evaluation of Ultrasonic Phased-Array Signal Processing Methodologies

- To assess the viability of existing SP algorithms to improve SNR and improve our ability to discriminate between signal responses from flaws versus those from non-flaws.

Initial preliminary evaluations (engaging domestic and international experts) include:

- Wavelets and other time-frequency distributions
- Hilbert-Huang transform (HHT)
- Split Spectrum Processing (SSP) and its variants
- Total Focusing Methodologies (TFM)
- 3D-SAFT
- Time Reversal Mirroring (TRM)
- Full Matrix Capture (FMC)
- Deconvolution approaches
- Neural and higher order statistical approaches to flaw signal identification

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CASS Focus Areas

Assessment of PA-UT and EC Examinations on the ID of CASS components

- Probe type Zetec Z0000857-1
  - Coil diameter 3.05 mm (0.12 in.)
  - Plus point coil design
  - Nominal probe operating frequency of 240 kHz
- Instrument Zetec MIZ-27 SI
- Frequencies 100 kHz, 250 kHz, 500 kHz
- Cracks generally exhibited phase angles of about 90 degrees or 270 degrees
- Used C-scans of both magnitude and phase responses for image analysis
- Degaussing approach was also implemented

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Technical Approach using EC (continued)

EC Probe, Sled Fixture and Gimbal Apparatus

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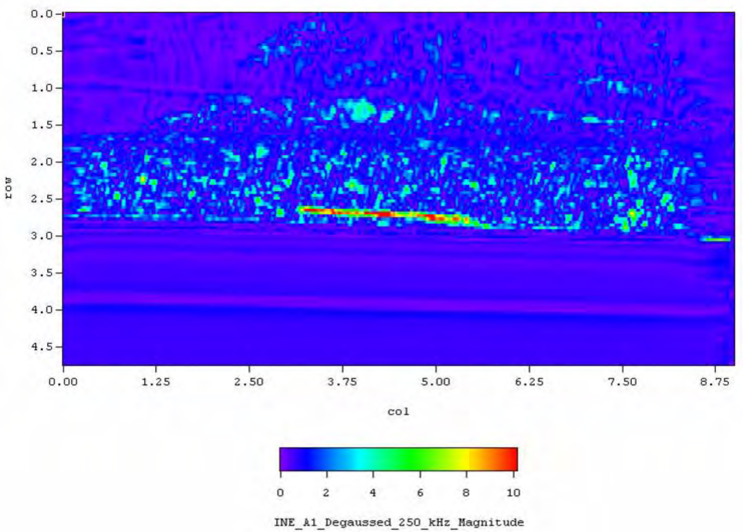
Example of EC Data (continued) (Scale on plot in inches)

WOG Specimen with MFC on Elbow Side of Weld



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CASS Focus Areas

Sound Field Propagation Assessments in CASS

- Sound Field Mapping through CASS Microstructures
  - Modality, frequency, incident angle, microstructure, etc.
- Corner Trap Signal Response and Dropout from CASS Samples
- Theoretical Modeling of Sound Field Propagation through CASS Microstructures and Austenitic Welds
- Analysis of Microstructures (Orientations, Types, Dimensions, etc.)
  - Polishing, etching and photomicrograph documentation

IRSN/CEA Collaboration (France)

- Validation of CIVA modeling results and PA-UT characterization of Manoir specimens

NRC/EPRI MOU

- Collaborate on a variety of CASS activities
  - PA-UT assessment of < 2” CASS cal blocks

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3rd International Workshop: Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping
January 28-29, 2011

Ultrasonic Phased Array Evaluation of Thick-wall Cast Austenitic Stainless Steel (CASS) Piping

MT Anderson, AA Diaz, SL Crawford, AD Cinson, TL Moran, P Ramuhalli and MS Prowant

Pacific Northwest National Laboratory, Richland, WA USA

Work supported by the US NRC, RES Project JCN N6398
Wallace Norris, NRC Program Manager

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Topics of Discussion

- CASS Inspection Issues
- Updates on Thick Section CASS Material
  - Methods for the In-situ Characterization of CASS Microstructures
  - Ultrasonic Phased-Array Signal Processing
  - IRSN/CEA Collaboration
- Ongoing/Future Work

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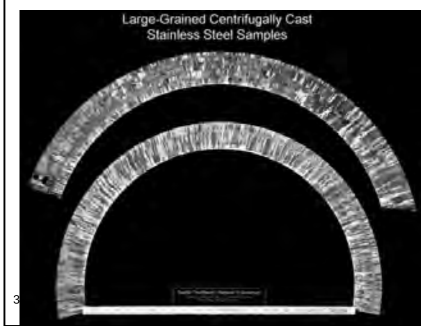
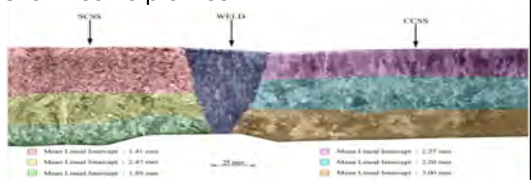
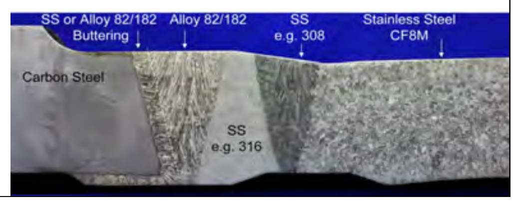
CASS Inspection Challenges

- Cast Austenitic Stainless Steel (CASS) in US Nuclear Power Plants (NPP)
  - Coarse-grained material, range of possible microstructures
    - Equiaxed, columnar, banded, layered, …
- Reliable ultrasonic inspection difficult
  - Beam skewing/partitioning, scattering and attenuation,…
    - Lower SNR, difficulties in signal (echo) discrimination and potential for incomplete insonification of the part
  - Low frequency phased array has shown some promise







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Methods for the In-situ Characterization of Cast Austenitic Stainless Steel (CASS) Microstructures

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Potential Microstructure Classification Methods

- Properties of CASS materials
  - Mechanical property specification the same – yet microstructure different
  - Elastically anisotropic and heterogeneous
    - Variable ultrasonic attenuation
    - Ultrasonic scattering
    - Ultrasonic speed variations leading to beam skewing/ partitioning
    - …
  - Casting process variations result in variable levels of delta ferrite
    - Variation in magnetic permeability and conductivity with microstructure
- Feasibility of ultrasonic and electromagnetic measurements for microstructure classification

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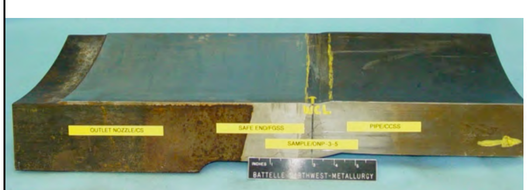
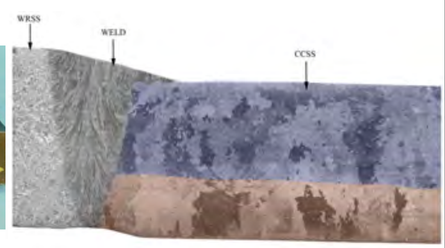
In-situ Microstructure Characterization

- Acoustic methods
  - Longitudinal and shear wave velocity
  - Attenuation
  - Backscatter
  - Diffuse field measurements

- Electromagnetic method
  - Multi-frequency eddy current (MFEC)





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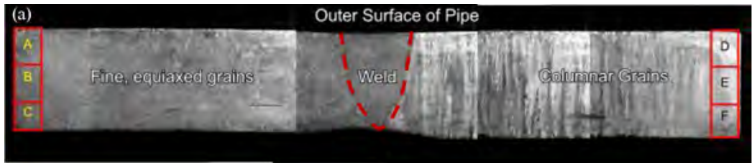
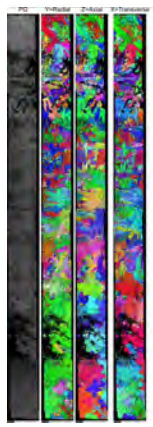
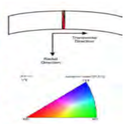
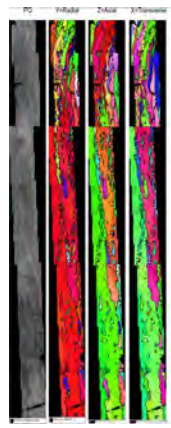
PNNL Round-Robin Test Specimens Microstructure Studies







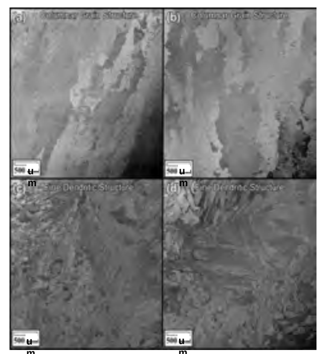
EBSD maps



Equiaxed

Columnar

Backscatter Electron Images



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Ultrasonic Wave Velocity and Attenuation

- Normal incidence longitudinal and shear (S-V) wave velocity
  - Ratio of shear to longitudinal TOF: "TOFRSL"
    - Frequency: 500 kHz
    - Equivalent longitudinal-to-shear wave velocity ratio
      - Ratio removes dependency on specimen thickness
- Normal incidence longitudinal wave attenuation
  - Ensemble and spatial averaging
    - Reduce measurement noise
    - Reduce impact of local microstructure variations
  - Frequency: 1.0 MHz

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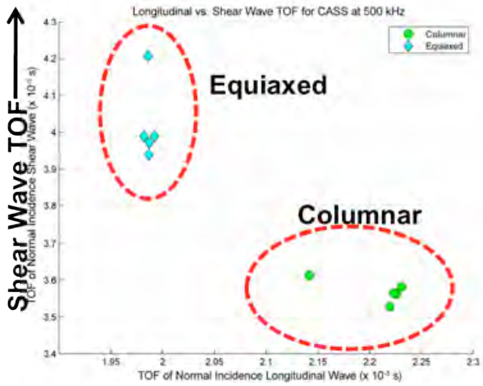
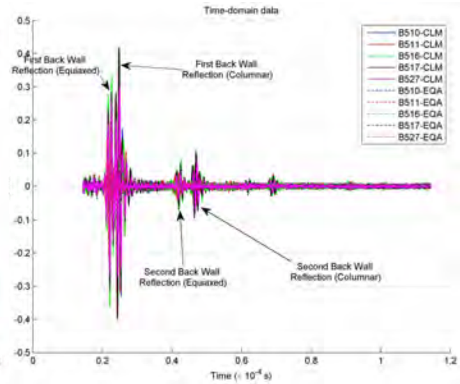
TOF and Attenuation Results



TOF Measurements



Attenuation Measurements
Time-domain Data (1 MHz Transducer)

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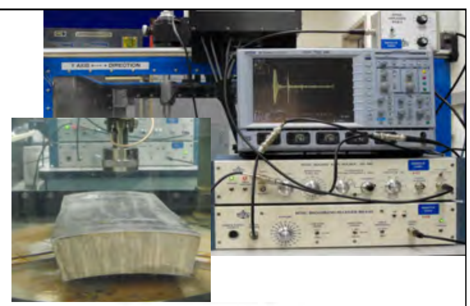
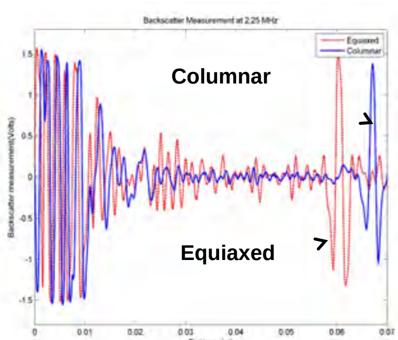
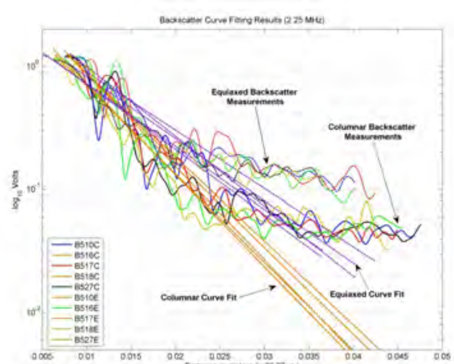
Backscatter

- Focused immersion transducer
  - 2.25 MHz longitudinal wave transducer
    - Focused approximately on specimen back surface





Single A-scan



Exponential curve-fit to backscatter measurement

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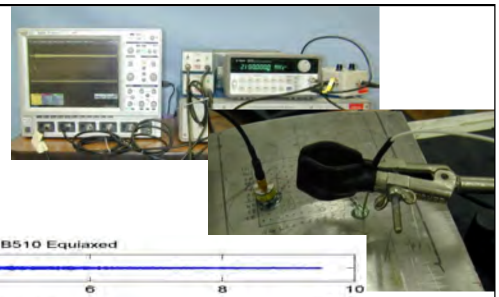
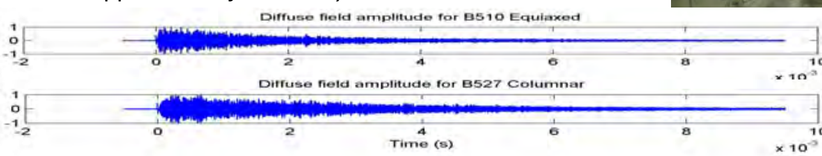
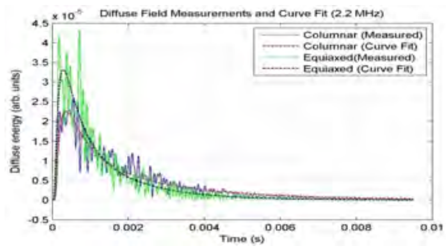
Diffuse Fields

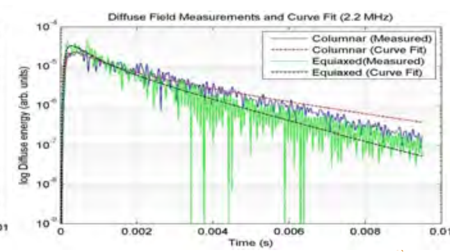
- Pitch-catch configuration
  - Transmit: 2.25 MHz 0.25” diameter probe
  - Receive: Microprobe (bandwidth approximately 2.5 MHz)







Curve Fit - (2.2 MHz)



Curve Fit (log-scale) - (2.2 MHz)

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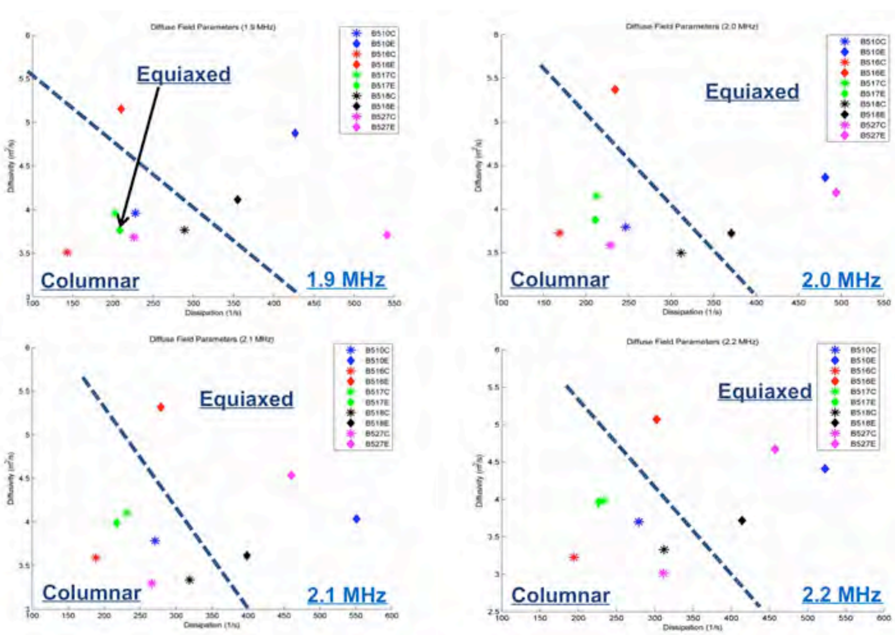
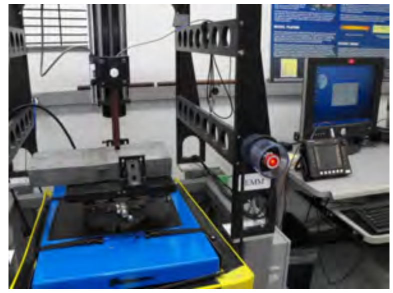
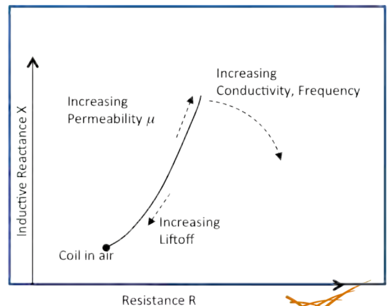
Diffuse Field Parameters



Electromagnetic Methods

- Eddy current measurement
  - Permeability, Conductivity, Frequency
- CASS casting process variations
  - Static casting vs. Centrifugal casting
  - Variable delta ferrite levels, resulting in variable magnetic permeability
- Delta ferrite levels may correlate with microstructure
  - Measured ferrite vs. calculated ferrite (from elemental composition) vs. microstructure
  - Measured ferrite: Fischer Technologies FerriteScope FMP-30
    - Measurements based on induction
    - Calculated (from elemental composition)
    - Composition measured using x-ray fluorescence (XRF)





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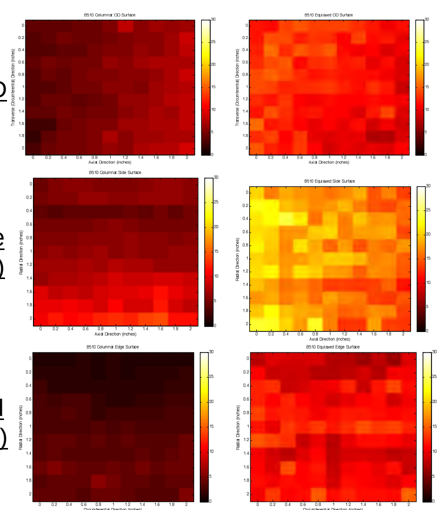
Delta Ferrite Measurements - Examples

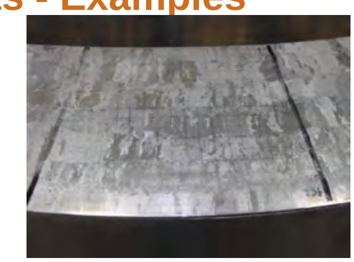
OD

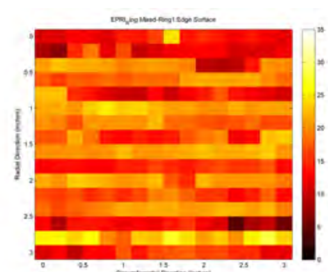
Side (AR)

End (CR)



Columnar Equiaxed





IHI-SW

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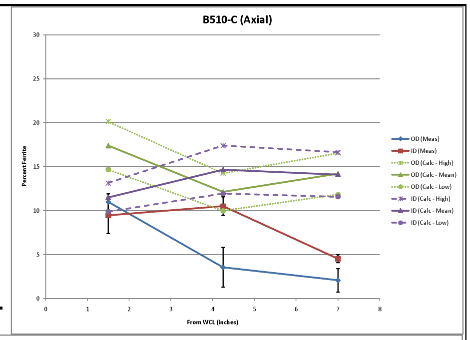
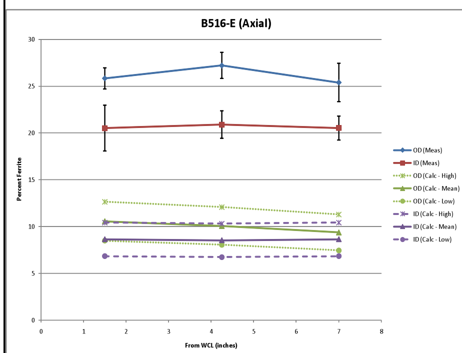
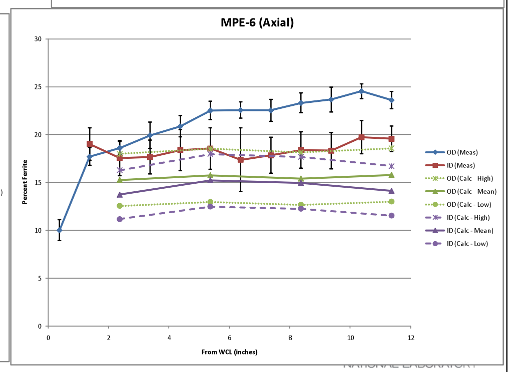
Delta Ferrite: Sample Results

- Data to date indicate some differences between columnar, equiaxed and mixed
  - Comprehensive analysis underway
    - OD-ID trends, measured vs. calculated, axial/circ trends, etc.







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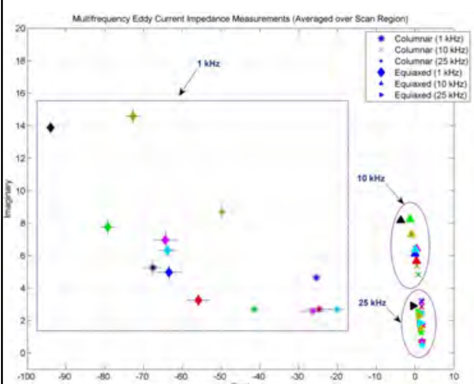
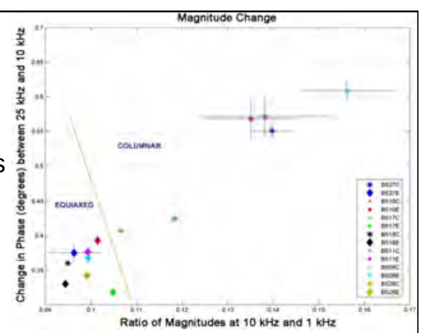
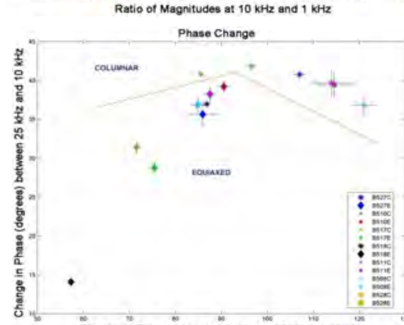
Eddy Current: Results

- Multifrequency measurements
  - Ratio of magnitudes at two frequencies
  - Change in phase angle with frequency



MFEC Data





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Summary

- Ultrasonic wave velocity and attenuation
  - Volume-averaged measurements
  - Potential, but require further investigation w/ mixed microstructures and higher frequencies
- Longitudinal wave backscatter
  - Normal incidence - Multiple scattering effects at higher frequencies
  - Greater potential
    - Microstructural variations as a function of depth
    - Attenuation coefficient, scattering coefficient calculation – correlation to microstructure?
- Diffuse fields
  - Multiple scattering - Volume-averaged measurement
  - Greater potential, but requires further investigation

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Summary (Cont'd.)

- Electromagnetic methods
  - MFEC: Dependent on permeability difference between microstructure classes
    - Limited depth of penetration
    - Effect of layered/mixed microstructures unclear
- Delta ferrite measurements
  - Limited correlation to microstructure observed
    - Correlations between casting processes (delta ferrite), chemical composition and microstructure?
    - OD-ID ferrite variation trend information – correlation to microstructure?
- *Multiple measurement approaches (acoustic, electromagnetic, etc.) may be necessary*!

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Ultrasonic Phased Array Signal Processing

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Why Signal Processing…

- Properties of CASS materials
  - Mechanical property specification the same – yet microstructure different
  - Elastically anisotropic and heterogeneous
    - Variable ultrasonic attenuation
    - Ultrasonic scattering
    - Ultrasonic speed variations leading to beam skewing/ partitioning
- Low frequency phased array has shown promise in CASS inspection
  - Challenges remain with respect to discriminating between flaw and non-flaw signatures
- Need: Signal processing tools
  - Enhancing SNR
  - *Discriminating between flaw and non-flaw signals*

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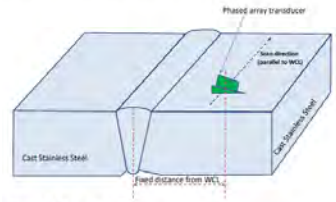
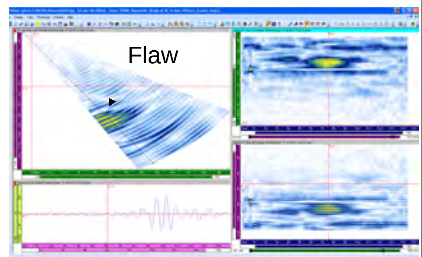
Approach and Status



- UT Signal Processing “Round Robin”
  - Request experts in UT signal processing to participate
  - Data supplied by PNNL -
    - Low frequency phased-array data in CASS welds
  - Results of algorithms rank-ordered for follow-on investigation
- Participants
  - Nine (9) researchers contacted
    - 7 agreed to participate plus PNNL also investigating other algorithms
- Data
  - Line scans (at multiple off-set distances to WCL)
  - At each position, data consists of phased-array measurements between 30 and 60 degrees (in 1 degree increments)
  - Data from 3 specimens
    - Easy to detect, somewhat-hard-to-detect and no-flaw
- Results
  - Results from 4 participants received



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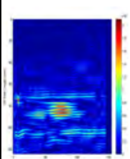
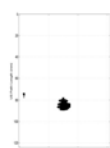
Sample Results

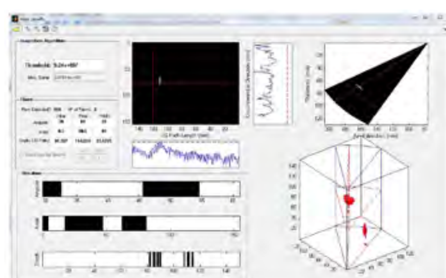
- Algorithms examined include HHT, SSP
- Data from multiple angles/files can be combined to give meaningful results



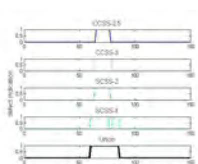
End view



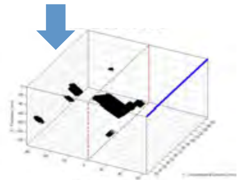
Extracted Region of Interest (ROI)



GUI Developed by One Participant



Flaw length estimate from multiple line scans



Combined ROI from one line scan

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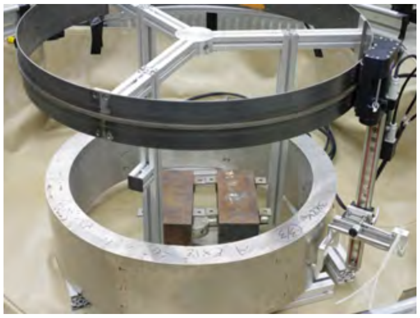
IRSN/CEA Collaboration

- CIVA Materials and NDE Modeling Software (CEA)
- Expertise and experimental data related to acoustic attenuation and back scattering (PNNL)
  - Mathematical Modeling of ultrasonic sound fields in austenitic welds (PNNL)
  - Manoir Ring Specimen (3", Large Grain Equiaxed)



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Ongoing/Future Work (In-situ Microstructure Characterization, Signal Processing Methods)

- Casting processes
  - Calculated chemical composition
    - XRF spectroscopy
  - Delta ferrite measurements
    - Axial, circumferential and thickness variations in multiple specimens
  - Correlate calculated and measured ferrite levels with microstructure
- Acoustic and EM measurements on multiple specimens
  - Expand measurements on other specimens with pure and mixed microstructures
  - Other acoustic and electromagnetic measurements
- Microstructure characterization using multiple measurement modes
- Results of scoping studies for signal processing methods
  - Select 2-3 best approaches for further evaluation
    - Larger data set to be used for additional evaluation

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Ongoing/ Future Work on Thick Section CASS

- Empirical measurements of sound beam densities and profiles in varied CASS microstructures – on-going
  - Incident angle, Inspection frequency, Focal depth, Modality, etc.
  - Provide validation data for theoretical modeling results
- Complete assessment of casting fabrication processes and their impact on resultant microstructures
- Continue to evaluate enhanced transducer/probe design, and other alternatives for improved detection and sizing in CASS materials
- Modeling sound fields in CASS – on-going

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Questions

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Additional Slides

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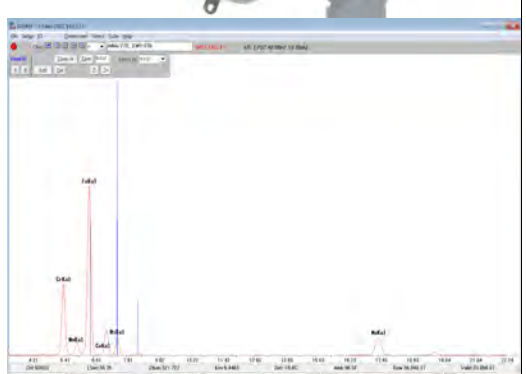
XRF for Elemental Composition

- Excitation by x-rays results in absorption of energy and ejected electrons
  - Other electrons fill resulting vacancy, accompanied by emission of x-rays (x-ray fluorescence)
  - Each element emits a characteristic x-ray spectrum
    - X-ray energy: which element is present
    - Number of x-rays: Amount of element present



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3rd International Workshop: Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping
January 28-29, 2011

Ultrasonic Phased Array Evaluation of Thin-wall Cast Austenitic Stainless Steel (CASS) Piping

MT Anderson, AA Diaz, SL Crawford, AD Cinson, TL Moran and MS Prowant

Pacific Northwest National Laboratory, Richland, WA USA

Work supported by the US NRC, RES Project JCN N6398
Wallace Norris, NRC Program Manager

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Outline

- Refresh on Thin CASS issues
  - Specimens and microstructures
  - Ultrasonic probes
- ISI Supplier Results on FlawTech Implanted Cracks in PZR Surgeline Specimens 9C001 and 9C002
  - 3 TFCs implanted in the weld in each specimen
- PNNL Data on TrueFlaw Cracks in PZR Surgeline Specimens
  - 5 TFCs grown in-situ in base metal
  - PNNL/ISI Supplier comparison on 2 flaws in 9C-002
- Beam Redirection
  - Axial and Lateral

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Grain Diameter Dimensional Analysis

- Ultrasonic PA data were acquired and analyzed on
  - 3 pressurizer (PZR) surge-line (pipe-to-elbow) specimens
    - Centrifugally cast-to-statically cast component configuration

Specimen	CCSS (Pipe Side) Minimum mm (in.)	CCSS (Pipe Side) Maximum mm (in.)	SCSS (Elbow Side) Minimum mm (in.)	SCSS (Elbow Side) Maximum mm (in.)
PZR Surge Line 7C-059	0.6 mm (0.02 in.)	6.7 mm (0.26 in.)	0.5 mm (0.02 in.)	6.3 mm (0.25 in.)
PZR Surge Line 9C-001	0.8 mm (0.03 in.)	13.9 mm (0.55 in.)	2.6 mm (0.10 in.)	41.0 mm (1.61 in.)
PZR Surge Line 9C-002	1.3 mm (0.05 in.)	25.6 mm (1.01 in.)	2.6 mm (0.10 in.)	41.0 mm (1.61 in.)

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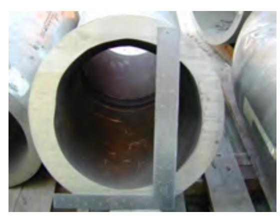
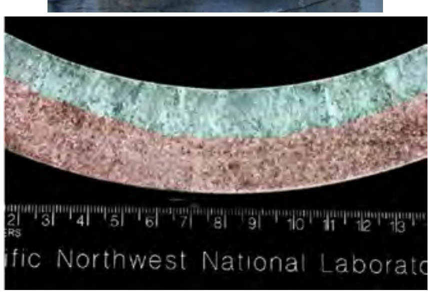
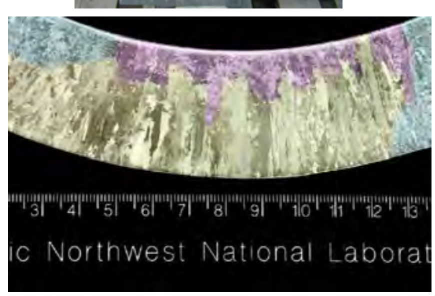
PZR Surge Line Specimens

Sample 7C-059







Pipe Side – CCSS
30 mm (1.2 in.) wall

Elbow Side – SCSS
39 mm (1.5 in.) wall

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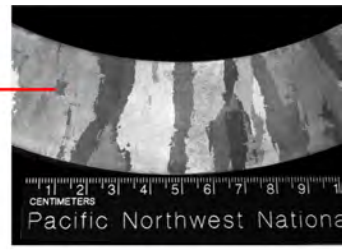
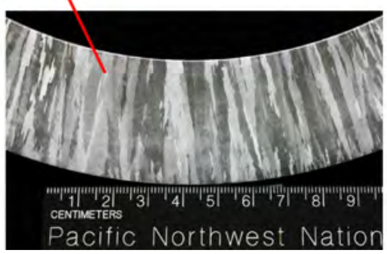
PZR Surge Line Specimens (WNP-3)



9C-002
Pipe Side
33 mm
(1.3 in.) wall



9C-001
Pipe Side
33 mm
(1.3 in.) wall

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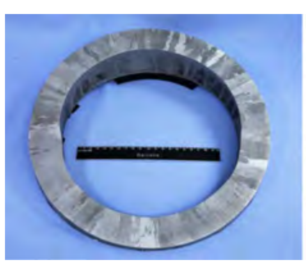
PZR Surge Line Specimens (WNP-3)

Microstructure of elbow segment from WNP-3 PZR surge line specimen
34 - 44 mm (1.3 - 1.7 in.) wall



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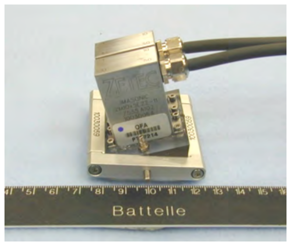
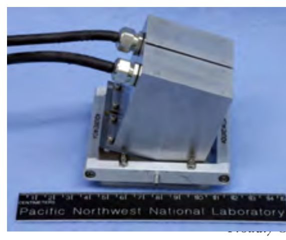
Phased Array Probes Employed: 2.0 MHz TRL 1.5 MHz TRL, 1.0 MHz TRL, 800 kHz TRL

2.0 MHz, 10 x 5, TRL



1.5 MHz, 10 x 3 TRL

1.0 MHz, 10 x 5, TRL



800 kHz,
10 x 5, TRL

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ISI Supplier Procedure and Equipment

- ASME Section XI, Appendix VIII, Supplement 10 qualified procedure for DMWs
- OmniScan and Ultravision software
- 1.5 MHz, 32 x 2 PA probe operating as a 32 x 1 linear array with electronic rastering
  - 64 x 15 mm total aperture
  - Element size: 1.8 mm primary and 7.3 mm secondary
  - Pitch: 2.0 primary and 7.5 mm secondary
  - Wedge footprint: 85 x 50 mm
  - Wedge angle 22.3 deg
  - Roof angle 7.0 deg

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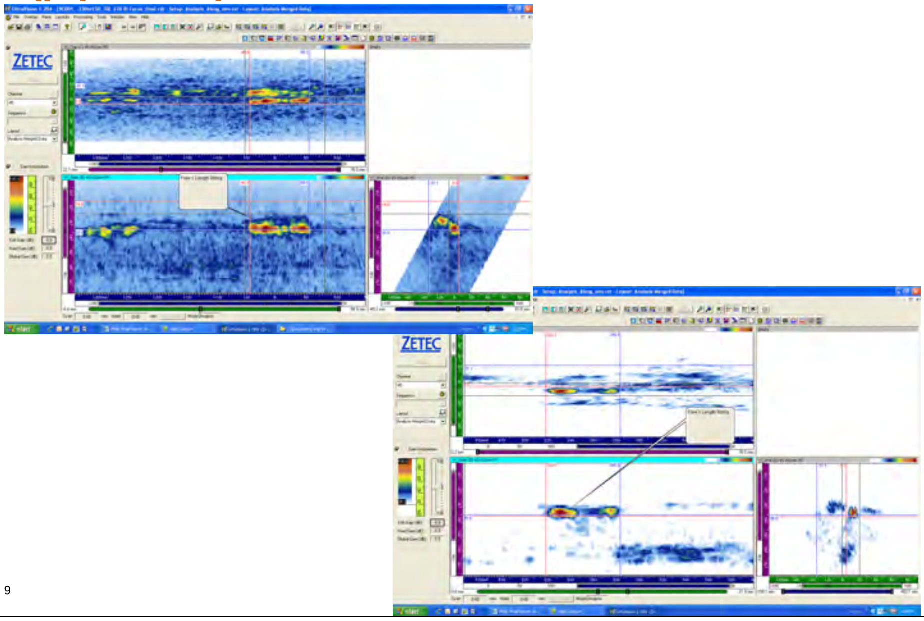
ISI Supplier Results Flaw 1 and 2 in 9C001 (pipe side)



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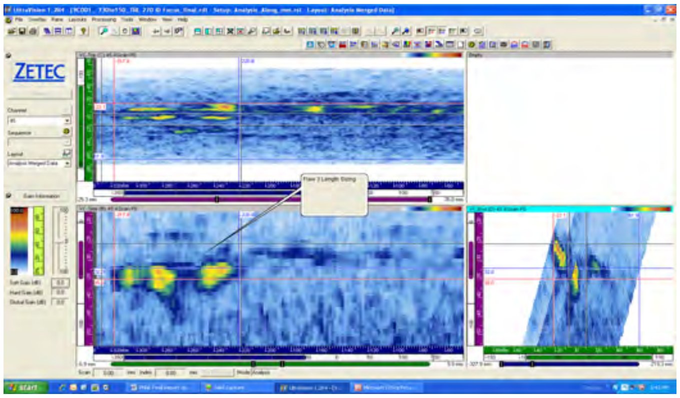
ISI Supplier Results - Flaw 3 in 9C001 (pipe side)



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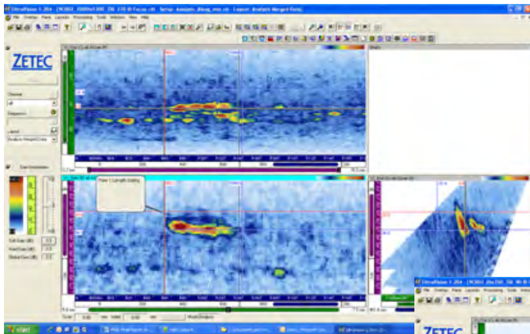
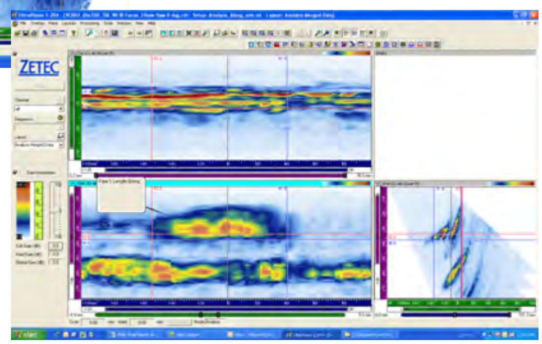
ISI Supplier Results - Flaw 1 in 9C002



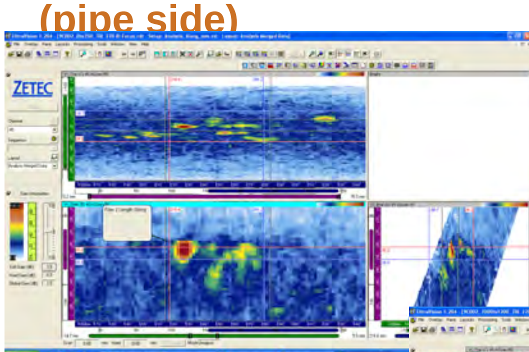
Elbow Side

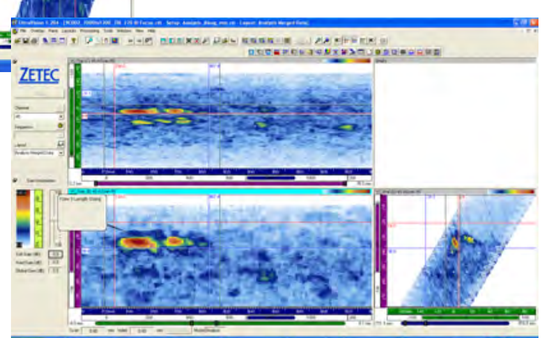


Pipe Side

11

ISI Supplier Results Flaw 2 and 3 in 9C002 (pipe side)





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ISI Supplier Results – Flaw Length Sizing

Specimen/Flaw	Reported Flaw Length Pipe Side (mm / inch)	Reported Flaw Length Elbow Side (mm / inch)	Actual Flaw Length (mm / inch)
9C-001/Flaw 1	80.7 / 3.18	Note 1	76.6 / 3.02
9C-001/Flaw 2	52.7 / 2.07	Note 1	51.1 / 2.01
9C-001/Flaw 3	79.0 / 3.11	Note 1	69.7 /2.74
9C-002/Flaw 1	69.8 / 2.75	76.4	76.7 / 3.02
9C-002/Flaw 2	50.4 / 1.98	Note 2	50.5 / 1.99
9C-002/Flaw 3	63.4 / 2.50	Note 2	69.7 / 2.74
9C-002/Base Metal Flaw 1110	Not detected	34.2 / 1.35	25.3 / 1.00
9C-002/Base Metal Flaw 1102	Not detected	21.2 / 0.83	19.3 / .076
RMSE	**5.7 / 0.22**	**5.3 / 0.21**	

Note1: No 90° Skew Exams performed on 9C-001
Note 2: Limited 90° Skew Exams performed on 9C-002 due to configuration/probe footprint conflicts

ASME Code Section XI-acceptable criterion for Length RMSE is less than 19.05 mm (0.75 in.)

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ISI Supplier Results – Flaw Depth Sizing

Specimen/Flaw	Reported Flaw Depth Pipe Side (mm / inch)	Reported Flaw Depth Elbow Side (mm / inch)	Actual Flaw Depth (mm / inch)
9C-001/Flaw 1	6.1 / 0.24	Note 1	6.4 / 0.25
9C-001/Flaw 2	6.4 / 0.25	Note 1	8.9 / 0.35
9C-001/Flaw 3	5.8 / 0.23	Note 1	8.3 / 0.33
9C-002/Flaw 1	6.5 / 0.26	3.8 / 0.15	7.5 / 0.30
9C-002/Flaw 2	6.9 / 0.27	Note 2	6.3 / .025
9C-002/Flaw 3	4.8 / 0.19	Note 2	4.8 / 0.19
9C-002/Base Metal Flaw 1110	Not detected	7.9 / 0.31	6.0 / 0.24
9C-002/Base Metal Flaw 1102	Not detected	4.0 / 0.16	3.4 / 0.13
RMSE	**1.5 / 0.06**	**2.4 / 0.10**	

Note1: No 90° Skew Exams performed on 9C-001
Note 2: Limited 90° Skew Exams performed on 9C-002 due to configuration/probe footprint conflicts

ASME Code Section XI-acceptable criterion for Depth RMSE is less than 3.18 mm (0.125 in.)

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Trueflaw Crack Characteristics

- Thermal fatigue cracks grown in specimen (vary on specimen composition)
- Leads to cracks that resemble service induced characteristics such as branching and discontinuities
- Create environments that pose real challenges
- Destructive validations on test samples provide best true state approximations

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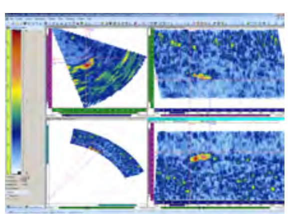
In-situ TrueFlaw Cracks: Validation Specimen

- Calibrate the crack generation process using validation specimen
- Collect ultrasonic phased-array data



- Destructive Examination (DE)
  - Correlates the DE with thermal fatigue process parameters

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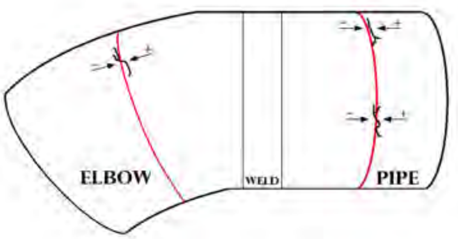
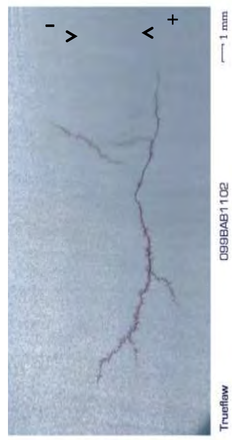
TrueFlaw Base Metal Flaws in CCSS Pipe (9C-002)





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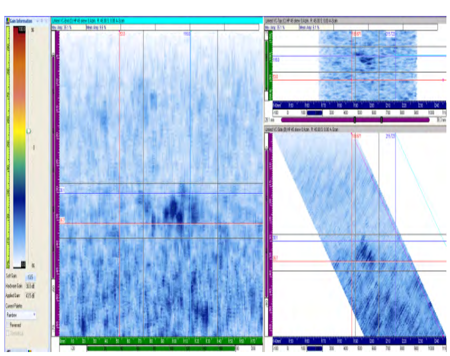
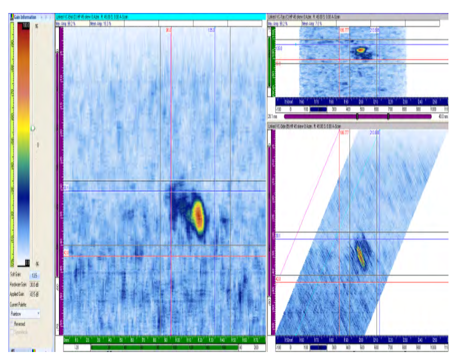
Flaw 1110: Inspection Comparison from Opposite Sides - Same Gain Level



2 MHz, Looking Positive,
Flaw Response: 35.1%



2 MHz, Looking Negative,
Flaw Response: 98.2%

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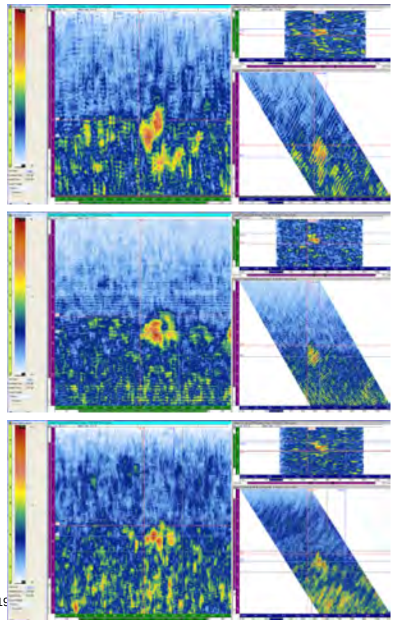
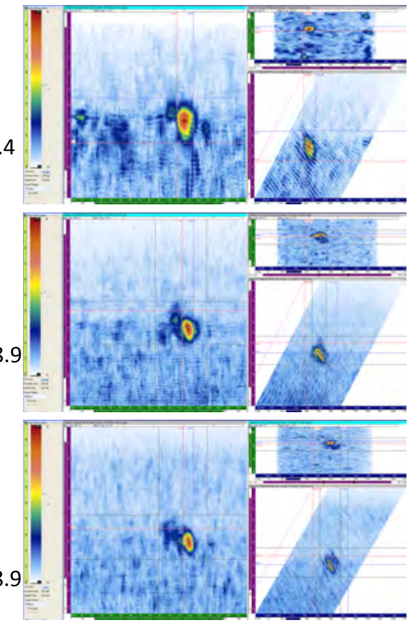
Flaw 1110 – Probe Frequency Comparison

Looking positive



Looking negative



800 kHz
SNR (dB)
8.9 16.4

1.5 MHz
SNR (dB)
11.4 18.9

2.0 MHz
SNR (dB)
11.8 18.9

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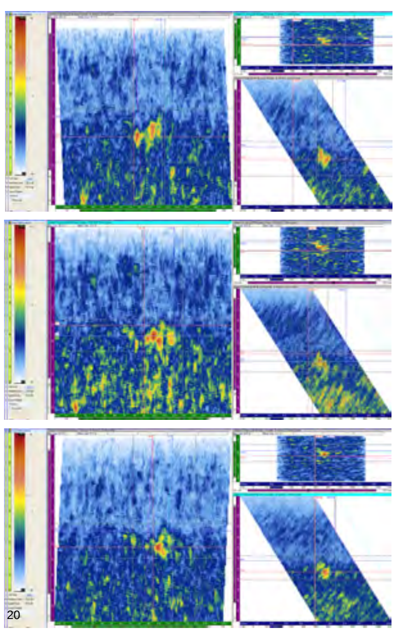
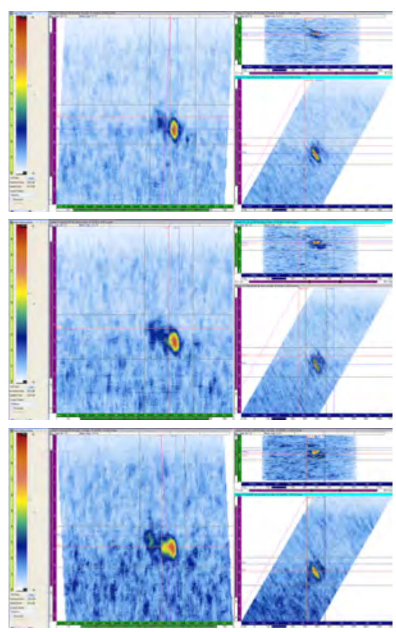
2.0 MHz Flaw 1110 – Skew Comparison





+10 Skew
SNR (dB)
11.2 19.9

No Skew
SNR (dB)
11.8 18.9

-10 Skew
SNR (dB)
12.4 16.2

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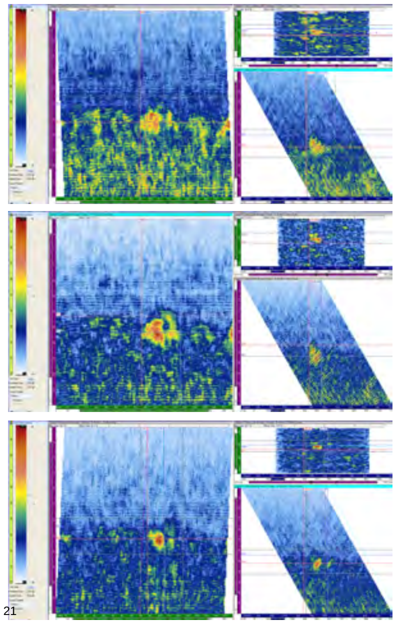
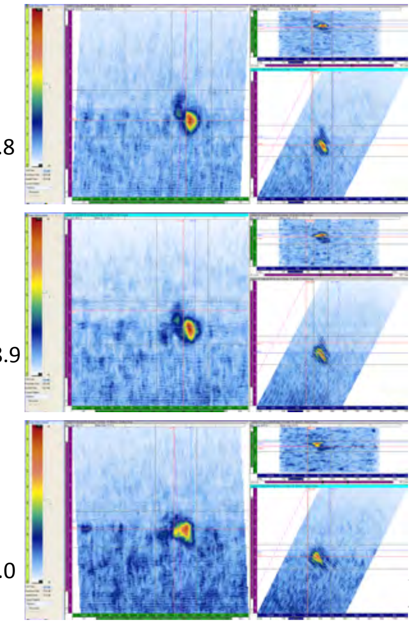
1.5 MHz Flaw 1110 – Skew Comparison



+10 Skew
SNR (dB)
9.4 18.8

No Skew
SNR (dB)
11.4 18.9

-10 Skew
SNR (dB)
12.3 17.0



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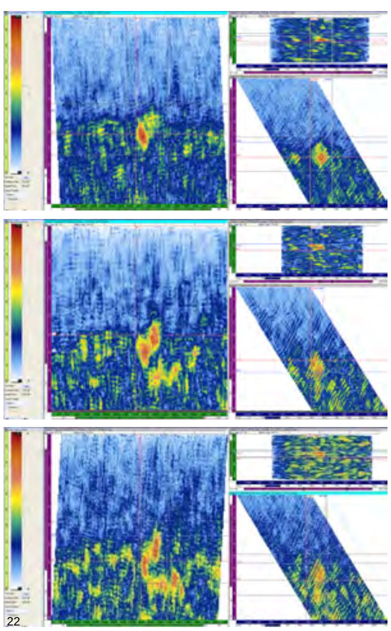
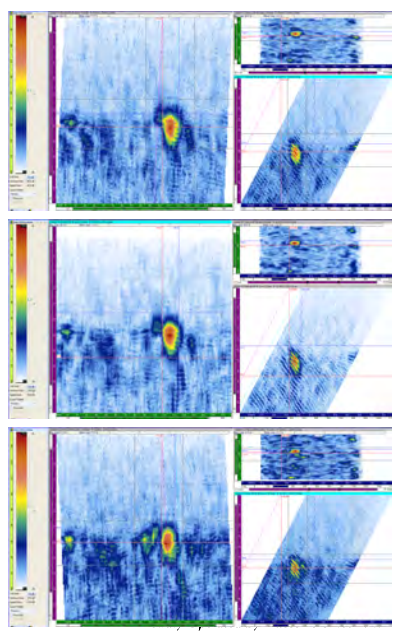
800 kHz Flaw 1110 – Skew Comparison



+10 Skew
SNR (dB)
10.2 15.8

No Skew
SNR (dB)
8.9 16.4

-10 Skew
SNR (dB)
9.1 13.2



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Raster Analysis

Flaw		True State	Pipe Side (looking positive)									Elbow Side (looking negative)								
			800 kHz			1.5 MHz			2.0 MHz			800 kHz			1.5 MHz			2.0 MHz		
			skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10
1100	Length (mm)	18.6	15.3	16.9	20.9	21.7	23.3	24.9	10.5	11.3	-	29.7	26.6	29.0	28.9	25.7	19.3	24.1	28.1	16.1
	Depth (mm)	3.4	5.1	5.8	4.9	4.6	-	4.8	7.4	-	-	6.7	6.7	7.5	6.0	4.5	7.1	-	-	2.5
	S/N		12.3	9.9	13.0	13.7	13.2	11.9	15.6	16.0	-	15.5	16.2	13.6	12.4	12.9	12.2	13.2	10.9	12.8
1102	Length (mm)	19.3	-	17.8	24.9	20.1	15.3	18.5	15.3	25.7	24.9	29.0	24.2	20.9	24.9	20.1	15.3	23.3	24.1	28.9
	Depth (mm)	3.4	-	4.9	4.6	-	-	-	-	-	-	-	-	4.7	-	3.4	5.3	-	-	-
	S/N		-	8.6	9.3	10.6	12.4	11.4	11.7	12.2	13.7	15.8	15.8	15.4	15.7	15.9	16.1	15.4	13.6	14.1
1110	Length (mm)	25.3	29.8	24.2	23.4	25.7	36.2	16.9	28.1	30.6	25.7	26.5	26.5	17.7	23.3	23.3	20.9	20.9	27.3	16.9
	Depth (mm)	6.0	6.7	4.6	6.8	5.5	5.3	4.0	5.7	3.3	5.2	3.9	-	-	4.9	5.1	5.5	-	-	-
	S/N		10.2	8.9	9.1	9.4	11.4	12.3	11.2	11.8	12.4	15.8	16.4	13.2	18.8	18.9	17.0	19.9	18.9	16.2
1087	Length (mm)	8.4	28.9	24.1	21.7	33.0	19.3	15.3	15.3	23.3	20.9	20.2	24.9	23.3	22.5	20.9	16.9	20.1	12.1	20.1
	Depth (mm)	3.4	3.9	3.5	4.4	6.0	3.8	4.1	3.7	-	3.6	3.8	3.3	4.4	4.8	3.4	4.4	-	-	4.3
	S/N		9.4	13.4	11.7	8.7	11.7	13.2	10.1	11.2	10.1	12.0	12.6	13.4	11.3	12.5	11.6	13.7	13.0	10.5
1089	Length (mm)	21.8	28.9	30.6	32.0	16.9	24.9	19.3	20.8	21.7	18.5	21.7	19.3	17.7	25.7	20.1	18.5	21.7	18.5	16.1
	Depth (mm)	6.0	6.1	5.9	6.2	-	6.5	3.9	4.1	-	-	6.2	4.7	4.8	6.0	6.3	4.5	3.6	-	4.0
	S/N		16.5	14.1	13.4	11.5	14.1	13.3	14.0	13.5	9.3	12.9	15.1	14.8	13.9	13.9	14.7	12.8	12.1	13.1
RMSE (Length)			**11.2**	**8.1**	**8.0**	**11.3**	**7.6**	**5.7**	**5.3**	**8.3**	**7.1**	**8.5**	**8.6**	**9.0**	**8.5**	**6.6**	**4.9**	**6.4**	**5.3**	**8.2**
RMSE (Depth)			**1.0**	**1.4**	**1.0**	**1.7**	**0.5**	**1.6**	**2.2**	**2.7**	**0.6**	**2.0**	**2.0**	**2.3**	**1.6**	**0.6**	**2.0**	**2.4**	**-**	**1.4**

ASME Code Section XI-acceptable criterion for Length RMSE is less than 19.05 mm (0.75 in.) and for Depth RMSE is less than 3.18 mm (0.125 in.)

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Line Scan Analysis

Flaw		True State	Pipe Side (looking positive)									Elbow Side (looking negative)								
			800 kHz			1.5 MHz			2.0 MHz			800 kHz			1.5 MHz			2.0 MHz		
			skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10	skew +10	skew 0	skew -10
1100	Length (mm)	18.6	16.1	14.5	16.5	24.9	16.9	15.3	20.1	18.1	18.5	39.4	26.1	13.3	16.1	16.5	17.3	40.2	19.3	18.5
	Depth (mm)	3.4	-	-	-	-	-	-	-	-	-	-	-	-	-	4.6	2.9	3.8	-	3.5
	S/N		12.8	13.0	13.9	13.8	15.5	17.4	12.9	13.0	14.8	11.1	11.6	12.2	12.3	11.5	11.5	12.2	11.7	11.2
1102	Length (mm)	19.3	13.7	12.9	22.5	18.1	17.7	10.9	15.7	33.0	37.0	22.5	20.5	20.5	26.9	24.1	30.6	22.9	21.3	23.3
	Depth (mm)	3.4	-	7.0	-	-	-	-	-	3.5	-	-	-	-	-	3.8	-	3.6	2.5	3.0
	S/N		6.5	8.3	7.4	8.8	9.4	8.2	8.6	10.7	10.2	13.4	14.7	15.6	15.0	17.2	17.7	16.3	15.9	16.1
1110	Length (mm)	25.3	30.6	33.8	28.5	31.8	30.6	17.3	27.7	14.1	22.5	39.8	40.6	39.0	25.3	16.1	20.5	16.1	15.3	28.9
	Depth (mm)	6.0	6.7	6.1	7.7	4.6	7.5	4.7	5.4	5.1	7.8	5.7	3.4	3.8	7.7	5.9	2.9	4.0	5.7	5.3
	S/N		7.3	7.8	8.3	7.7	8.8	10.3	9.7	9.4	9.3	14.3	14.2	12.9	16.0	15.2	15.7	16.5	15.6	12.7
1087	Length (mm)	8.4	19.3	22.5	25.7	27.7	21.3	22.5	16.9	18.5	13.3	23.3	20.5	24.9	26.5	22.5	20.9	20.9	13.1	13.3
	Depth (mm)	3.4	3.9	4.0	-	2.5	4.2	3.4	2.4	2.3	3.3	3.7	-	-	3.3	3.2	2.6	3.6	2.2	-
	S/N		10.5	11.6	11.5	11.9	12.8	14.4	11.1	9.9	10.6	11.9	13.6	12.0	12.4	12.0	16.0	12.6	11.5	10.6
1089	Length (mm)	21.8	28.5	28.9	29.3	21.7	26.9	16.9	21.3	16.9	13.7	21.3	19.3	18.9	24.9	24.1	21.3	23.7	22.5	20.1
	Depth (mm)	6.0	6.4	5.7	-	5.0	-	-	4.5	6.2	5.4	6.4	-	-	6.3	6.5	-	5.0	5.2	5.1
	S/N		12.4	13.8	15.5	11.8	13.6	10.6	13.5	12.1	8.1	12.7	14.7	14.6	10.6	12.7	15.0	10.3	11.6	13.1
RMSE (Length)			**6.8**	**8.7**	**8.7**	**9.6**	**6.7**	**8.6**	**4.3**	**9.4**	**9.1**	**13.2**	**9.4**	**10.0**	**9.0**	**8.0**	**7.8**	**12.0**	**5.1**	**3.3**
RMSE (Depth)			**0.5**	**1.8**	**1.7**	**1.1**	**1.2**	**0.9**	**1.1**	**0.7**	**1.1**	**0.3**	**2.6**	**2.2**	**1.0**	**0.6**	**1.9**	**1.0**	**0.9**	**0.6**

ASME Code Section XI-acceptable criterion for Length RMSE is less than 19.05 mm (0.75 in.) and for Depth RMSE is less than 3.18 mm (0.125 in.)

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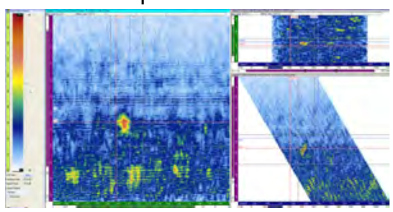
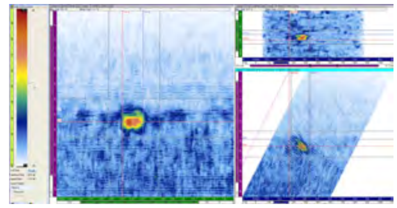
PNNL and ISI Supplier 1.5 MHz Comparison on TrueFlaw Crack 1102 – 19.3 mm length

Pipe Side

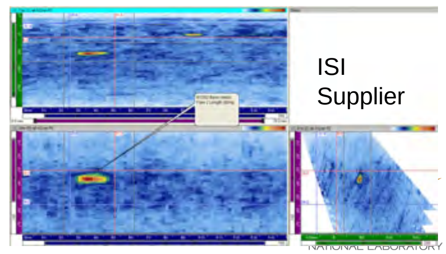


Elbow Side



	Elbow Side Length (mm)	Depth (mm)
True	19.3	3.4
PNNL	20.0 (-6 dB)[1]	3.4
PNNL	*29.5 (-12 dB)*	
ISI Supplier	21.2 (-12 dB)	4.0

[1]Note: PNNL typically length sizes at – 6 dB



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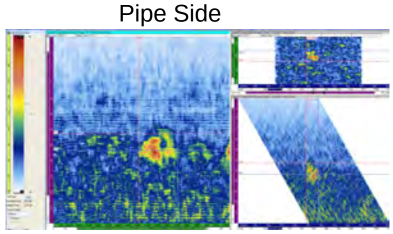
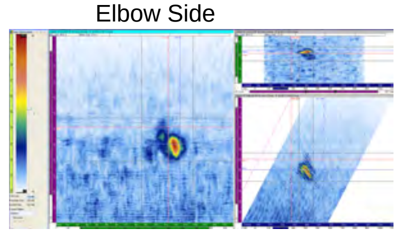
PNNL and ISI Supplier 1.5 MHz Comparison on TrueFlaw Crack 1110 – 25.3 mm length

Pipe Side

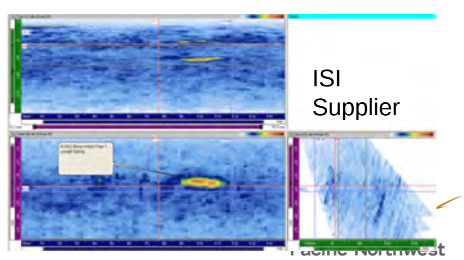


Elbow Side



	Elbow Side Length (mm)	Depth (mm)
True	25.3	6.0
PNNL	13 (-6 dB)[1]	5.1
PNNL	*31.0 (-12 dB)*	
ISI Supplier	34.2 (-12 dB)	7.9

[1]Note: PNNL typically length sizes at – 6 dB



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Summary of PNNL/ISI Supplier Results

- ISI Supplier was invited to conduct an independent inspection of cracks in 2 small bore CASS piping specimens
- Implanted cracks were effectively detected and characterized by both ISI Supplier and PNNL
  - ISI Supplier's long probe limited acquisition to predominately one side for implanted cracks
- Cracks grown in-situ
  - PNNL detected from both sides
  - PNNL showed favorable response from one side
  - ISI Supplier detected only from favorable side (inspected from both)
- All detected cracks were sized by both ISI Supplier and PNNL within ASME limits on length and depth

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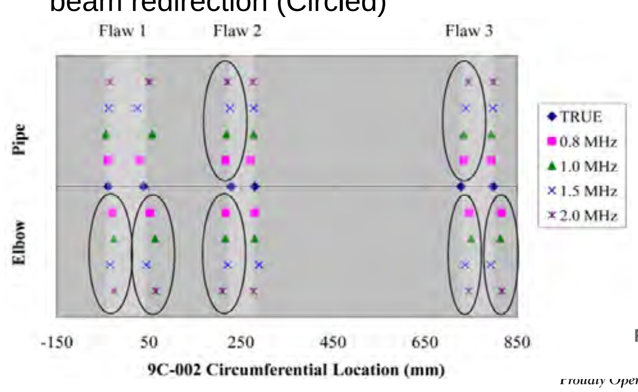
Addressing Lateral Beam Redirection

- Volumetric line scan data
  - Optimal view of flaw with similar metal path
  - -6dB drop endpoints were extracted
- Nominal lateral spot size: 5-7 mm
  - 2-4 mm accepted end point shifts
  - Exceeding 2-4 mm will be considered possible lateral beam redirection (Circled)



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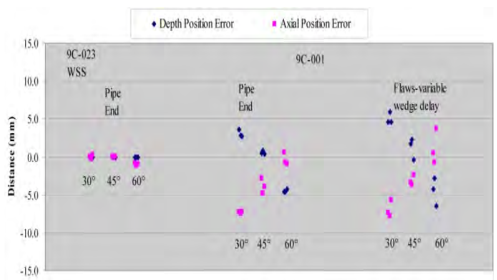
Addressing Axial Beam Redirection

- 1.5 MHz, short raster scan data analyzed
- Calibrated focal laws on wrought stainless steel
- Axial and depth positions indicate relationships



	WSS End (mm)	9C-001 End (mm)	9C-001 Flaw (mm)	9C-002 End (mm)	9C-002 Flaw (mm)
30 Degree					
1	0.07	-7.28	-7.37	-5.37	-1.29
2	-0.24	-7.45	-7.78	-3.70	-3.76
3	0.27	-7.29	-5.68	-6.28	-4.72
45 Degree					
1	0.04	-2.82	-3.32	-2.88	-1.04
2	-0.09	-4.77	-3.71	-1.38	-3.15
3	0.03	-3.94	-2.43	-1.54	-3.17
60 Degree					
1	-0.87	0.63	0.55	-0.58	0.58
2	-1.12	-0.75	-0.77	1.13	-0.82
3	-0.96	-0.98	3.74	0.35	0.02

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Conclusions on Beam Redirection Study

- CASS material causes redirection of sound beam:
  - Lateral redirection could account for over/under sizing length of circumferentially orientated flaws
  - At 45 degrees, axial redirection has been observed to be 3 mm on average
  - At 30 degrees, axial redirection could reach as high as 7 mm from true state

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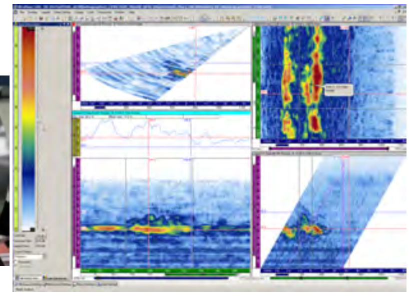
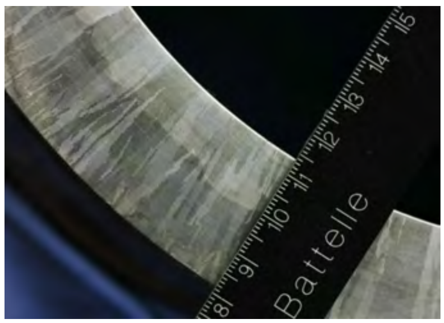
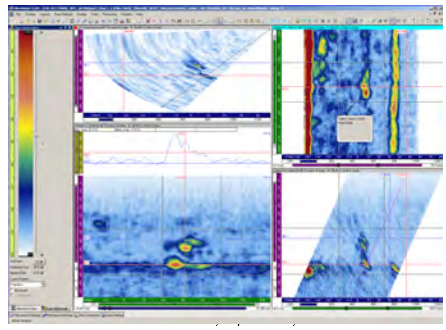
In Progress: Evaluating Full Structural Weld Overlays

- CASS Pipe-to-Carbon Steel Nozzle DMW
  - FlawTech implanted flaws





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Future Work

- Continue to evaluate CASS PZR materials
  - New materials acquired from Calvert Cliffs
    - Polishing and etching samples to display microstructure
    - Place cracks in CASS
  - EPRI calibration block samples
- Continue to conduct confirmatory research of advanced signal processing methods, enhanced transducer/probe design, and other alternatives for improved detection and sizing in CASS materials



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ADDITIONAL SLIDES

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PZR Surge Line Results: Length Sizing Units: mm

Specimen/ Flaw	True-State Length mm	800 kHz CCSS mm	800 kHz SCSS mm	1.0 MHz CCSS mm	1.0 MHz SCSS mm	1.5 MHz CCSS mm	1.5 MHz Raster CCSS mm	1.5 MHz SCSS mm	2.0 MHz CCSS mm	2.0 MHz SCSS mm
7C-059										
1	101.6	104.7	114.9	116.1	112.9	116.5	-	102.4	119.3	96.6
2	50.6	63.0	19.1	69.2	61.4	34.8	-	34.8	36.0	57.1
3	50.6	72.0	-	49.3	39.3	49.7	-	74.0	45.8	62.4
4	152.6	190.5	160.2	186.4	181.2	187.3	-	181.3	181.4	143.3
9C-001										
1	76.6	89.3	92.3	96.3	94.5	91.5	76.6	83.3	104.4	77.4
2	51.1	56.4	74.5	59.2	72.8	64.1	51.1	46.8	37.8	57.8
3	69.7	77.1	69.4	70.3	77.1	88.4	69.7	69.1	93.2	64.0
9C-002										
1	76.7	68.6	79.9	100.3	96.5	62.0	88.2	79.0	101.3	90.5
2	50.5	53.2	67.2	57.4	73.9	53.3	50.3	63.3	54.1	66.9
3	69.7	60.8	70.2	68.0	91.0	55.3	54.0	55.3	53.8	71.9
RMSE		***15.7***	***16.0***	***16.6***	***18.5***	***16.9***	***8.0***	***14.4***	***19.4***	***9.1***

ASME Code Section XI-acceptable criterion for Length RMSE is less than 19.05 mm (0.75 in.)

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PZR Surge Line Results: Depth Sizing Units: mm

		800 kHz		1.0 MHz		1.5 MHz			2.0 MHz	
Specimen/ Flaw	True State Length mm	CCSS mm	SCSS mm	CCSS mm	SCSS mm	CCSS mm	Raster CCSS mm	SCSS mm	CCSS mm	SCSS mm
7C-059										
1	10.9	12.6	11.5	10.6	11.8	10.9	-	11.5	11.4	10.6
2	9.3	11.6	9.6	11.3	9.1	9.2	-	8.3	10.9	10.5
3	9.3	9.8	-	10.4	10.0	10.6	-	10.0	11.1	10.3
4	15.6	16.3	14.5	15.0	14.7	14.5	-	14.9	15.0	15.3
9C-001										
1a	3.4	5.0	4.0	3.4	3.2	4.2	3.5	2.5	3.5	5.2
1b	6.4	7.5	7.9	5.8	6.2	5.7	5.2	7.7	6.1	6.9
2	8.9	8.6	8.0	7.7	7.1	8.1	7.1	9.2	11.5	11.2
3	8.3	11.1	7.2	9.7	9.0	8.8	7.8	7.7	10.3	9.0
9C-002										
1a	4.8	4.3	6.9	4.8	NA	4.3	4.2	4.5	4.4	5.8
1b	7.5	9.5	7.9	9.3	6.4	7.4	6.5	4.6	7.9	9.0
2	6.3	6.4	8.1	7.9	8.2	6.6	6.7	4.4	6.0	7.0
3	4.8	6.3	NA	6.5	3.6	5.3	8.3	5.1	6.0	6.9
RMSE		***1.5***	***1.8***	***1.2***	***1.7***	***0.7***	***1.5***	***1.2***	***1.3***	***1.3***

ASME Code Section XI-acceptable criterion for Depth RMSE is less than 3.81 mm (0.125 in.)

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PZR Surge Line Results: Signal-to-Noise

	800 kHz		1.0 MHz		1.5 MHz			2.0 MHz	
Specimen/ Flaw	CCSS dB	SCSS dB	CCSS dB	SCSS dB	CCSS dB	Raster CCSS dB	SCSS dB	CCSS dB	SCSS dB
7C-059									
1	17.0	15.7	16.6	18.3	14.7	-	18.7	18.2	22.4
2	13.7	10.4	14.2	11.4	14.3	-	11.6	16.9	11.1
3	14.5	--	16.2	9.5	17.7	-	17.5	19.9	18.1
4	15.1	17.4	16.3	15.8	17.3	-	16.6	15.7	19.0
9C-001									
1	20.0	15.2	20.7	14.2	21.1	22.6	16.3	19.4	18.1
2	19.6	15.5	18.9	14.0	17.8	21.3	15.1	20.7	15.6
3	17.4	13.7	17.2	18.1	16.4	17.4	18.9	15.5	16.7
9C-002									
1	16.6	24.6	16.8	22.6	17.6	18.4	11.2	18.3	16.5
2	13.9	20.0	14.9	21.0	15.9	19.7	21.7	17.5	19.9
3	17.2	16.7	18.0	19.7	18.1	18.9	17.3	17.1	17.9
Mean	**16.5**	**16.6**	**17.0**	**16.5**	**17.1**	**19.7**	**16.5**	**17.9**	**17.5**

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LIFETIME, IN-SERVICE INSPECTION, AGING MANAGEMENT OF CAST DUPLEX STAINLESS STEEL COMPONENTS ON REACTOR COOLANT PRIMARY CIRCUIT

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G B Consulting

CASS WORKSHOP January 28-29, 2011 Seattle Washington USA

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CONTENT

- Problem & context – CASS Program objectives and contents
- Metholology applied for In-Service Inspection Integrity
- Studies on properties of aged materials
- Life evaluation & Resistance assessment and strategy
- Summary

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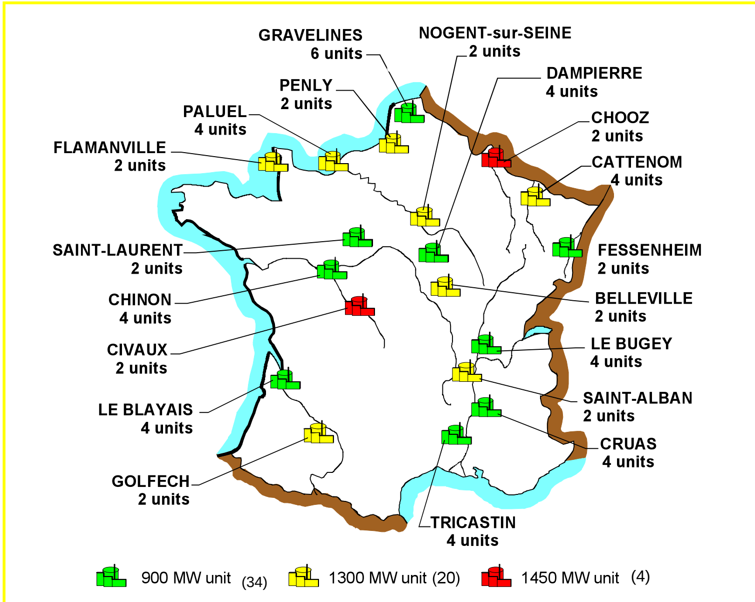

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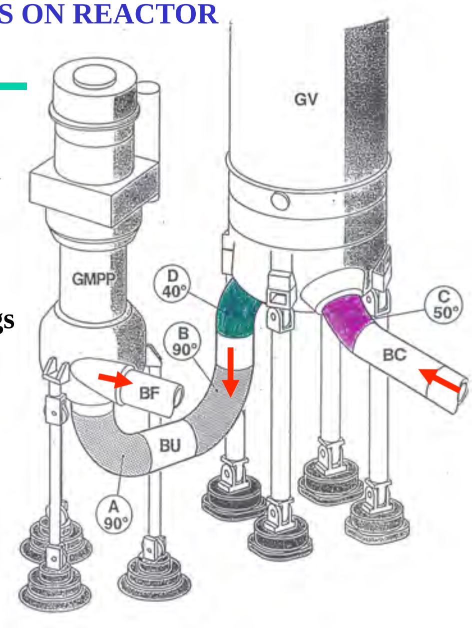
CAST DUPLEX COMPONENTS ON REACTOR COOLANT CIRCUIT

- Elbows
  - One hot elbow - inlet SG
  - 4 cold elbows
    one outlet SG
- Laterals on primary circuit legs
- Valve casings
- Primary pump casing

cast Materials concerned :
- CF 8
- CF 8 M
- CF 3



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PROBLEM

☞ **THERMAL AGING OF CAST STAINLESS STEEL COMPONENTS FOR TEMPERATURE RANGE 285°C -> 325°C.**

- Ductile tearing resistance decreasing in relation with
  2 phase
  1st One hight chromium contain and Chemical composition, and 2nd one ferrous contain
- Possible cast defects needing ISI (characterization)
- Margins for rupture assessment are decreasing with time in operation needing integrity assessment and Toughness evaluation.

☞ **JUSTIFY LOW PROBABILITY OF RUPTURE DURING THE LIFE OF COMPONENTS with DEVELOPMENT of CRITERIA**

and planning for component replacement.

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PROGRAM OBJECTIVES AND CONTENT (1/2)

OBJECTIVES

- Some components of the primary loop of PWR are made in cast duplex stainless steel (CF8M): elbows, valve casings, laterals.
- Thermal ageing at PWR service functions temperatures (285°C – 325°C) thermal aging ⇨ Decreasing of the toughness properties of the steel
- Occurrence of casting defects necessary to apply ISI (NDE program)
- Integrity assessment of these components
- Supported by a large R&D program

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PROGRAM OBJECTIVES AND CONTENT (2/2)

CONTENT OF THE R&D PROGRAM

- Development of prediction formulas for mechanical characteristics of ages materials
- Improvement of the surveillance methods (in-service inspection on components)
- Assessement of the margins included in the mechanical analyses
- Better evaluation of the fatigue and tearing behaviour of the casting defects

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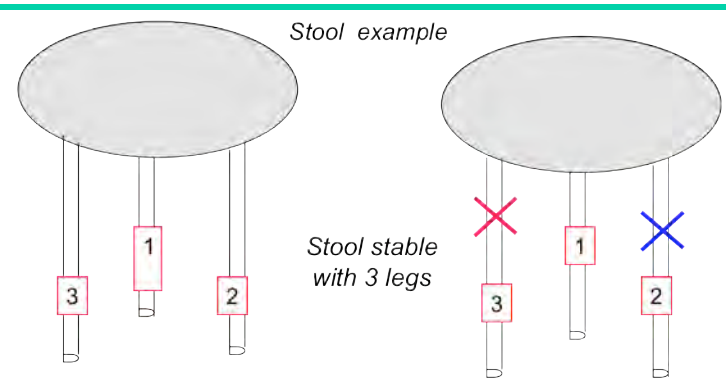
CAST DUPLEX STAINLESS STEEL COMPONENTS INTEGRITY JUSTIFICATION AND DEMONSTRATION



1 In-Service inspection flaw characterization

2 Metallurgical aspect aging and toughness characterisation

3 Mechanical analysis Integrity assessment

UT
ET
RT Gamma Radiography
PT

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STUDIES ON PROPERTIES OF AGES MATERIALS (2/2)

METALLURGIC SURVEILLANCE PROGRAM

- Development of predictives formulas applied on 3 loops and 4 loops reactors :
  - For hot elbows, and
  - For cold elbows and also valve casing, laterals connections
- Development of predictive formulas

  Kcv = f (T, t, Cr*) J = f (Kcv)
- Engagement of ISI program to characterize cast defects size
- To understand the aging mecanism
  - ✓ Ingots cast at the same as the components in operating was introduce in furnace at different temperatures
  - ✓ Laboratorys aging treatment

    285°C ⇐ Temperature ⇐ 400°C

    - Times up to 100, 000 Hours

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BACKGROUND AND HISTORY ON THERMAL AGING OF CAST COMPONENTS IN PRIMARY CIRCUITS

During the 80's, the thermal aging phenomenon was identified after Utility large R&D program of activities and confirming the aging phenomenom on Cast Duplex Stainless components on Primary circuits on hot leg temperature 325°C and cold leg temperature 285°C;

French Utility and the Manufacturer decided to engage actions to predict the metallurgical aging mechanism to assess for:

✓ 1st step 40 years prediction,

✓ 2nd step 40 years evaluation.

The objectives were to assess the ability of the cast elbows in existing plants to continue operating conditions on the components respecting safety requirements :

❶ By inspection NDE on components characterization of cast defects size

❷ Definition of acceptance Criteria (metallurgical aspect)

The criteria /sensitivity to thermal ageing is Chromium equivalent

❖ C*éq = %Cr + %Si + %Mo > 23.5%

➢ ferrite content for cast material < 20% .

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METHOLOGY APPLIED ON CAST DUPLEX STAINLESS STEEL COMPONENTS

The methology applied was engaged in three phases and important steps in parallel

- Determination of the toughness at the end of life taking account :
  - Materials parameters in function of chemical composition for each components
  - The development of prediction formulas
    - Hot components
    - Cold components

Classification all of components considering the sensitivity under thermal aging

- inspection of components to characterize the indication (cast defect) inside the components (position – location – size – evolution during time in operation)

Classification all of components considering cast defects CHARACTERIZATION (position – location – size)

- Mechanical analyses to justify the aptitude to maintain components in opération in all condition of loading
  - 2nd category (level A)
  - 3rd category (level C)
  - 4th category (level D)

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PROGRAMME OF INSPECTION

- Actions => Inspection

Inspection of all of Sensitive elbows
Classification of the Elbows following flaw evaluation after ISI

Gamma Radiography

PT inspection examination and
if necessary replica

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TOOLS APPLIED TO FOLLOW THE DECREASING OF THE CHARACTERISTICS OF COMPOMENTS OR REPLACEMENT OF ELBOWS

MAINTENANCE STRATEGY - NDE examination

☞ **NDE – In-service Inspection tools to characterize flaw in compoments**

→ Standard gamma radiography (gammagraphy) for elbow;
to characterize flaw inside thickness of elbow

and on radio film application of contrast measurement by optical density numerisation

→ PT inspection examination for defect on outside surface periodic inspection (and possible to perform replica)

☞ **Special tools to follow the toughness decreasing measurement on site on components by**

Method of ageing Measurement
Based on Thermal Electric Power TEP

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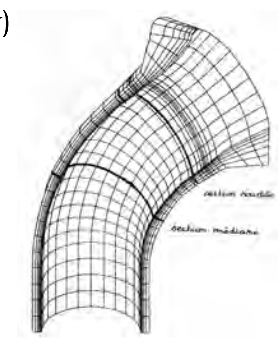
PROGRAMME OF INSPECTION

- Actions => Inspection

Inspection of all Sensitive cast elbows and hierarchical Classification of the Elbows :

. flaw (ASTM 2 - ASTM 1)
. Number of indications (shrinckage cavity)

Aggregate or isolated shrinckage cavity or
On line threaded shrinckage cavity



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In-Service Inspection

1- Hot Elbow inlet SG

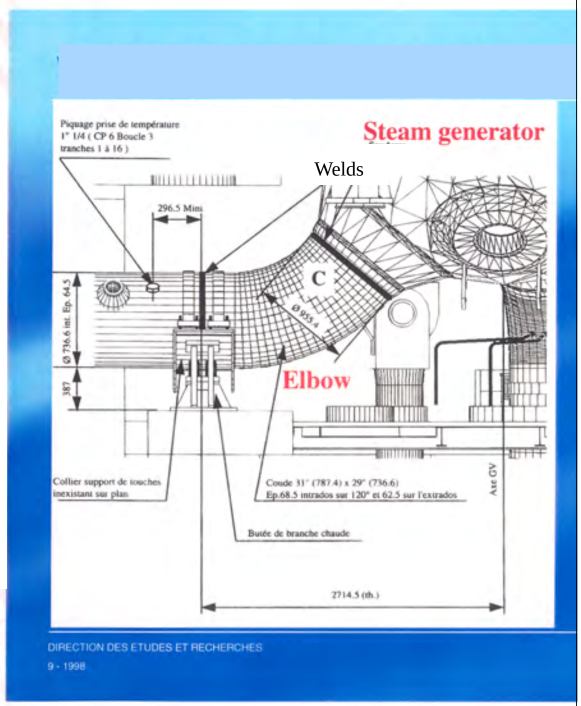
Gamagraphy central source Irridium 192

Simple elbow wall (thickness)

2- Cold Elbow Outlet SG

Gamagraphy central source Irridium 192

Simple elbow wall (thickness)



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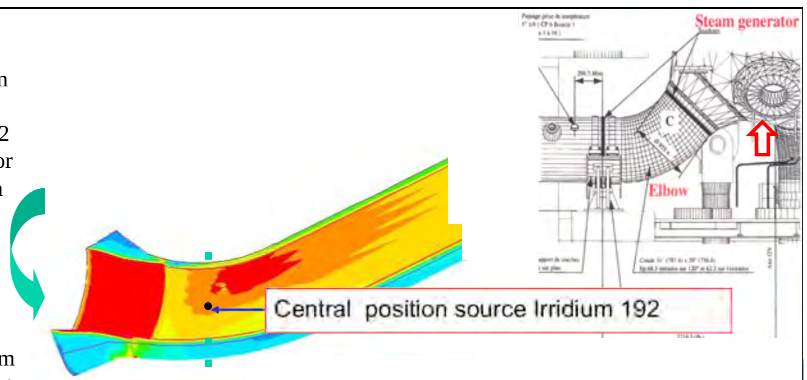
Introduction of source Irridium 192 by hot box or cold box in SG



Steam Generator

Gamagraphy central source Irridium 192

Simple elbow wall (thickness)

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TOOLS APPLIED TO FOLLOW THE DECREASING OF THE CHARACTERISTICS OF COMPOMENTS OR REPLACEMENT OF ELBOWS

MAINTENANCE STRATEGY - NDE examination

- **NDE – In-service Inspection tools to characterize flaw in components**
  - → Standard gamma radiography (gammagraphy) for elbow; to characterize flaw inside thickness of elbow

    and on radio film application of contrast measurement by optical density numerisation
  - → PT inspection examination for defect on outside surface periodic inspection (and possible to perform replica)
- **Special tools to follow the toughness decreasing measurement on site on components by**

  Method of ageing Measurement
  Based on Thermal Electric Power TEP

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TOOLS APPLIED TO FOLLOW THE DECREASING OF THE CHARACTERISTICS OF COMPOMENTS OR REPLACEMENT OF ELBOWS

MAINTENANCE STRATEGY

- **NDE – In-service Inspection tools to characterize flaw in components**
  - → Standard gammagraphy and on radio film

    application of contrast measurement by optical density numerisation
  - → PT inspection examination for defect on outside surface periodic inspection (and possible to perform replica)
- **Special tools to follow the toughness decreasing measurement on site on components by**

  Method of ageing Measurement
  Based on **Thermal Electric Power TEP**

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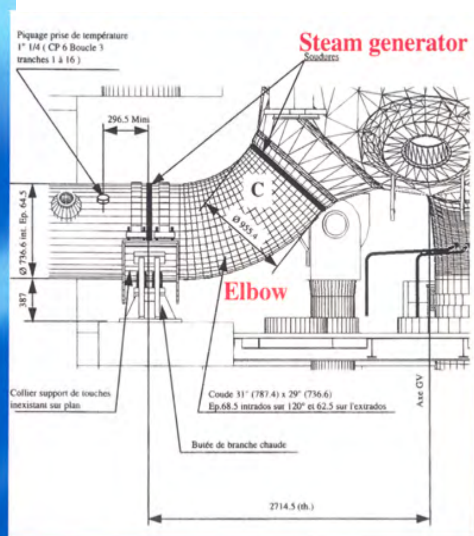
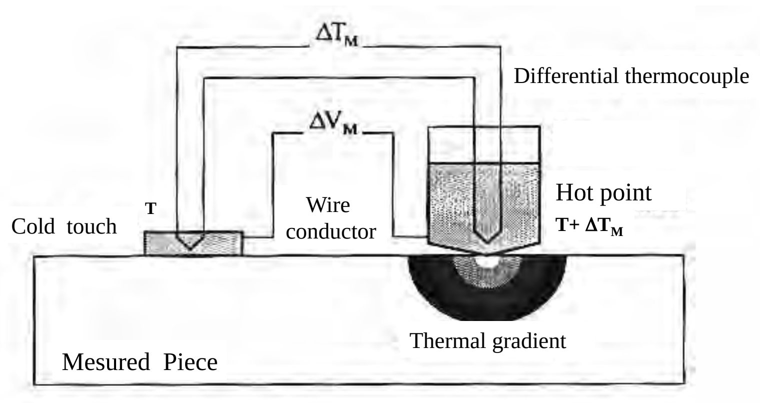
APLLICATION TEP ON REEL ELBOW ON SITE



- TEP inspection of hot-leg elbow (C) during outage
- Material sampling
- Comparison of TEP on elbow with (1) TEP on sampled material and (2) mechanical characteristics of sampled material

TEP = Application of Seebeck effect



APPLICATION OF SEEBECK EFFECT

Principle

To determine the evolution of microstructure induce by SEEBECK effect of a differential thermocouple to mesure voltage between material to be mesured and the reference material well known

and toughness evaluation of the material

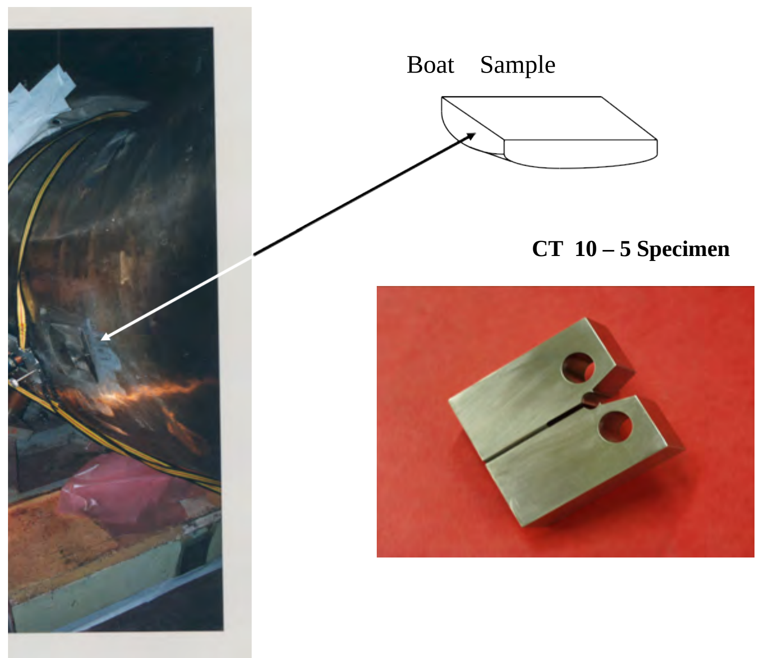
- junctions between the piece for measurement and a reference metal well known and characterised;
- measurements are at temperatures

$$T \quad \text{and} \quad T + \Delta T_M.$$

$\rightarrow \Delta V_M$ = low voltage provided by the SEEBECK effect

$$\text{TEP} \quad \Delta S = \Delta V_M / \Delta T_M$$

$$\Delta S \; ; \; \Delta V \; ; \; \Delta T \; (\mu V/°K)$$



MAJOR PARAMETERS

- Temperature hot leg and cold leg
- Operating time
- chemical composition with equivalent chromium and ferrite
- Material properties (Toughness and TEP results)
- Defects characterization size and location (ISI results)
- Mechanical behaviour
- Support actions engaged by EDF Maintenance strategy

Mechanical analysis

- Actions => Mechanical analysis

JUSTIFICATION OF BEHAVIOUR OF ALL ELBOWS

Mechanical analyses to justify the aptitude to maintain components in opération in all condition of loading

- 2nd category (level A)
- 3rd category (level C)
- 4th category (level D)

- All transients in different categories
  - 2nd
  - 3rd Small Break LOCA
  - 4th LOCA
- Defect (Reference defect or real defect after ISI)
- Results comparison toughness after computation with toughness obtained on Materials evaluation

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MECANICAL BEHAVIOUR OF ELBOWS

- **ANALYSIS OF DETECTED FLAWS**
- **GENERIC ANALYSIS OF REFERENCE DEFECT and REAL DEFECTS FOLLOWING INSPECTION**
  - All the elbows all type of loading and all position of flaws
  - Use of the specific behavior of cast defect
  - Simple analysis for ranking
  - Finite element approach of the worst cases

CONCLUSION

All the elbows are acceptable for 40 years of operation and on-going actions for 60 years .

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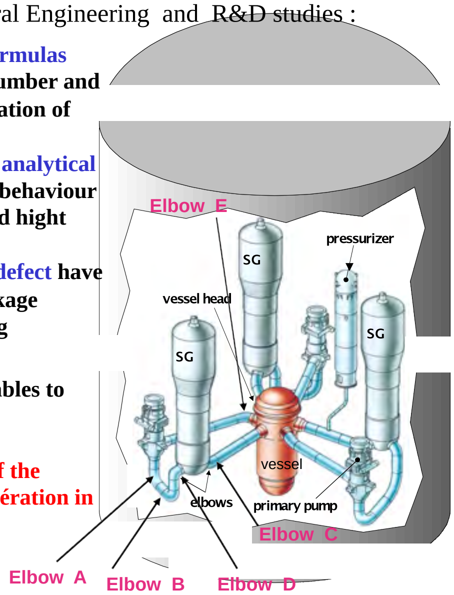
The integrity assessment of cast duplex stainless steel components on plants in operation relies on several Engineering and R&D studies :

- **Development of accurate prediction formulas bases on a very important database (number and variety of products, temperatures, duration of ageing)**
- **Tests on large-sized elbows containing analytical notches have proven their satisfactory behaviour for severe situations (low toughness and hight loading levels)**
- **Tests on mock-ups containing casting defect have shown the superior resistance of shrinkage cavities to fatigue and to ductile tearing (compared to "cover" notches)**
- **Development of the numerical tool enables to perform repetitive elbow calculations.**

- **Justification by mechanical analyses of the aptitude to maintain components in opération in all condition of loading**
  - ⇨ **2nd category**
  - ⇨ **3rd category**
  - ⇨ **4th category**



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Cast Stainless Ultrasonic Examination Feasibility Study for Ringhals

Claes Sandelin
Ringhals

Mark Dennis
EPRI

January 28, 2011

Topics of Discussion

- Cast Stainless Steel Ultrasonic Examination Feasibility Study for Ringhals
  – Statically cast stainless steel valve3119643NS

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Cast Stainless Steel Ultrasonic Examination Feasibility Study - Project Tasks

- Determine the feasibility of performing ultrasonic examinations of cast stainless steel components
  - Design & procure ultrasonic transducer(s)
  - Installation of EDM Notches
  - Ultrasonic data examination and analysis of Ringhals AB mockups
    - Statically cast stainless steel valve3119643NS

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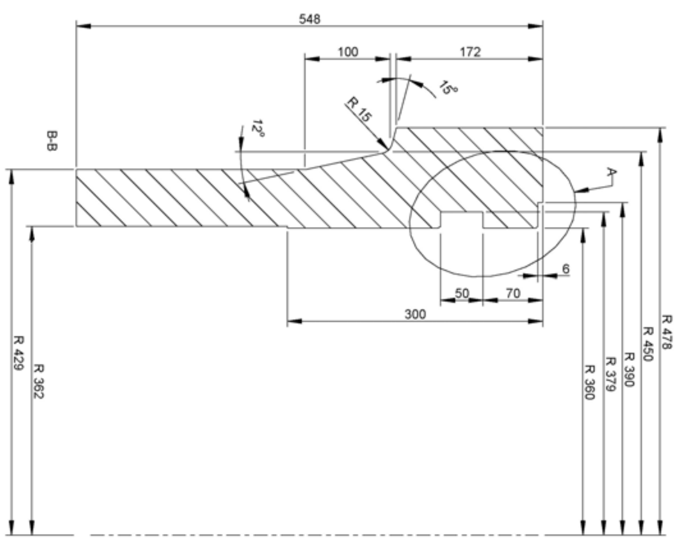
Cast Stainless Steel Valve Mockup Sample 3119643NS



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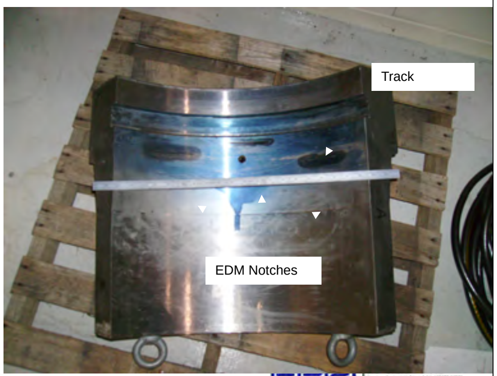
Cast Stainless Steel Valve Mockup Sample 3119643NS

- The sample was provided to EPRI by Ringhals.
- The notches were installed by EPRI.



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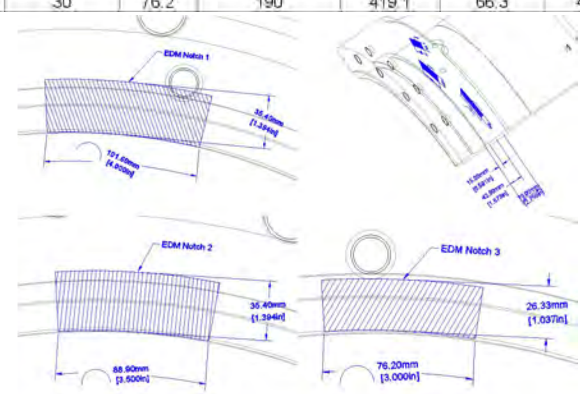
Sample 3119643NS Notch Locations

EDM Notch #	Notch Height (mm)	Notch Height (% of Thickness)	Notch ID Length (mm)	Axial Location From Thick Side of Sample (mm)	Start Circ Location on ID (mm)	Start Circ Location on ID (deg)	End Circ Location on ID (mm)	End Circ Location on ID (deg)
1	35.4	30	101.6	162.5	76.2	12.1	177.8	28.1
2	35.4	30	88.9	135	254	40.2	342.9	54.3
3	26.33	30	76.2	190	419.1	66.3	495.3	78.4



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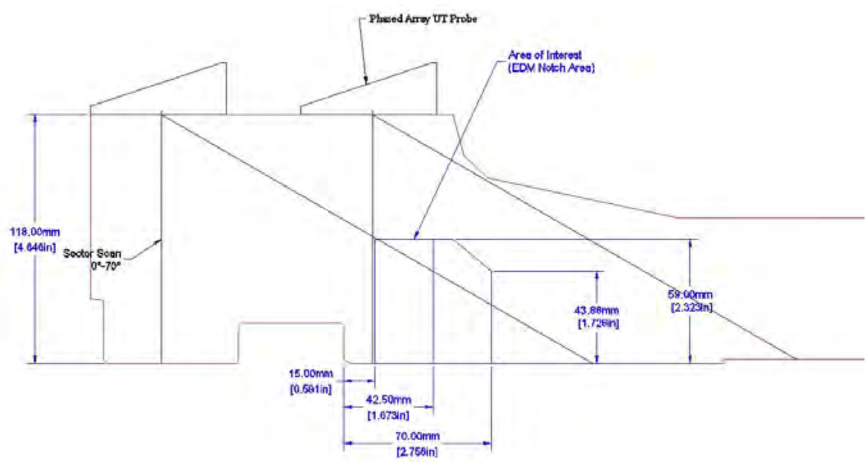
Thick Side Scan Setup
Sample 3119643NS



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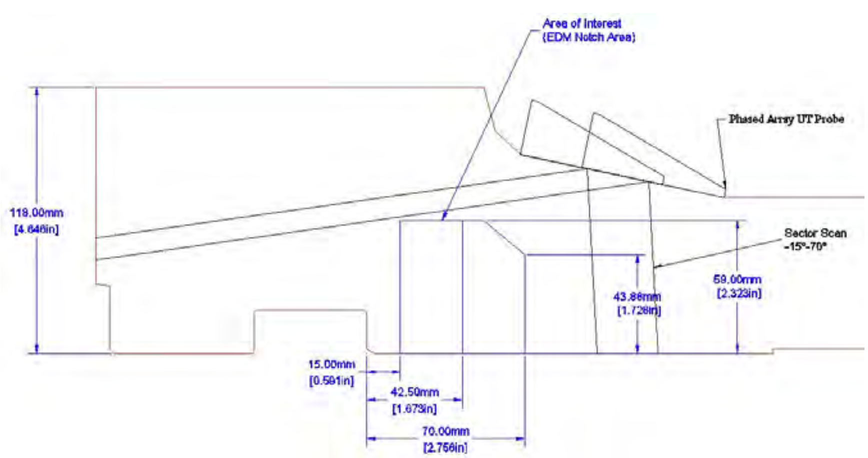
Taper Region Scan Setup
Sample 3119643NS



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Ultrasonic Evaluation Equipment
Sample 3119643NS – Initial Scans

- Ultrasonic Systems
  - R/D Tech TOMOSCAN III/PA
  - Zetec DYNARAY
- Ultrasonic Array
  - GEIT 115-000-576 - 500 kHz 2x16 (3.6 x 9.6 mm) Dual Phased Array (~57.6 mm x 19.2 mm)
  - Coupled to GEIT Wedge 360-152-101
- Data Acquisition and Analysis
  - UltraVision 1.2R4 & 3.1R9

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Ultrasonic Evaluation Equipment
Sample 3119643NS – Initial Scans

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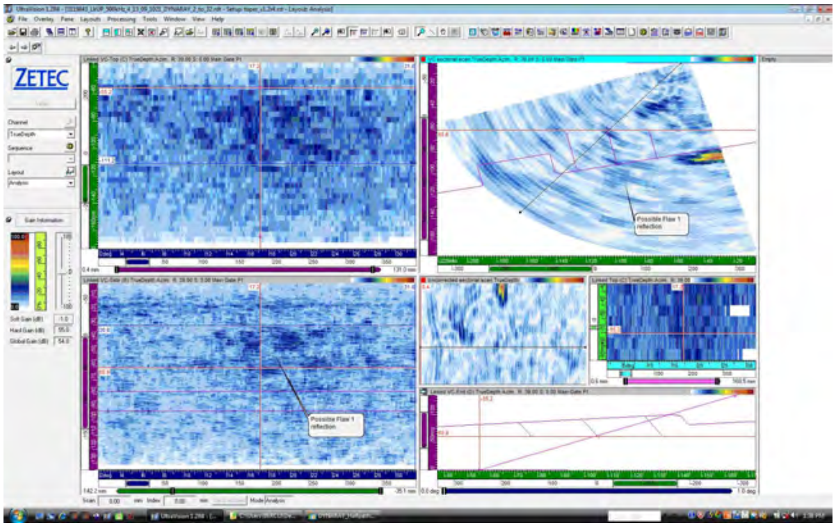
Notch 1 Seen from Taper - DYNARAY



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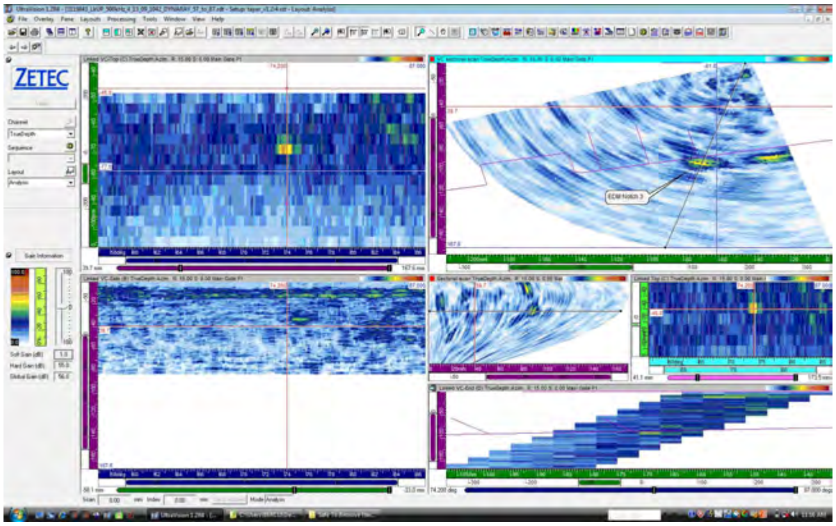
Notch 3 Seen from Taper - DYNARAY



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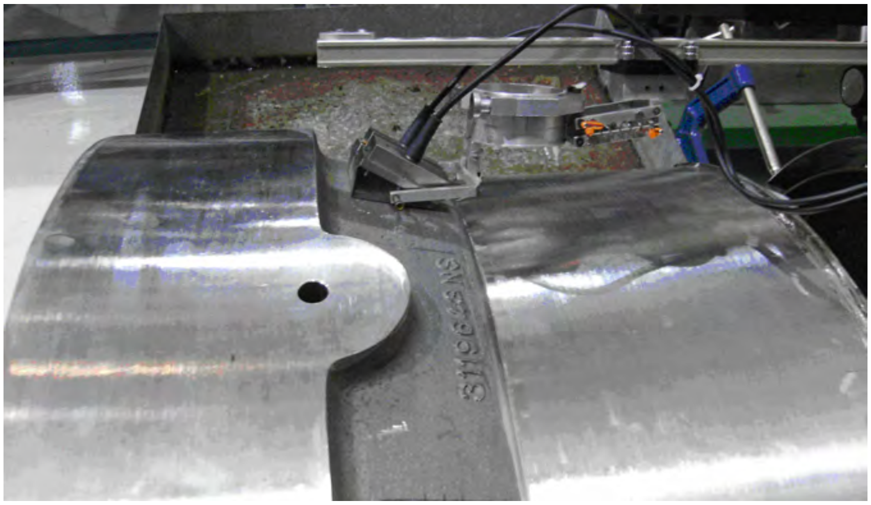
Raised Lettering and Geometry Preventing Scanning of Notch 2 from Taper



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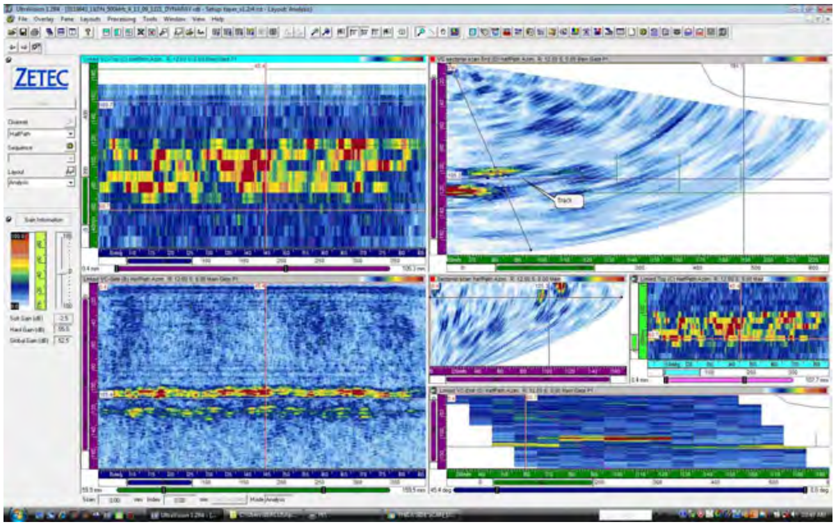
Back Wall Signal and ID Change - DYNARAY



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Initial Test Results
Sample 3119643NS

- Results while scanning from the Taper Side
  - Notch 1 & Notch 3 were detectable
  - Raised lettering and geometry prevented scanning of Notch 2
  - The DYNARAY provided better signal-to-noise ratios
- Results while scanning from the Thick Side
  - No Indications of EDM notches
  - Back wall signal present throughout scan
  - ID change visible while scanning over the track

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Changes Implemented Before Final Scans
Sample 3119643NS

- Taper was machined smooth to eliminate raised lettering and geometry issues to allow for detection of Notch 2
- Two larger 500 kHz arrays and wedges were designed
  - GEIT 115-000-738 - 500 kHz 3x10 Dual Phased Array (For Taper Scans)
    - GEIT Wedge 360-152-221
  - GEIT 115-000-739 - 500 kHz 3x10 Dual Phased Array (For Flange Scans)
    - GEIT Wedge 360-152-222

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Ultrasonic Evaluation Equipment
Sample 3119643NS – Final Scans

- Ultrasonic Systems
  – Zetec DYNARAY
- Ultrasonic Array
  – GEIT 115-000-738 - 500 kHz 3x10 Dual Phased Array - Coupled to GEIT Wedge 360-152-221
  – GEIT 115-000-739 - 500 kHz 3x10 Dual Phased Array - Coupled to GEIT Wedge 360-152-222
- Data Acquisition and Analysis
  – UltraVision 1.2R4 & 3.1R9

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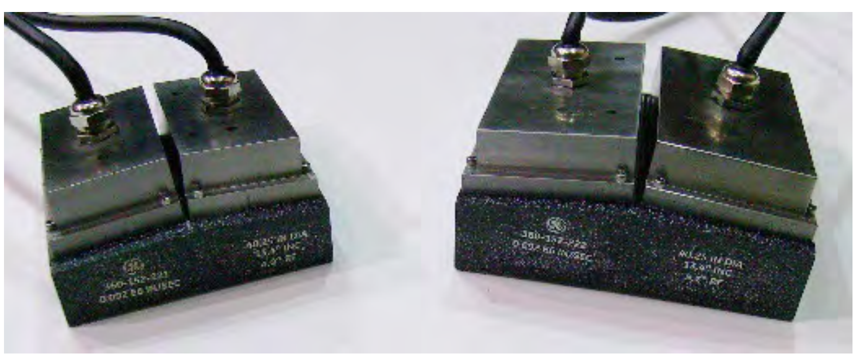
Ultrasonic Evaluation Equipment
Sample 3119643NS – Final Scans

- Small (115-000-738) Scanning on the Taper
- Large Probe (115-000-739) Scanning on the Flange



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Ultrasonic Evaluation Equipment Sample 3119643NS – Final Scans

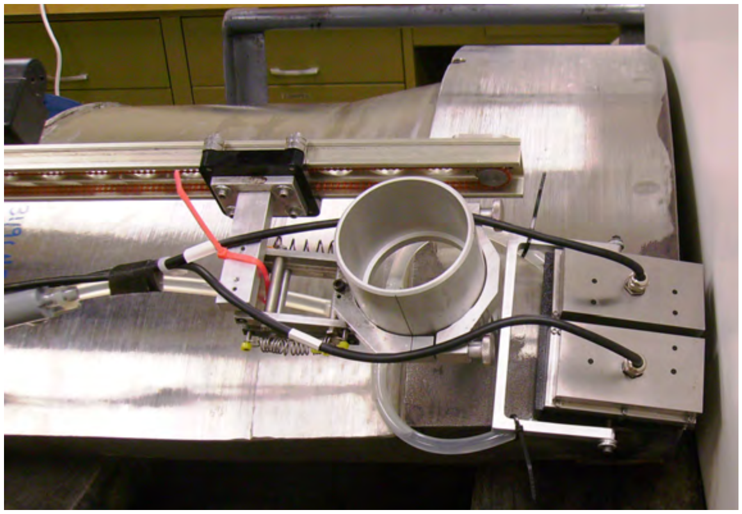

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Image of Notch 3 as Seen on a 15-30° Merge Taken from the Taper with Probe 115-000-738

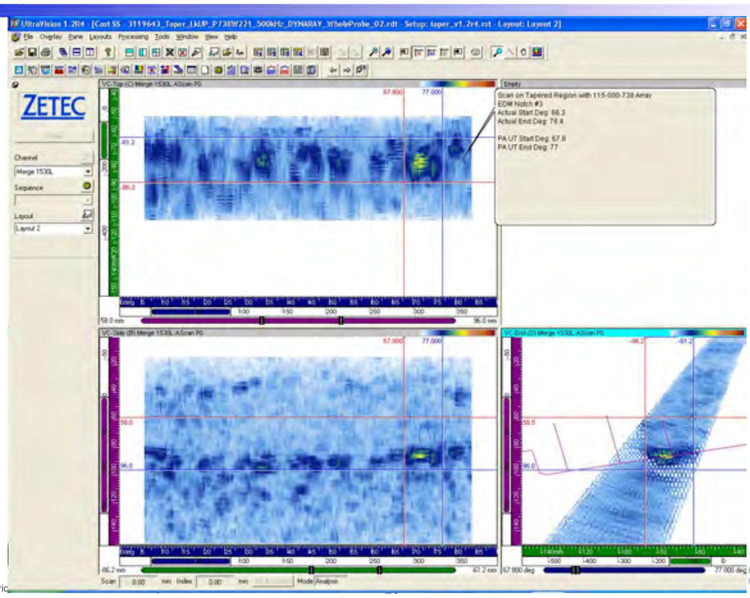

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Image of Notch 1 as Seen with 30° Taken from the Flange with Probe 115-000-739

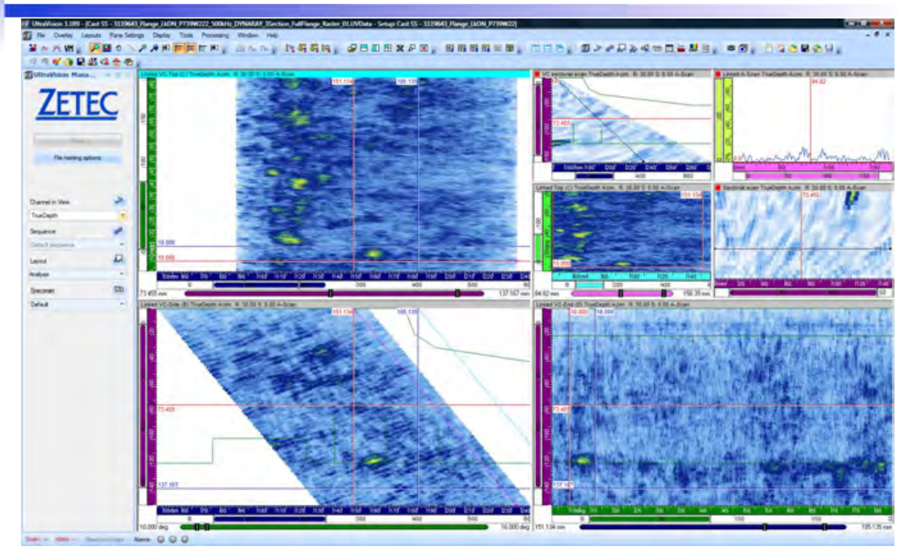

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Image of Notch 2 as Seen with 30° Taken from the Flange with Probe 115-000-739

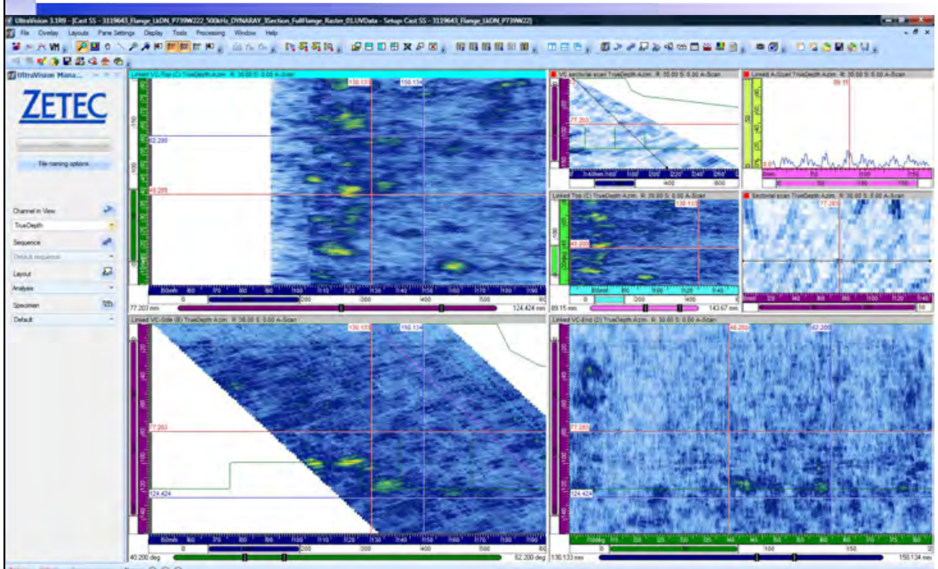

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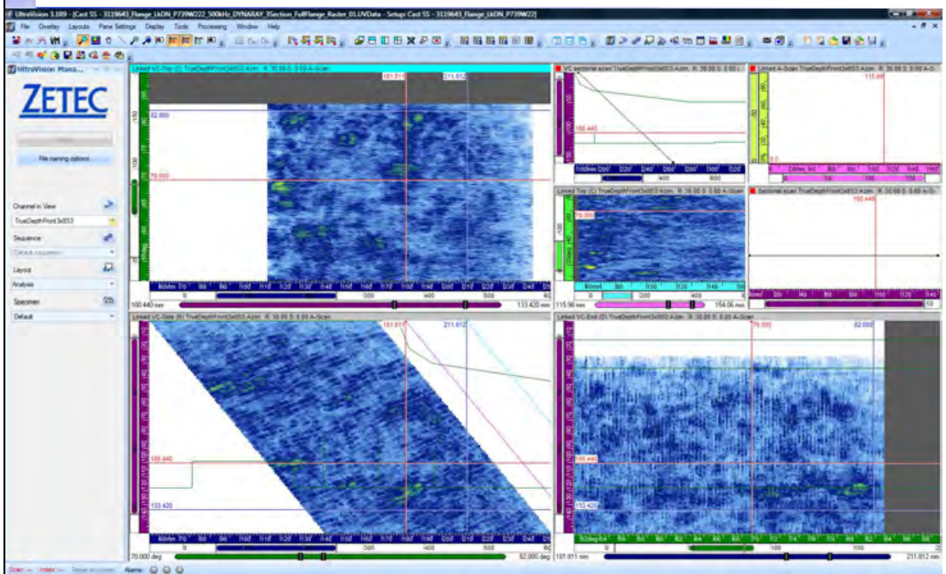
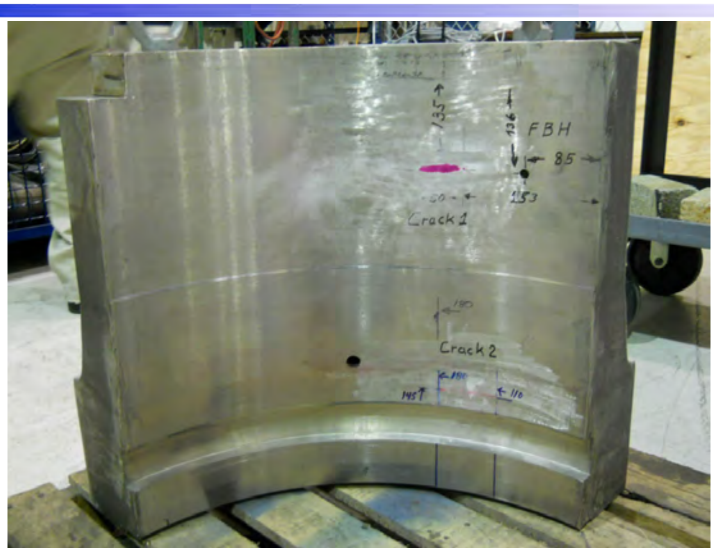
Image of Notch 3 as Seen with a 3x8 Array at 30° Taken from the Flange with Probe 115-000-739



Final Test Results
Sample 3119643NS

- Results while scanning from the Taper Side
  - Only Notch 3 was detectable due to the geometry and the probe size
- Results while scanning from the Thick Side
  - All three EDM notches were detected
  - Due to the geometry, a 3x8 subset of array elements was used to image Notch 3

New Cracks Installed by AREVA NP Uddcomb AB



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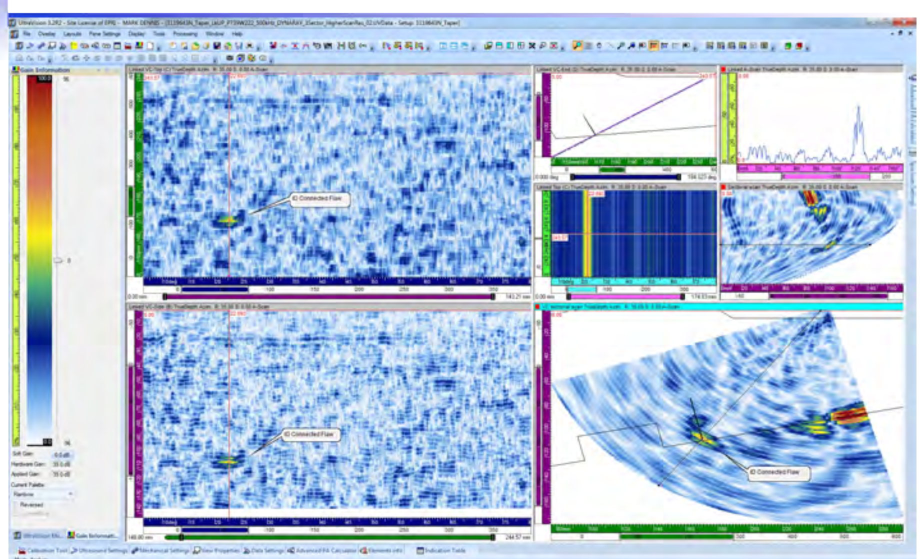
Crack #2 – Preliminary Results (From Taper)



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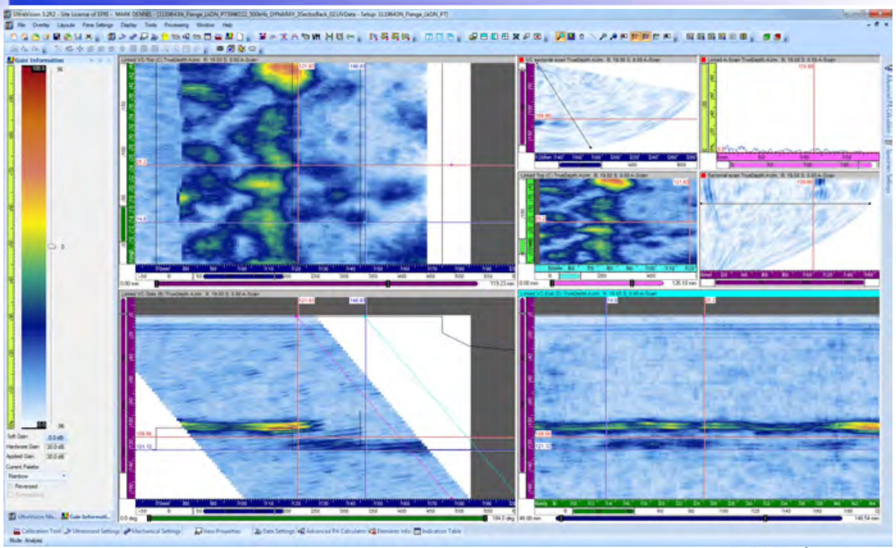
Crack #2 – Preliminary Results (From Flange)



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Conclusion & Recommendations

- The three EDM notches contained in the statically CSS valve mockup were detected using the larger 500 kHz ultrasonic phased array probe.
- The AREVA NP Uddcomb AB installed crack was detected with both the larger and smaller 500 kHz ultrasonic phased array probes (preliminary results).
- Ultrasonic measurement of length and height was outside the scope of this investigation. It should be noted that techniques described in this investigation and the results presented represent a best effort for the components tested.
- While the results of this investigation demonstrate gradual improvements in the inspection of CSS components, the following items should be considered as potential enhancements:
  - The use of fixed angle low frequency (~ 500 kHz) conventional probes may provide more ultrasonic energy into the component at less cost with potential signal-to-noise ratio improvement.
  - The use of large low frequency (~ 500 kHz) immersion probes or flexible array probes may reduce complications related to surface conditions.

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ACOUSTIC AGREE

VATTENFALL

Nonlinear NonDestructive Testing

Fingerprint of Cast Stainless Steel Examination of rods submerged in water

Acoustic Agree AB
Ronneby, Sweden

ACOUSTIC AGREE

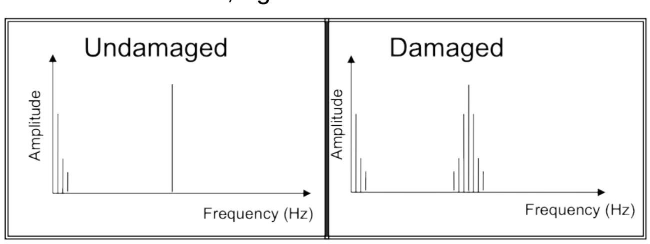
VATTENFALL

Method

- A crack behaves strongly nonlinear and can be used to detect cracks in objects.
- Materials that we have verified before: steel, aluminum, brass, titanium, rubber, wood and carbonfiber reinforced composites. Also sintered hardmetals was verified successfully.

Schematic identification

- Frequency spectrums are used in calculations of damage level
- Left: without crack, right: with crack



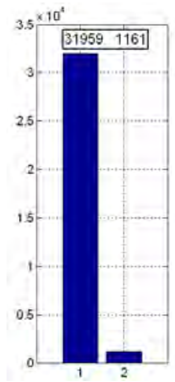
Fingerprint
Cast stainless steel valve

VATTENFALL

Test of damage level before and after implementation of crack.

Bar 1 has crack
- 31959

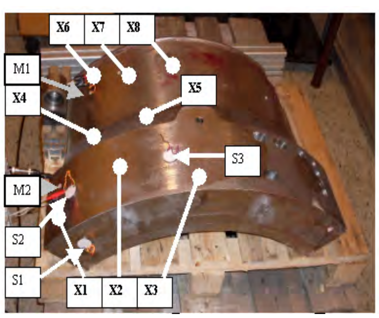
Bar 2 has no crack
- 1161

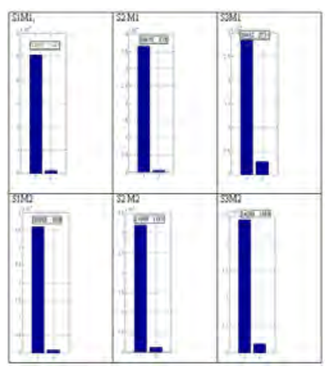


The white dots are sensors and transducers mounted on the object.

Set up/Results CASS

VATTENFALL





Configuration	After introducing crack	Before introducing crack
S1M1	50805	1141
S2M1	36635	578
S3M1	28482	2731
S1M2	35959	859
S2M2	31959	1161
S3M2	24289	1609

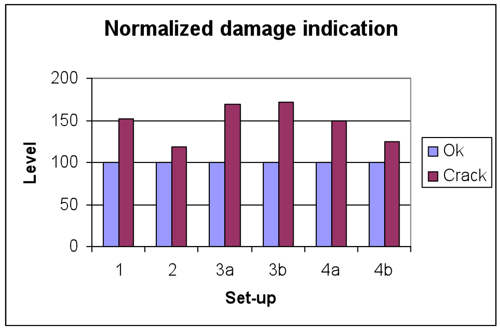
Waterfilled cracks
Results Bars

VATTENFALL

Setup 3 a/b

Two rods made of steel were used to verify if the method is applicable to objects submerged in water. One rod contains cracks while the other don't

Picture of set-up: wet rods mounted in seals (dry transducers)



Setup 1: Dry rod mounted in seals.
Setup 2: Dry rod lying on support
Setup 3a: Wet rod mounted in seals (dry sensors)
Setup 3b: Wet rod mounted in seals (dry sensors), after 48 hours submerged in water
Setup 4a: Wet rod hanging in fish wire (wet sensor)
Setup 4b: Wet rod hanging in fish wire (wet sensor) after 48 hours submerged in water

Short presentation AREVA NP Uddcomb AB Testblocks

Per Arne Bjurling
Manager Testblocks
Business Area Nuclear Services

AREVA

AREVA NP Uddcomb – Historical highlights

- 1969 - Uddcomb Sweden AB was formed as a joint venture between Uddeholm, Combustion Engineering and the Swedish Government.
- 1991 - The workshop and Uddcomb Sweden was closed down. Totally 15 RPV´s (BWR and PWR), RPV internals, SG´s, Pressurizers and much more where manufactured during the period of operation.
- 1991 - A MBO of Uddcomb Engineering was performed. The company moved to the present location at Kockums, The Karlskrona Naval Shipyard.
- 2002 – The operations at Uddcomb Engineering Helsingborg AB started.
- 2005 - Framatome ANP acquired the company and the operations in Karlskrona and Helsingborg was merged into one company.
- 2008 – Renamed to AREVA NP Uddcomb AB

AREVA NP Uddcomb AB

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AREVA

Some of our services for the Nuclear Market

- BA Nuclear Plants and Nuclear Services provides services within (examples):

BA Nuclear Plants

- *Design specifications*
- *Load bases*
- *Re-design of process system*
- *System design*
- *Detail design*
- *Re-qualification of components and systems*
- *Installation and commissioning*

BA Nuclear Services

- *Repair Engineering*
- *On site installation*
- *Piping and Component Replacement*
- *Workshop Manufacturing*
- *Test Blocks*

AREVA NP Uddcomb AB

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AREVA

Testblock history

- AREVA NP Uddcomb has manufactured Testblocks as long as nuclear power has existed in Sweden.
- The first Testblocks where manufactured for the Ågesta reactor in Stockholm in the early 60th.
- The Sizewell B reactor in England is inspected with qualifications made on Testblocks manufactured by Uddcomb in the 80th.
- Since the early 90th has Uddcomb manufactured more than 200 Testblocks according to ENIQ requirements only for the Swedish nuclear industry.
- Blocks have also been delivered to USA, Japan, Ukraine, Korea, France, Finland, Netherlands, Germany.

AREVA NP Uddcomb AB

Testblocks - 2011-01-04 Confidential - © AREVA NP - Sid 5

AREVA

Testblock - Defects

- Geometric defects
- Implants
- Weld solidification cracks
- Lack of fusion
- Mechanical fatigue cracks
- EDM notches
- Weld solidification cracks DAS182

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Defects

Weld solidification cracks in carbon steel Surface breaking

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Testblocks

Main circulation Pump, PWR

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Defects

Mechanical Fatigue Crack

Small defects

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Defects

Mechanical Fatigue Crack

Large defects

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Testblocks

Testblock for Outlet Nozzle PWR DAS182

Delivered for

The SERP project

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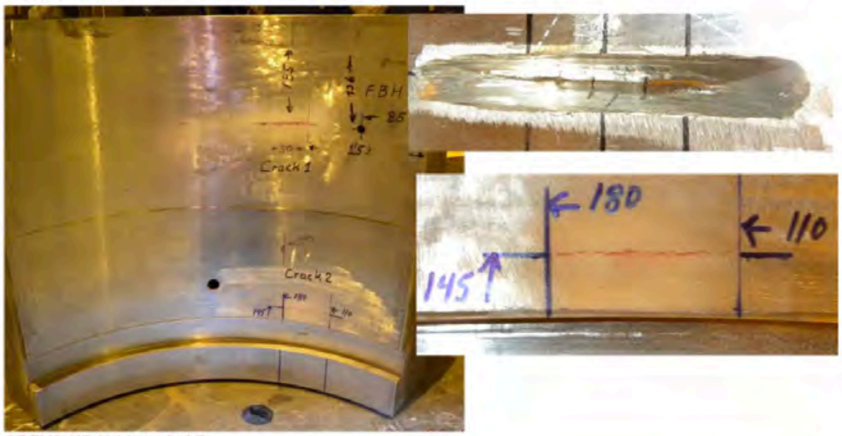
System 313 SSC Valve block

Valve block



AREVA NP Uddcomb AB

AREVA

Summary

- ANPU can provide a wide range of realistic defect types in welds and in adjacent base metal materials.
- The function and character of the defect types are evaluated in different projects and approved by the Swedish QB, SQC, as realistic cracks like IGSCC and IDSCC (DAS 182) as well as lack of fusions and slag inclusions. SQC is following the rules of ENIQ.
- The size of the defects are not limited to length and depth and can be embedded.
- The defects can be tilted to follow HAZ or an expected propagation direction.
- Testblock in CASS material with a weld and nozzle blocks with DMW have successfully been delivered in different projects.
- New markets are opening up not only in the nuclear industry.

AREVA NP Uddcomb AB

AREVA

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GDF SUEZ

Laborelec NDT Activities

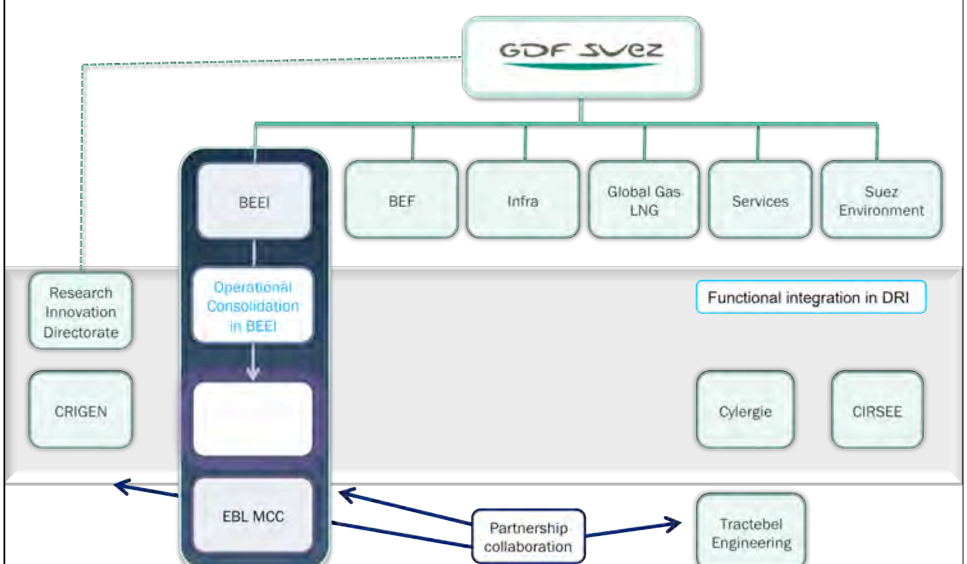
D Moussebois

3rd International Workshop for the Inspection of Cast Austenitic Stainless Steel Piping

2/15/11

LABORELEC within GDFSUEZ

Research and technical expertise center in electrical power technology within GDF SUEZ



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LABORELEC NDT Activities

- Non Destructive Testing Expertise for Electrabel in GDF-Suez
- Development and assessment of NDT probes, techniques and procedures to detect, size and follow degradations
- Monitoring and assessment of inspection programs
  - ➔ assessment of components health, mainly in the field of the electricity production : Nuclear and Fossile Power Plants, Combined Cycles Power Plants; or outside : e.g. petrochemistry, …
- Electrabel Qualification Body for NDT inspections of classified components in Nuclear Power Plants

2/15/11 3

LABORELEC
GDF SUEZ

Belgian PWRs – Some Reminders

- Design, fabrication & operation basis for belgian PWRs :
  - 10 CFR on Energy, USNRC rules
- Mandatory documents for mechanical components :
  - ASME Code
  - 'Transposition to Belgium of the ASME requirements, Sections III et XI, division1'.
- Safety Report and Technical Specifications for each unit.
- Ten year re-assessment of the belgian PWRs is mandatory by law.
  - For the current interval ➔ ASME XI, 92 edition
- Additional References documents for qualification of NDT inspections :
  - ENIQ European methodology for qualification of non-destructive testing
  - Politique EBL qualifications méthodes NDT
  - TWQ - Modalités des qualifications NDT en Belgique

2/15/11

LABORELEC
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Inspection of nozzles to CASS primary piping welds

- ASME requirements on NPP primary components & Safety Authorities requirements to inspect nozzles to RCP welds.
- First trials in 2005 show no good results due to geometry and UT low permeability.
- Nozzle to piping welds ➔UT inspection of complex surfaces, geometric limitations
- Cast Stainless Steel ➔ complex material regarding UT permeability, UT limitations
- Full scale mock-up : 14''nozzle to primary piping, UT permeability similar to some belgian NPPs
- Priority to detection of circumferential flaws in the ASME zone
- CEA – LBE Collaboration project : UT PA 2D-matrix low frequency transducer adjustable to the surface of the piping (reception tests : 02-2011). To be used with M2M & Dynaray systems.
- Primary environment ➔mechanical joints instead of rubber support for the UT elements
- Modeling with CIVA : support to design, identification of mechanical and ultrasonic maximal stress zones, beam distortion modelling by using Voronoi diagram (2011)
- In parallel : Feasibility study for the dedicated scanner

2/15/11 5

Modelling Example

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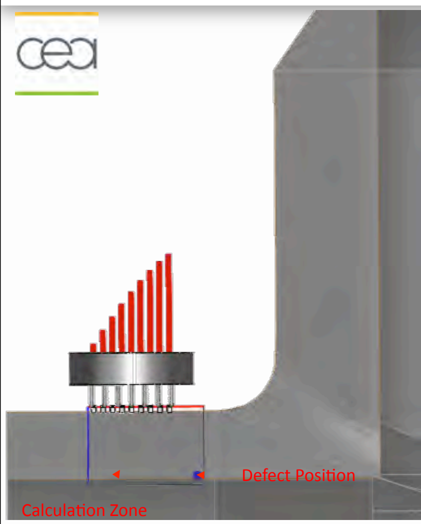
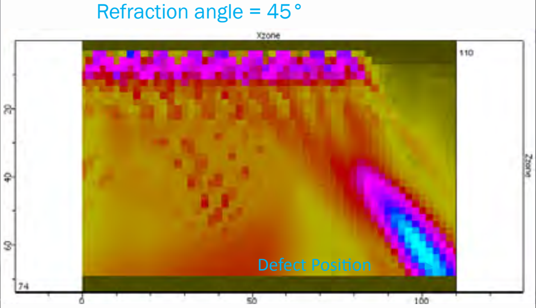
Transducer Design: 9x7 éléments



- Flaw : external to the weld
- Orientation : 0°
- Laws :

Focus depth = 65 mm

Refraction angle = 45°



Amplitude reference in the defect area = 0 dB

Transducer Design: 9x7 éléments

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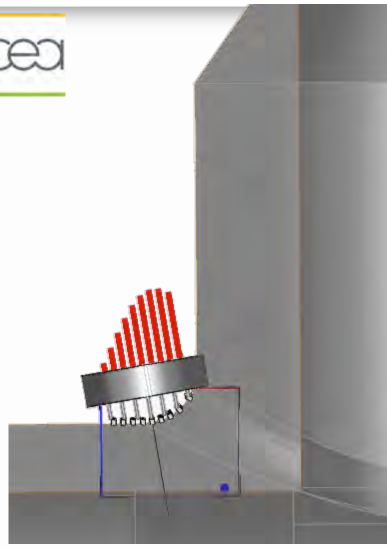
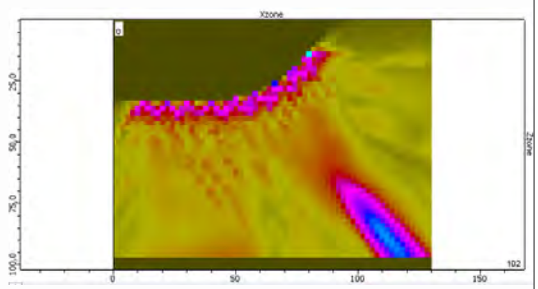
cea



- Flaw : internal to the weld
- Orientation : 0°
- Delay laws:

Focus depth = 76,5 mm

Refraction angle = 33°



Delta Amplitude in the defect area = 1 dB

List

Transducer Design: 9x7 éléments

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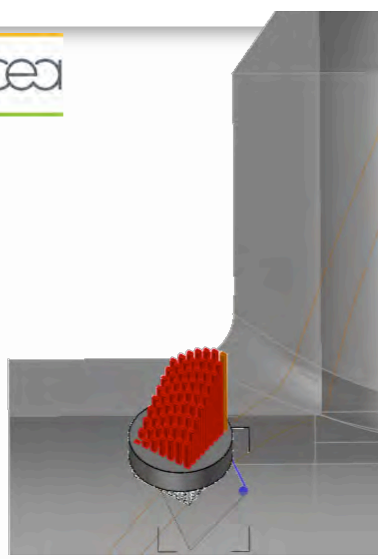
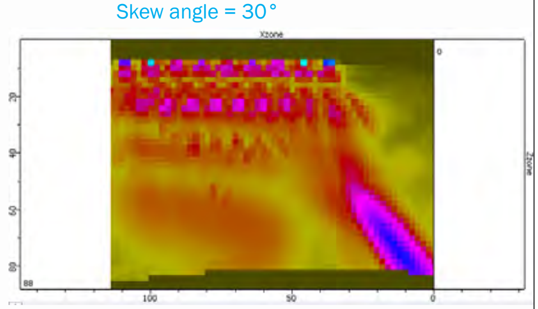


- Flaw : external to the weld
- Orientation : 45°
- Delay laws:

Focus depth = 66 mm

Refraction angle = 44°

Skew angle = 30°



Delta Amplitude in the defect area = 4 dB

List

Transducer Design: 9x7 éléments

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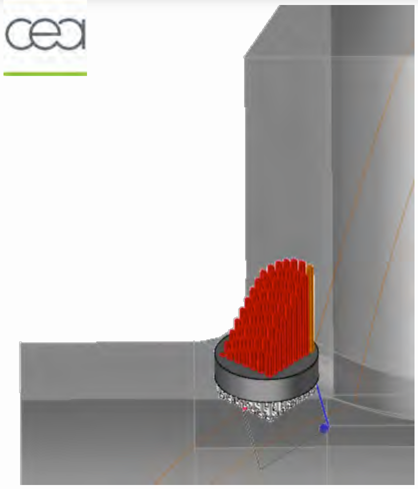
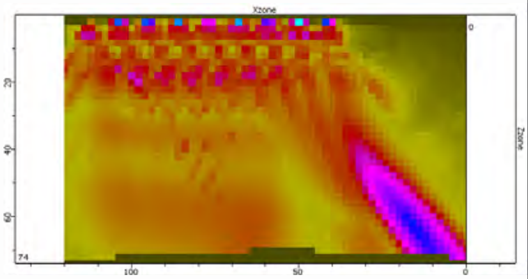


- Flaw : internal to the weld
- Orientation : 45°
- Delay laws:

Focus depth = 66 mm

Refraction angle = 45°

Skew angle = 21.6°



Ecart amplitude zone défaut = 3 dB

List

Transducer Design: 9x7 éléments

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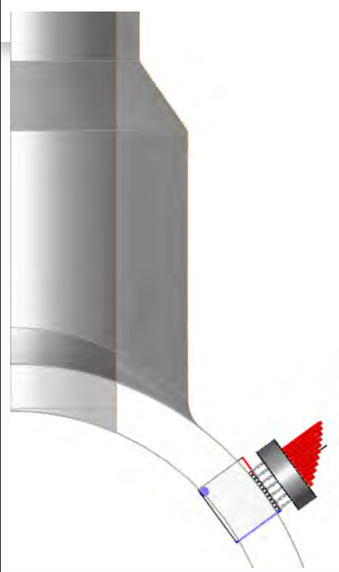
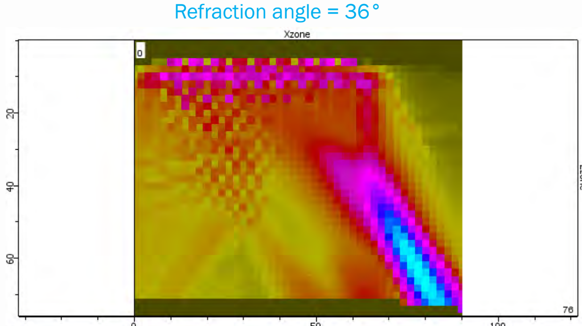


- Flaw : external to the weld
- Orientation : 90°
- Delay laws:

Focus depth = 68.6 mm

Refraction angle = 36°



Delta amplitude defect zone = 1 dB

List

Transducer Design: 9x7 éléments

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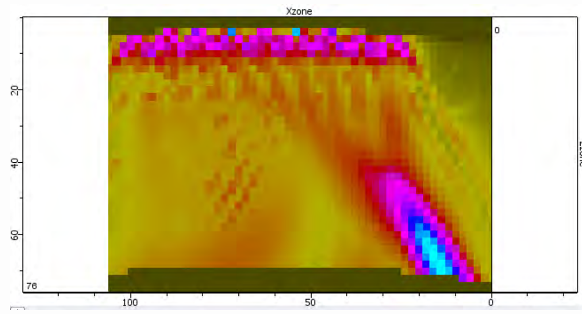
- Flaw : internal to the weld
- F• Orientation : 90°
- Delay laws:

Focus depth = 68.6 mm

Refraction angle = 36°



Delta amplitude defect zone = 1 dB

list

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Laborelec Germany
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42281 Wuppertal
Germany

Study on the Ultrasonic Inspection for CASS

3 International Workshop on
Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

Jan. 28 - 29, 2011, Seattle, WA

Kazunobu Sakamoto

Nuclear Energy System Safety Division

JNES

1

Contents

- Background
- Objective of the research program
- Research scheme
- Materials
- UT capability on CASS
- Visualization of the ultrasound propagation
- Summary

2

Background

-Cast Austenitic Stainless Steel (CASS) is widely used for the reactor coolant piping in PWRs

-Difficulty of UT on CASS,
Past study concluded that 20%TW flaws in the CASS piping was detectable

-Although UT is required on CASS piping as ISI program, no sizing capability has been verified yet

-Progress in NDE techniques have been seen over the past 10 years

-Active researches on CASS inspection in the world

Objective of the research program

-To comprehend the UT capability on CASS, using up to date technologies
- Detection capability
- Sizing Capability

-To accumulate the knowledge about the UT on CASS

-Summarize the regulatory requirement regarding CASS inspection

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Research Scheme

Investigation / Planning

◆Research on the current NDE status in Japan, US and European countries
◆ASME code committee status (structural integrity)
◆Test planning

Preliminary study

◆Base data using calibration block etc.
･Grain structure
･Characteristics of UT propagation
･Visualization of UT path

V&V

NDE Verification

◆Detection capability of UT
◆Sizing capability of UT
◆Destructive verification

V&V

UT Simulation

◆Grain Structure Modeling
◆2D, 3D simulation

Structural Integrity

◆Acceptance Standard
◆Crack growth and residual life evaluation from verified flaw size

Inspection Requirement

◆Method
◆Inspection Interval
◆Margin
etc.

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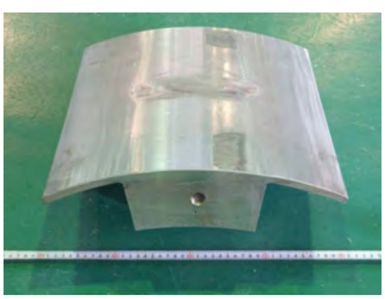
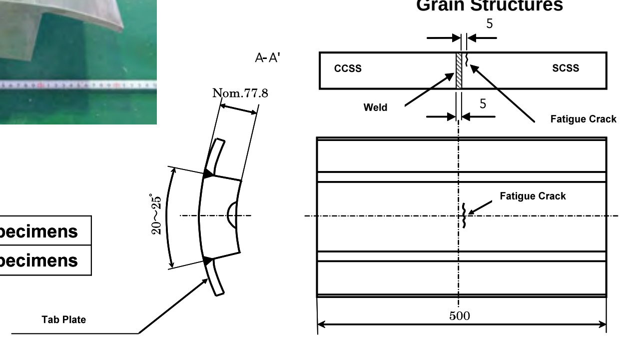
Materials



Grain Structures



Crack in CCSS	2 Specimens
Crack in SCSS	2 Specimens

Test specimens with fatigue cracks

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UT Capability on CASS

-Applied UT techniques-

Applied UT probe by Team A (Conventional UT, Phased Array UT)

Probe	Matrix PA	Matrix PA	1C40× 30 LAD45A	1C30× 20 LAD36	IC38,1LA36 (V392)
Frequency	0.5MHz	1MHz	1MHz	1MHz	1MHz
Mode	L	L	L	L	L
Angle	～55°	～55°	45°	36°	36°

Applied UT probe by Team B (Large size probe)

Probe	A	B	C	D
Probe dimension (mm)	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80
Frequency	1MHz	1MHz	1MHz	1MHz
Mode	L	L	L	L
Angle	40.7°	40.7°	45°	47.4°
Focus depth (mm)	65-75	65-75	45-65	40-60

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Detection Capability

Preliminary result of study on flaw detection capability

Test Block		A		B		C		D	
Crack length (mm) (by manufacturing record)		36		62		36		38	
Crack depth (mm) (by manufacturing record)		3.7～3.8		7.9～8.6		4.0～4.3		8.4	
Crack location		SCSS		SCSS		CCSS		CCSS	
Probe location		CCSS	SCSS	CCSS	SCSS	CCSS	SCSS	CCSS	SCSS
Team A	Matrix PA (0.5MHz)	○	△	○	○	○	○	○	○
	Matrix PA (1MHz)	○	○	○	○	○	△	○	○
	Conventional UT (1C40x 30LAD45)	×	×	○	×	○	×	×	○
	Conventional UT (1C30x 20LAD36)	○	△	○	○	○	×	×	○
	Conventional UT (1C38 1LA36 (V392))	○	○	○	○	○	×	○	○
Team B	Probe A (1MHz, Focus depth:65-75mm)	○	○	○	○	○	○	○	○
	Probe B (1MHz, Focus depth:65-75mm)	○	○	○	○	○	○	○	○
	Probe C (1MHz, Focus depth:45-65)	○	○	○	○	○	○	○	○
	Probe D (1MHz, Focus depth:40-60)	○	○	○	○	○	○	○	○

○ :Clearly Detected (SN>2)
△ :Detected (SN: less than 2)
× :Undetected

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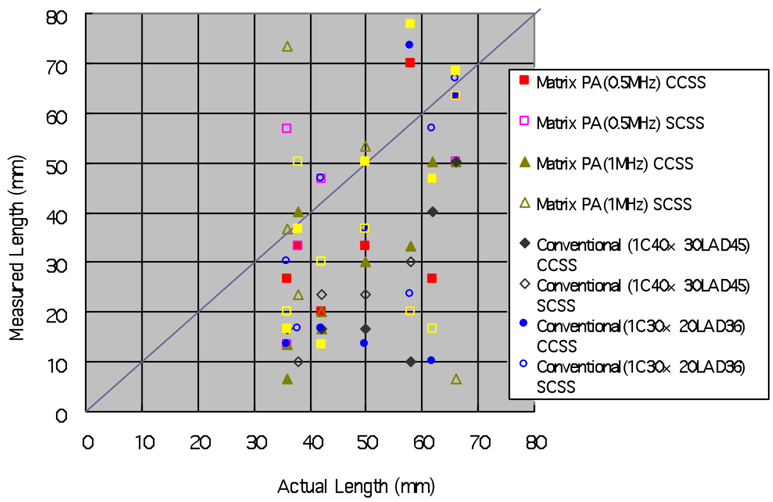
Length Sizing Capability

Team A



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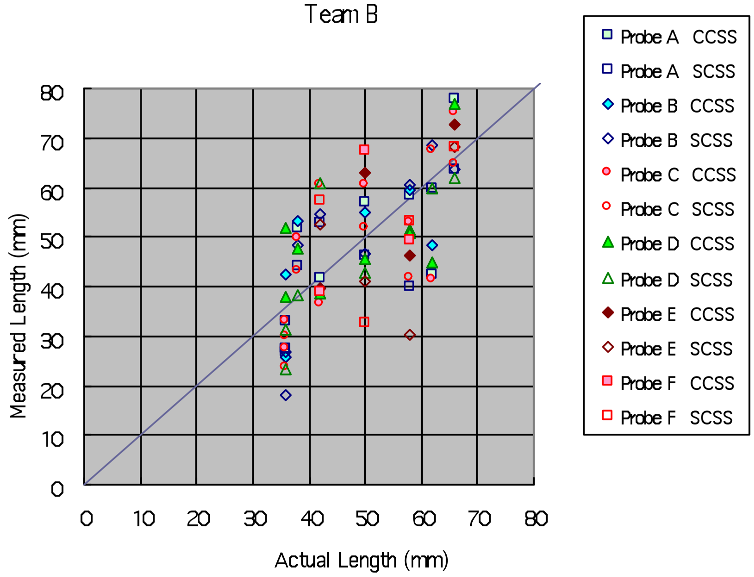
Length Sizing Capability

Team B



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Depth Sizing Capability

Preliminary result of study on flaw depth sizing capability

Test Block		A		B		C		D	
Crack length (mm) (by manufacturing record)		36		62		36		38	
Crack depth (mm) (by manufacturing record)		3.7~3.8		7.9~8.6		4.0~4.3		8.4	
Probe location		CCSS	SCSS	CCSS	SCSS	CCSS	SCSS	CCSS	SCSS
Team A	Matrix PA (0.5MHz)	×	×	18.1	×	×	×	×	×
	Matrix PA (1MHz)	×	×	15.5	8.5	×	×	×	×
	Conventional UT (1C40x 30LAD45)	×	×	×	×	×	×	×	×
	Conventional UT (1C30x 20LAD36)	×	×	×	×	×	×	×	×
	Conventional UT (1C38 1LA36 (V392))	×	×	×	×	×	×	×	×
Team B	Probe A (1MHz, Focus depth:65-75mm)	×	×	×	7.8	×	×	13.5	×
	Probe B (1MHz, Focus depth:65-75mm)	×	×	×	9.4	×	×	×	×
	Probe C (1MHz, Focus depth:45-65)	×	×	×	×	×	×	×	×
	Probe D (1MHz, Focus depth:40-60)	×	×	×	×	×	×	×	×

× :Impossible to size

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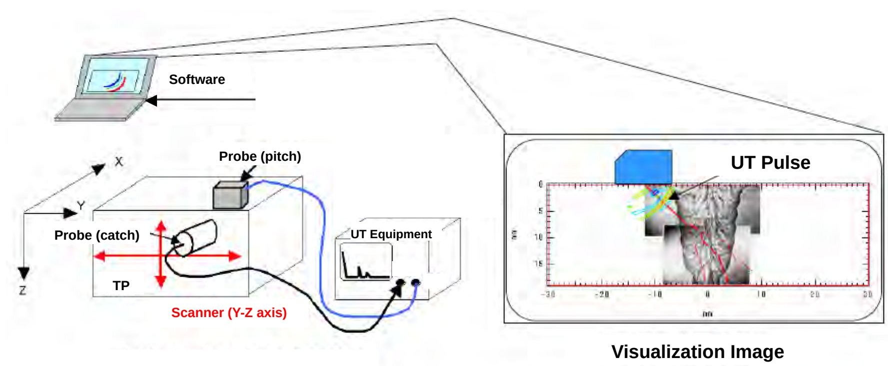
Visualization of UT Propagation



Schematic image of the visualization of ultrasound propagation

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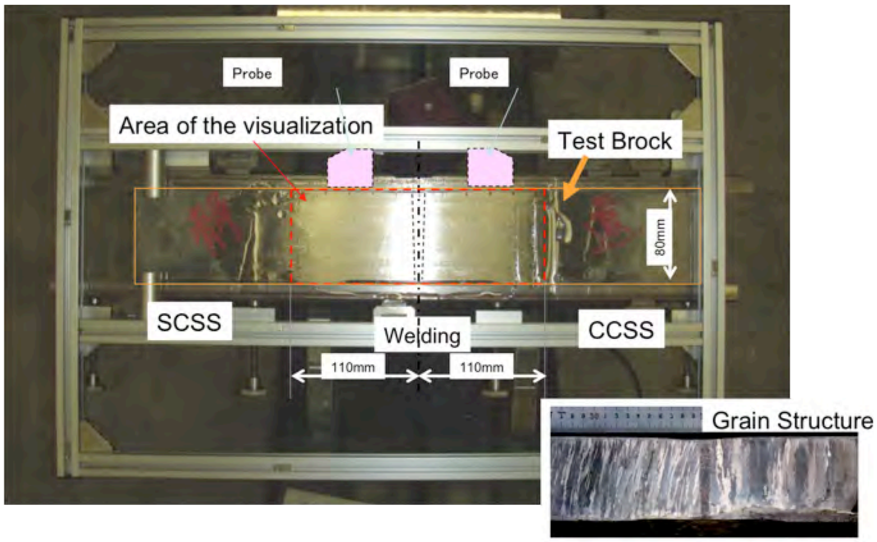
Visualization of UT Propagation



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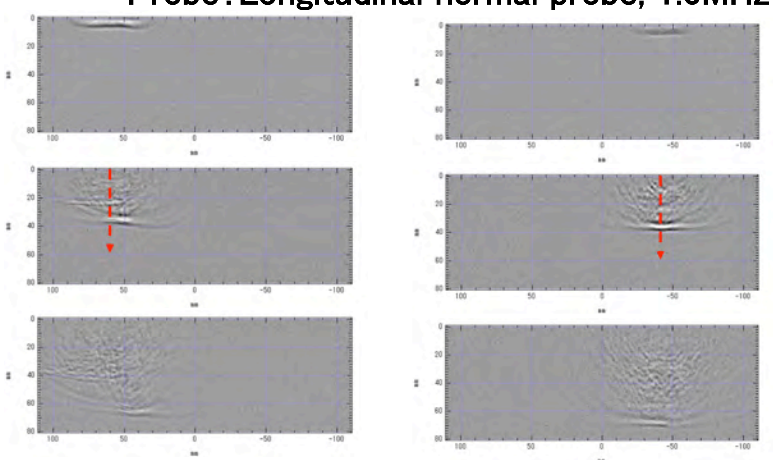
Result #1 Wave Propagation in the CCSS
Probe : Longitudinal normal probe, 1.0MHz



(a) Snapshots of ultrasound propagation in SCSS (b) Snapshots of ultrasound propagation in CCSS

- - - - : Nominal beam direction

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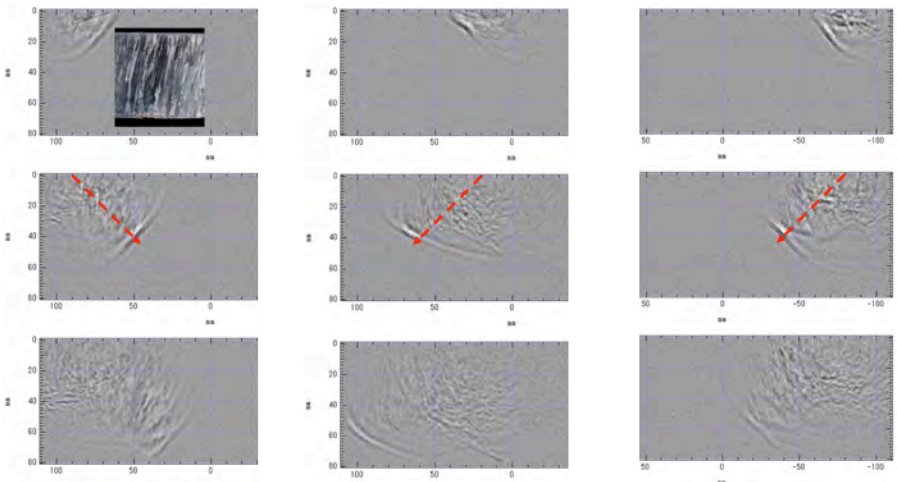
Result #2 Wave Propagation in the CCSS
Probe : Longitudinal 45 degree, 1.0MHz



(a) ultrasound propagation in SCSS (b) ultrasound propagation in SCSS (c) ultrasound propagation in CCSS

: Nominal beam direction

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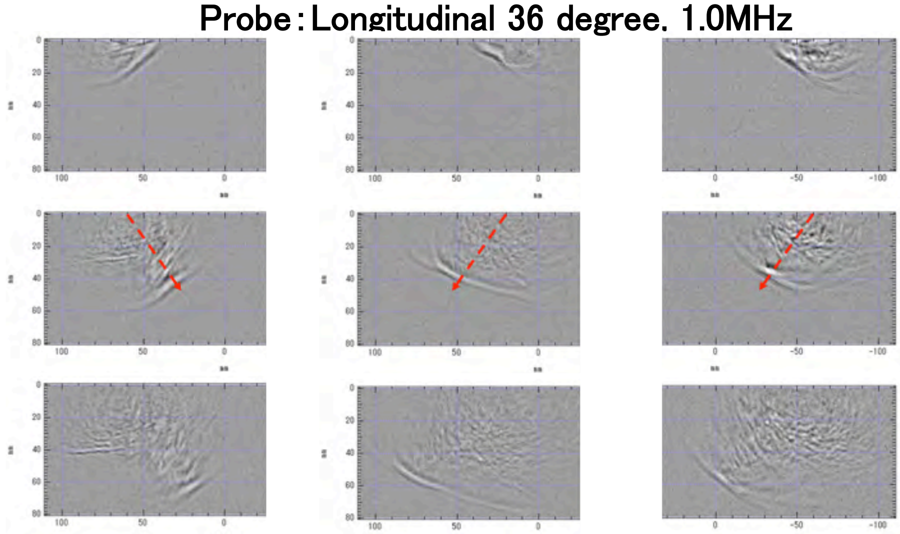
Result #3 Wave Propagation in the CCSS
Probe : Longitudinal 36 degree, 1.0MHz



(a) ultrasound propagation in SCSS (b) ultrasound propagation in SCSS (c) ultrasound propagation in CCSS

: Nominal beam direction

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Summary

JNES has been carrying out the research on NDE for CASS as five year program since 2009FY. The preliminary UT data and visualization image of ultrasound propagation was obtained so far.

The unique ultrasound beam propagation such as skew due to the coarse grained and acoustically anisotropic crystal structures was observed through the visualization technique. Application of this visualizing technique to the various CASS specimens is planned. And mathematical analysis and simulation model development will be carried out to understand the phenomena theoretically.

In addition, more UT data will be obtained and carried out destructive verification of the true flaw size to comprehend the inspection capability. International cooperation in this area might be efficient for better understanding and earlier solution.

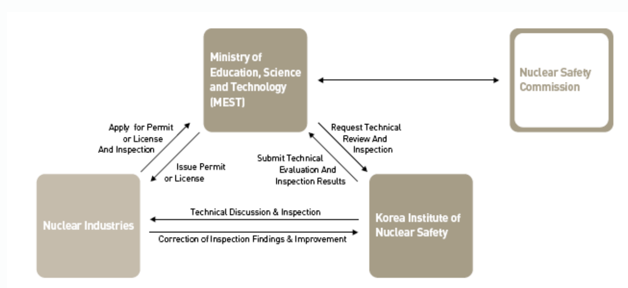
Thank you!

Current Status of CASS Work in KINS (Round Robin Test of RCOP -2)

Jin Ki HONG
Mechanical and Materials Department
Korea Institute of Nuclear Safety

KINS is ?

- The Korea Institute of Nuclear Safety(KINS) was founded through a special legislation by the National Assembly in 1990 with a specific mission to develop and implement nuclear safety regulation.
- KINS is entrusted as a technical expert organization by the Ministry of Education, Science and Technology(MEST), the regulatory autho rity, to perform various regulatory



Mechanical and Materials Department Slide 2

RCOP-2

- RCOP-2 : Regional Cooperative Project-2
  - Objective : NDE Reliability Evaluation throug NDE Round Robin Test for the Cast Stainless Steel Piping
  - Country : Korea, Japan, China
  - Period : 2007.4~2010.3(3 year)
  - Participants in Korea

Mechanical and Materials Department

Slide **3**

RCOP-2

- In Korea, 3 teams carried out the RRT and KEPRI have evaluated the results of 3 teams.

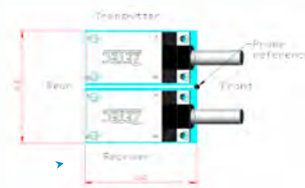
- Participants in Korea
  - Korea Institute of Nuclear Safety (KINS)
  - Korea Electric Power Research Institute (KEPRI)
  - Korea Plant Service and Engineering (KPS)
  - Doosan Heavy Industry (DHI)
  - Korea Hydro and Nuclear Power (KHNP)

Mechanical and Materials Department

Slide **4**

Inspection Procedure

- “A”Team
  - Technique: Manual Phased Array UT
  - Participant : 2
  - UT System : Tomoscan III
  - Transducers
    - Circumferential Scan : 1.5M, 8X4
    - Axial Scan : 1.5M, 32X2



Scan direction	Axial Scan	Circ. Scan
Frequency	1.5MHz	1.5MHz
Total aperture	64X15	28X16
# of Total elements	64	32
# of Primary axis	32	8
# of elements secondary axis	2	4
Elements size primary axis	1.8 mm	3.3 mm
Elements size primary axis	7.3 mm	3.8 mm
Primary axis pitch	2 mm	3.5 mm
Secondary axis pitch	7.5 mm	4 mm

Mechanical and Materials Department

Slide 5

Inspection Procedure

- “B”Team
  - Technique: Encoded Phased Array UT
  - Participant : 2
  - UT System : Omniscan PA
  - Transducers
    - Circumferential Scan : 1.5M, 8X4
    - Axial Scan : 1.5M, 32X2

Mechanical and Materials Department

Slide 6

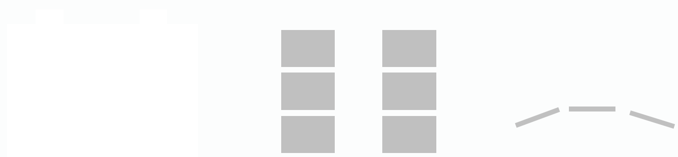
Inspection Procedure

- "C"team
  - Technique: Automatic Conventional UT & PA
  - Participant : 2
  - UT system : IntraSpect/Omniscan PA

Inspection Procedure

- "C"team
  - Segmented RL probe

Search Unit	05C25X45LAD35	05C38X50LAD45
Frequency	0.5MHz	0.5MHz
Beam Angle	35˚	45˚
Mode	Longitudinal	Longitudinal
Element Configuration	Segmented TRL	Segmented TRL
Number of Elements	12	28
Elements Size	2(25X45)	2(38X50)
Footprint Aperture	55x55	70x85
Beam Direction	Circumferential	Axial
Band Width (%)	> 60	> 60



Front Top Side

Inspection Procedure

◆Summary and Comparison of the Inspection Procedure

	A	B	C	
Technique	PA	PA	Conventional UT	PA
Equipment	Tomoscan III	Omniscan	IntraSpect	Omniscan
Probe	Cir. Scan:32X2 Axial Scan:8X4 Pitch-Catch	Cir. Scan:32X2 Axial Scan:8X4 Pitch-Catch	Segmented RL Pitch-Catch 35°/45°	0.5MHz : 84(3X28) 0.7MHz : 84(3X28) Pitch-Catch
Frequency	1.5MHz	1.5MHz	0.5MHz	0.5MHz, 0.7MHz
Scan Mech.	Manual	Manual Encoded S canner	Automatic Scanner	Automatic Scanner
Length Sizing	Full dB Drop	Full dB Drop	Full dB Drop	

RRT Results

No	Sample Id	Flaw Id	Teams			
			A	B	C-PE	C-PA
1	Chinese	1		O		
		2	O			
		3	O			O
		4		O		O
		5				O
		6	O	O		O
		7				
		8		O	O	O
		9		O	O	O
		10				
		11				
		12				
		13				O
		14	O			
		15	O	O	O	
		16				
2	JNES-EDM-A	1		O	O	
		2			O	O
		3		O	O	O
		4		O	O	O
		5	O	O	O	O
		6	O		O	O
		7	O	O	O	O
		8			O	O
3	JNES-EDM-C	1	O	O	O	O
		2	O	O	O	O
		3	O	O	O	O
4	KPS-3750-04	1	O	O	O	O
		2	O	O	O	O
		3	O	O	O	O
		4	O	O	O	O
		5	O	O	O	O
5	KPS-3750-05	1	O	O	O	O
		2		O	O	O
		3	O	O	O	O
		Total	18	22	22	25

Summary

- Chinese Test block
  - High attenuation compare to other test blocks
  - Very low S/N ratio
  - The OD flaws are out of examination scope
  - Circumferential position of flaws shifted between RRT result and drawing
  - Too many small flaws => Difficult to analysis
  - The IP did not consider the mid-thickness embeded flaws
- Japanese Test block
  - Relatively good S/N ratio in both SCSS & CCSS
  - Flaw length and depth are properly distributed

Summary

- Korean Test block
  - Good S/N ratio
  - Flaws are long and deep => no small flaws
  - Can not discriminate applied techniques => 100% detection

Conclusions

- Low Freq. PA shows best performance
  - Manual PA < Auto. PE < Encoded 1.5MHz PA < Low Freq. PA
- Need to more time to evaluate statistical analysis

Mechanical and Materials Department

Slide **13**

Trueflaw: Cracking CASS

Iikka Virkkunen, CASS workshop 2011-01-27

TRUEFLAW

Trueflaw makes real cracks

Natural cracks

- Natural thermal fatigue cracks
- No welding
- For development, training, qualification

Certified Quality

- ISO 9001 certified quality
- Depth known through destructive validation
- Process validated by independent auditors

TRUEFLAW

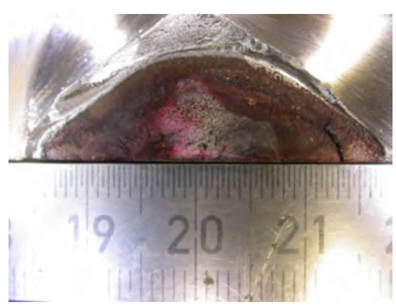
Trueflaw approach

Specification   Validation   Acceptance   Production

TRUEFLAW

DT for reliability

- Representative:
  - Material
  - Crack size
  - (Component geometry)
- Database over 300 validation cracks



TRUEFLAW

Reliable production

- Reliable in-situ production to actual test blocks
- Critical defect parameters confirmed from destructive validation
- No reliance on supplementary inspection
- Production repeated to any number of samples
- WYSIWYG

TRUEFLAW

True flaws in CASS

Most recent example: PNNL CASS samples

- Target depths: 3.3 mm (10%, 0.13") and 6.6 mm (20%, 0.26")
- CASS samples supplied by PNNL
- Tube sample for validation
- Proper sample including bend

TRUEFLAW

Validation

- Trueflaw produced validation cracks
- Sample sent to PNNL for intermediary NDT


TRUEFLAW 070BAB1089 1 mm

TRUEFLAW

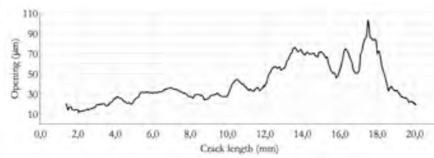
Destructive analysis

- Validated depths: 3.4 mm and 6.0 mm


TRUEFLAW 070BAB1089 1 mm

TRUEFLAW

Production to validated recipe



TRUEFLAW

Trueflaw CASS capabilities

Experience

- CASS like any other austenitic stainless steel for Trueflaw
- Large grain size causes increased crack tortuosity

Challenges

- The bigger the crack, the longer it takes to grow
- CASS inspection targets large
- Production times:
  - 6 mm depth to CASS: 35 days
  - 15 mm (to wrought ASS): 66 days

TRUEFLAW

Conclusions

- Trueflaw has
  - experience and
  - proven capacity to

  manufacture real cracks to CASS

TRUEFLAW

Flaw Tolerance Evaluation of Thermally Aged Cast Austenitic Stainless Steel Piping

Presented at 3rd International Workshop on CASS Piping
Seattle, WA
January 28 & 29, 2011

Timothy J. Griesbach
Structural Integrity Associates, Inc.

Structural Integrity Associates, Inc.

Timothy J. Griesbach

Introduction

- CASS piping material is known to be very ductile, flaw tolerant, and resistant to stress corrosion cracking
- Unfortunately, the CASS materials are also difficult to inspect using UT exam and are susceptible to thermal aging (embrittlement)
- Long-term management of the aging concerns in CASS materials is a priority for plant license renewal
- It is desirable to use a flaw tolerance approach with some inspections to demonstrate structural margins against fracture

/2

Flaw Tolerance of CASS Piping - Slide 2

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Objectives of Flaw Tolerance Studies

- Provide a methodology for developing acceptable flaw sizes for inspection of cast austenitic stainless steel (CASS) piping using the flaw tolerance approach
  - *Acceptable Flaw Size* – Initial flaw size from inspection such that the allowable flaw size will not be reached during operation (includes consideration of potential flaw growth)
- Establish a reasonable acceptable flaw size that the inspection technology should be capable of detecting
- Develop a Code methodology for managing aging of CASS materials
- Define the role of inspections for demonstrating piping integrity

/3

Flaw Tolerance of CASS Piping - Slide 3

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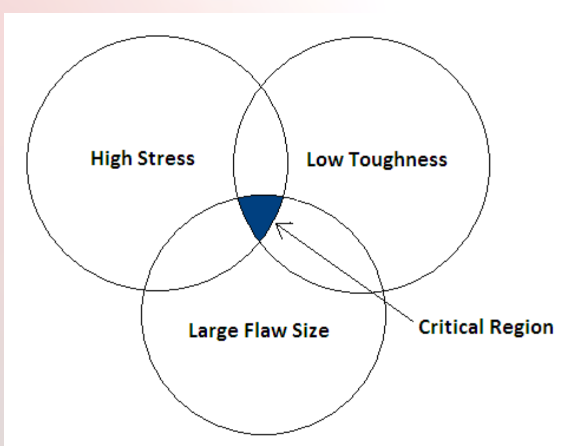
Background of Fracture Prevention



- Fracture may occur in a structure under a combination of conditions involving high stress, low toughness, and the presence of a large (critical size) flaw
- The ASME Code defines margins to prevent failure
- Code safety factors are applied to loads or flaw size

/4

Flaw Tolerance of CASS Piping - Slide 4

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ASME Code Issues and Questions

- The NDE person asks, "What is the flaw depth I need to detect to assure structural integrity of these CASS components?"
- The answer is not a simple one. It depends on:
  - **Flaw length** – should we assume a 360 degree flaw or a flaw of reasonable length?
  - **Fracture toughness** - should we use the absolute lowest bound in the industry based on CF8M properties or representative (best estimate) toughness properties?
  - **Material strength properties** - should we use the Code minimum values or should we use actual/more realistic tensile and yield properties?
  - **Loads/stresses** - should we use the maximum bounding loads/stresses in the industry or typical loads/stresses?
  - **Safety factors** - for management of CASS components, should we use the full Code safety margins (S.F. = 2.77) or something less?

/5

Flaw Tolerance of CASS Piping - Slide 5

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Components in PWRs Made from CASS Materials

- Cold Leg Piping (Westinghouse-designed plants)
- Hot Leg Piping (Westinghouse-designed plants)
- Main Coolant Piping Elbows and Safe Ends
- Surge Line Piping
- Surge Line Nozzles
- Accumulator Injection Nozzles in the Cold Leg
- Reactor Coolant Pump Casings

/6

Flaw Tolerance of CASS Piping - Slide 6

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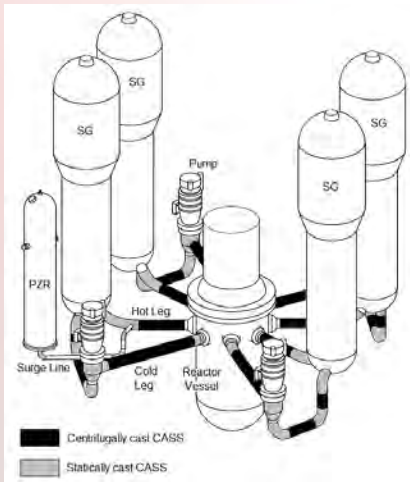
Locations of CASS Piping Materials in Westinghouse-Designed Plants



Initial Focus on Flaw Tolerance of Cold Leg Piping

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Flaw Tolerance Evaluation

- Determine fracture toughness for a representative set of CASS piping materials
- Determine stress-strain properties
- Determine typical loads/stresses
- Determine both critical flaw size (safety factor of unity) and allowable flaw size (ASME Section XI safety margins)
- Account for crack growth
- Determine acceptable flaw size for an example CASS piping application

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Consider a Limit Load Solution for CASS Piping (DFN < 20%)

- Consider sample Cold Leg Pipe made from CASS material
- Use typical tensile properties to determine flow stress
- Use sample load combinations to determine stress ratio = $(\sigma_m + \sigma_b)/\sigma_f$
- Use C-5000 procedure (Table C-5310-1) to determine maximum allowable flaw depths and lengths

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Flaw Tolerance of CASS Piping - Slide 9

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Consider EPFM Analysis for CASS Piping

- Consider sample Cold Leg Pipe made from CASS material (R = 15 in., t = 2.25 in.)
- Use J-R Curve for CF8M as a function of delta ferrite content (from Chopra report)
- Use load combinations to determine stress ratio
- Use EPFM to evaluate critical and allowable flaw depths and lengths

/10

Flaw Tolerance of CASS Piping - Slide 10

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Survey of Stresses in CASS Cold Leg Piping in PWRs

Estimated stresses in cold leg piping:

- Range of membrane stress (axial)
  - P_m = 6 – 9 ksi
- Range of thermal + dead weight bending stress
  - P_b = 1.5 - 11 ksi
- Assume P_m = 8.89 ksi, and P_b = 10.28 ksi
- Stress Ratio = $(\sigma_m + \sigma_b)/\sigma_f$ = (8.89 + 10.28)/57.1
  = .336

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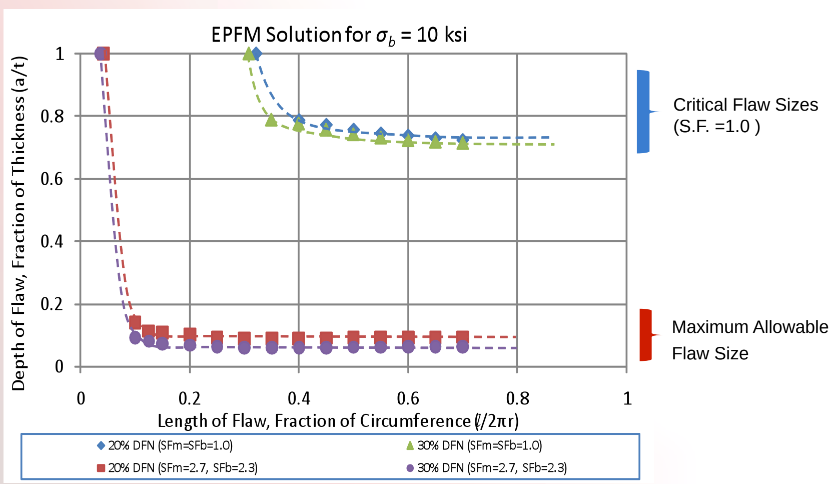
Sample EPFM Results



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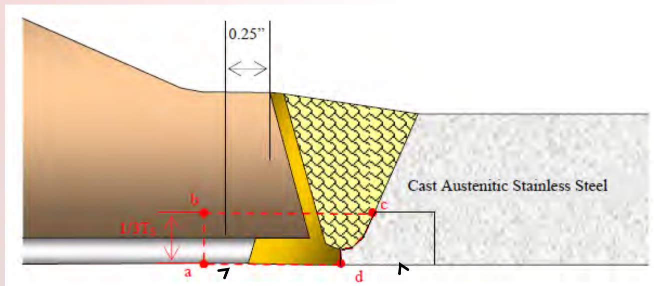
Exam Volume for DMW with CASS



Current Examination Volume per ASME Section XI, Appendix VIII Supplement

Proposed CASS Piping Examination Volume

Note: At present, volumetric examination of the CASS material is not required because a qualified examination method does not exist

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Flaw Tolerance of CASS Piping - Slide 13

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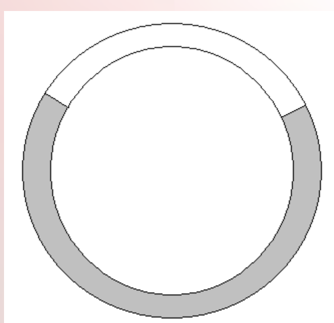
Example of Critical Flaw Size in CASS Piping (Using S.F. = 1.0)



- Consider the maximum critical flaw size to be a through-wall flaw approx. 35% of the circumference
- The critical flaw size uses a safety factor of 1.0
- This is the flaw size that would be required to fail the pipe

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Flaw Tolerance of CASS Piping - Slide 14

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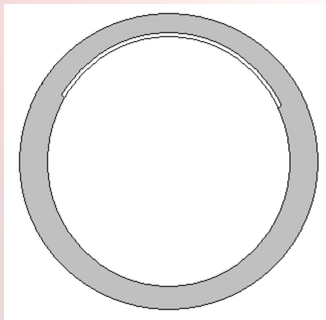
Example of Maximum Allowable Flaw Size (Aged CF8M Material)



- Example showing the maximum allowable flaw size for the case of aged high delta ferrite (~ 30%) CASS piping with low toughness and high design stress levels using EPFM analysis
- Maximum depth (a/t) = 0.10 for a 35% circumference flaw

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Flaw Tolerance of CASS Piping - Slide 15

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How Can this Issue be Managed?

- One "issue" is that CASS piping is difficult to inspect and there are uncertainties in the material properties, stresses and flaws that are needed to calculate safety margins
- Determination of margins can be improved if we know more about the component(s) of interest, such as:
  - Maximum loads and stresses in the component
  - Plant modifications or mitigations (e.g., weld overlay)
  - Material type (CF3, CF8, CF8A or CF8M), ferrite content, and saturated fracture toughness
  - Any prior inspection results
  - Future inspections using improved methods

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Flaw Tolerance of CASS Piping - Slide 16

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Methods for Improved Evaluation of CASS Piping

- Use plant-specific design and materials information
- Characterize material toughness using correlations with chemistry or by measuring delta ferrite with a ferrite meter
- Screen and categorize risk significance of components and locations using risk-based methods
- Use probabilistic fracture mechanics methods to address conditional probability of failure instead of safety factor
- Use best-available inspection techniques selectively to verify the absence of flaws greater than the maximum allowable flaw size

=> How good do the inspection techniques have to be?

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Flaw Tolerance of CASS Piping - Slide 17

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What is the Value of Inspection for CASS Piping?

- **An inspection is only as good as the reliability of the inspection technique**
- **NDE reliability is defined as the probability of non-detection as a function of the flaw size (or depth). That is, what is the probability that a flaw of a given depth may have been missed?**
- **Using a deterministic analysis, the probability of non-detection must be very low (essentially zero) to qualify as a valid inspection technique**
- **However, using a probabilistic analysis, the reliability of detection is just one more uncertainty to be characterized in the overall analysis**

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Flaw Tolerance of CASS Piping - Slide 18

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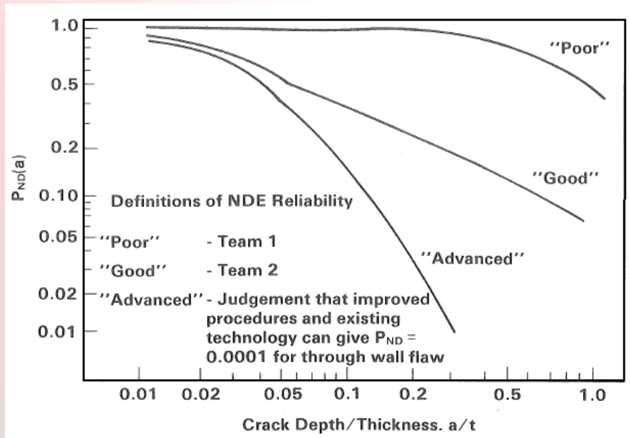
Characterization of NDE Reliability (from Detection of IGSCC in Wrought SS Pipe)



DETECTION OF IGSCC IN 10-in. STAINLESS PIPE FROM ROUND ROBIN
[Simonen (1990)]

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Flaw Tolerance of CASS Piping - Slide 19

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How Can we Characterize the Reliability of a Piping System?

1) **Deterministic Fracture Mechanics Analysis**
   - All inputs defined as bounding (conservative values)
   - Single calculation
   - Final result in terms of safety margin or conservative remaining life value

2) **Probabilistic Fracture Mechanics Analysis**
   - All inputs defined as probability (density) functions
   - Multiple calculations sample from the density functions
   - Final results in terms of conditional probability of failure

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Flaw Tolerance of CASS Piping - Slide 20

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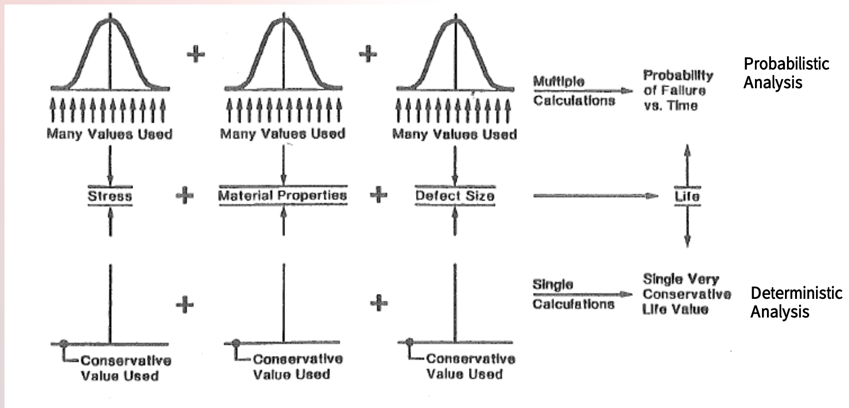
Deterministic vs. Probabilistic Analyses



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Flaw Tolerance of CASS Piping - Slide 21

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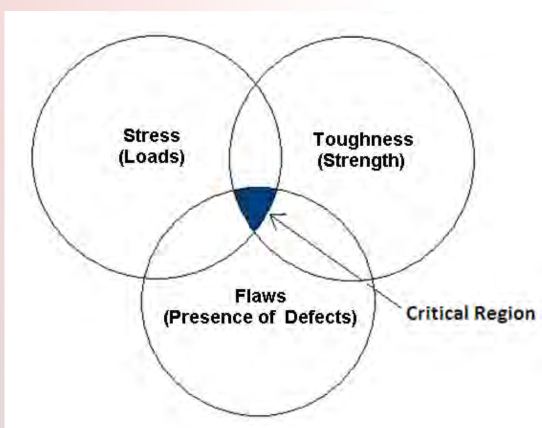
Determination of Load-Carrying Capability Nature is Random



- There is no single failure value
- Multiple tests may yield different results

How can we predict failure?

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Flaw Tolerance of CASS Piping - Slide 22

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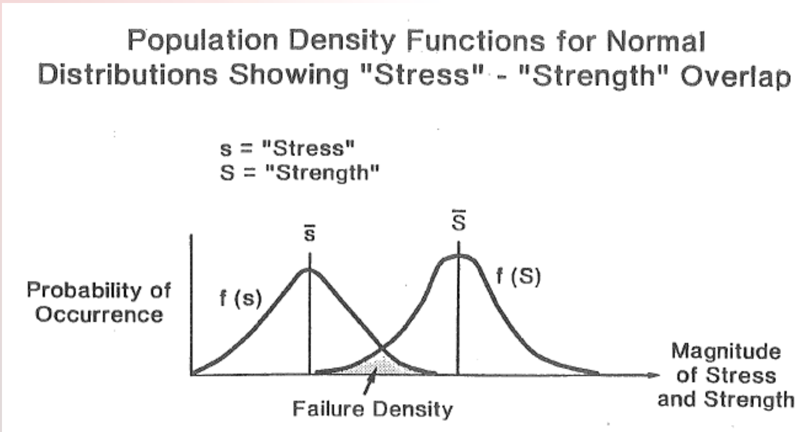
Predicting Structural Failure Using Probability Functions



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Flaw Tolerance of CASS Piping - Slide 23
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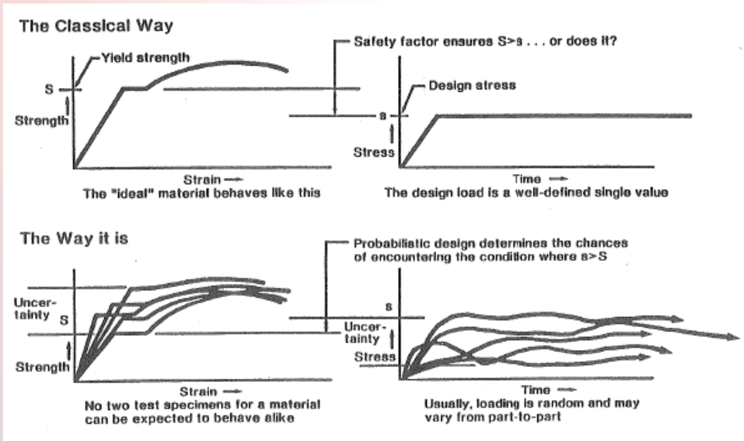
Short Course in Probabilistic Design



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Flaw Tolerance of CASS Piping - Slide 24
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What does this Mean for Structural Analysis of CASS Piping?

- We are developing a probabilistic fracture mechanics (PFM) model of the CASS piping system
- We can define inputs as probability functions and explicitly characterize mean values and uncertainties
- Changes in properties (e.g., toughness and strength) can be estimated directly from experimental data
- A safety goal (e.g., conditional probability < 10^{-6}/reactor-yr) can be established as a failure criteria consistent with other safety issues (e.g., Pressurized Thermal Shock)
- Results of PFM analysis can be used to evaluate essential variables, determine sensitivity to changes and uncertainties, consider options to manage the issue, and propose flaw acceptance standards for CASS piping

/25

Flaw Tolerance of CASS Piping - Slide 25

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Summary

- PFM methods are gaining more acceptance for nuclear plant applications
- Key benefit of probabilistic engineering methods –
  - "Engineering, safety, and economic insights can be gained from the logic and thought processes inherent to the analysis."
  - Better insights lead to better solutions.
  - Solutions can be achieved to optimize safety, cost, or both.

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Flaw Tolerance of CASS Piping - Slide 26

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Probabilistic Model of Reliability of Cast Austenitic Stainless Piping

Tim Griesbach, David Harris,
Merric Qian and Danen Heath

3rd International Workshop on
Future Directions for the Inspection of Cast Austenitic Stainless Piping

This work was sponsored by EPRI under contract EP-P37140/C16772. Project Manager, Doug Kull.

Seattle, Washington
January 2011

1

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Background

- Prolonged exposure of cast austenitic stainless steel to commercial power reactor operating temperatures has long been known to lead to some degree of thermal aging embrittlement.
- Time and temperature result in reduction of crack growth resistance and increase in yield and tensile strength.
- Increased chance of failure due to decreased toughness and ductility of concern.
- Many studies and much data available.
- Much scatter in toughness and tensile test results.

2

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Background

- Large grain size makes inspection difficult.
- Material scatter complicates confident estimation of critical crack sizes.
- What size cracks do we need to find?
- What are the sizes of cracks that occur in these materials?
- Probabilistic approach called for to account for scatter in material properties and flaw sizes.

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Examples of PFM Methods for Structural Analysis of Nuclear Plant Components

- Stress corrosion cracking in BWR piping
- Pressurized thermal shock (PTS) of PWRs
- PRAISE Code Methodology is widely accepted as the basis for Code and regulatory decisions to address these issues
- PFM piping codes being developed by NRC, including EPRI participation
  - Pro LOCA
  - xLPR
- The same methods can be applied to CASS piping.

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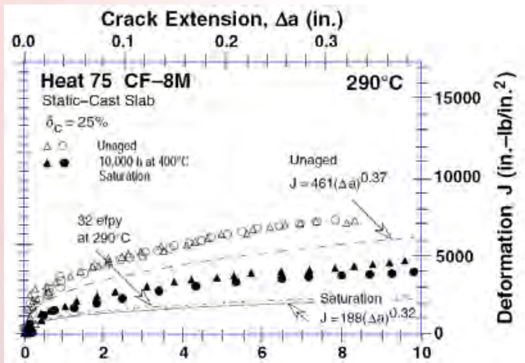
Background

- Example of Reduction of Toughness



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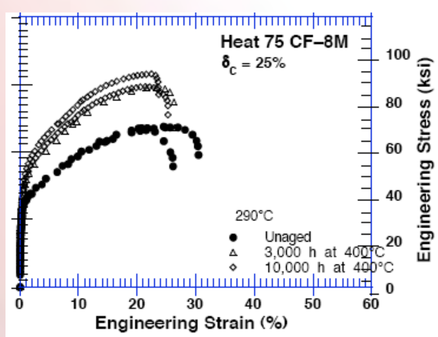
Background

- Example of Change in Tensile Properties



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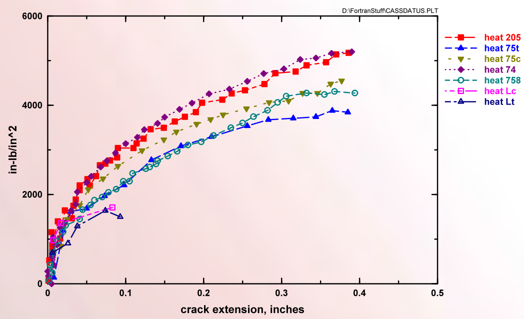
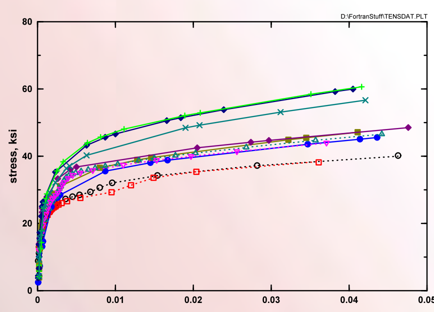
Background

- Example of Scatter in Toughness
- CF8M fully aged, 290 C



Background

- Example of Scatter in tensile properties
- CF8M 290 C dashed lines unaged, solid lines fully aged



Background

- Data and correlations reported by Chopra and co-workers at ANL provide starting point.
  - NUREG/CR-4513 and 6154 primarily used
- Fully embrittled CF8M concentrated upon
  - Larger effect than CF3 and CF8
- Full embrittlement occurs in a few years at operating reactor conditions, so partially embrittled material not considered here.

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Background

- Analysis composed of two parts
  - Part I: Estimation of critical crack sizes that produce failure with a given probability
  - Part II: Estimation of probability of such cracks being there
    - Initially
    - Effect of subcritical crack growth
    - Effect of inspection

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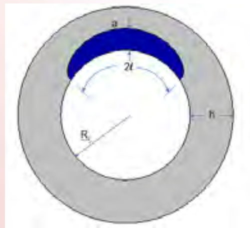
Part I Overview

- Critical crack sizes based on elastic-plastic fracture mechanics, concentrating on part-through crack



- Elastic-plastic fracture mechanics employed for specified loads (could be random, but deterministic for now)

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Part 1 Overview

- Deterministic EPFM
- Applied J from Zahoor, EPFM Handbook
  - Tension loading solution used

$$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{F}\right)^m \qquad J_R = C(\Delta a)^n$$

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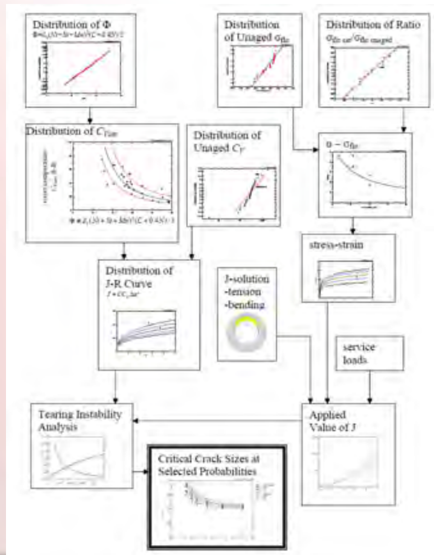
Part 1 Overview

Probabilistic model



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Material Scatter

- Governing relations drawn primarily from NUREGs
- Charpy energy used for fracture correlations
- Composition and delta ferrite parameter (Φ), used as governing variable.

$$\log_{10} C_{Vsat} = d_0 + d_1 e^{-d_3 \Phi} \quad [1]$$

$$J = \{404(25.4)^n (C_V)^{0.41}\}[\Delta a]^n \quad [2]$$

$$n = 0.244 + 0.06 \log_{10}(C_V) \quad [3]$$

$$\varepsilon = \frac{\sigma}{E} + \alpha \frac{\sigma_{flo}}{E}\left(\frac{\sigma}{\sigma_{flo}}\right)^m \quad [4]$$

$$\alpha = \frac{1}{c_1 \sigma_{flo}^{c_2} - c_3} \quad [5]$$

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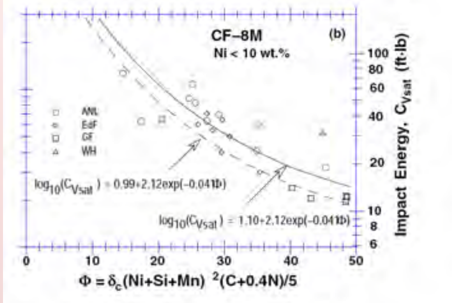
Material Scatter (toughness)

Data on Fully Saturated Charpy for CF8M



Scatter is apparent, median Cvsat given by expression (ft-lb)

$$\log C_{Vsat} = 0.871 + 2.12e^{-0.041\Phi}$$

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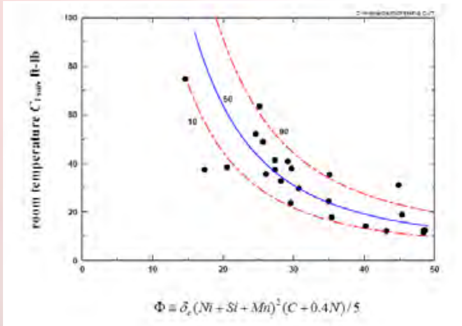
Material Scatter (toughness)

- Cvsat taken to be lognormally distributed with above equation for median and a shape parameter μ equal to 0.279.

$$p(x) = \frac{1}{\mu x\sqrt{2\pi}} e^{-\frac{1}{2\mu^2}\left[\ln\left(\frac{x}{x_{50}}\right)\right]^2}$$

- Figure below shows median and 10th and 90th percentiles of lognormal showing good representation of data.



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Material Scatter (toughness)

- Statistical distribution of Cvsat defined in previous slide for a given Φ
- Once Cvsat is defined, the J-resistance curve is defined.

$$\log_{10} C_{Vsat} = d_0 + d_1 e^{-d_3 \Phi}$$

$$J = \{404(25.4)^n (C_V)^{0.41}\}[\Delta a]^n$$

$$n = 0.244 + 0.06 \log_{10}(C_V)$$

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Material Scatter (tensile)

- Statistical description of crack growth resistance curve given above.
- Tensile properties also subject to scatter

$$\varepsilon = \frac{\sigma}{E} + \alpha \frac{\sigma_{flo}}{E} \left(\frac{\sigma}{\sigma_{flo}} \right)^m$$

$$\alpha = \frac{1}{c_1 \sigma_{flo}^{c_2} - c_3}$$

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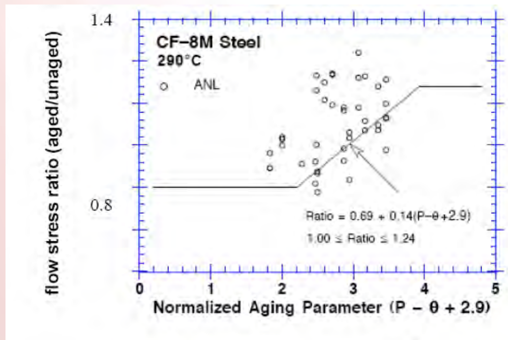
Material Scatter (tensile)

- Saturated flow stress is related to unaged flow stress.



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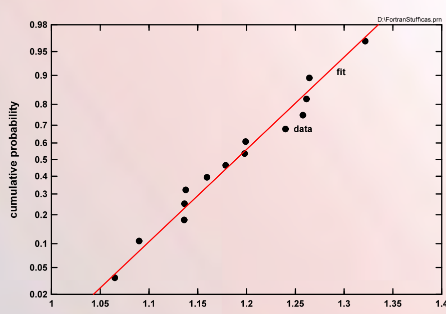
Material Scatter (tensile)

- Data for aging parameter greater than 3 taken to be representative of fully saturated conditions.
- Following figure shows statistical distribution of ratio of aged to unaged flow stress
- Good fit to normal distribution observed
  - Mean=1.189
  - Standard deviation = 0.071



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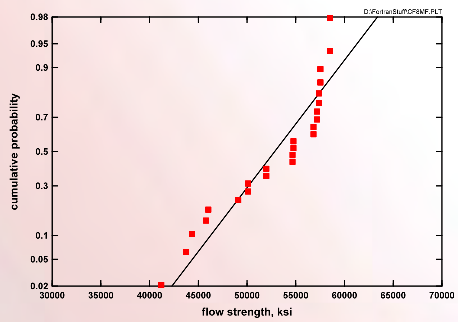
Material Scatter (tensile)

- Data on tensile properties of unaged CF8M at 650 F obtained from earlier compilation (24 values, SI report 0800209.401)
- Cumulative distribution of unaged flow strength estimated from data [Flow strength = (yield strength + tensile strength)/2]



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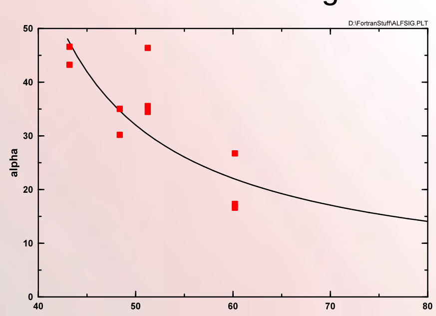
Material Scatter (tensile)

- Random aged flow strength obtained from distribution of ratio of aged and unaged strength and distribution of unaged flow strength.
- Parameter alpha in Ramberg-Osgood relation depends on the flow strength



$$\alpha = \frac{1}{c_1 \sigma_{flo}^{c_2} - c_3}$$

c1 = 0.008848
c2 = 0.64778
c3 = 0.08077

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Material Scatter (Φ)

- Embrittlement depends on composition and delta ferrite content

$$\Phi \equiv \delta_c (Ni + Si + Mn)^2 (C + 0.4N) / 5$$

- Values of input to Φ obtained for 152 heats and used to define statistical distribution of Φ

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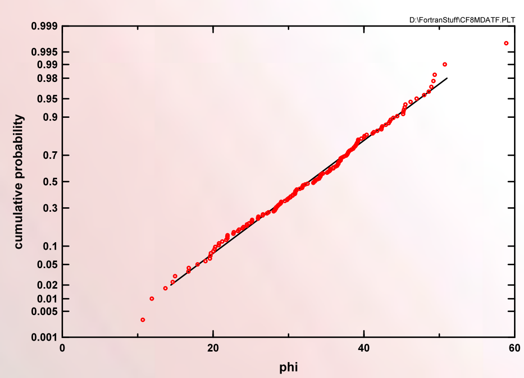
Material Scatter (Φ)

- Normal distribution of Φ



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Summary of Material Statistics

- Aged flow strength randomly distributed
  - Related to random unaged flow strength and random ratio
  - Alpha related to flow strength
- Aged toughness randomly distributed
  - Related to aged Charpy (coefficient and exponent)
  - Charpy related to composition and delta ferrite
- Composition and delta ferrite can be random, or defined by measurement.
- Maximum use made of NUREG correlations.
- Agreement between predicted values (J-da, stress-strain) and data not always good.

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Results of Example Problem

- Monte Carlo simulation used
- 3 million trials in example problem, run on pc
- OD=32 inches
- Thickness=2.25 inches
- Pressure=2250 psi (results in tensile stress of 8.56 ksi)
- Bending stress of 20 ksi
- Random Φ

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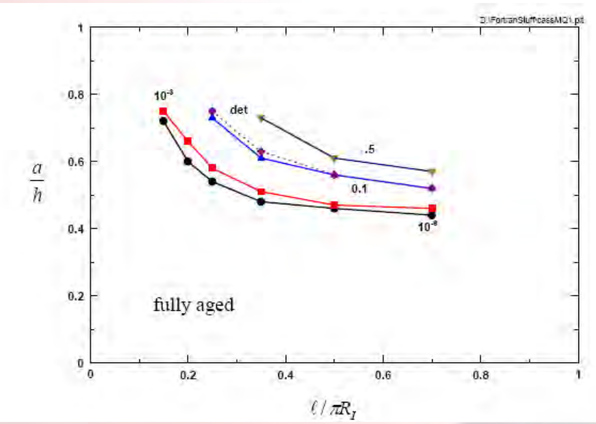
Results of Example Problem

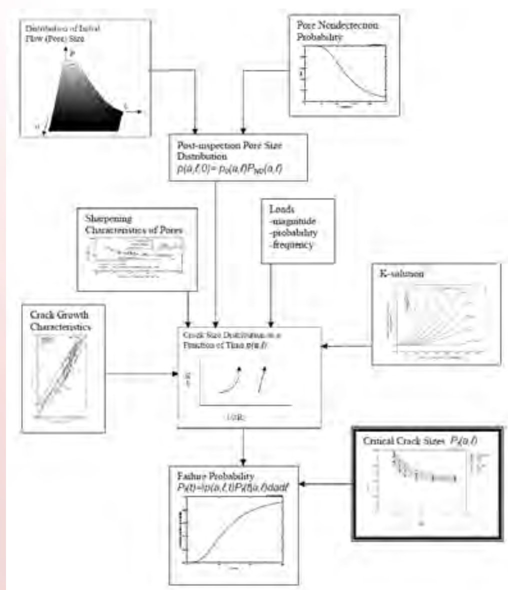
- Crack sizes resulting in a given failure probability (crack instability)

$P_f(a.\ell)$



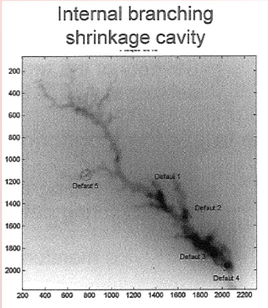
Part II: Overall Model

- Overall failure probability



Part II: Initial Defects

- Casting defects



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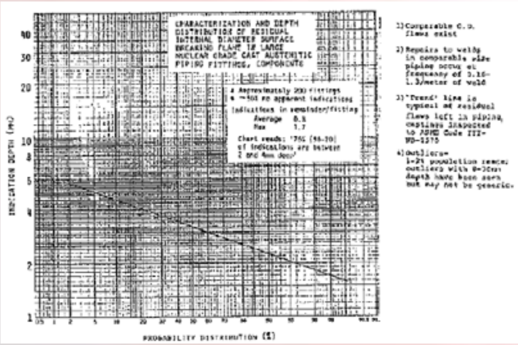
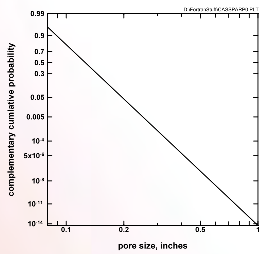
Part II: initial defect size distribution

Lapides, *Materials Evaluation*, 1986
- Lognormal, median 0.126 inches, shape 0.279





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Part II: Detection Probability

- Detection Probability
  - Initial estimate from Johnson, EPRI, 1979
  - Shifted to right to hit POD(a/h=0.3)=0.57 (Anderson, et al., SMirt 19) to provide optimistic curve
  - Shifted down by 0.4 to provide pessimistic curve

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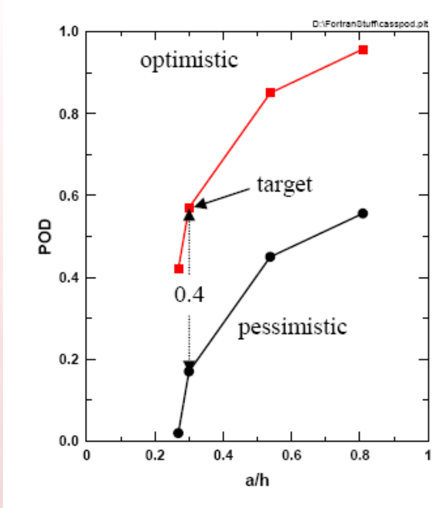
Part II: Detection Probability

- Detection Probability



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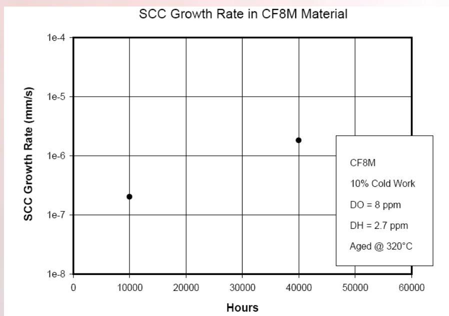
Part II: Crack Growth

- Fatigue Crack growth can be analyzed using conventional fracture mechanics (expected to be small)
- Stress corrosion crack growth
  - Figure from Yamada, et al,. 2009 (applicability to current problem?)
- 10^-7 mm/sec = 7.5 inches in 60 years



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Part II: Comments

- Overall model of reliability (Part II) not exercised
- Crack sizes for failure large, even at low probabilities
- Results presented are for CF8M. Other materials (CF3 CF8 less susceptible to embrittlement).

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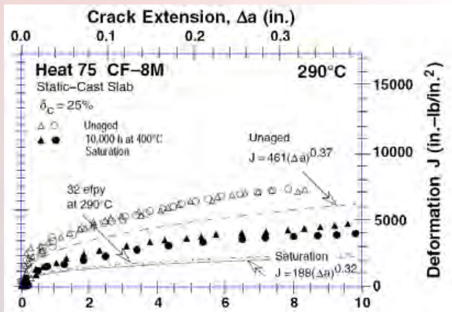
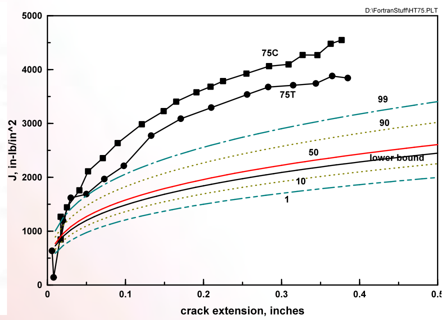
Concerns

- Statistical fits to data not always good





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Concerns

- Preliminary results predict that tolerable crack sizes (at a given probability) are larger for aged material than unaged.
  - Contrary to expectations
  - Increase in strength could reduce applied J (reduced plasticity) that more than offsets toughness reduction
- Higher strength is expected to lead to reduced toughness
  - Insufficient data available to define correlation of strength and toughness

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Concerns

- Loads not well characterized.
- Example is for a specific load.
- More complete set of data may allow possible improved characterization of distributions of random variables.
- More complete set of data would allow possible correlations between random variables to be explored.
- MORE DATA!!

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Status of Project

- Initial Phase 1 scoping study completed
- Preliminary model developed to perform PFM analysis of typical CASS pipe
- Initial results from scoping analysis are encouraging
- Waiting to begin Phase 2
  - Develop firm technical basis
  - Perform more detailed analyses
  - Prepare a proposed ASME Section XI Code change for flaw acceptance standards in CASS piping

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LMT TEST

Delivering the Expertise, the Technologies and the Workforce of the future, - Today!

3rd International Workshop

Future Directions

for the

Inspection of Cast Austenitic Stainless Steel Piping

LMT TEST

Delivering the Expertise, the Technologies and the Workforce of the future, - Today!

- ***Who we are…….***
  - Established in 1975 as the industry's first independent nuclear inspection company.
  - LMT, Inc. has provided NDE services to a majority of the US Nuclear Fleet for over three decades. We have a successful history of providing these services, most notably the delivery of fully automated encoded Phased Array Ultrasonic Testing of piping and components.
  - In 1994, LMT, Inc. formed a strategic alliance with Anatec International, expanding its depth and service to the Domestic and International Energy Industry. This collaboration enables delivery of comprehensive NDE Services including advanced Eddy Current Testing, Quality Services and Inspection Program Development.

Delivering the Expertise, the Technologies and the Workforce of the future, - Today!

- ***What are LMT's CASS related activities of late……..***
  - In July of 2010, LMT provided Fully Encoded Phase Array UT services to Pacific Northwest National Laboratory. This project was in support of NRC research on Ultrasonic Examination of Cast Stainless Steel Piping Welds.
  - Performed independent (essentially blind) inspection of cracks in 2 small bore CASS piping specimens.
    - Reported Flaw results were within ASME RMSE criteria for length and depth.
    - For technical summary of this project please reference PNNL presentation "*Update on Thin-Wall CASS Piping Inspection*".

Delivering the Expertise, the Technologies and the Workforce of the future, - Today!

Wherever our customers are……….

………. We are there!

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tblechinger@lmttest.com

SOUTHERN COMPANY
Energy to Serve Your World®

Plant Vogtle

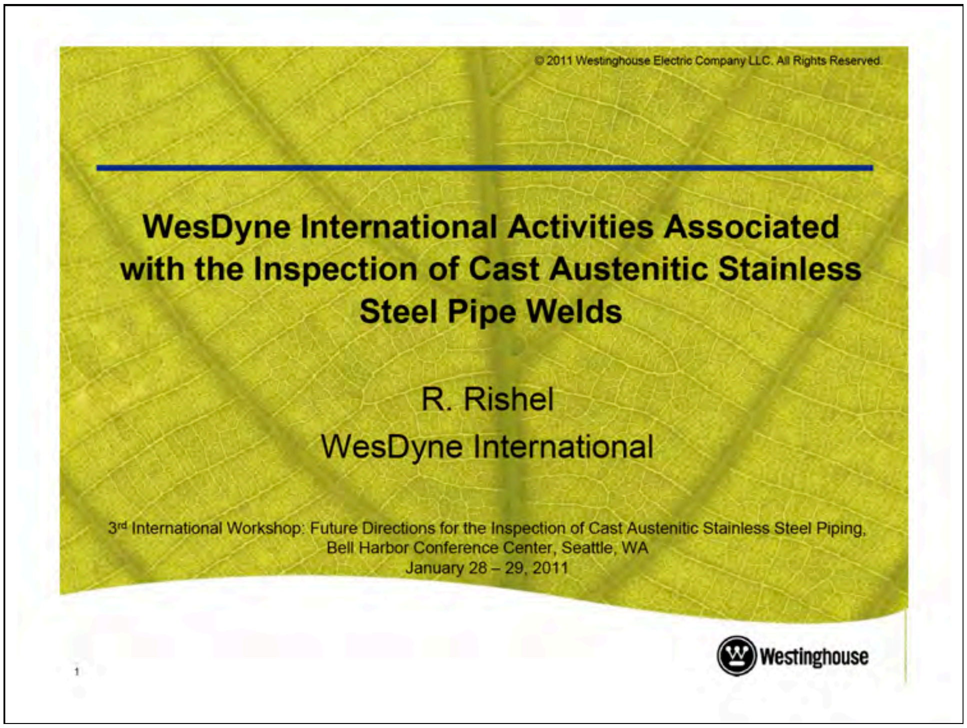
- *Waynesboro, GA*
- *Westinghouse (PWR) 4 loop – 2 Units*
- *Commercial Operation – 1988 and 1990*
- *Cast Stainless Location – RCS HL and CL*

Plant Farley

- *Dothan, AL*
- *Westinghouse (PWR) 3 loop – 2 Units*
- *Commercial Operation – 1977 and 1981*
- *Cast Stainless Location – RCS HL and CL, Regen Ht Ex*

Plant Hatch

- *Baxley, GA*
- *General Electric (BWR) – 2 Units*
- *Commercial Operation - 1975 and 1979*


© 2011 Westinghouse Electric Company LLC. All Rights Reserved.
WesDyne International Activities Associated with the Inspection of Cast Austenitic Stainless Steel Pipe Welds
R. Rishel
WesDyne International
3rd International Workshop: Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping,
Bell Harbor Conference Center, Seattle, WA
January 28 – 29, 2011
1
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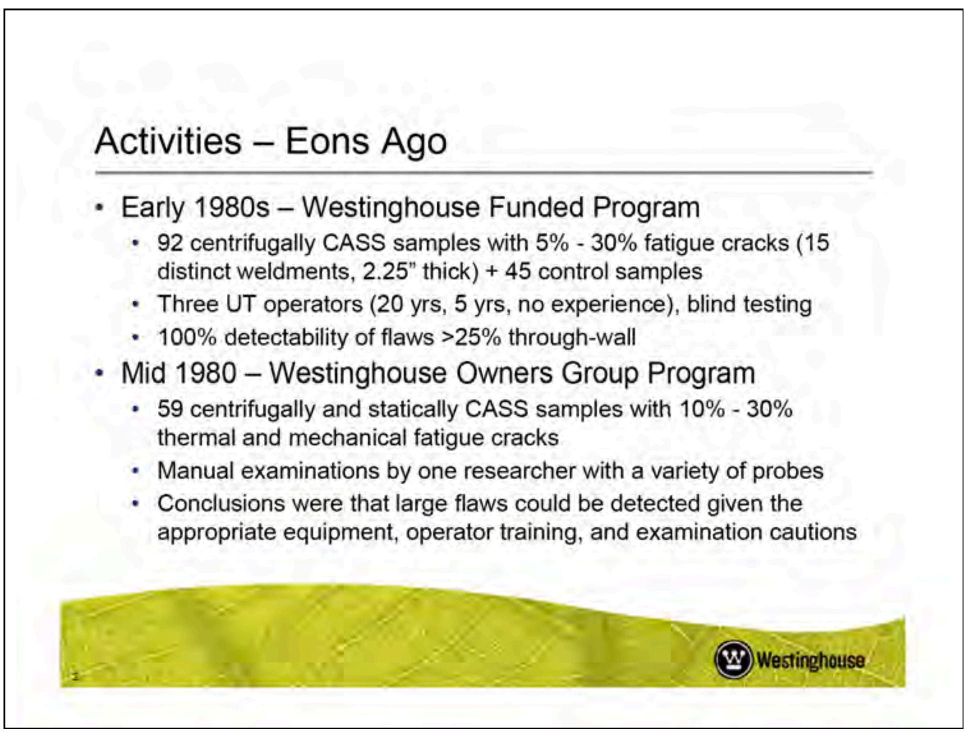
Activities – Eons Ago
• Early 1980s – Westinghouse Funded Program
• 92 centrifugally CASS samples with 5% - 30% fatigue cracks (15 distinct weldments, 2.25" thick) + 45 control samples
• Three UT operators (20 yrs, 5 yrs, no experience), blind testing
• 100% detectability of flaws >25% through-wall
• Mid 1980 – Westinghouse Owners Group Program
• 59 centrifugally and statically CASS samples with 10% - 30% thermal and mechanical fatigue cracks
• Manual examinations by one researcher with a variety of probes
• Conclusions were that large flaws could be detected given the appropriate equipment, operator training, and examination cautions
2
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Activities – More Recent

- 2005 – Trial Inspections on CASS Welded Samples (WesDyne-TRC)
  - 25 defects (fatigue cracks, lack of fusion, slag, solidification cracks)
  - Mechanized phased array UT (2x33, 1 MHz, dual)
  - Positive results, 24 of 25 flaws detected (open and semi-blind tests)

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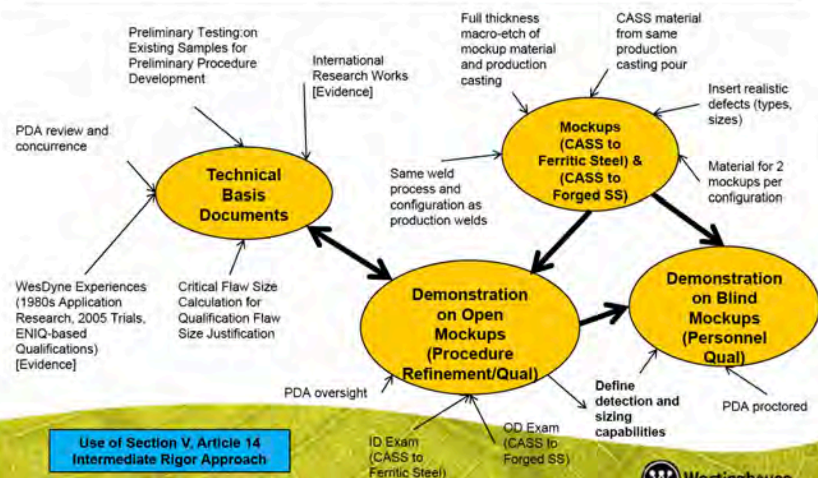
Activities – Near Future (now to 2013)



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Recent Ultrasonic Research and Development Activities and Results for CAST Stainless Steel in INSS

October 20, 2010
Yasuo Kurozumi
Institute of Nuclear Safety Systems, Inc.

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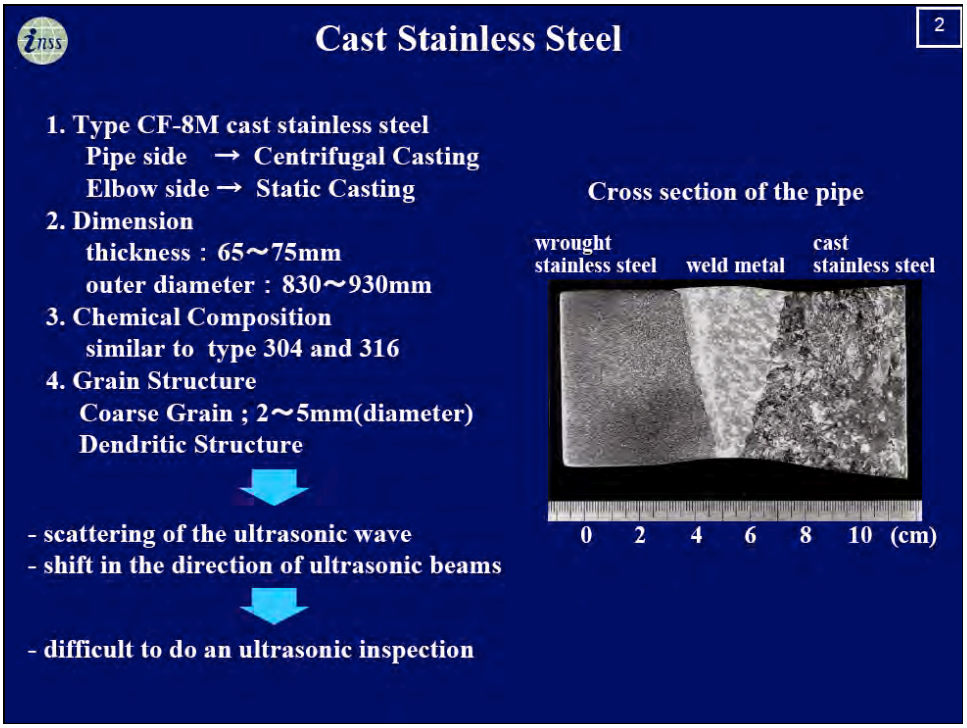
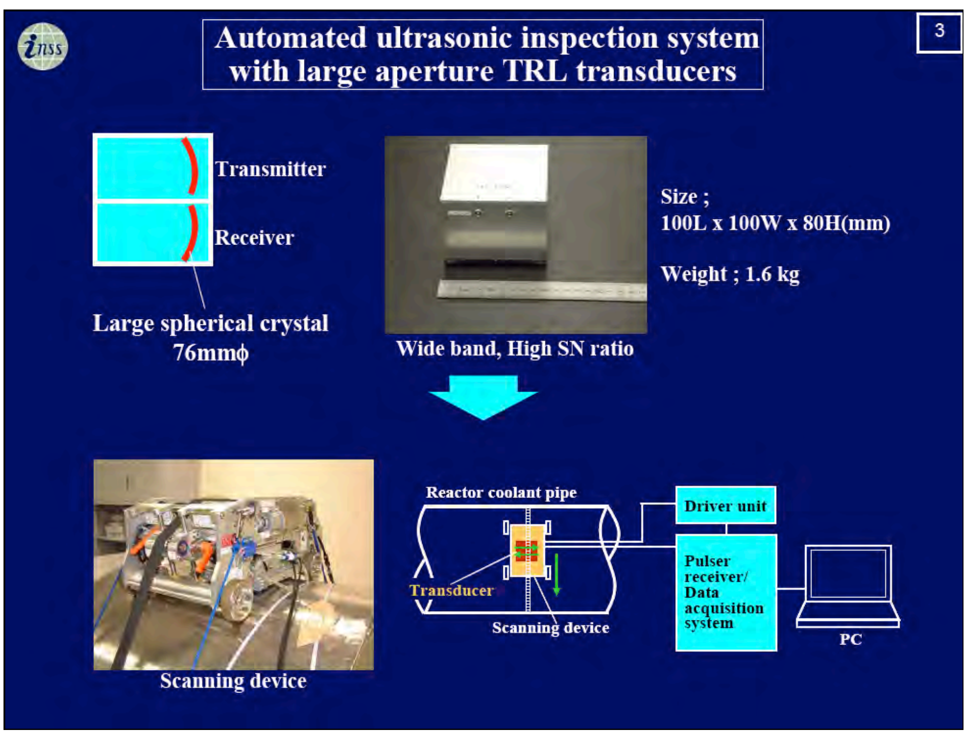
Contents

- Detection performance on each weld design
- Depth and Length Sizing of Fatigue Cracks in Cast Stainless Steel Test Piece
- On-site verifications


Cast Stainless Steel
2
1. Type CF-8M cast stainless steel
Pipe side → Centrifugal Casting
Elbow side → Static Casting
2. Dimension
thickness : 65〜75mm
outer diameter : 830〜930mm
3. Chemical Composition
similar to type 304 and 316
4. Grain Structure
Coarse Grain ; 2〜5mm(diameter)
Dendritic Structure
- scattering of the ultrasonic wave
- shift in the direction of ultrasonic beams
- difficult to do an ultrasonic inspection
Cross section of the pipe
wrought stainless steel
weld metal
cast stainless steel
0 2 4 6 8 10 (cm)


Automated ultrasonic inspection system with large aperture TRL transducers
3
Transmitter
Receiver
Large spherical crystal 76mmϕ
Wide band, High SN ratio
Size ;
100L x 100W x 80H(mm)
Weight ; 1.6 kg
Scanning device
Reactor coolant pipe
Transducer
Scanning device
Driver unit
Pulser receiver/ Data acquisition system
PC

Specifications of probes used in this study

4

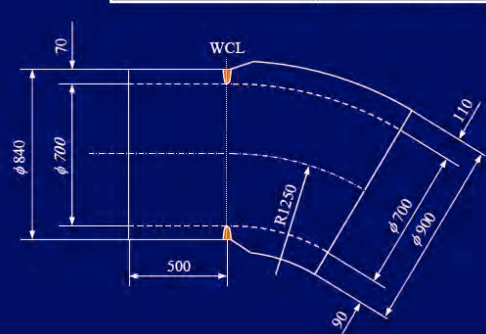
Probe	Type A	Type B	Type C
Type	Longitudinal-wave angle, twin crystal	Longitudinal-wave angle, twin crystal	Longitudinal-wave angle, twin crystal
Outside Dimensions (mm)	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80
Frequency	1 MHz	1 MHz	1 MHz
Transducer Shape	Spherical surface	Spherical surface	Spherical surface
Angle of Refraction	40.7°	47.4°	55°
Focal Depth(mm)	65-75	45-65	40-60

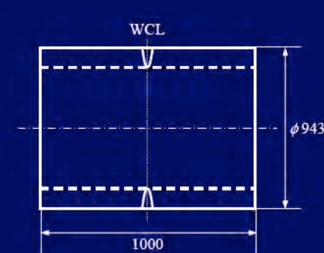
We used only type A probe for detection performance test.
Roof angles are ranged from 6.7 to 7.6°.

Mock-up test assemblies used for detection test

5

Type	Category I	Category III
Configuration	Pipe + Elbow	Pipe + Pipe
Material	CCS + SCS	CCS + SCS
Weld process	SMAW + SAW	narrow gap TIG
Defects	EDM slit, Fatigue crack Incomplete penetration	EDM slit, Fatigue crack





Ultrasonic data image sample (Detection test)

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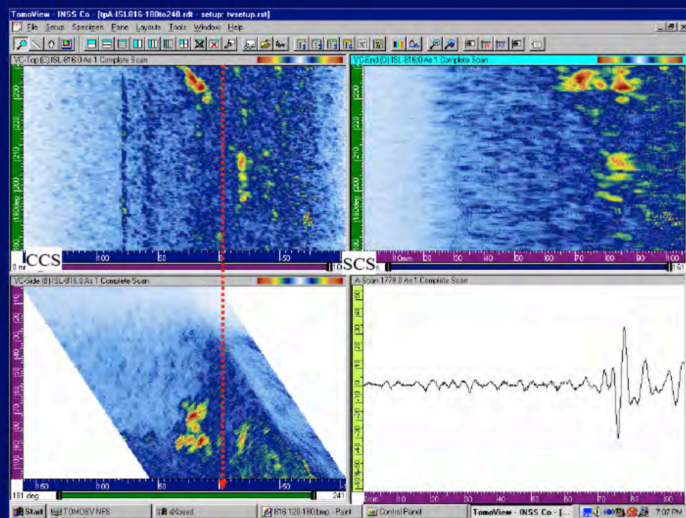
- Category I test assembly -

C scan

D scan



B scope

A scan

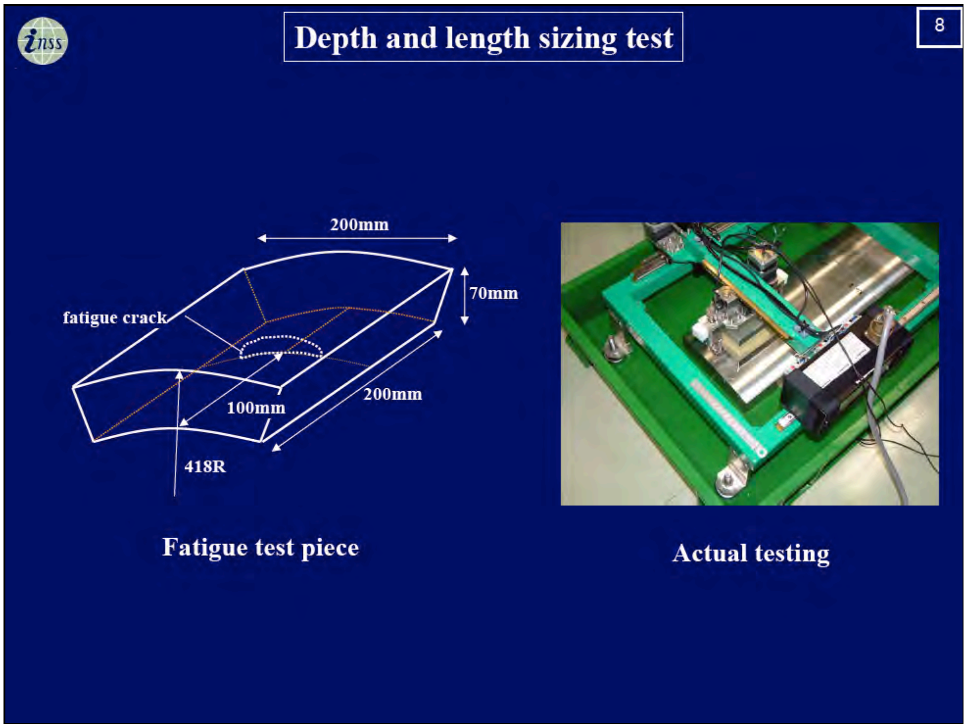
scanning direction

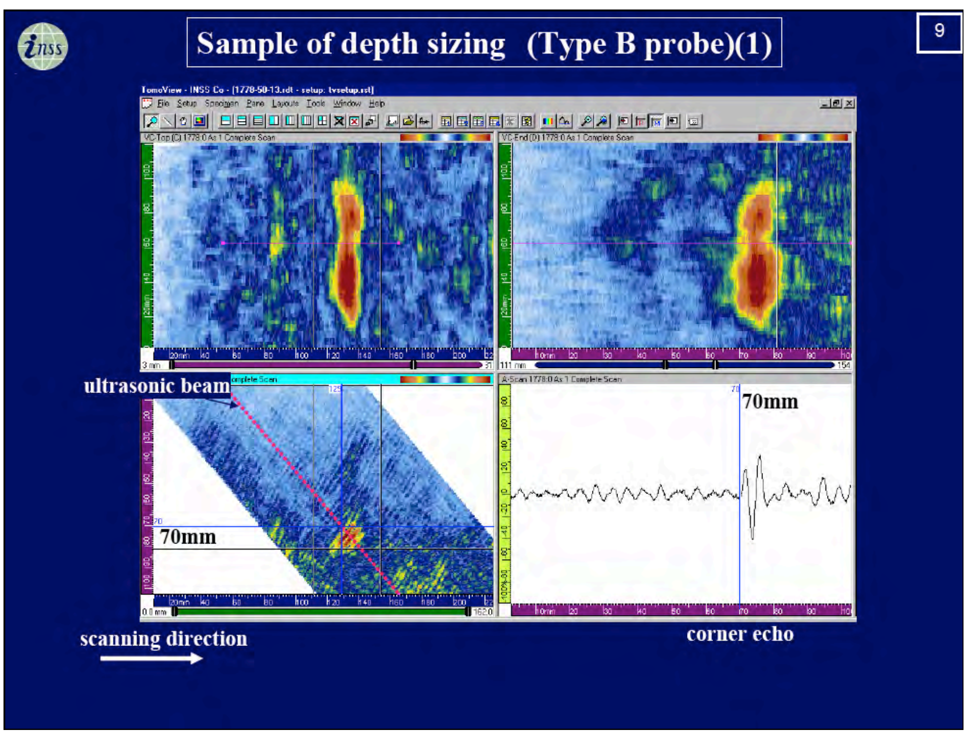
weld center line

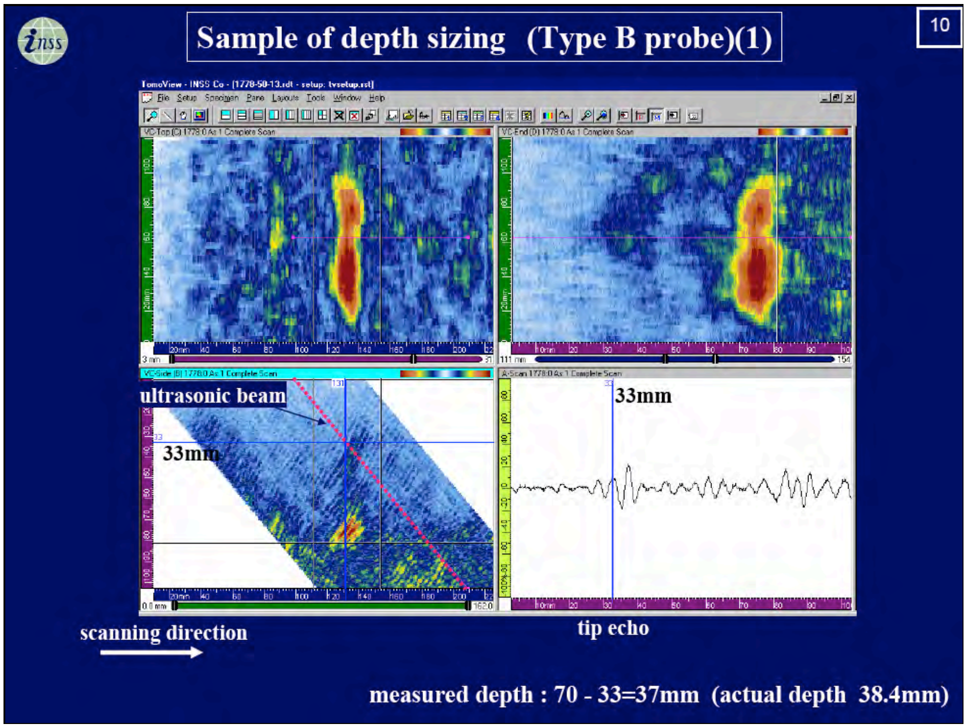
Detection performance

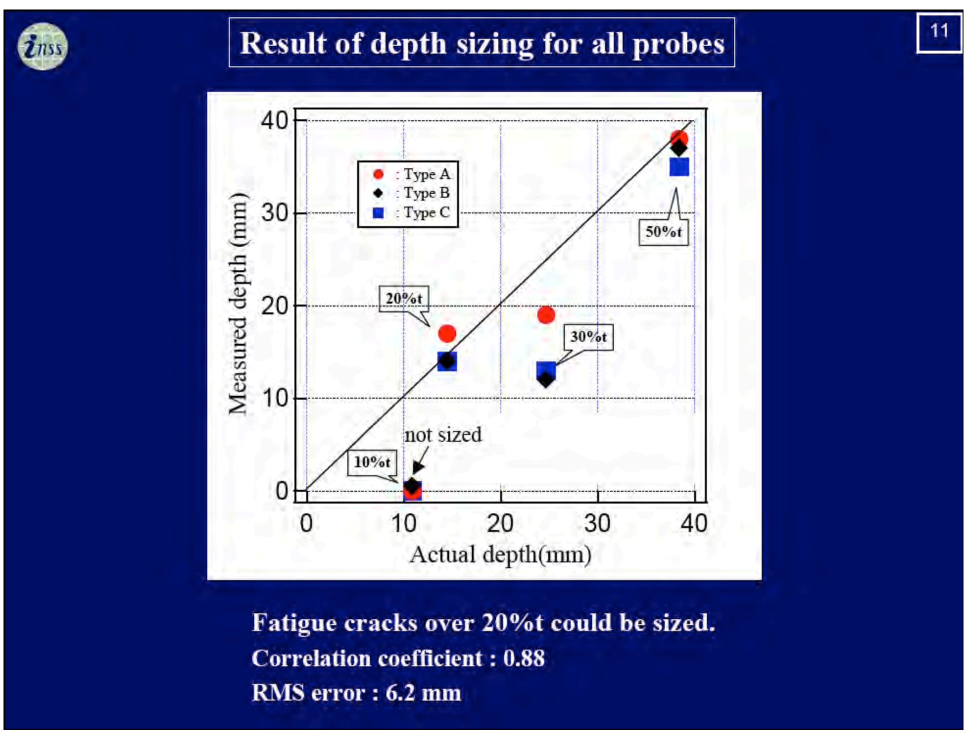
7

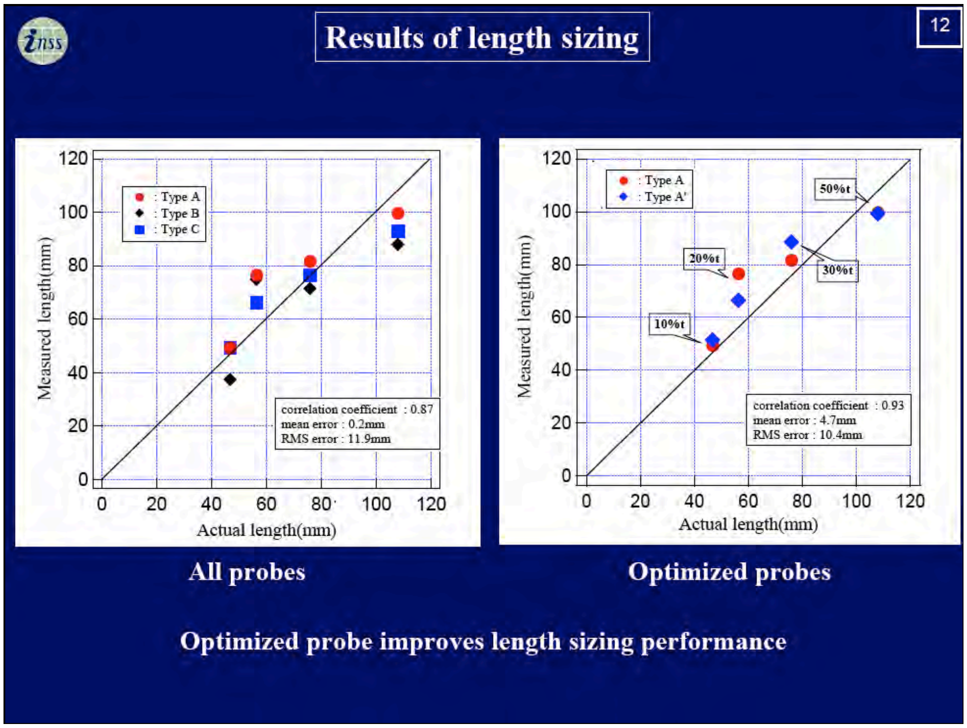
Category I Test assembly	Category III Test assembly
Detected all defects. Some false call were observed. Flaw detection rate = 1.0 False call rate = 0.25	Detected all defects. No false call was observed. Flaw detection rate = 1.0 False call rate = 0

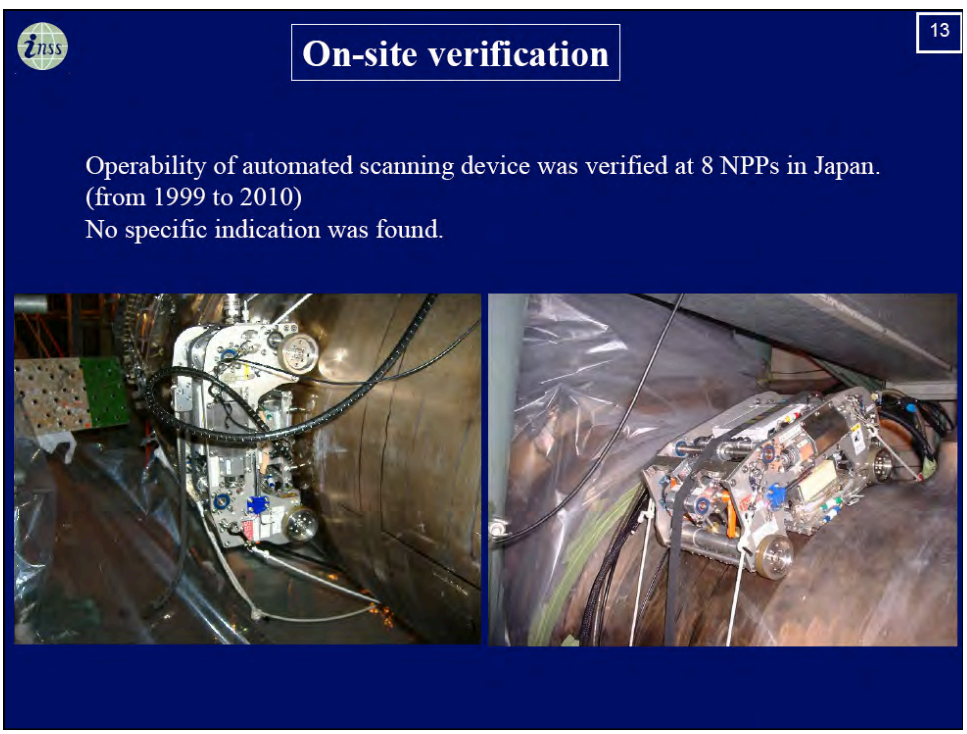

Depth and length sizing test
8
200mm
70mm
fatigue crack
200mm
100mm
418R
Fatigue test piece
Actual testing

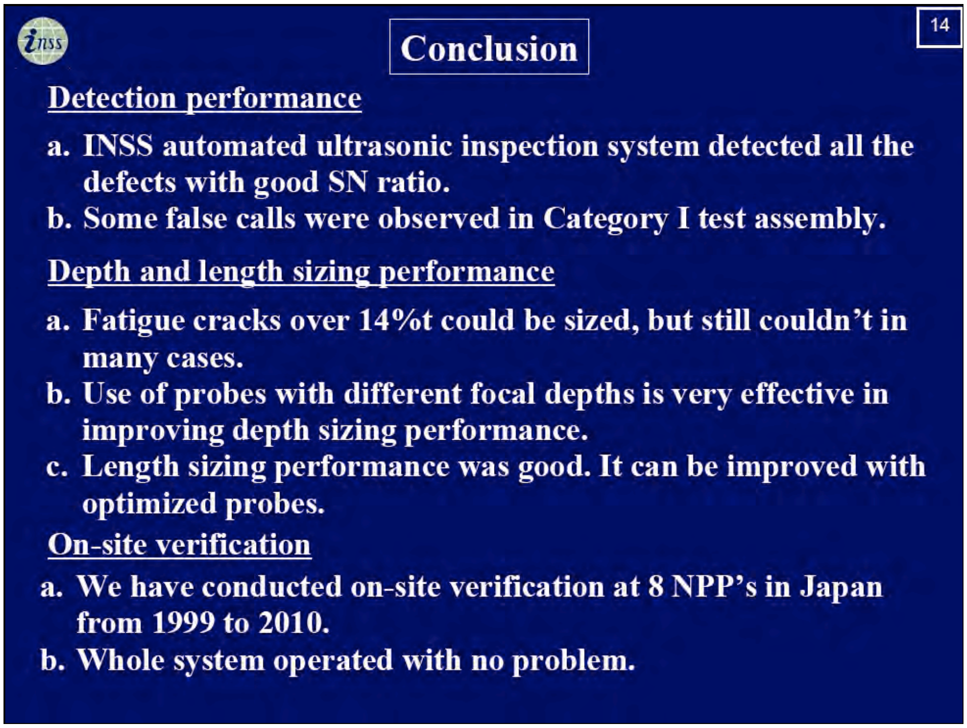

Sample of depth sizing (Type B probe)(1)
9
ultrasonic beam
70mm
70mm
scanning direction
corner echo


Sample of depth sizing (Type B probe)(1)
10
ultrasonic beam
33mm
33mm
scanning direction
tip echo
measured depth : 70 - 33=37mm (actual depth 38.4mm)


Result of depth sizing for all probes
11
: Type A
: Type B
: Type C
Measured depth (mm)
Actual depth(mm)
0
10
20
30
40
0
10
20
30
40
10%t
20%t
30%t
50%t
not sized
Fatigue cracks over 20%t could be sized.
Correlation coefficient : 0.88
RMS error : 6.2 mm


Results of length sizing
12
: Type A
: Type B
: Type C
correlation coefficient : 0.87
mean error : 0.2mm
RMS error : 11.9mm
Measured length(mm)
Actual length(mm)
: Type A
: Type A'
50%t
30%t
20%t
10%t
correlation coefficient : 0.93
mean error : 4.7mm
RMS error : 10.4mm
All probes
Optimized probes
Optimized probe improves length sizing performance


On-site verification
13
Operability of automated scanning device was verified at 8 NPPs in Japan.
(from 1999 to 2010)
No specific indication was found.


Conclusion
14
Detection performance
a. INSS automated ultrasonic inspection system detected all the defects with good SN ratio.
b. Some false calls were observed in Category I test assembly.
Depth and length sizing performance
a. Fatigue cracks over 14%t could be sized, but still couldn't in many cases.
b. Use of probes with different focal depths is very effective in improving depth sizing performance.
c. Length sizing performance was good. It can be improved with optimized probes.
On-site verification
a. We have conducted on-site verification at 8 NPP's in Japan from 1999 to 2010.
b. Whole system operated with no problem.