Chockie Group International, Inc.

Future Directions
for the Inspection of CASS

Summary Report

4th International Workshop on the Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

May 22-25, 2012
Seattle, WA

The Challenge

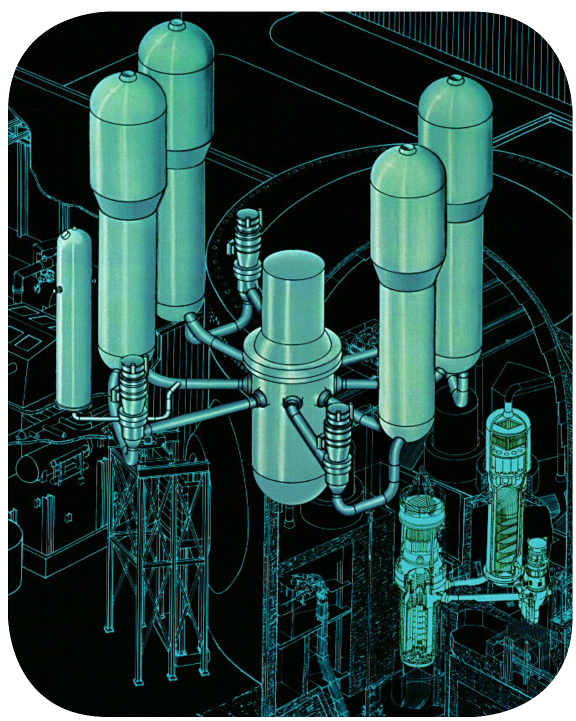
Cast austenitic stainless steel (CASS) is used in the primary coolant piping system in pressurized water reactors (PWRs) in the United States, Japan, Sweden, France, and other countries. The attributes that make CASS a good candidate for the primary piping system significantly hamper the ability to effectively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

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

In recent years there have been significant advances in CASS inspection techniques, critical flaw evaluation, transducer and signal processing development, and ASME Code actions. The workshop focussed on these developments and where work remains to be done.

The Previous Workshops

The first workshop was held in San Diego in 2006. The second and third workshops were held in Seattle in 2009 and 2011. These workshops resulted in the establishment of several important initiatives including critical flaw evaluation and international cooperative inspection research programs.



The 4th Workshop

The 4th International Workshop was held at the Bell Harbor Conference Center in Seattle, Washington, on May 24 - 25, 2012. 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 twenty-three participants from six countries:

- Finland
- Sweden
- France
- Canada
- Japan
- United States

They represented utilities, vendors, regulators, inspection companies, and research organizations.

Workshop Objectives

The objectives for the 4th International Workshop were much the same as those of the previous workshops. Specifically, the objectives were to:

- Build upon the results of the previous workshops
- Review the current state-of-the-art in the inspection and critical flaw assessment of CASS piping
- Establish the foundations for international cooperative improvement initiatives

Workshop Agenda

The workshop was structured to:

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

As has been the situation at the past three workshops, the first session was devoted to a review of CASS inspection and analyses programs, flaw tolerance analysis, and recent advancements in inspection capabilities. This was to provide the group with a common understanding of the current status of CASS-related inspection development activities and issues.

The subjects that were addressed during the first session included:

- Summary of CASS inspection developments
- Industry activities and research
- ASME Code actions
- Regulatory concerns

The second session of the workshop involved open discussions among the participants. Prior to the workshop the participants were presented with a list of proposed discussion topics. These are shown in the list below.

At the Zetec Sponsored Reception: Doug Kull (EPRI NDE Center) and Tim Griesbach (Structural Integrity Associates, Inc.)

Discussion Topics

Macrostructure Characterization

- In-situ characterization

Critical Flaw Size

- Influencing factors

Signal Processing

- Criteria for signal evaluation

Sound Field Characterization & Modelling

Inspectability Issues

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

Physical Constraints

- Surface condition issues
- Accessibility issues

Vintage CASS Material

- Casting processes & variables
- Availability & reproductions

Flaw Fabrication Issues for Mock-ups

New Plant CASS Material

- Plant configuration issues

Inspection Strategies

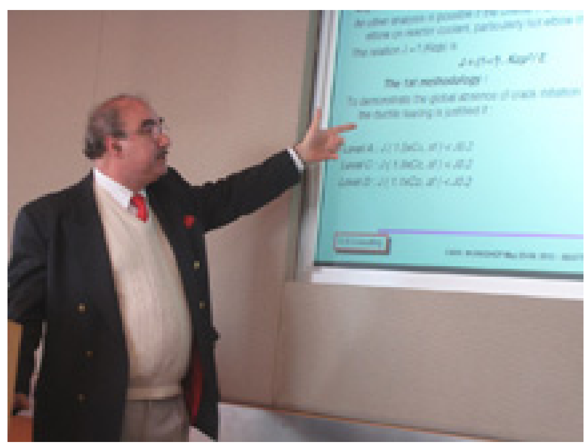
- Inspections from outer & inner surfaces
- Inspection from ID/OD using UT & ET
- RT inspection strategies

The Presentations

Participants were requested to provide a brief overview of their recent CASS-related activities. They were made aware that the presentation information would be used as the basis for the Workshop discussions and would be disseminated along with a summary of the workshop discussions to workshop participants and to other organizations that wished to support the improvement of the inspection of CASS nuclear power plant piping. Only a few of the participants at this or any of the other three Workshops declined to provide such presentations due to concerns with the proprietary nature of their recent work.

Presentations at this Workshop were made by:

- EPRI NDE Center*
- Georges Bezdikian Consulting Co.
- US Nuclear Regulatory Commission
- Zetec
- AREVA NP Uddcomb AB
- Trueflaw
- Imasonic SAS
- DEKRA Industrial
- Structural Integrity Associates
- Institute of Nuclear System Safety, Inc.*



Presentation by Georges Bezdikian
(Georges Bezdikian Consulting Co.)

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* Mr. Swain from the EPRI NDE Center and Dr. Kurozumi from the Institute of Nuclear System Safety, Inc. (INSS) in Japan were not able to attend. However they provided presentation material on recent ASME XI CASS and CASS activities at INSS activities, respectively.

Copies of the presentation slides are available in the associated document entitled, *Summary Report Attachments*. The twelve technical presentations were:

- Cast Stainless Steel Piping Update
  Mark Dennis – EPRI (USA)
- Aging Management, In-Service Inspection and Integrity Assessment for Fitness for Service of CASS Components on Reactor Coolant Primary Circuit: Industrial and Strategy Aspects
  Georges Bezdikian – Georges Bezdikian Consulting Co. (France)
- Regulatory Issues Related to the Examination of Cast Austenitic Stainless Steel
  Stephen Cumblidge – US Nuclear Regulatory Commission (USA)
- Zetec Activities Related to Inspection of CASS Components & Welds
  Guy Maes - Zetec (Canada)
- AREVA NP Uddcomb AB Testblocks
  Per Arne Bjurling – AREVA Uddcomb AB (Sweden)
- More cracks in CASS
  Iikka Virkkunen – Trueflaw (Finland)
- IMASONIC CASS 2012
  Gerard Fleury – Imasonic SAS (France)
- DEKRA Industrial CASS Activities
  Torbjörn Sjö and Peter Alzén – DEKRA Industiral (Sweden)
- A Proposed Flaw Tolerance Approach for CASS Piping
  Timothy J. Griesbach – Structural Integrity Associates, Inc. (USA)
- Probabilistic Analysis of Reliability of Cast Austenitic Stainless Steel Piping
  David Harris – Structural Integrity Associates, Inc. (USA)
- Our Experience of Ultrasonic Inspection for CAST Stainless Steel
  Yasuo Kurozumi – Institute of Nuclear Safety Systems, Inc (Japan)
- Cast Stainless Steel Inspection: An Overview of ASME Section XI Activity
  Ronnie Swain – EPRI NDE Center (USA)

The Next Steps

At the end of the presentation and discussion sessions the group reviewed the list of proposed development activities that was produced at the Third Workshop in 2011. The participants at the current Workshop felt that these were still the relevant issues that needed to be addressed. The issues were grouped into three 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)?

Discussions During the Break: David Harris (Structural Integrity) & Iikka Virkkunen (Trueflaw)

- 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?

Inspection System

- 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?

Lunch Break

Acknowledgments

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

- Zetec — for their encouragement and their sponsorship of the Friday evening reception
- The Bell Harbor Conference Center
- The Seattle Marriott Waterfront and the Edgewater Hotels (the Workshop's host hotels)

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

Workshop Participants

Junichi Akagawa
Nuclear Engineering Ltd.(NEL)
JAPAN
jakagawa@neltd.co.jp

Peter Alzén
DEKRA Industrial
SWEDEN
peter.alzen@dekra.com

Georges Bezdikian
Georges Bezdikian Consulting Co.
FRANCE
georges.bezdikian@orange.fr

Per Arne Bjurling
AREVA NP Uddcomb AB
SWEDEN
perarne.bjurling@areva.com

Alan Chockie
Chockie Group International, Inc.
USA
chockie@chockiegroup.com

George Connolly
EPRI
USA
gconnolly@epri.com

Stephen Cumblidge
U.S. Nuclear Regulatory Commission
USA
stephen.cumblidge@gmail.com

Mark Dennis
EPRI NDE Center
USA
mdennis@epri.com

Gerard Fleury
Imasonic SAS
FRANCE
no@imasonic.com

Giselle García Roldán
Swedish Radiation Safety Authority
SWEDEN
giselle.garciaroldan@ssm.se

Timothy Griesbach
Structural Integrity Associates, Inc.
USA
tgriesbach@structint.com

David Harris
Structural Integrity Associates, Inc.
USA
dharris@structint.com

Ryosuke Katsumata
Nuclear Engineering Ltd.(NEL)
JAPAN
rkatsumata@neltd.co.jp

Doug Kull
EPRI NDE Center
USA
dkull@epri.com

Andre Lamarre
Olympus NDT
CANADA
andre.lamarre@olympusn

John Lareau
WesDyne
USA
lareaujp@westinghouse.com

Robert MacLellan
Rolls-Royce
USA
ramaclellan@rbrooks.com

Guy Maes
Zetec
CANADA
gmaes@zetec.com

Hans Martinsen
Ringhals NP
SWEDEN
hans.martinsen@vattenfall.com

Hajime Shohji
Central Research Institute of Electric Power Industry
JAPAN
shohji@criepi.denken.or.jp

Torbjörn Sjö
DEKRA Industrial
SWEDEN
torbjorn.sjo@dekra.com

Iikka Virkkunen
Trueflaw
FINLAND
iikka@trueflaw.com

Keiji Watanabe
Central Research Institute of Electric Power Industry
JAPAN
wkeiji@criepi.denken.or.jp

For additional information contact

Alan Chockie
Chockie Group International, Inc.
Phone: +1 (206) 367-1908
chockie@chockiegroup.com

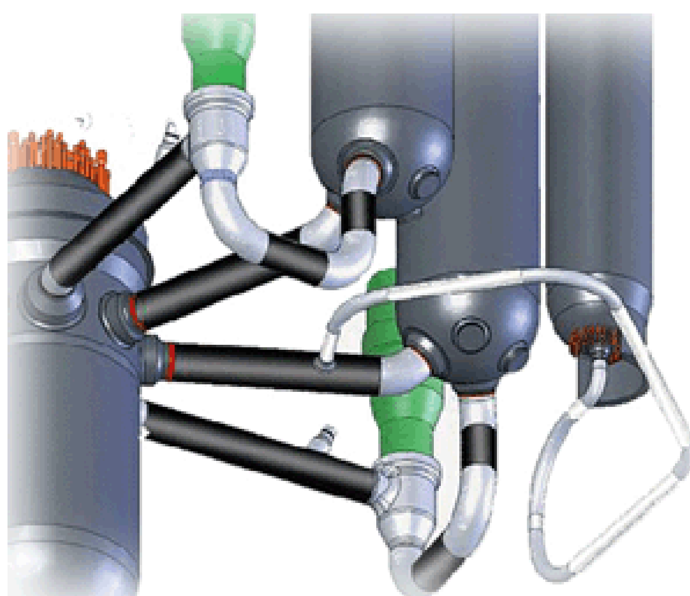
Chockie Group International, Inc.

4^{th} International Workshop

Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

Summary Report Attachments:

Workshop Presentations



May 24-25, 2012
Bell Harbor Conference Center
Seattle, Washington

Summary Report - Workshop Attachments

4th International Workshop on the Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

May 24 - 25, 2012
Seattle, WA

The Workshop

The two-day workshop was held at the Bell Harbor Conference Center in Seattle, Washington, on May 24 - 25, 2012. 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

As has been the case at the past Workshops, the participants provided a wealth of information in their presentations and during the group discussions. The presenters gave an overview of their recent and planned CASS-related activities. Copies of the presentation slides are included in the this Attachment.

Presentations were made by:

- EPRI
- Georges Bezdikian Consulting Co.
- US Nuclear Regulatory Commission
- Zetec
- AREVA NP Uddcomb AB
- Trueflaw
- Imasonic SAS
- Dekra Industrial
- Structural Integrity Associates

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

Summary Report

For a copy of the Summary Report please contact

Alan Chockie
Chockie Group International, Inc.
Seattle, WA USA
Phone: +1 (206) 367-1908
e-mail: chockie@chockiegroup.com

[1] Dr. Yasuo Kurozumi from INSS in Japan and Ronnie Swain from the EPRI NDE Center were not able to attend the workshop. However both provided presentation slides on their recent CASS activities.

Table of Contents

Click on the title to go to the presentation

[1] Dr. Kurozumi and Mr. Swain were not able to attend. However they provided presentation material on recent CASS activities at INSS and the ASME Section XI CASS activities, respectively.

Chockie Group International, Inc.

4th International Workshop

Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

Welcome

Chockie Group International, Inc.

4th International CASS Workshop

Workshop Agenda

Thursday – May 24

1:30	Lunch
2:30	Introductions & Review of Previous Workshops
3:00	Presentations, including
	EPRI CASS Activities
	NRC - Regulatory Issues
	EDF CASS Program
4:00	Break (15 minutes)
4:15	Presentations, including CASS Activities at:
	Ringhals
	AREVA NP Uddcomb
	Trueflaw
	Zetec
5:15	Wrap-up Day 1
6:30	Zetec Reception at the World Trade Center
8:00	Dinner at the World Trade Center

Friday – May 25 (at the World Trade Center)

8:00	Continental Breakfast at the World Trade Center
9:00	Presentations, including CASS Activities at:
	Imasonic
	DEKRA Industrial
	Structural Integrity
10:30	Break (15 minutes)
10:45	Group Discussions
12:00	Lunch
1:00	Group Discussions
2:30	Break (15 minutes)
2:45	Identify Future Actions / Initiatives
3:30	Wrap-up - Workshop Conclusion

Participants

First Name	Last Name	Organization	Country	email Address
Junichi	Akagawa	Nuclear Engineering Ltd.(NEL)	JAPAN	jakagawa@neltd.co.jp
Peter	Alzén	DEKRA Industrial	Sweden	peter.alzen@dekra.com
Georges	Bezdikian	GEORGES BEZDIKIAN Consulting Co.	FRANCE	georges.bezdikian@orange.fr
Per Arne	Bjurling	AREVA NP Uddcomb AB	SWEDEN	perarne.bjurling@areva.com
Alan	Chockie	Chockie Group International, Inc.	USA	chockie@chockiegroup.com
George	Connolly	EPRI	USA	gconnolly@epri.com
Stephen	Cumblidge	U.S. Nuclear Regulatory Commission	USA	stephen.cumblidge@gmail.com
Mark	Dennis	EPRI	USA	mdennis@epri.com
Gerard	Fleury	Imasonic SAS	FRANCE	no@imasonic.com
Giselle	García Roldán	Swedish Radiation Safety Authority	SWEDEN	giselle.garciaroldan@ssm.se
Timothy	Griesbach	Structural Integrity Associates, Inc.	USA	tgriesbach@structint.com
David	Harris	Structural Integrity Associates, Inc.	USA	dharris@structint.com
Ryosuke	Katsumata	Nuclear Engineering Ltd.(NEL)	JAPAN	rkatsumata@neltd.co.jp
Doug	Kull	EPRI	USA	dkull@epri.com
Andre	Lamarre	Olympus NDT	Canada	andre.lamarre@olympusn
John	Lareau	WesDyne	US	lareaujp@westinghouse.com
Robert	MacLellan	Rolls-Royce	USA	ramaclellan@rbrooks.com
Guy	Maes	Zetec	CANADA	gmaes@zetec.com
Hans	Martinsen	Ringhals NP	SWEDEN	hans.martinsen@vattenfall.com
Hajime	Shohji	Central Research Institute of Electric Power Industry	Japan	shohji@criepi.denken.or.jp
Torbjörn	Sjö	DEKRA Industrial	Sweden	torbjorn.sjo@dekra.com
Iikka	Virkkunen	Trueflaw	FINLAND	iikka@trueflaw.com
Keiji	Watanabe	Central Research Institute of Electric Power Industry	JAPAN	wkeiji@criepi.denken.or.jp

Cast Stainless Steel Piping Update

Mark Dennis
EPRI – NDE Modeling & Simulation Program Manager

4th International Workshop Future Directions for the Inspection of Cast Austenitic Stainless Steel Piping

May 24-25, 2012

Contents

- EPRI Collected Ultrasonic Data on PNNL Cast Stainless Steel Piping Samples
- 2D Flexible Array Results on Heavy-Wall Cast Stainless Steel Piping

EPRI UT Data Obtained From PNNL Cast Elbows

- PNNL procured 1.6” thick cast piping from a cancelled nuclear plant and installed thermal fatigue flaws.
- EPRI has collected data from three of the PNNL cast elbows:
  - 9C-002
    - TruFlaw thermal fatigue flaws
  - Sample 7C-059
    - Traditional thermal fatigue flaws

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Equipment
EPRI UT Data Obtained From PNNL Cast Elbows

- Instruments:
  - Zetec DYNARAY
  - Zetec OmniScan
  - Zetec μTomoScan
- Transducers:
  - GEIT 1.5 MHz 4x8 Dual Array (16mmx28mm)
  - Zetec 1.5 MHz 4x8 Dual Array (16mmx28mm)
  - RTD 1.5 MHz Dual 45°(15mmx25mm)
  - RTD 1.5 MHz Dual 60°(15mmx25mm)

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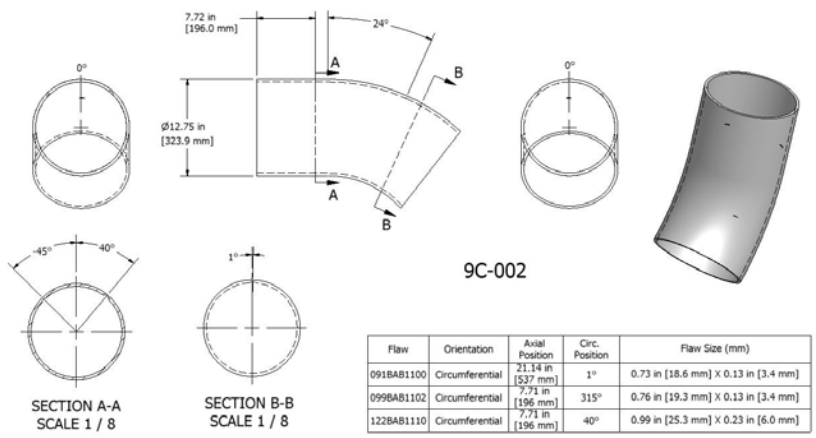
9C-002 Configuration Drawing



Flaw	Orientation	Axial Position	Circ. Position	Flaw Size (mm)
091BAB1100	Circumferential	21.14 in [537 mm]	1°	0.73 in [18.6 mm] X 0.13 in [3.4 mm]
099BAB1102	Circumferential	7.71 in [196 mm]	315°	0.76 in [19.3 mm] X 0.13 in [3.4 mm]
122BAB1110	Circumferential	7.71 in [196 mm]	40°	0.99 in [25.3 mm] X 0.23 in [6.0 mm]

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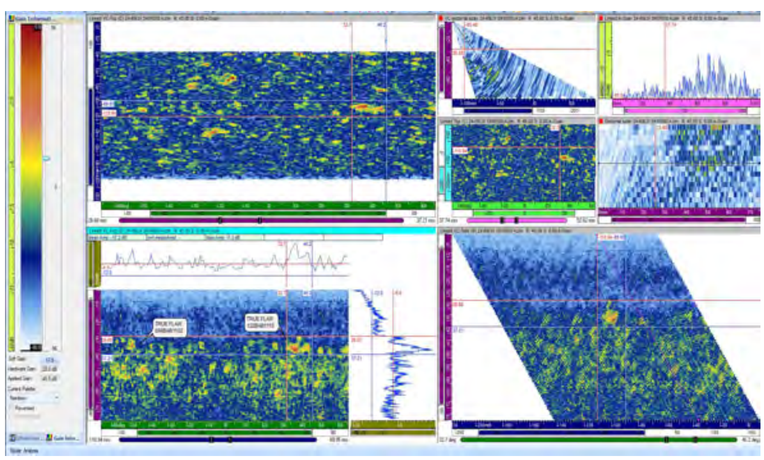
Dynaray, Probe: GEIT 115-000-763, Sample 9C-002 True Flaw 122BAB1110_Looking toward elbow, Signal to Noise Ratio: 10.4dB



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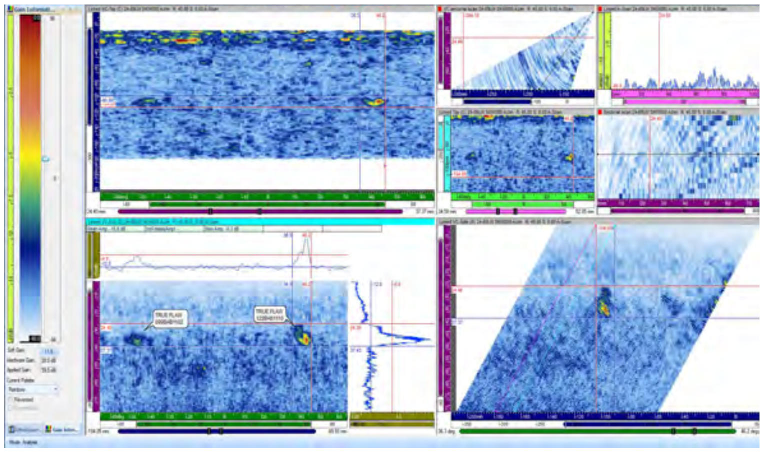
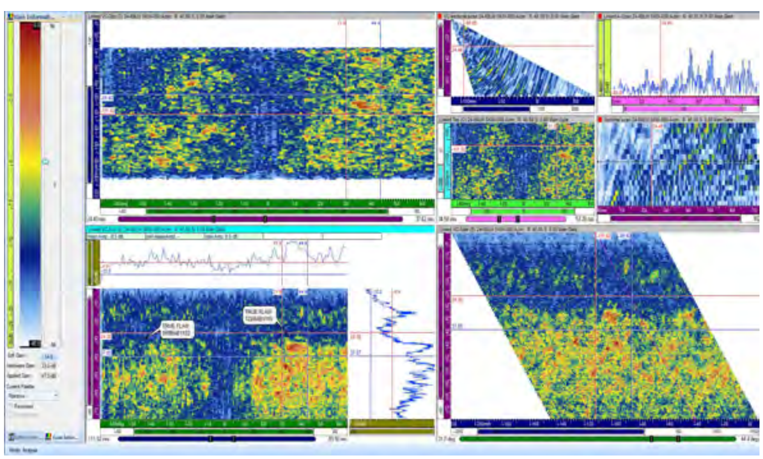
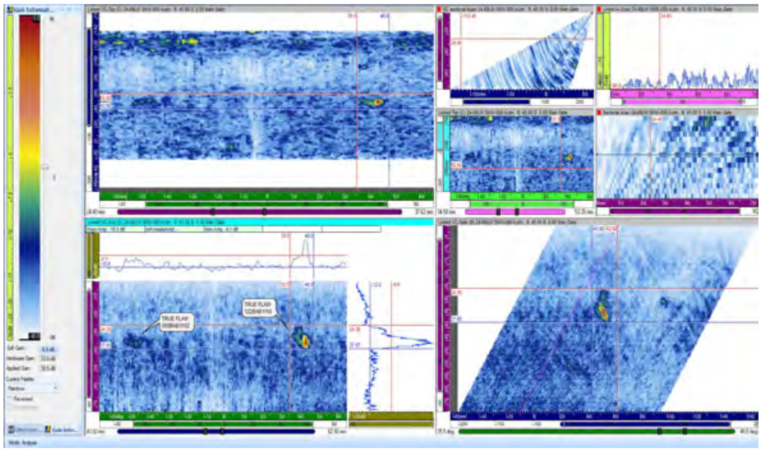
Dynaray, Probe: GEIT 115-000-763, Sample 9C-002 True Flaw 122BAB1110_Looking toward pipe, Signal to Noise Ratio: 17.1dB



OmniScan, Probe: GEIT 115-000-763, Sample 9C-002 True Flaw 122BAB1110_Looking toward elbow, Signal to Noise Ratio: 7.9dB



OmniScan, Probe: GEIT 115-000-763, Sample 9C-002 True Flaw 122BAB1110_Looking toward pipe, Signal to Noise Ratio: 15.8dB



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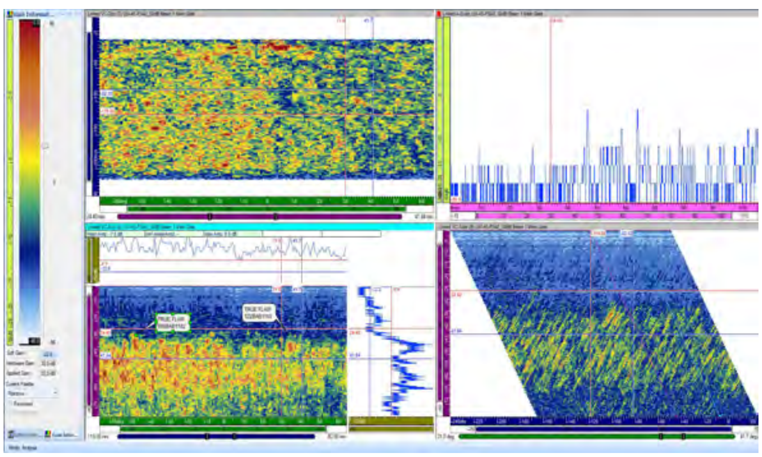
uTomo, Probe: RTD 04-224_45°RL, Sample 9C-002 True Flaw 122BAB1110_Looking toward elbow, Signal to Noise Ratio: 6.8dB



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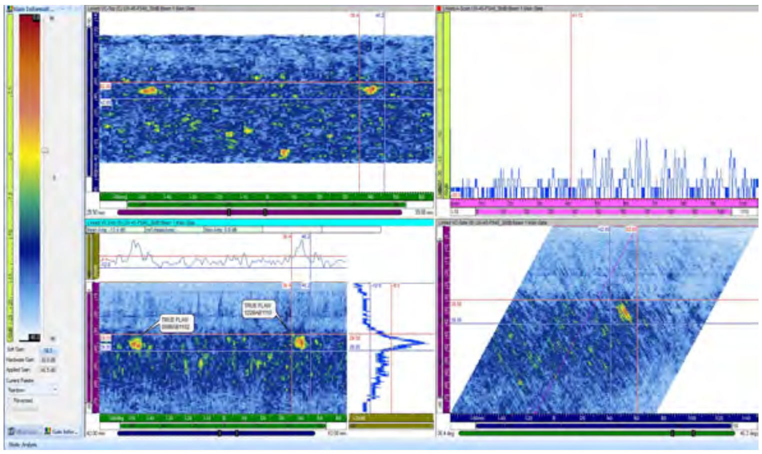
uTomo, Probe: RTD 04-224_45°RL, Sample 9C-002 True Flaw 122BAB1110_Looking toward pipe, Signal to Noise Ratio: 12.0dB



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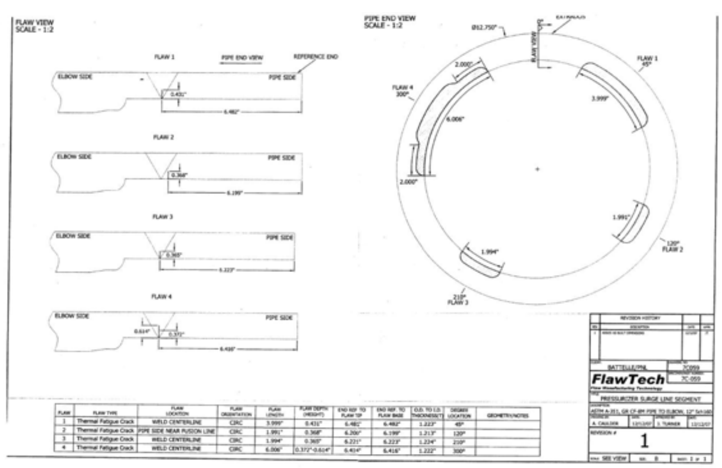
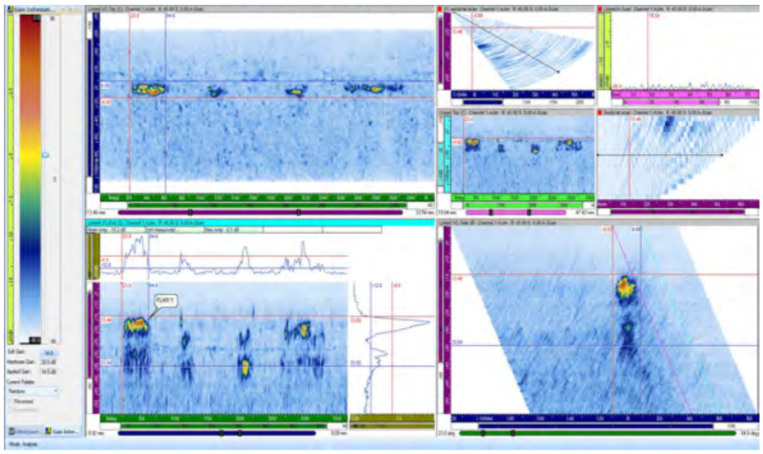
7C-059 Configuration Drawing



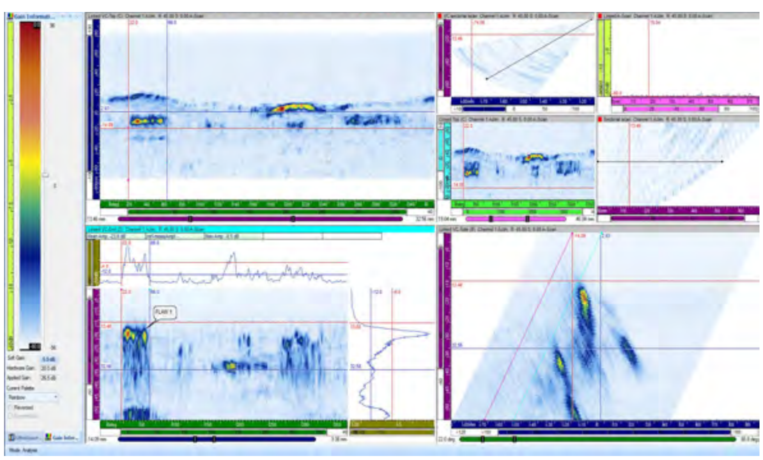
FLAW	FLAW TYPE	FLAW LOCATION	FLAW ORIENTATION	FLAW LENGTH	FLAW DEPTH (HEIGHT)	END REF TO FLAW TIP	END REF. TO FLAW BASE	O.D. TO I.D. THICKNESS(T)	DEGREE LOCATION	GEOMETRY/NOTES
1	Thermal Fatigue Crack	WELD CENTERLINE	CIRC	3.999"	0.431"	6.482"	6.482"	1.223"	45°	
2	Thermal Fatigue Crack	PIPE SIDE NEAR FUSION LINE	CIRC	1.991"	0.368"	6.200"	6.199"	1.213"	120°	
3	Thermal Fatigue Crack	WELD CENTERLINE	CIRC	1.994"	0.365"	6.221"	6.223"	1.224"	210°	
4	Thermal Fatigue Crack	WELD CENTERLINE	CIRC	6.006"	0.372"-0.614"	6.404"	6.416"	1.222"	300°	

EPRI ELECTRIC POWER RESEARCH INSTITUTE

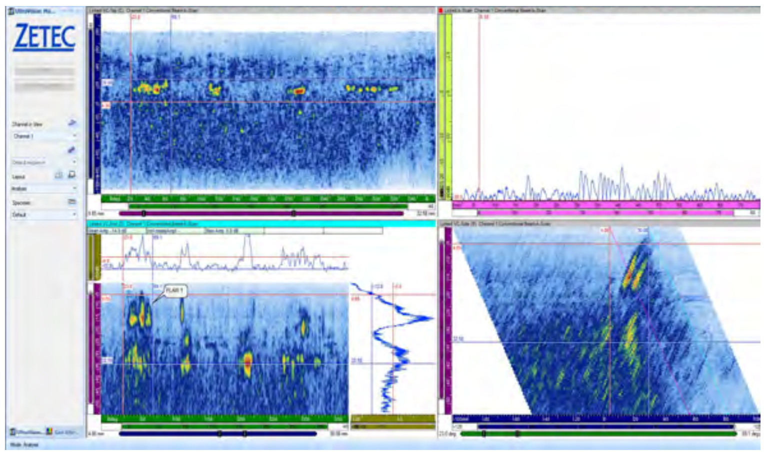
Dynaray, Probe: GEIT 115-000-763, Sample 7C-059 Flaw 1_Looking toward elbow, Signal to Noise Ratio: 19.9dB



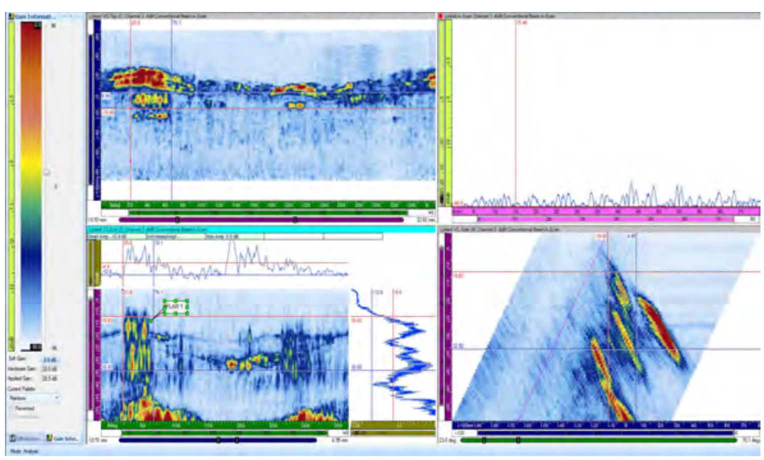
Dynaray, Probe: GEIT 115-000-763, Sample 7C-059 Flaw 1_Looking toward pipe, Signal to Noise Ratio: 21.4dB



Dynaray, Probe: RTD 04-224_45°RL, Sample 7C-059 Flaw 1_Looking toward elbow, Signal to Noise Ratio: 16.6dB



Dynaray, Probe: RTD 04-224_45°RL, Sample 7C-059 Flaw 1_Looking toward pipe, Signal to Noise Ratio: 18.3dB



Observations

EPRI UT Data Obtained From PNNL Cast Elbows

- For TruFlaws:
  - Better signal-to-noise was obtained by looking towards the pipe side versus looking towards the elbow (sometimes up to 6 dB improvement).
  - DYNARAY data yielded better signal-to-noise ratios than the OmniScan for the phased array transducers.
  - DYNARAY and μTomoscan data with conventional transducers provided similar signal-to-noise ratios.
  - The phased array data was generally better than the conventional data (by as much as 5 dB).
- For “Traditional” Thermal Fatigue Flaws:
  - Lower signal-to-noise ratios were obtained from the TruFlaws than the "traditional" thermal fatigue flaws. (The TruFlaws are more than 50% smaller)
  - The phased array and conventional data gave essentially the same signal-to-noise ratios.

Contents

- EPRI Collected Data on PNNL Cast Stainless Steel Piping Samples
- 2D Flexible Array Results on Heavy-Wall Cast Stainless Steel Piping

Ongoing Projects
Inspection Results on CASS Greater than 2" Thick

- Objective
  - Determine optimum NDE parameters for flaw detection and characterization in heavy wall CASS materials
- Method
  - Utilize both conventional and phased array UT techniques
  - Multiple Frequencies (0.5 MHz to 1.5 MHz)
- Initial Results
  - Inspection angles larger than 40° were not effective for flaw detection.
  - Ultrasonic frequencies greater than 0.5 MHz were not useful.
- New Cast Data Acquired by EPRI
  - ~35-inch (889.0 mm) diameter cast stainless steel pipe with a thickness of ~4.72-inch (120.0 mm)
  - TruFlaw Thermal Fatigue Cracks (15 mm & 30 mm TWE):
  - 500 kHz 2D Flexible Array
  - 0-50° L Sector Scan

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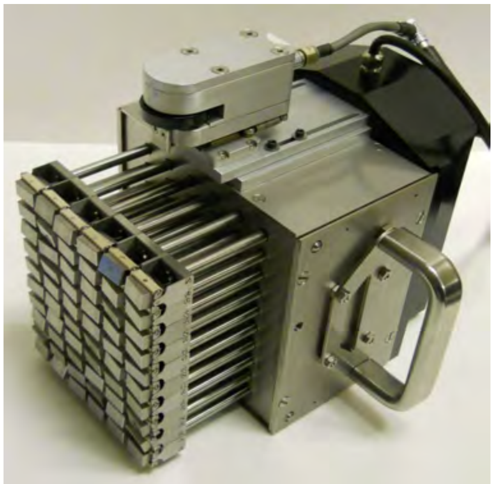
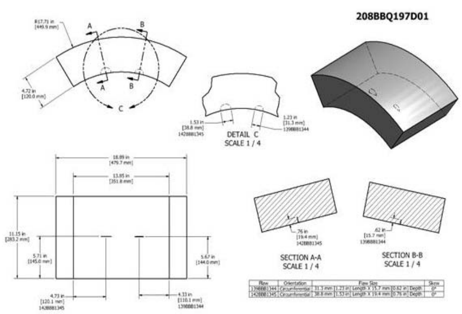
Imasonic Flexible Array Transducer

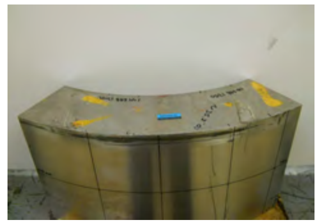
- Frequency
  - 500 kHz
- Element Configuration
  - 6 X 10 Matrix Array
  - 109 mm x 125 mm
  - ~13lbs

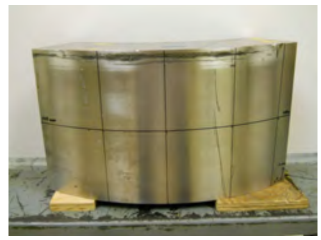


20

Sample 208BBQ197D01 Design Drawing
35.42"OD, 4.72" Wall thickness





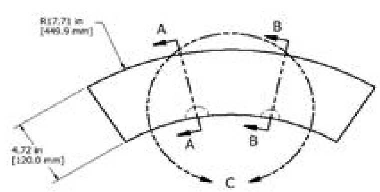


Design Flaw Height:15 mm

21

EPRI ELECTRIC POWER RESEARCH INSTITUTE

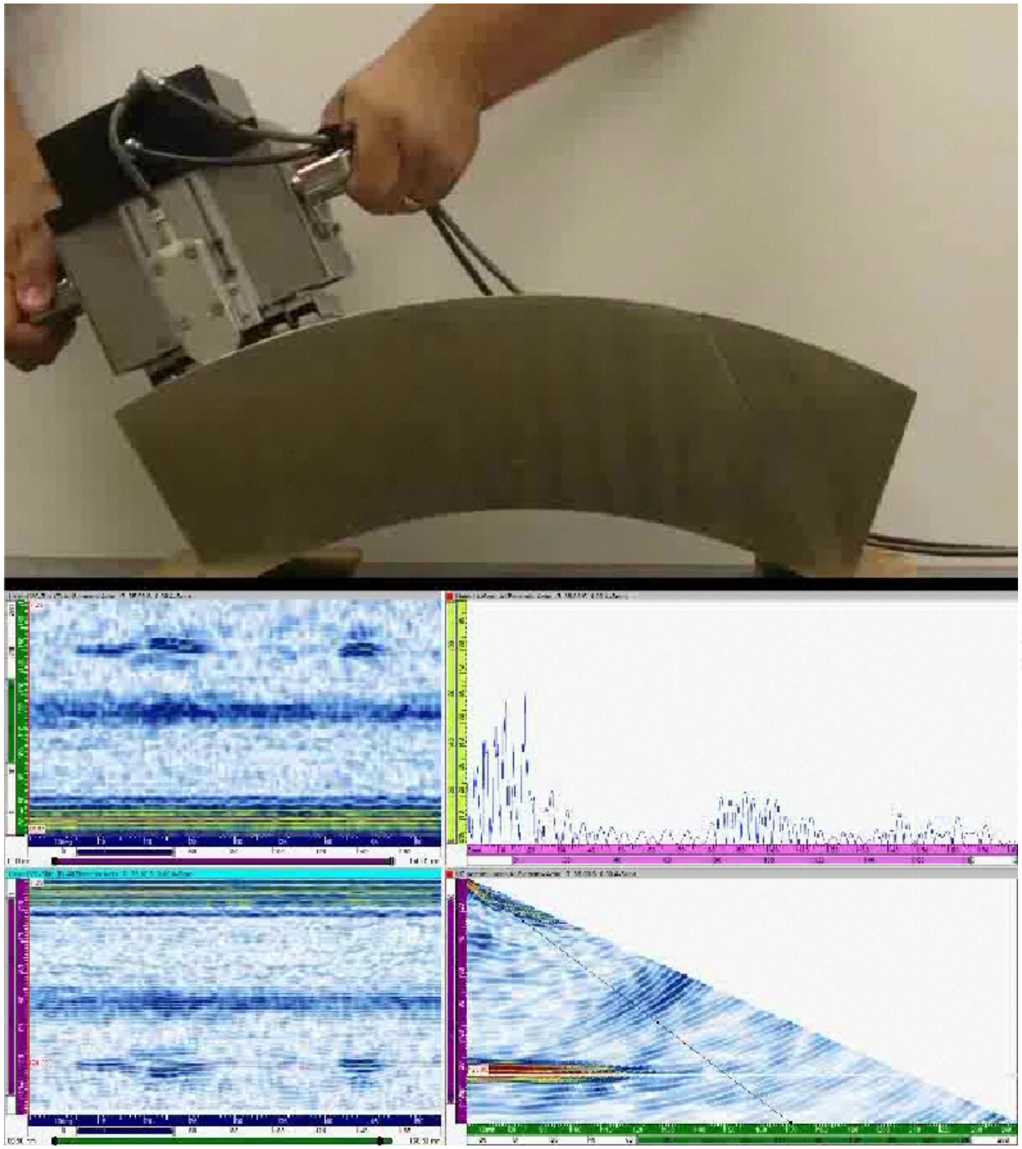
2D 500Khz Flex Array Scanning

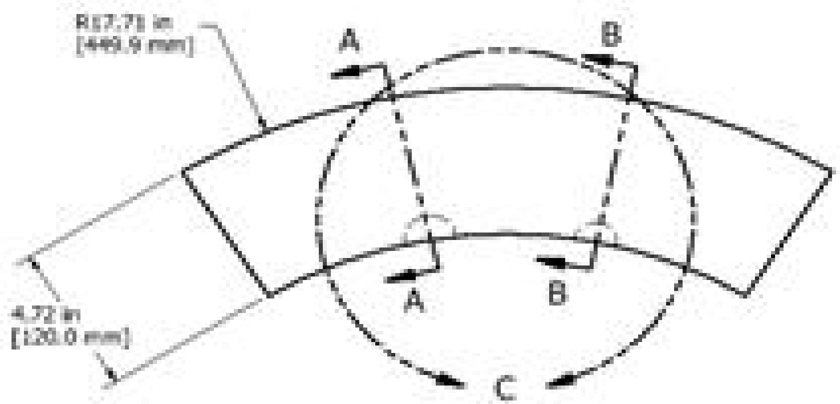


22

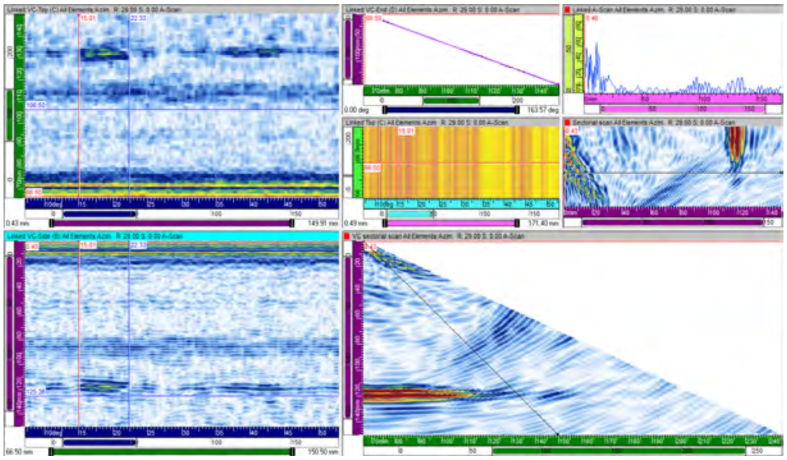
EPRI ELECTRIC POWER RESEARCH INSTITUTE

2D 500Khz Flex Array Scanning





DYNARAY, Sample 208BBQ197, Flaw 142BBB1345 LKDN, Probe: 2D 500KHz Flexible Array, Detection Angle 29°, Measured Flaw Length: 2.26”



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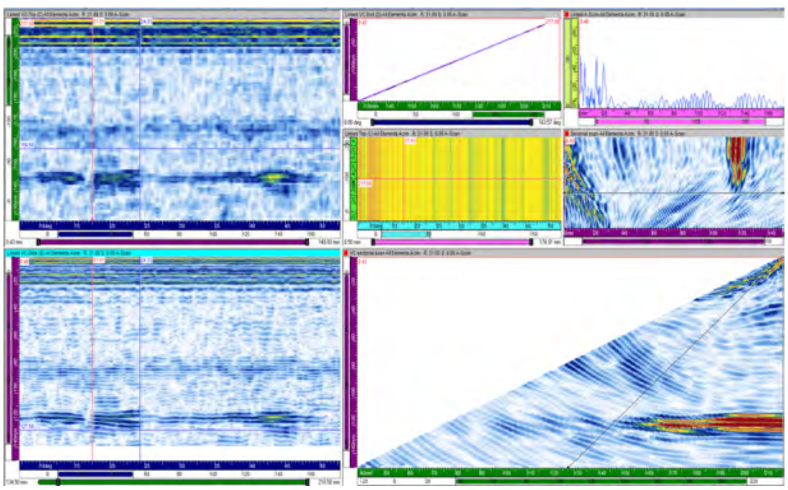
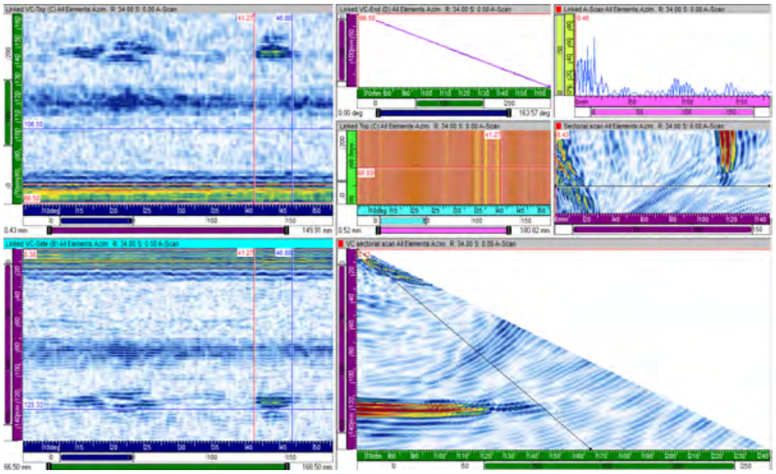
DYNARAY, Sample 208BBQ197, Flaw 142BBB1345 LKUP, Probe: 2D 500KHz Flexible Array, Detection Angle 31°, Measured Flaw Length: 2.10”



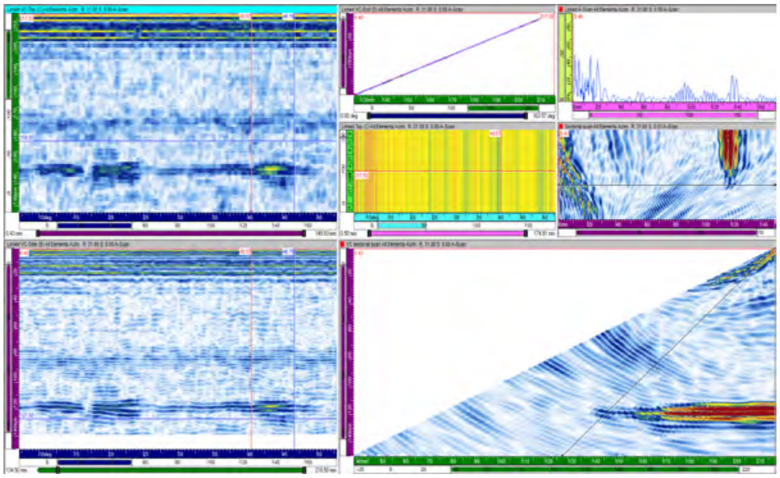
24

DYNARAY, Sample 208BBQ197, Flaw 142BBB1344 LKDN, Probe: 2D 500KHz Flexible Array, Detection Angle 34°, Measured Flaw Length: 1.73”



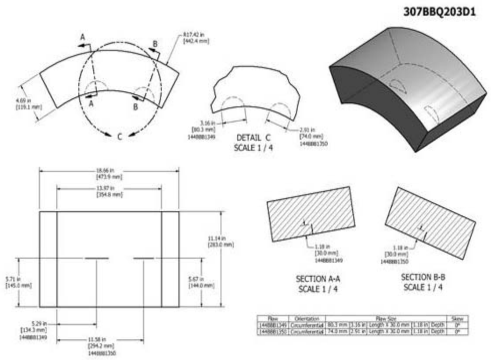
25

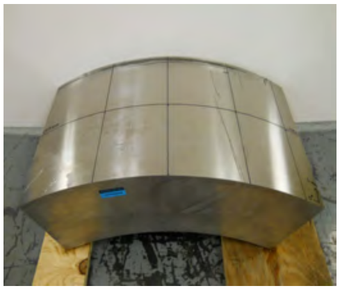
DYNARAY, Sample 208BBQ197, Flaw 142BBB1344 LKUP, Probe: 2D 500KHz Flexible Array, Detection Angle 31°, Measured Flaw Length: 1.91”



26

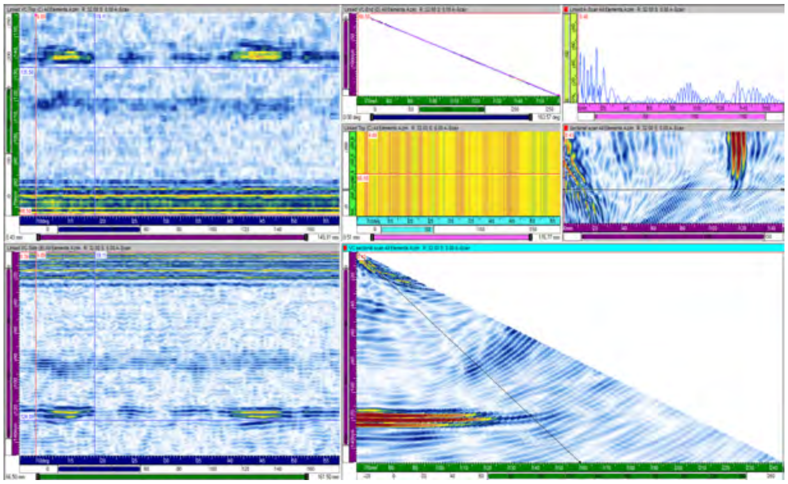
Sample 307BBQ203D01 Design Drawing 34.82”OD, 4.69” Wall Thickness



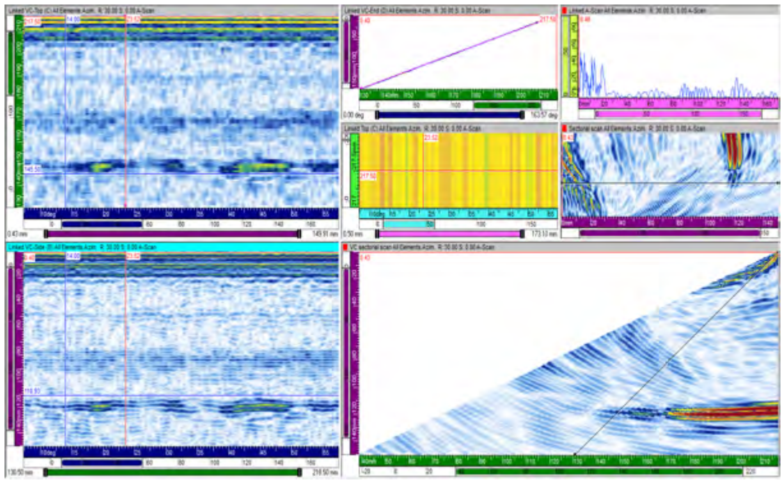


Design Flaw Height:30 mm

DYNARAY, Sample 307BBQ203D01, Flaw 142BBB1350 LKDN, Probe: 2D 500KHz Flexible Array, Detection Angle 32°, Measured Flaw Length: 2.84”

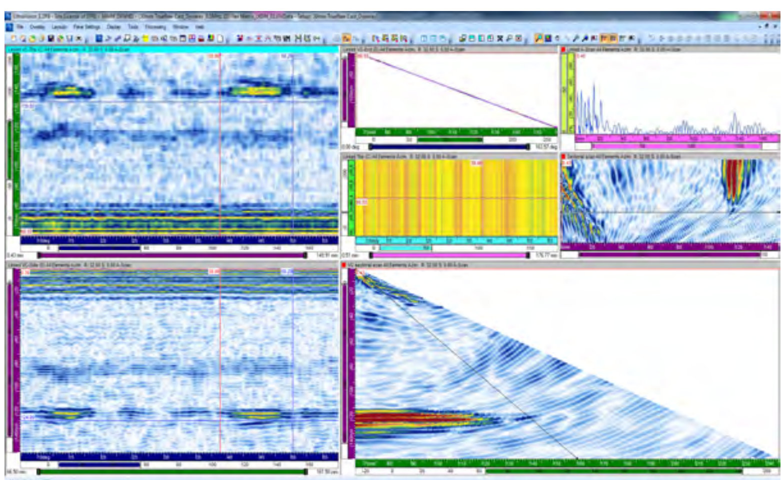


DYNARAY, Sample 307BBQ203D01, Flaw 142BBB1350 LKUP, Probe: 2D 500KHz Flexible Array, Detection Angle 30°, Measured Flaw Length: 2.94”



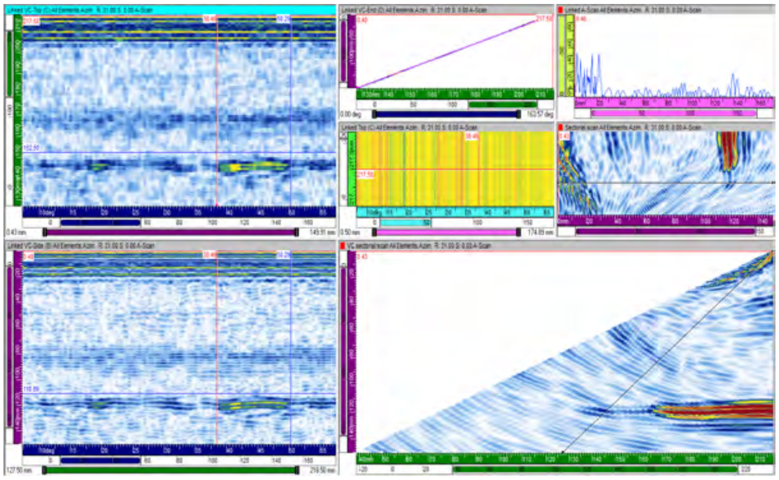
29

DYNARAY, Sample 307BBQ203D01, Flaw 142BBB1349 LKDN, Probe: 2D 500KHz Flexible Array, Detection Angle 32°, Measured Flaw Length: 3.53”



30

DYNARAY, Sample 307BBQ203D01, Flaw 142BBB1349 LKUP, Probe: 2D 500KHz Flexible Array, Detection Angle 31°, Measured Flaw Length: 3.65”



Preliminary Conclusions

- The 500 kHz 2D flexible array was able to detect the thermal fatigue cracks in both specimens.
- The lower angles consistently performed better (~31° on average).
- Ultrasonic responses were similar regardless of the beam direction.
- The deeper designed cracks provided better signal responses.
- Tip signals were not available for crack depth sizing.
- Future work:
  - Comparison of measured versus true flaw length.
  - Evaluation of 2D flexible array on other samples.

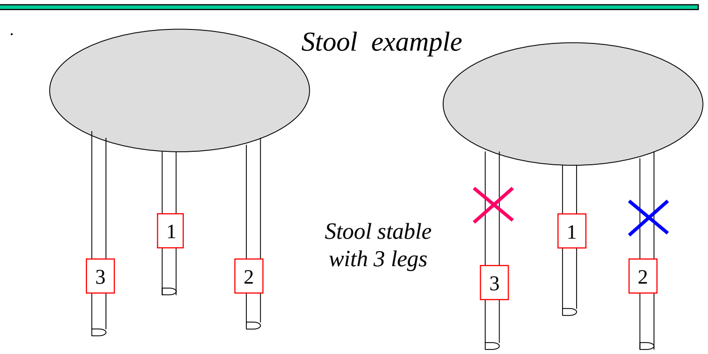
Together…Shaping the Future of Electricity

AGING MANAGEMENT, IN-SERVICE INSPECTION AND INTEGRITY ASSESSMENT FOR FITNESS FOR SERVICE OF CASS COMPONENTS ON REACTOR COOLANT PRIMARY CIRCUIT

Industrial and Strategy aspects

Georges. BEZDIKIAN
Senior Consultant Engineer
Georges Bezdikian Consulting Co.
georges.bezdikian@orange.fr

CAST DUPLEX STAINLESS STEEL COMPONENTS INTEGRITY ASSEMENT AND FITNESS FOR SERVICE

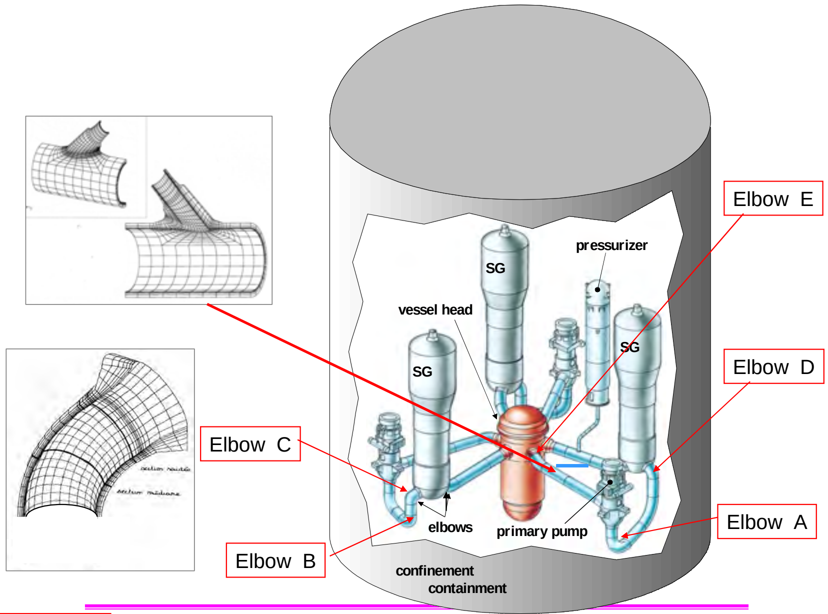


1 Metallurgical aspect aging and thoughness evaluation

2 In-Service inspection flaw characterization

3 Mechanical analysis Integrity assessment

Fitness for Service



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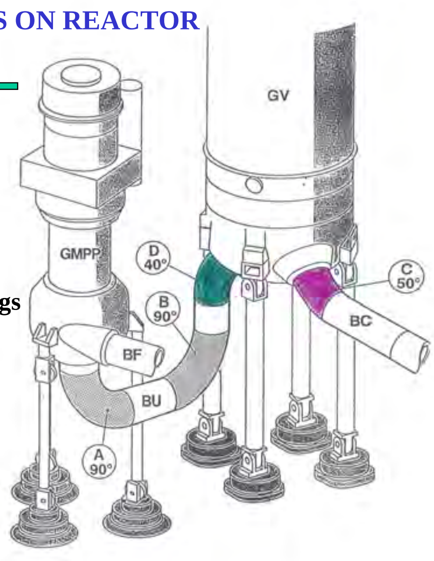
CAST DUPLEX COMPONENTS ON REACTOR COOLANT CIRCUIT

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

Cast Materials concerned :
- CF 8
- CF 8 M ⇦
- CF 3



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THERMAL AGING OF CAST COMPONENTS IN PRIMARY CIRCUITS IMPORTANT POINTS

R&D and Engineering investigations and studies:

- **understanding of aging problem and mechanism (period 80s & beginning of 90s)**
- **the first aging forecasts were formulated (prediction formula),**
- **variations in manufacturing processes from different suppliers (founders) were subjected to very detailed study,**
- **the first radiographic checks were performed on the most sensitive hot leg and cold leg elbows, to demonstrate that foundry flaws in the walls were stable, compared with the original checks. Surface tests were also carried out for emerging flaws,**
- **mechanical resistance was generically analyzed, toughness evolution during time in operation at operation temperatures (325°C – 285°C).**

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MATERIALS, ASSESSMENT and IN-SERVICE INSPECTION PROGRAM : OBJECTIVES AND CONTENT

OBJECTIVES

- Knowledge Thermal ageing phenomenon 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 to justify behaviour in all case of loading (normal, upset, emergency and faulted)
- Supported by a large R&D program

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)
- Better evaluation of the fatigue and tearing behaviour of the casting defects
- Assessement of the margins included in the mechanical analyses

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STUDIES ON PROPERTIES OF AGED MATERIALS (1/2)

Results after R&D actions during 80's until beginning of 90's

AGING MECHANISMS

⇒ 2 Phases : Austenitic phase + Ferritic phase (10 to 30 % vol.)
⇒ Spinodal decomposition of the Ferritic Iron – Cr Solution
⇒ Associated worst situations high ferrite content in percent > 20%

FRACTURE MECHANISMS

- Embrittlement and hardenning of the ferrite (unmixing of the ferritic Iron-Cr solid solution)
- Cleavages in ferrite grains – Bridging by austenite ligaments
- A continuous energy input is needed to extend the cracks

AGING PARAMETERS

Most significant parameter %Cr content + %Si content + %Mo content

Manufacturing parameters heat treatment solution (1 or 2 heat treatment)

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STUDIES ON PROPERTIES OF AGED MATERIALS (2/2)

METALLURGIC SURVEILLANCE PROGRAM

Results after R&D actions during 80's

- 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*) with Cr* = Cr eq J = f (Kcv)
- To understand the aging mecanism
  - ✓ Ingots cast at the same as the components in operating was collected during the fabrication and in the beginning of 80's was introduce in furnaces at different temperatures
  - ✓ Laboratories aging treatment

    285°C ⇐ Temperature range ⇐ 400°C

    Times up to 100, 000 Hours
- Engagement of ISI program to characterize cast defects size

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PROBLEM IMPORTANT POINTS

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

- Ductile tearing resistance decreasing in relation with 2 phases
  1st One hight chromium contain and Chemical composition, and 2nd one ferrous contain more than 20%

☞ **Possible cast defects needing ISI (characterization)**

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

- Margins for rupture assessment decreasing with time in operation needing integrity assessment and toughness evaluation.

☞ **and planning for component replacement if necessary.**

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

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

FITNESS FOR SERVICE ; Parameters for Integrity Assessment :

❶ Definition of acceptance Criteria (metallurgical aspect)

The criteria /sensitivity to thermal ageing is Chromium equivalent

- C*éq = %Cr + %Si + %Mo
- ferrite content for cast material.

❷ By inspection NDE on components characterization of cast defects size

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❶ Cast Duplex Stainless steel components on Primary circuit

Hot Elbows and Cold elbows

Creusot Loire (1) ***CF 8 M***
Manoir (FAM) (1) ***CF 8 M***
Henricot ***CF 8 M but with Cr*eq. < 23 %***

Laterals

Manoir (FAM) (1)
Henricot ***Cr*eq. < 23,5%***

Cast valves casing RCP / RIS

Manoir (FAM) (1)
Henricot ***Cr*eq. < 23,5%***

Primary pump casing GMPP George Fischer ***CF 8***

(1) **Only Creusot Loire et MANOIR** are concerned by thermal aging
=> Cr* > 23,5%

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❷ Cast Duplex Stainless steel components on Primary circuit

MATERIAL PRATICALLY NOT SENSITIVE TO THERMAL AGING

It was identified that some material are not pratically concerned by thermal aging phenomenon

- CF 3
- CF 8
  - CF 8 material concerned primary pump casings, from the R&D program it was identified that the decreasing of toughness is not significative under thermal aging

    On French PWR fleet of units, primary pump casings are not concerned by CASS termal aging.

    Cr* under criteria Cr* < 23.5 % (largelly under 23.5 %)
  - CF3 same remark than CF8
- Case of CF8M Henricot elbows are Cr* < 23.5% (% of Mo are very low) in consequence not sensitive to thermal aging
- Centrifigated cast components : CF 8 straight pipe on MCL are not concerned by thermal aging also

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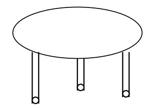
METHOLOGY APPLIED ON CAST DUPLEX STAINLESS STEEL COMPONENTS

3 legs - Stool



The methology applied was engaged in three phases and important steps in parallel + Industrial strategies aspects by components

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

Classification of all 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 conditions of loading Normal, Upset, Emergency and Faulted
  - 2nd category (level A ASME Code)
  - 3rd category (level C ASME Code)
  - 4th category (level D ASME Code)
- Industrial strategy on Plants

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MAJOR PARAMETERS

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

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ACTION ❶ - MATERIAL PROGRAM on THERMAL AGING and DATA BASE

❑ Actions => Metallurgical aspects material properties - Toughness evaluation associated with expertises and elbows replacement during SGR for expertises

- **58 PRODUCTS :**
  - CF 8
  - CF 3
  - CF 8 M

All cast duplex SS components: CF8 / CF8M
*** Static CASS CF8M/CF8, and**
*** Centrifugated CASS components CF8**

- **ORIGINE :**
  - FRAMATOME
  - EDF (Ingots and special products available)
  - Litterature review

Data bases :

Temperature range	300°C to 400°C and also 285°C to 300°C
Aging time	0 to 100 000 h
Chemical composition	Carbon 0.018 % to 0.009 %
	Chromium 18.4 % to 23.1 %
	Ferrite (δ) 5 % to 45 %

- Data bank cover all on site components and al manufacturers Elbows, nozzles, pump casing and valves casing

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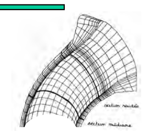
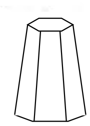
THERMAL AGING MATERIAL PROGRAM DATA BASE



- **CHECK VALVES FROM PLANTS**
  - 4 Check valves CASS casings
    - Ferrite containt 18 % to 24 %
    - Operating time + 60 000 h
    - Toughness and tensile and charpy measurements

- **SPECIMEN FROM INGOTS MANUFACTURED WITH ORIGINAL ELBOWS**
  - cold and hot elbows aged in furnaces at temperature range 285°C <=> 325°C <=> 400°C,
  - Toughness and tensile, CT and charpy measurements



Fundry ingot with elbow manufactured

- **SMALL SPECIMEN FROM ON SITE COMPONENTS**
  Cut off from 5 hot elbows CT 10-5
  60 000 h to 100 000 h of operation and 12 specimen from each elbows

- **ELBOWS FROM SGR IN EDF PWR PLANT**
  3 hot elbows and 2 cold elbows in 1995 with 100 000 h on operation
  Program up to 1998 → 2005

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Boat sample specimen
For direct toughness
measurement

To determine ageing characteristics by boat sample cutting off

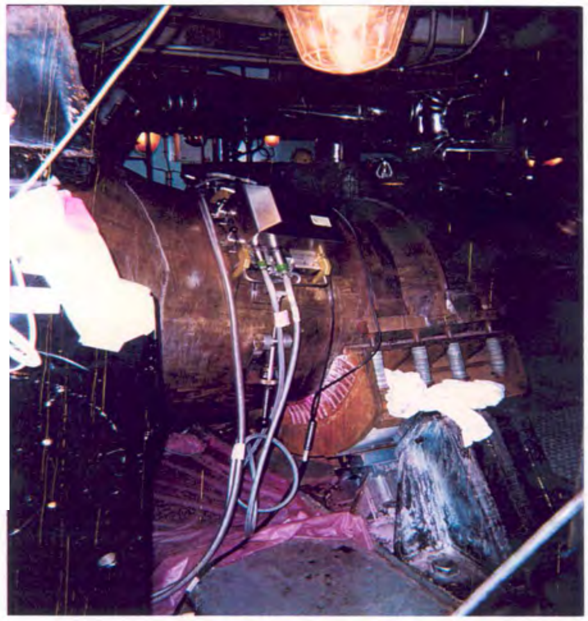
on elbows

⇒ boat sample cutting off

or small specimen

⇒ in situ toughness measurement

by follow on ingot aged in laboratory



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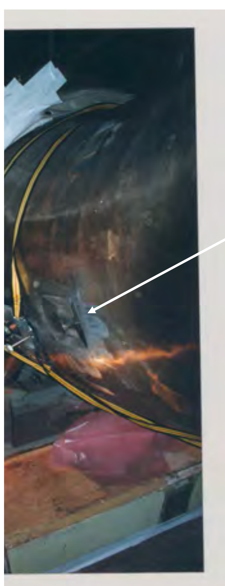
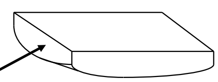


Boat Sample



CT 10 – 5 Specimen

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ELBOWS REPLACED DURING STEAM GENERATORS REPLACEMENT

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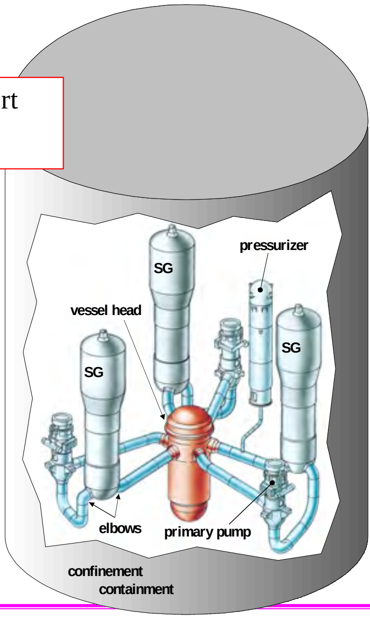
R&D Program in Support

Mettalurgical aspects



2 major Programs

A – Expertises specimen from elbows removed during SGR

B – Expertises of CT specimen (CT10-5) cutt off on surface of elbows

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Actions Program - What it is needed to do? 1/3

Knowledge of fabrication and history of manufacturing

- History of cast elbows fabrication for each elbows
  - Manufacturing processes from different suppliers were subjected to very detailed study.
    - Example in France : **Manoir** [double heat treatment (temperature, duration and conditions of heat treatment)], and
    - Example in France : **Creusot Loire** [simple heat treatment (temperature, duration and conditions of heat treatment)],
  - Detailled knowledge chemical composition of each elbows
    - %Cr content %Si content %Mo content
    - % ferrite content
- History of fabrication inspection results (Radiography, etc) and identification of flaws (location, size, situation,)
  - ASTM 2 - ASTM 1
- Hierarchical classification of each elbows and identification sensitivity to thermal aging

N° Elbow	**Chemical composition**	Cr* (Cr eq)	% ferrite	Flaws
001	%Cr + %Si + %Mo	---------	% ferrite	ASTM 2 (7x35)
002				

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Actions Program - What it is needed to do? 2/3

- Metallurgical aspect classification
  - Evaluation of Cr *, for each elbow % Cr , %Si, %Mo Manufacturer report
    Cr * = % Cr + %Si + %Mo
  - Application of prediction formula
  - The prediction of aging was carried out with exprimental results of CASS thermal aging in function of chemical composition and from ingots also elbows or CASS valves casings removed from plants
  - Formulas model is:

Kcu20°C (or Kcv320°C) [X.hour at T°C] = 10 . (a + b %Si + c %Cr + d %Mo)

Kcv = f (T, t, Cr*) J = f (Kcv)

- Prediction formula
  - Hot elbows formula (Manoir or Creusot Loire)
  - Cold elbows + lateral + Valve casing formula

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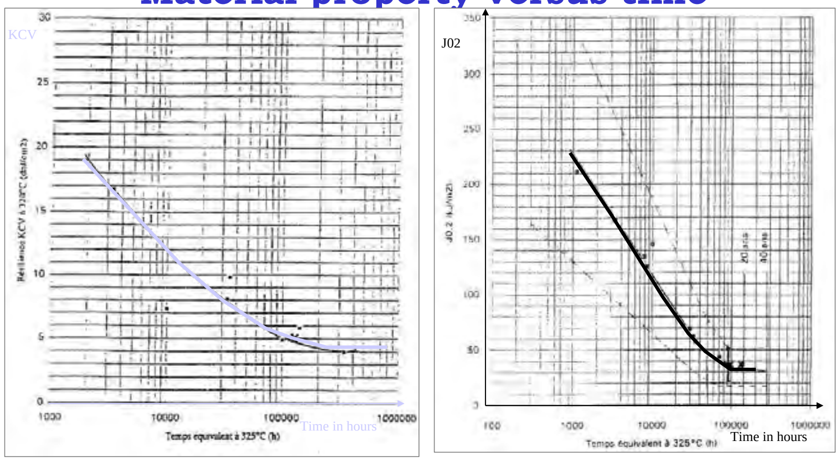
Material property versus time



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Actions Program - What it is needed to do? - 3/3

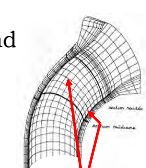
- Identification of flaws detected or characterized during manufacturing by funder (ASTM 1 or ASTM 2) Original inspection results.

REFERENCE DEFECT <u>covering</u> all sizes possible of flaws in function of capabilities of Inspection method

- Analysis of surface emerging flaws or inside thickness flaws (shrinkage cavities) identified and surface cracks repaired during component fabrication : shape, dimensions.

⇒ Determination of a reference defect : a = 10 mm ; 2c = 40mm assumed as a surface crack or inside thickness crack (conservative approach)

⇒ REAL DEFECT after In-Service Inspection at real location and real dimensions;size (length & high) and maximum values



Reference defect postulated at the intrados

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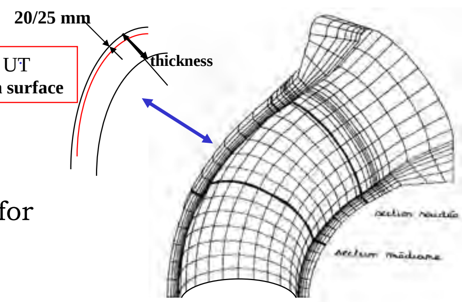
PROGRAMME OF INSPECTION

- Actions => Inspection

Inspection different options were explored

- UT

Zone concerned by UT
First 20/25 mm from surface



- Gamma Radiography
- PT inspection examination for emerging on surface and if necessary replica

UT examination was only actually under R&D development not yet industrial tools

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**

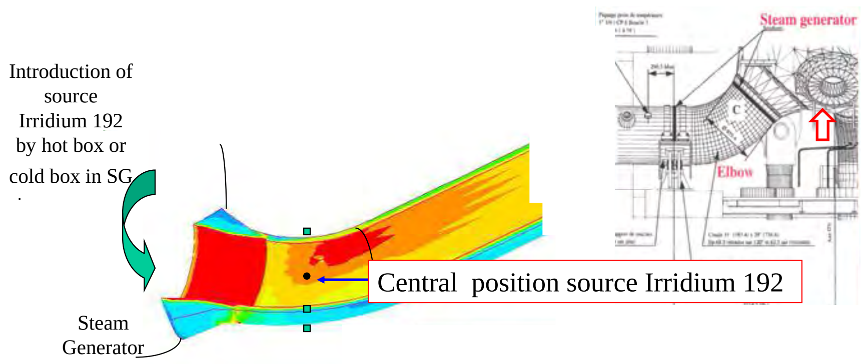
☞ **Standard gamma radiography** (gammagraphy) for elbow; to characterise flaw inside thickness of elbow

and on radio film ; application of contrast measurement by optical density digitization

☞ **PT inspection examination for defect applied on outside emerging surface – Periodic inspection and possible to perform Replica**

☞ **Special tools to follow the toughness decreasing measurement on site on components using a dedicated**

Method of ageing Measurement
Based on Thermal Electric Power TEP



Gamagraphy central source Irridium 192

Simple elbow wall (thickness)

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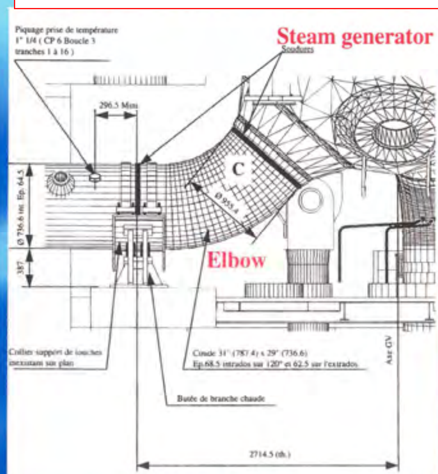
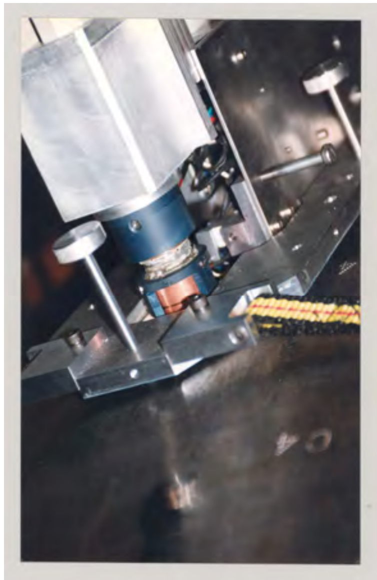
APLLICATION TEP ON REEL ELBOW ON SITE



- 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



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Cast elbows replacement for expertises during SGR

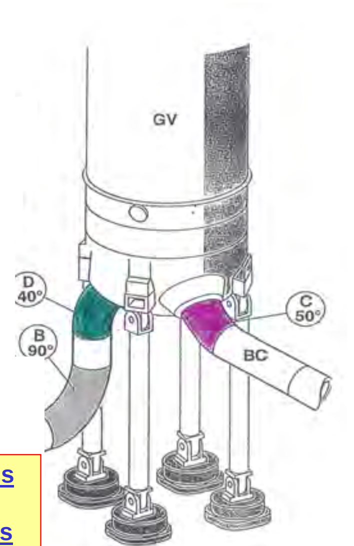
=> Dampierre 3 in 95, replacement of 5 elbows 37 C , 38 C et 43 C and elbows 37 D et 38 D,

=> Gravelines 4 in 2000, replacement of elbows for expertises 49 C - 43 B and coudes 49D and 45C

=> Tricastin 4 in 2004, replacement elbows 35 C et 36 C.

Expertise of elbow 36C

Very good correlation between toughness Measurement on specimen cut off on elbows removal also expertises on elbows removed and prediction formulas



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SGR and CAST DUPLEX STAINLESS STEEL ELBOWS on REACTOR COOLANT CIRCUIT REPLACEMENT

- 4 elbows removed after **GRAVELINES unit 4 SGR** in 2000
- 2 elbows removed after **TRICASTIN unit 4 SGR** in 2004
- 1 elbows removed after **CHINON B unit 1 SGR** in 2007

CHINON B1 SGR = ELBOWS replaced
Transportation Steam Generator and elbow
Welded in the factory AREVA at St Marcel

GRAVELINES 4 SGR = ELBOWS replaced

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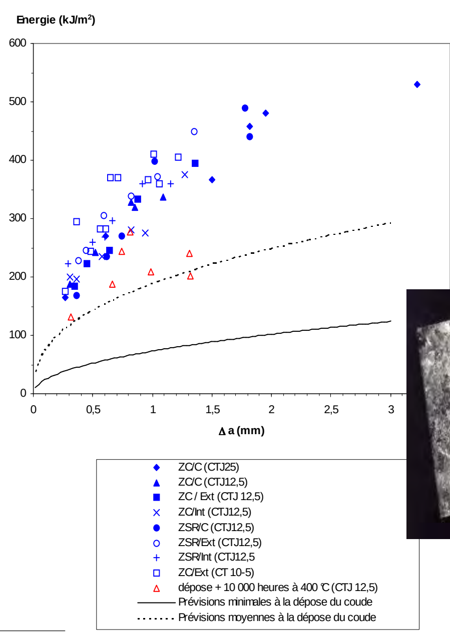

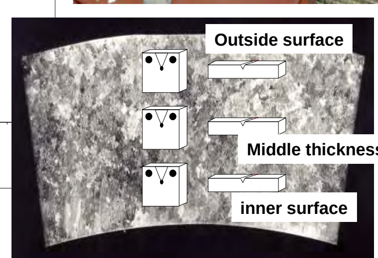

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SPECIMEN FOR THERMAL AGEING EVALUATION

TENSILE SPECIMEN

CHARPY SPECIMEN

TOUGHNESS CT SPECIMEN

These specimens were cut off from :

- **inside surface zone,**
- **medium thickness zone, and**
- **outside surface zone.**

Also, zones were selected on specimen in different parts of the cast elbows:

- **current zone,**
- **feedhead foundry zone,**
- **and also cooler foundry zones.**

FURNACES FOR AGING LABORATORY AT LES RENARDIERES EDF R&D

3 furnaces at CHINON (hot cell lab) and 3 furnaces at Les Renardières (R&D lab)
[at different temperatures 325℃ – 350℃ et 400℃]

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R & D Complementary Program
LARGE and SEVERAL TESTS - SCALE 1 and SCALE 2/3

☞ **Scale 2/3 thermal aged elbow with surface cracks -pressure + bending load**

Stable crack growth

☞ **Scale 1 Thermal aged cast defect**

Pressure + bending
No crack initiation

CONCLUSION

No instable crack growth and through wall cracks for load in the range of plant applied level D Loads.

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TESTS ON AGED CAST ELBOWS

OBJECTIVES

- Check out that it is possible to obtain a large amount of stable crack extention, even in low toughness steels
- Check out the validity and the accuracy of refined Fe method analyses (based on J Parameter)

DESCRIPTION OF THE TESTS

- 2/3 scale of primary circuit elbows (O.D. = 580 mm, t = 44 mm)
- Accelerated thermal ageing treatment at 400° C
- Machined notch : semi-elliptical shape, outer surface

Test I.D.	Test Temp. (°C)	Loading Conditions	Notch location	Notch orientation	Notch Lentgth and depth 2c-a (mm)
SEM1	320	In-plane bending	Flank	Longi.	210 - 10.5
SEM2	320	In plane bending	Near flank*	Circum	88 – 14.7
SEM3	60	Pressure +	Flank	Longi.	210 – 10.5
		In-plane bending	Near flank*	Circum *15° to. towards extrados	88 – 14.7

- « SEM» large test facility

MAIN EXPERIMENTAL RESULTS – TEST ANALYSES

- UP TO 12 mm OF STABLE CRACK GROWTH

- **Other Experimental test - Scale 1 elbow at 325°C temperature and 155 Bar pressure**

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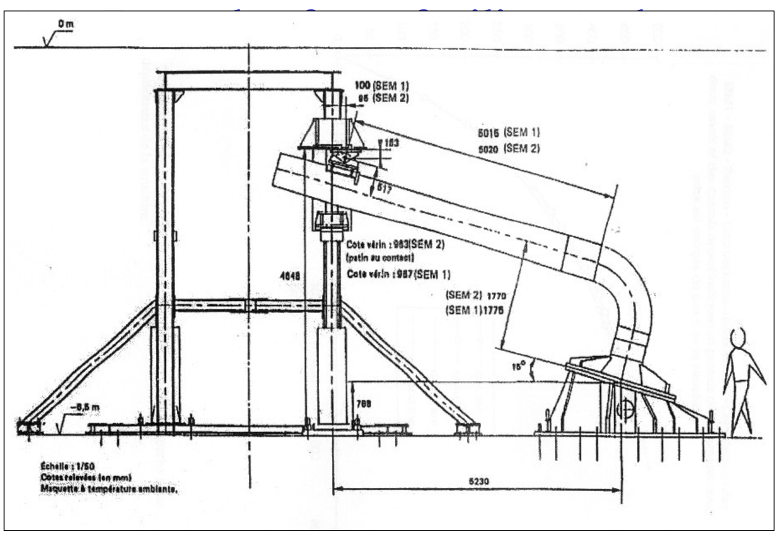
Test facilities at EDF R&D Laboratory



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Tests on aged elbows :

-Three reduced scale (2/3)

- and one scale 1

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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 by Group A Materials

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METHODOLOGY USED FOR THE RESISTANCE ASSESSMENT OF CASS COMPONENTS

REFERENCE DEFECT covering all sizes possible of flaws

- Analysis of surface cracks (shrinkage cavities) identified and repaired during component fabrication : shape, dimentions

⇒ Determination of a reference defect : a = 10 mm ; 2c = 40 mm assumed as a surface crack (conservative approach)

«GENERIC» CRACK ASSESSMENT

- Reference defect postulated in all zones of the elbows mainly at intrados
- Fatigue crack growth evaluation (transients applied during 40 – 60 years)
- Ductile tearing analysis :
  - Normal and emergency conditions : no crack initiation
  - Faulted conditions : limited amount of tearing (< 3 mm)
- End-of-life toughness properties are considered

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MECANICAL BEHAVIOUR OF ELBOWS

- **ANALYSIS OF DETECTED FLAWS**
- **GENERIC ANALYSIS OF REFERENCE DEFECT (10 x 40)**
  - All the elbows all type of loading and all position of cracks
  - Use of the specific bahavior 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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Mechanical analysis elbows for Plants lifetime – 40 years and 60 years

This study focuses on Fracture Mechanics failure modes:

- o brittle fracture,
- o ductile tearing
  - - ductile tearing initiation
  - - tearing instability.

Calibration of safety factors for piping in the ductile tearing regime

Using the above probabilistic calibration methodology, partial safety factors depend both on :

- o the target probability of failure,
- o and on the scatter or uncertainty of input data.

The target probability of failure is defined :

- o for tearing initiation :
- o for instability :

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safety factors should be used with the following characteristic values of the main parameters to insure the consistency of methodology :

- o 16% fractile (mean minus one standard deviation) for toughness $J_{0.2}$ and $J\Delta a$,
- o 5% fractile (mean minus 1.65 standard deviation) for yield strength,
- o 84% fractile (mean plus one standard deviation) for stress and flaw size.

Partial safety factors accepted by the Safety Authority on piping in the ductile tearing regime are a little more conservative as follows; two levels of criteria are defined for integrity studies:

for piping, if the results shows that the criteria

- *global analysis of tearing initiation and stability* are verified,
  in this case the demonstration of integrity is demonstrated,

- *separate analyses of initiation and stability for piping,*
  this second case and criteria is to demonstrate the stability of piping with the absence of crack initiation

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Global analysis of tearing initiation and stability

Criteria 1

Envelope or global analysis of tearing initiation and stability for piping

For the primary pipes components, the first methodology relies on a single equation for both initiation and unstable extension of ductile tearing. The absence of crack initiation and unstable extension of the ductile tearing is justified if :

Level A : Kcp (1.5 C_A, af) < min (K1c/1.5 ; Kjc/1.35)
Level C : Kcp (1.3 Cc, af) < min (K1c/1.35 ; Kjc/1.25)
Level D : Kcp (1.1 C_D, af) < min (K1c/1.2 ; Kjc/1.1)

Kcp is K_I plastic correction ;
C_A is loading condition level A
C_D is loading condition level D
Cc is loading condition level C
af is the maximum crack height at the end of propagation.

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Criteria 2

Separate analyses of initiation and stability for piping

An other analysis is possible if the criteria 1 is not confirmed for a pipe or cast elbow on reactor coolant, particularly hot elbow inlet SG.

The relation J = f (K**cp**) is

$$J = (1-\nu^2) \cdot Kcp^2 / E$$

The 1st methodology :

To demonstrate the global absence of crack initiation and unstable propagation of the ductile tearing is justified if :

Level A : J (1.5xC_A, af) < J0.2
Level C : J (1.3xCc, af) < J0.2
Level D : J (1.1xC_D, af) < J0.2

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Criteria

The 2nd methodology :

Separate demonstration is necessary:

a) the absence of crack initiation if :

Level A : J (1.3xCA, af) < J0.2

Level C : J (1.1xCc, af) < J0.2

b) in ductile range, instability of the crack postulated under 3mm

Level A : J (1.5xCA, af + Δa) < JΔa /2

Level C : J (1.3xCA, af + Δa) < JΔa /1.8

Level D : J (1.1xCA, af + Δa) < JΔa /1.3.

Toughness properties

16% values of J0.2 after 0.2 mm of crack extension

J-Δa curves in the ductile regime

taking into account thermal ageing(hot leg conditions).

Temperature	$J_{0,2}$ (kJ/m2)	J_1 (kJ/m2)	J_3 (kJ/m2)
20°C	48	85	133
320°C	60	110	179

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SUMMARY

- **Fitness for service of elbows has been justified for 40 years and after 40yrs – 60 years**
- **Maintenance strategy with Gamma Radiography each 10 years**
  - → **Standard gammagraphy inside elbow - Central position source Irridium 192 to characterise flaw inside elbow thickness**
  and on radio film application of contrast measurement by optical density numerisation
- **Large validation program has been done and will be completed by on-going actions**
- **Complementary program**
  - « boat samples » from elbows
  - Expertises from 5 elbows SGR since 1995
  - and 4 elbows from SGR in 2000 GRAVELINES 4,
    and 2 elbows from SGR in 2004 TRICASTIN 4,
    and 1 elbow from SGR in 2007 CHINON B 1,
  - and on-going action or coming soon next SGR with elbows removal BLAYAIS 1 -BLAYAIS 2 - CRUAS 4

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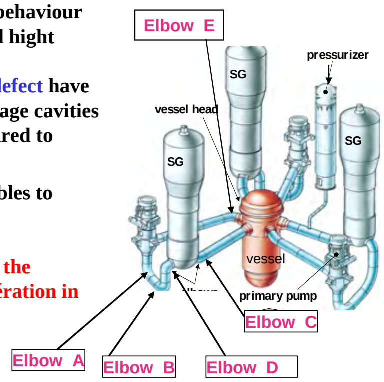
The integrity assessment of cast duplex stainless steel components on plants in operation relies on several Engineering and R&D studies :

- **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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[9]- THERMAL AGEING OF STEELS FROM EXPERTISES AND UNDERSTANDING OF AGEING MECHANISMS TO A MAINTENANCE STRATEGY FOR OPERATING NUCLEAR POWER PLANTS
G. BEZDIKIAN – P. OULD - EOSOPE International Conference – Paris France 2004

Regulatory Issues Related to the Examination of Cast Austenitic Stainless Steel

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

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

May 24-25, 2012

Seattle, WA

1

Regulatory Requirements

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

- 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

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

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

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

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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UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Regulatory Issues

- CASS components on one or both sides 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
- Requests for relief are often required due to coverage issues

5

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Regulatory Issues

- 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.
- Appendix VIII Supplement 9 does not yet exist for CASS materials. Appendix III rules are used for CASS
  - "Cast materials may preclude meaningful examinations because of geometry and attenuation variables."

6

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Progress

- NUREG/CR 7122 "An Evaluation of Ultrasonic Phased Array Testing for Cast Austenitic Stainless Steel Pressurizer Surge Line Piping Welds"
  - Used encoded phased array scans using 0.8 MHz to 2 MHz probes
  - thermal fatigue flaws ranging from 10-50% through-wall in NPS 12 schedule 160 piping were detectable
  - The flaws were accurately length and depth sized in an open examination

7

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UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Progress

- A Code Case is being developed to provide guidance on ASME Section XI Appendix III examinations of cast stainless steel
  - Code Case would give guidance on angles, frequency, and probe aperture
  - Different guidance for different thicknesses of CASS material

8

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

PFM of CASS

- NRC staff were afforded the opportunity to informally review “Probabilistic Reliability Model for Thermally Aged Cast Austenitic Stainless Steel Piping”
- NRC staff provide an extensive list of comments.

9

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Summary

- The difficulties in inspecting CASS components challenges our ability to demonstrate the structural integrity of plants.
- Potential for new degradation mechanisms in CASS components could challenge structural integrity and functionality of the reactor coolant system
- NRC supports the approach to address ultrasonic examination of austenitic or dissimilar metal welds for which with CASS piping material 2” thick or less

10

ZETEC

Zetec Activities Related to Inspection of CASS Components & Welds

4th International CASS Workshop
24-25 May 2012, Seattle (WA), USA

ZETEC

Mission

Zetec is a leading supplier of mission critical NDT solutions for the industry

Our technology, testing methods, integrated systems, and services keep the industry safe, productive, and cost efficient.

2

4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

ZETEC

*a*NDT Solutions, Zetec-Québec

- *a*NDT (advanced Non-Destructive Testing) Solutions
- Market Focus: ''Encoded'' inspection solutions
- Technology Focus: PA UT & Eddy Current Array
- Value Proposition : Expertise
- PA UT Products :
  - DYNARAY® & ZIRCON® product lines
  - UltraVision®, industry leading software suite
  - Standard and custom PA probes
  - Integrated, Customized and Qualified Solutions
  - Customer Support and Field expertise

3

4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

ZETEC

Expertise

- UT Applications Team : mixture of physics engineers & UT industry veterans
- Strong theoretical background in acoustics
- Relevant practical experience gained from :
  - Active participation to various international RRTs
  - Formal qualification exercises in Europe and USA, involving CASS and DM welds
  - In-service inspection on CASS & DM welds using advanced UT techniques
  - Design and implementation of AUT solutions

4

4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

ZETEC

Zetec Activities - CASS

- DYNARAY
- UltraVision
- Industry Support

4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

5

ZETEC

DYNARAY Product Line

Inspection of CASS components requires PA UT system capable to ***efficiently drive low-frequency arrays*** :

- Bandwidth down to 0.20 MHz
- High excitation pulse, 200 V at 50 Ohm
- Pulse width up to 1,000 ns
- High PRF, even for long pulses at 200 V

4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

6

ZETEC

DYNARAY Product Line

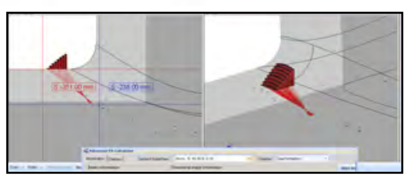
- Launched late 2007
- Used for CASS inspections worldwide : research institutes, laboratories, NDE service vendors
- Configuration : up to ***256 phased array beam forming channels***
- ***Modular concept***, allowing for "reduced configurations and "upgrading" :
  - Non-multiplexed : Lite (64/64PR), 128/128PR, 256/256PR
  - Multiplexed: 64/256PR

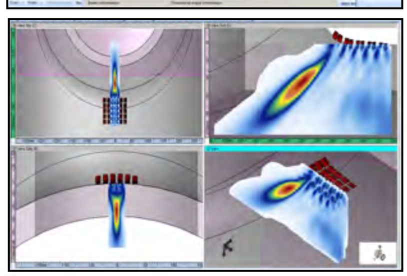
ZETEC

ULTRAVISION

COMPLETE UT AND PHASED ARRAY INSPECTION PACKAGE

- Probe design
- Technique development
- Inspection coverage and capability assessment
- Data acquisition
- Data analysis
- Reporting

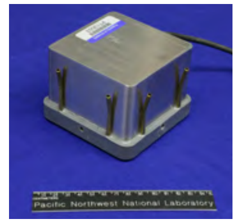


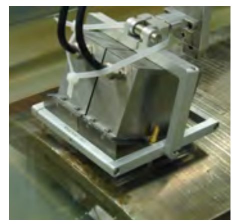


ZETEC

Industry Support

- Long-time collaboration with PNNL and EPRI on LF TRL PA probe design
- Technical support to customers for design and practical implementation of PA probes and examination techniques for CASS components
- Software customization and support for advanced inspection techniques
- Participation to ASME TG on CASS
- Participation & sponsoring of CASS Workshops, ☺





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4th International CASS Workshop, Seattle (WA), USA, 24-25 May 2012

AREVA NP Uddcomb AB Testblocks

Cass meeting Seattle 2012-05-24-25

AREVA NP Uddcomb AB

AREVA

Testblocks

Main circulation

Pump, PWR

AREVA NP Uddcomb AB

Testblocks - 2011-01-04 Confidential - © AREVA NP - Sid. 2

AREVA

Testblocks

Testblock for Outlet Nozzle PWR DAS182

Delivered for

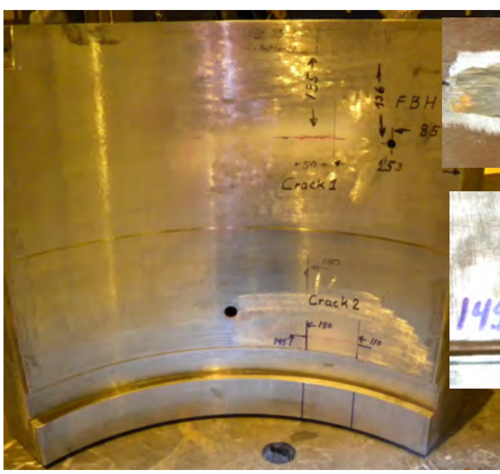
The SERP project

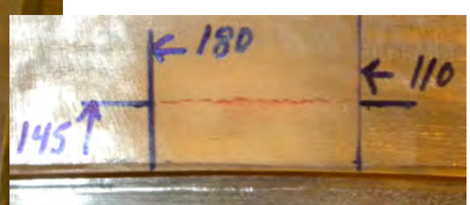
AREVA NP Uddcomb AB

AREVA

System 313 SSC Valve block

Valve block



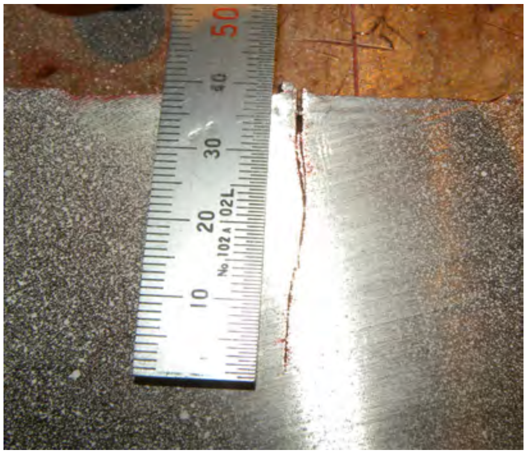


AREVA NP Uddcomb AB

AREVA

R&D defect implant in CASS material

- Trial creating defect during casting process.



AREVA NP Uddcomb AB

AREVA

More cracks in CASS

Iikka Virkkunen, CASS workshop

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

1

What's new since 2011?

2011

- First cracks produced to CASS
- "Can be done"

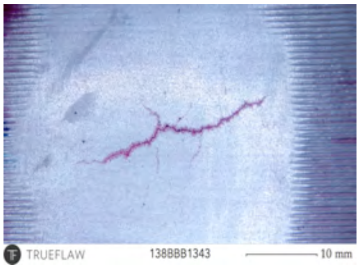
2012

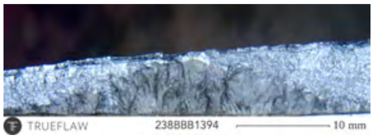
- Greater depth: up to 30 mm
- More experience

TRUEFLAW

2012 highlights

- Collaboration with EPRI
  - Heavier sections
  - Bigger cracks
  - Presented in 9th NDE

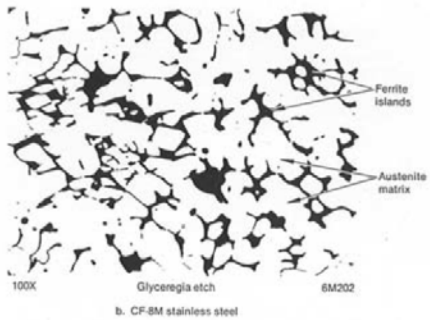




TRUEFLAW

The complexities of CASS

- Complex microstructure
- 10-30 % ferrite
- Subject to thermal ageing



TRUEFLAW

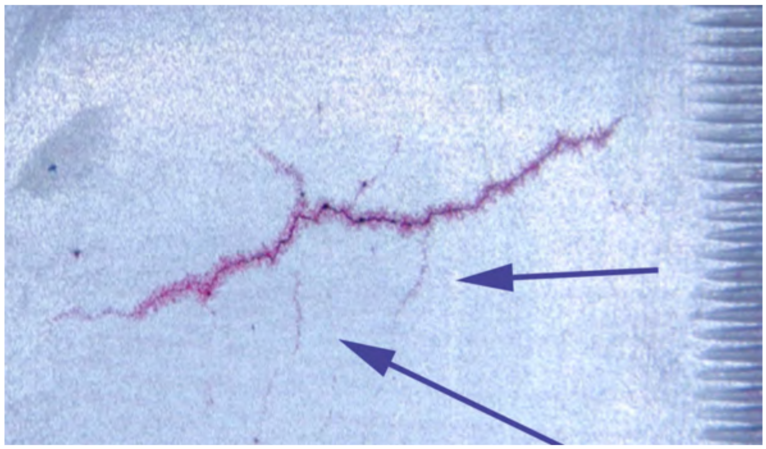
CASS and thermal fatigue

- Austenite and ferrite have different thermal expansion
- Any temperature causes micro stresses between phases
- Increases susceptibility to thermal fatigue?

- Preliminary evidence shows:
  - 20% lower temperature difference needed to make cracks
  - increased susceptibility to secondary cracking

TRUEFLAW

3



Further actions

- Small thermal fatigue test planned to confirm this issue (time permitting)
- Interested to find more information about CASS been used in components susceptible to thermal fatigue
- Implications for NDE
  - array of micro-cracks => noisier than expected

TRUEFLAW

Conclusions

- Trueflaw has
  - experience and
  - proven capacity to

  manufacture real cracks to CASS

TRUEFLAW

IMASONIC

Imasonic - 2012

IMASONIC

CASS 2012

IMASONIC

Imasonic - 2012

Overview

Company
Design means
Phased array probes
Flexible and TRL probes

IMASONIC

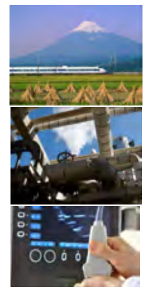
Company and team

Some figures

- IMASONIC SAS
- Created in 1989 in Besançon - France
- 76 people
- Exportation 83%
- ISO 9001-2008

Vocation

- To act for health, safety and quality
- To design and manufacture ultrasonic transducers in an innovative and competitive way.



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Company and team

New facilities of 3000m² in 2007

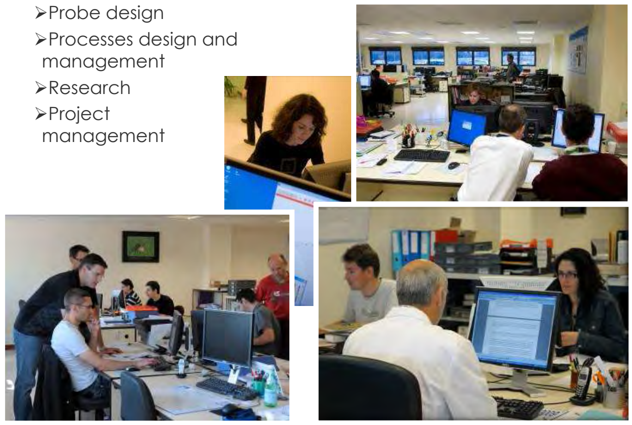
Imasonic - 2012

IMASONIC

Company and team

R&D activities

- Probe design
- Processes design and management
- Research
- Project management



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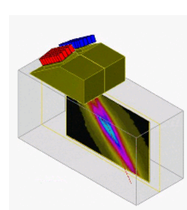
Manufacturing & Design means

Beam simulation

- In house softwares for quick evaluation

- CIVA 10 Software (CEA)



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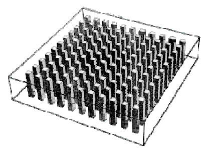
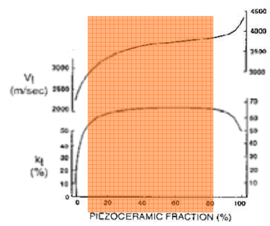
IMASONIC

Electroacoustical designs - Probe manufacturing

Piezocomposite technology

Frequency range: 0.2MHz - 20MHz
- ➢Wide bandwidth (70 to 90%)
- ➢Cross coupling (-30/-40 dB)





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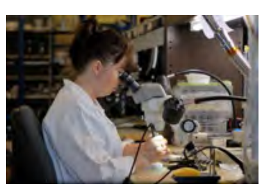
Manufacturing & Design means

Production and control

➢Production of piezocomposite structures (machining)

➢Probe assembly



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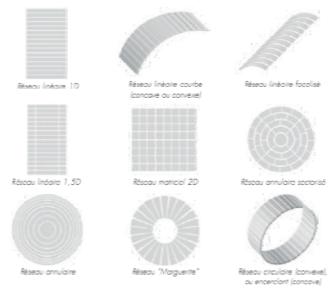
IMASONIC

Phased Array probes

Phased array: a general concept…

…and many variable parameters

- Array type
- Frequency
- Number of elements
- Pitch
- Elevation
- Acoustic matching
- Coupling method
- Housing geometry
- Cable length
- Connector
- …



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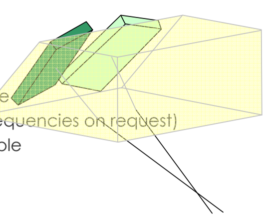
TRL Phased Array probes

- Typical designs
  - Matrix or linear
  - Integrated or removable wedge
  - From 500KHz to 3MHz (higher frequencies on request)
  - Standard configurations available

- Typical applications
  - Welds (wrought) , safe end
  - Primary loop, cast components
  - Petrochem Reactor



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New developments

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Linear flexible transducers

- ➢Real time measurement of each active element for real time delay laws calculation (licence cea)
- ➢Already developed designs

Freq. (Mhz)	Number of elements	Pitch (mm)	Total operture (mm)
1.5	24	1.7 x 22	41 x 22
2	24	1.4 x 17	34 x 17
2	32	1.4 x 17	45 x 17
4	24	0.9 x 9	22 x 9

cea

IMASONIC

New developments

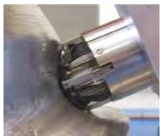
Imasonic - 2012

Matrix flexible transducers

- ➢Real time measurement of each active element for real time delay laws calculation (licence cea)
- ➢Already developed designs

cea

Freq. (MHz)	Number of elements	Pitch (mm)	Total operture (mm)
2	7x12	4x2,8	28x34
2	8x8	4x3,5	32x28
2,7	5x12	3x1,5	15x18
3,3	4x12	3,1x2,1	12,5x25



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for health, safety and quality

To contact us, meet us, visit us

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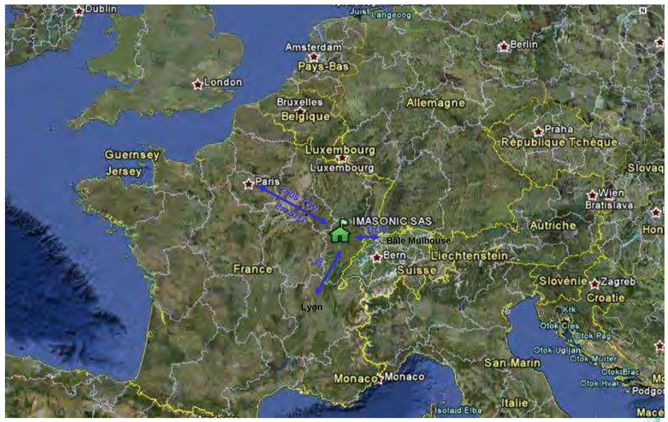

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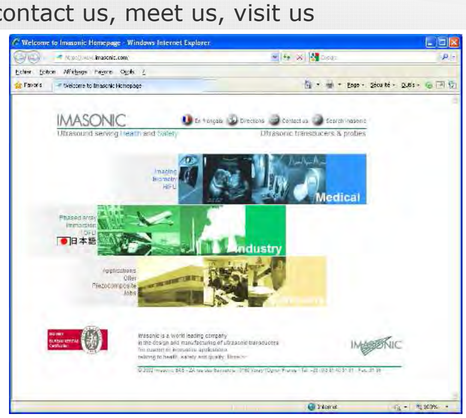


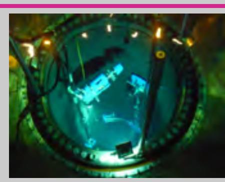
www.imasonic.com

philippe.dumas@imasonic.com

gerard.fleury@imasonic.com

DEKRA Industrial

Torbjörn Sjö and Peter Alzén, Business Area Nuclear 2012



DEKRA
On the safe side.

DEKRA INSPECTION MATERIAL TESTING

DEKRA

DEKRA - tradition

Established 1925 in Berlin: Deutscher Kraftfahrzeugs-überwachungs verein

1970s: Start of periodical car testing

1996: Start of the Internation-alisation

2005: Entry into the industrial testing business

Today: European market leader, TOP 4 worldwide

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Slide 2 © 2011 DEKRA

DEKRA INSPECTION MATERIAL TESTING

DEKRA

DEKRA in General

One of the leading service provision companies in Europe

- Based in Stuttgart
- Operates in more than 50 countries
- Divided into 3 Business Units and 15 Service Lines
- Generates more than 2 billion Euros in sales
- Employs around 28,000 employees

DEKRA Industrial - Torbjörn Sjö

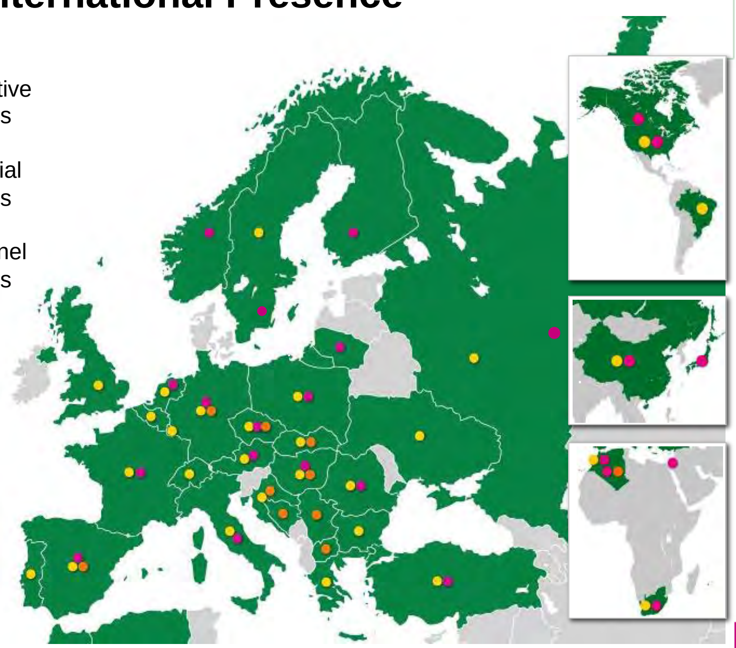
3

DEKRA INSPECTION MATERIAL TESTING

DEKRA

International Presence

- DEKRA Automotive in 28 countries
- DEKRA Industrial in 23 countries
- DEKRA Personnel in 10 countries



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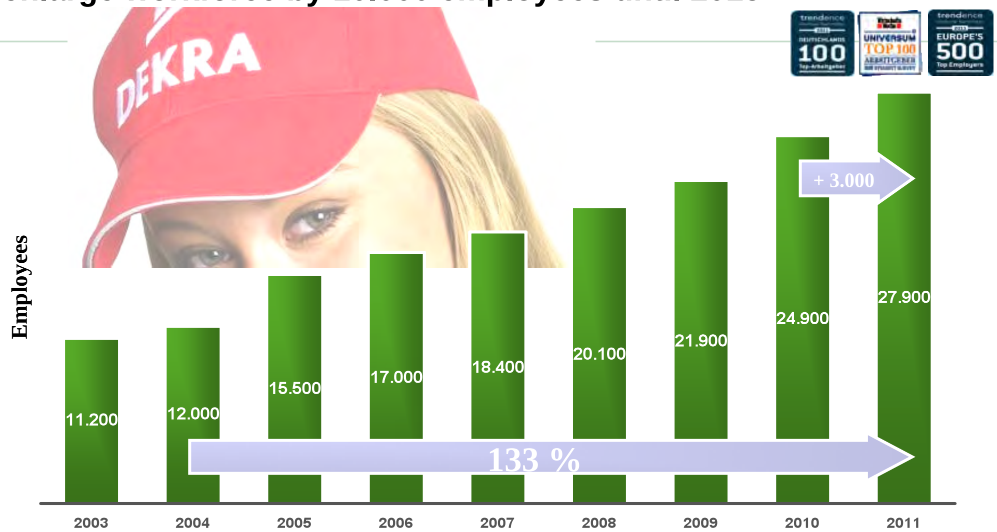
DEKRA INSPECTION MATERIAL TESTING

DEKRA

DEKRA proofs again to be an attractive employer and plans to enlarge workforce by 10.000 employees until 2015



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DEKRA INSPECTION MATERIAL TESTING

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DEKRA Material Testing & Inspection

Inspection

- Notified Body for Pressure Equipment, Lifts, Machinery and Rail
- Approved Body for In Service Inspection of Pressure Equipment, Lifts, Hoisting Equipment and Machinery and Rail
- Fire Protection, Explosion Protection, Electrical Inspection
- Expediting of manufacturing and prefabrication
- Supervision of welding, incl. documentation
- Supervision of construction
- Testing of structural steelwork
- Delivery control / PMI

Non Destructive Testing

- Radiographic Test, digital and conventional
- Ultrasonic Test, standard and phased array
- Surface Crack Test
- Leak Test
- Visual Test
- Mobile Hardness Testing

Destructive Testing

- Tensile Test
- Impact Test
- Bend Test
- Hardness Test Lab
- Surface Roughness Test
- Metallography
- Material analysis
- Corrosion testin

Failure Analysis

- Light optical microscope
- Scanning electron microscope (SEM)
- Materialanalysis
- Corrosionanalysis
- Analysis of damage mechanisms
- Simulation of technical heat treatment

Welding and Qualification

- Welder Qualification & Certification
- Welding Procedure Qualification
- Welding Cabins & Training
- Consulting concerning welding technique in general

Seite 6

DEKRA INSPECTION MATERIAL TESTING

DEKRA

DEKRA Industrial – Highlights 2011
Material Testing & Inspection

Pooling of Resources

- **Construction of Nuclear Power Plant Olkiluoto 3 (Finland)**
  - **Peak Phase:**

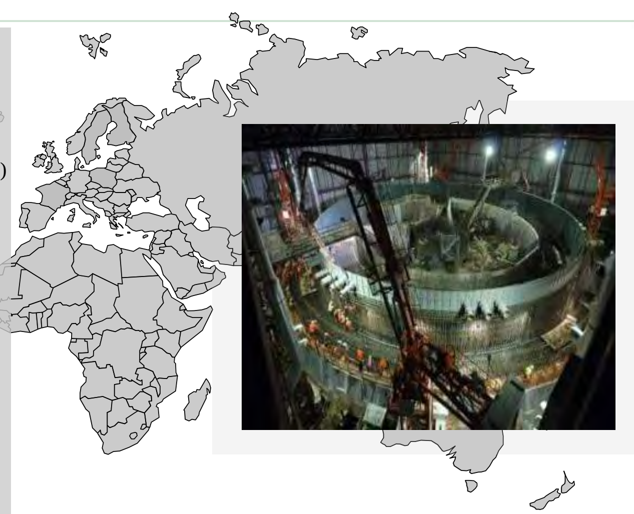
45 Employees from DEKRA Industrial Oy (Finland)
→ NDT (35) and Inspection Organisation (10)

16 Employees from DEKRA Industrial Lithuania

10 Employees from DEKRA Material Testing GmbH (Germany)
→ Construction Surveillance

5 Employees from DEKRA Industrial France
→ Construction Surveillance

3 Employees from DEKRA Industrial Sweden



DEKRA INSPECTION MATERIAL TESTING

DEKRA

Mechanized inspection

- DEKRA more than 800 persons with NDT certificates

- Mechanized inspection:
  - More than 80 persons with NDT certificates
  - More than 10 design engineers
  - Conformance with international standards, CE-marking, ENIQ and ASME

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DEKRA INSPECTION MATERIAL TESTING

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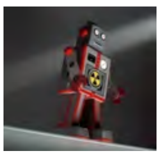
Experience

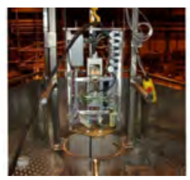
Development

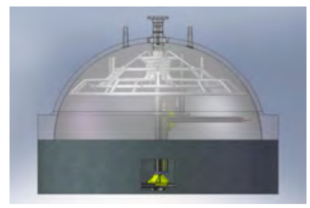
- Design of manipulators
  - Vessel, Nozzle, BMI
  - Internals
  - Piping
  - Control systems
- NDE development
  - Sizing TOFDT
  - Phased array
  - ET
  - VT, Replica
- Probes for special applications

Inspections

- BWR
- PWR
- VVER
- RBMK
- Conventional industry







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DEKRA INSPECTION MATERIAL TESTING

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Development of manipulators for PWR

The task was to perform a qualified inspection of all vessel welds including nozzles, bottom nozzles and VT of the radial supports in Ringhals 2,3 and 4

Conclusion: a new concept is demanded in order to perform a full vessel exam in 5 days

The Customers voice:
“A scope of this extent has never been performed before”

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DEKRA INSPECTION MATERIAL TESTING

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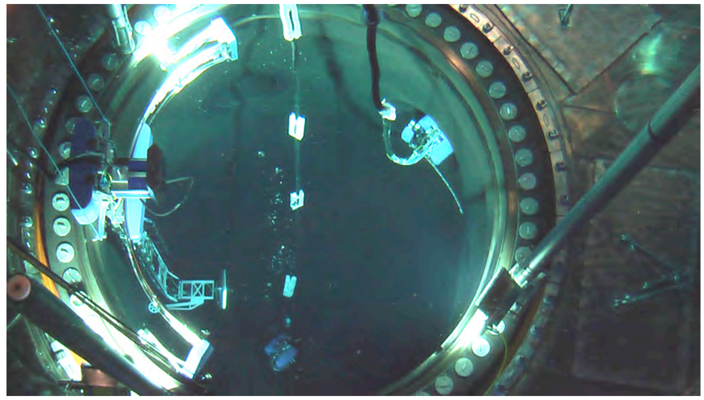
Inspection orders for Ringhals 2-4 and Beznau 1-2

- **Parallel inspection!**
- **Inspection of the whole reactor in 5 days**
  - **Skidbladner:** Circumferential and longitudinal shell welds including the bottom dome
  - **Särimner**: Inlet and Outlet Nozzles, Nozzle to shell welds, inner radius and connection welds
  - **Gungner**: BMI Nozzle and J-groove
  - **Draupner**: Moulding VT tool for BMI J-groove weld



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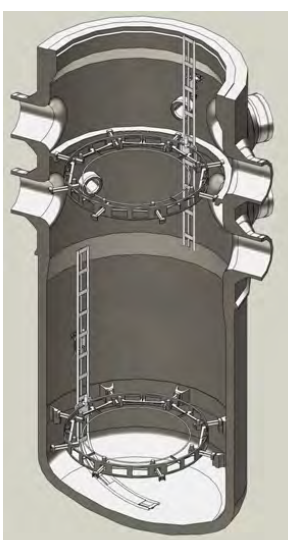
VVER Vessel concept for reduced inspection time with 3 manipulators



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Standardized Controllers

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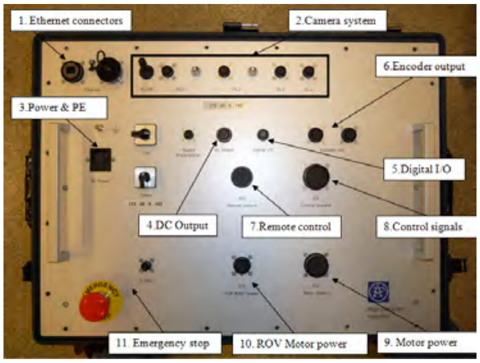
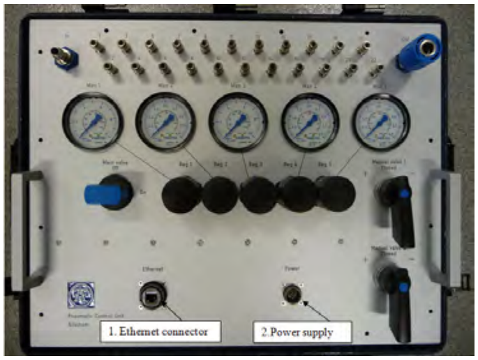


The Motor Control Unit (MCU) designed for 6-scanning axis including local intelligence, power supply and motor drives and remote controls for ROV functions and surveillance camera functions



The pneumatic box provides all the manipulators pneumatic functions; clamping cylinders, protecting overpressure, buoyancy functions, etc

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Vessel manipulator …

Skidbladner

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- Light weight and easy to handle
  - Neutrally buoyant
- Allows for parallel activities
- Inspection of circumferential and longitudinal shell welds including the bottom dome
- Positioning and attachment in known reference points in the vessel
  - Upper region (four positions)
  - Lower region (four positions)

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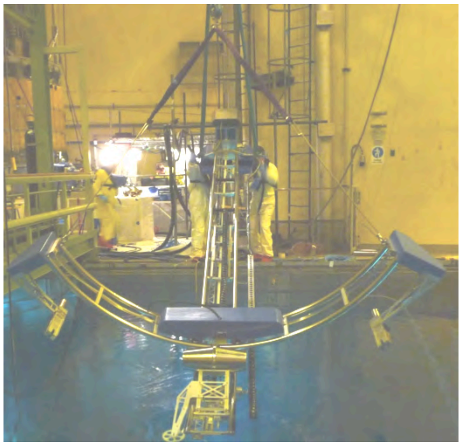
… Vessel manipulator

Skidbladner

- **Launching and fixation**
  Manually by two operators, from refueling machine or auxiliary bridge
- **Fixed references**
  The radial support guides give a repeatable and precise position in direct relation to the vessel, with no need for complicated positioning system
- **Facilitates parallel work**
  For other manipulators or Inspection cameras etc.



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Nozzle manipulator

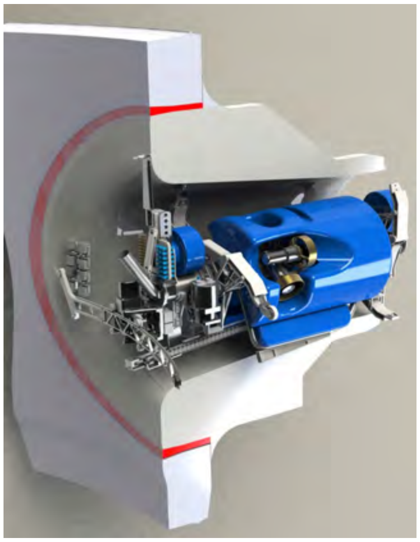
Särimner

- ROV- Scanner
  … manoeuvring between nozzles

Manually launched into the water from the auxiliary bridge, with no need of polar crane.

The ROV functions and centering is remotely controlled with a wireless joystick

- Inspection of:
  - Nozzle to shell welds
  - Inner radius
  - Connection welds
  - Nozzle bore



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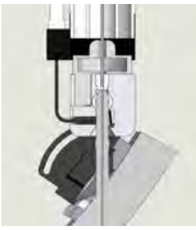
BMI Manipulator
Gungner

- ROV-Scanner
  … manoeuvring between nozzles
  (Surveillance by an underwater camera)
- Inspection of:
  - Inner surface of nozzle
  - Connection weld
  - J- groove from ID
  - J- groove and HAZ from OD of Nozzle



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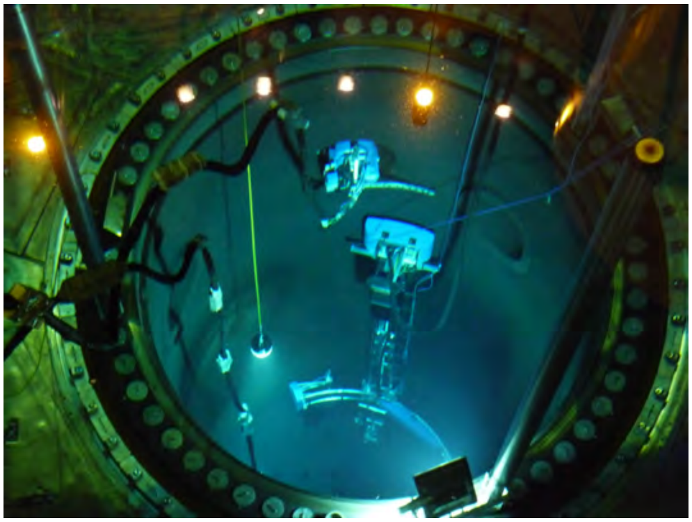
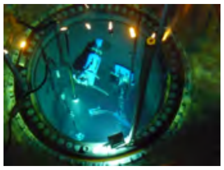
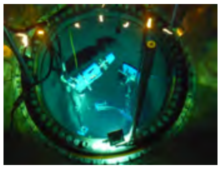
Parallel work in Ringhals 3, September 2010
Full vessel inspection in 5 days. Probably a world record!







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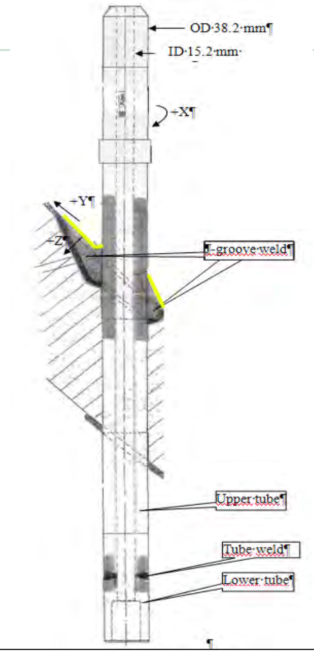
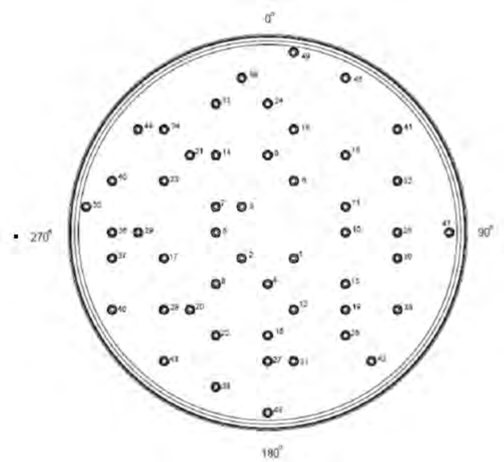
BMI Inspection from below





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DEKRA INSPECTION MATERIAL TESTING

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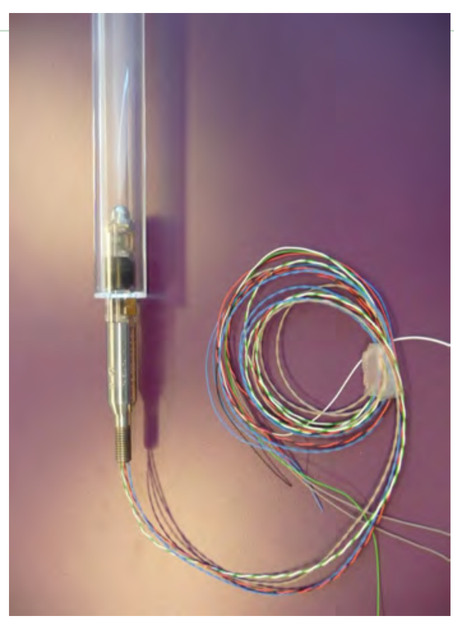
Transducers for tube inspection

General Characteristics

These transducers are adapted individually to the inspection constraints

- Housing customized for the mechanical environment (inspected parts, scanner, wedges, etc)
- Diameter: down to 9mm
- Nominal frequency: 4 to 10MHz
- Longitudinal /circumferential orientation
- Integrated cable
- Customized connection
- Spring-loaded holder



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DEKRA INSPECTION MATERIAL TESTING

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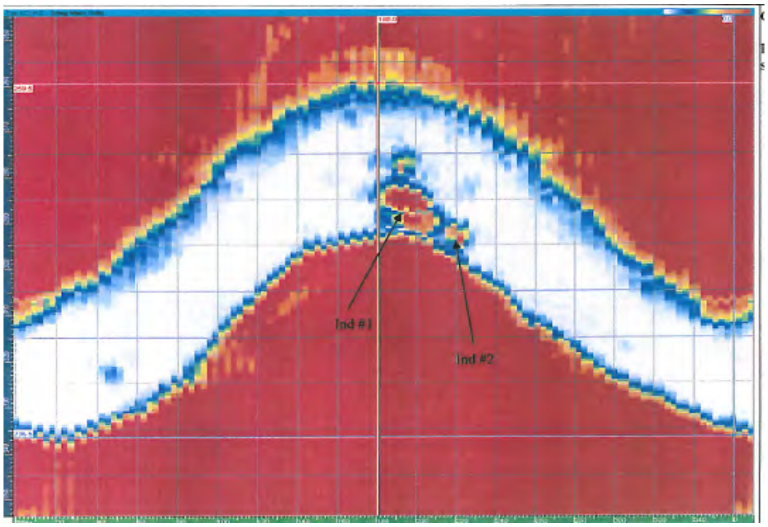
Technique, BMI ID Inspection



Fusion face inspection, with reportable defects

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DEKRA INSPECTION MATERIAL TESTING

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Technique, BMI ID ET Inspection

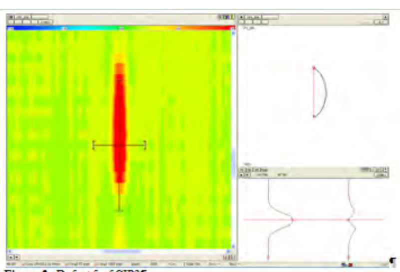


Figure 2 - Defect 5 of CIP2

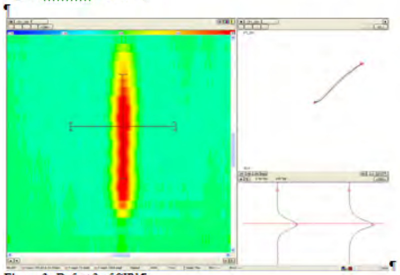
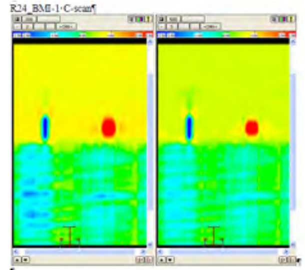


Figure 3 - Defect 2 of CIP1

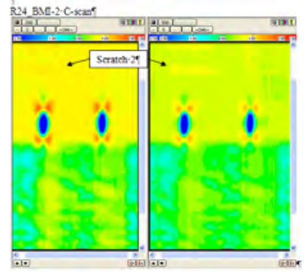
Left:1.14mm deep defects in EPRI blocks

Right: 5 and 7mm deep defects in the tube weld, supplied by RAB

R24_BMI-1-C-scan



R24_BMI-2-C-scan



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DEKRA INSPECTION MATERIAL TESTING

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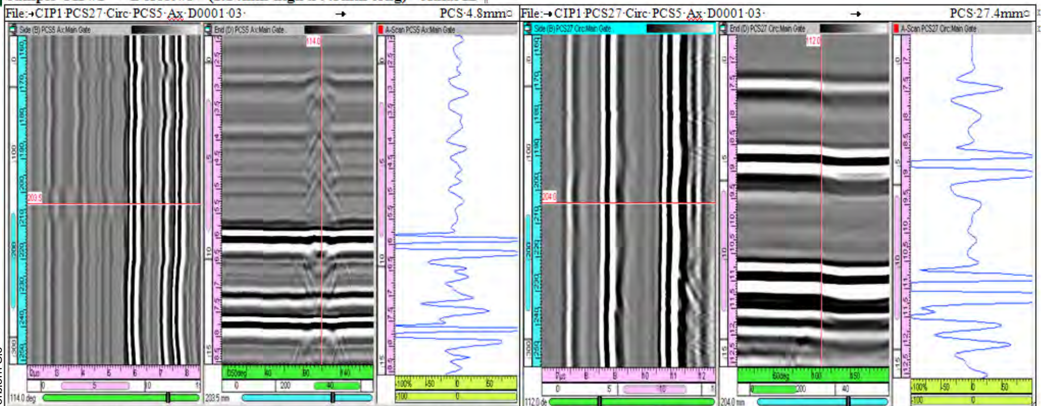
Technique, BMI ID TOFD Inspection

Sample CIP#1 → Defect#3 - (1.14mm high x 9.5mm long) - Axial ID

File: CIP1 PCS27 Circ PCS5 Ax D0001 03 → PCS 4.8mm | File: CIP1 PCS27 Circ PCS5 Ax D0001 03 → PCS 27.4mm



PCS	Lateral Wave			Upper Tip					Lower Tip					Length / Orientation					Height (mm)	Comments
	Circ (mm)	Axial (mm)	Time (µs)	Circ (mm)	Axial (mm)	Time (µs)	ΔT (µs)	Depth (mm)	Circ (mm)	Axial (mm)	Time (µs)	ΔT (µs)	Depth (mm)	Circ X1	Circ X2	Axial Y1	Axial Y2	Orien C / A		
4.8	114°	192	2.59	-	-	-	-	-	114°	203.5	2.77	0.18	1.54	114°	114°	199	208	A	1.54	Lateral disturbance and tip from shallow ID axial flaw. No clear lateral break.
27.4	112°	183	7.23	-	-	-	-	-	112°	204	7.23	0	-	112°	112°	-	-	A		Lateral disturbance from shallow flaw. Orientation not obvious.

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DEKRA INSPECTION MATERIAL TESTING

DEKRA

Moulding VT Tool

Draupner

- A moulding tool based on the BMI Nozzle manipulator concept which will be remotely controlled with rods and a wire system
- The moulding tool makes a mould from the full circumferential of the BMI J-groove weld
- Detection target 2mm x 3µm

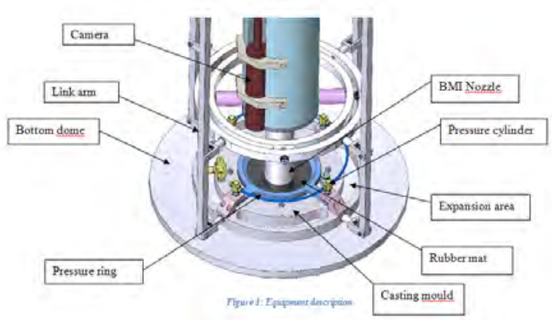

Figure 1: Equipment description

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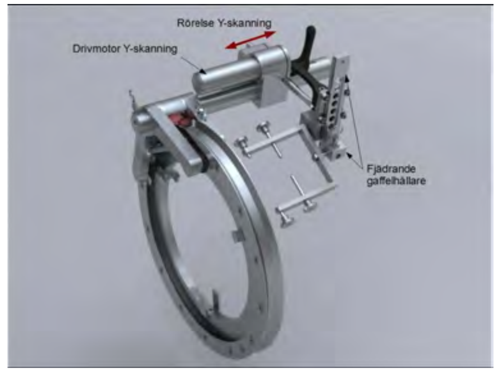
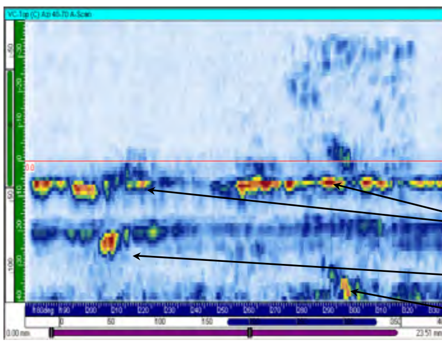
DEKRA INSPECTION MATERIAL TESTING

DEKRA

PUTS – Mechanized Inspection of stainless steel welds in piping – A new standard

- The project has qualified Phased array techniques for all Swedish NPPs lead by Forsmark
- Single sided inspection
- Thickness 6-40mm
- Qualified for all weld types





Direct longitudinal response

SLL

Shear (S)

Figure: Merge 40-70 degrees

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DEKRA INSPECTION MATERIAL TESTING

DEKRA

PUTS Test blocks

- The utilities supplied 16 test blocks, 6 more were manufactured during the project
- These blocks contains 123 defects, which can be used from two sides giving 240 ”possibilities” .

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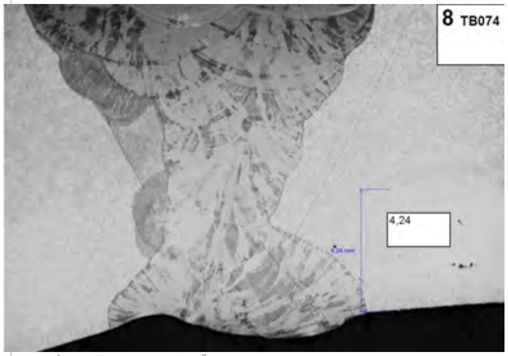
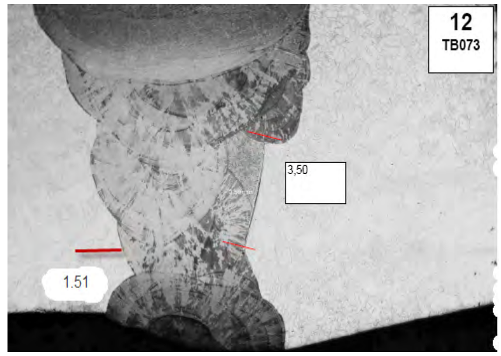
DEKRA INSPECTION MATERIAL TESTING

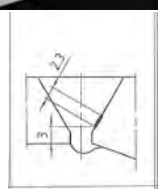
DEKRA

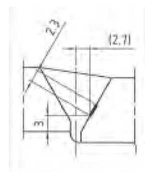
PUTS Test blocks

- Some defects were cut open:









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DEKRA INSPECTION MATERIAL TESTING

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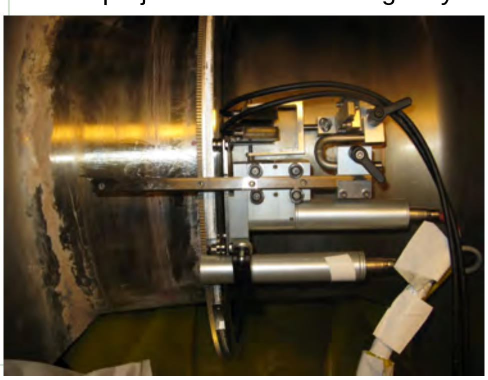
PUTS – Field experience

- Successful implementation on site 2011
- Single sided inspection
- Nine inspections performed, 100 welds
- Dose budget important
- The project noted as a strength by WANO



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DEKRA INSPECTION MATERIAL TESTING

DEKRA

Mühleberg the Incore-Monitor-Housings

- Implementation on site 2012
- ET and UT
- Access under the core grid

- Manipulator weight: 10 kg
  Diameter x Length: ⌀ 36 x 1000 mm
- Local position accuracy both directions: ± 2 mm (Within the same fixati

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DEKRA INSPECTION MATERIAL TESTING

DEKRA

Control rod inspection – new manipulator: Styrbjörn Starke

Inspection speed increased
4 times!

- 169 rods in 4 days
- New probe head, UT and ET
- Handles two control rods in parallel
- Two manipulators used, four control rods in operation

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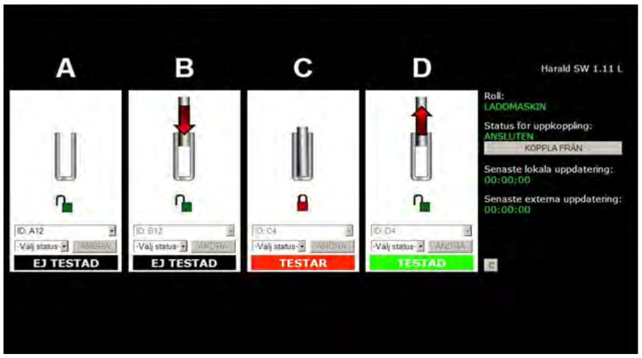
DEKRA INSPECTION MATERIAL TESTING

DEKRA

Control Rod Inspection – Harald blåtand Software



- Two manipulators can be used in parallel
- Harald BT to facilitate communication between the refueling machine and the inspection

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DEKRA INSPECTION MATERIAL TESTING

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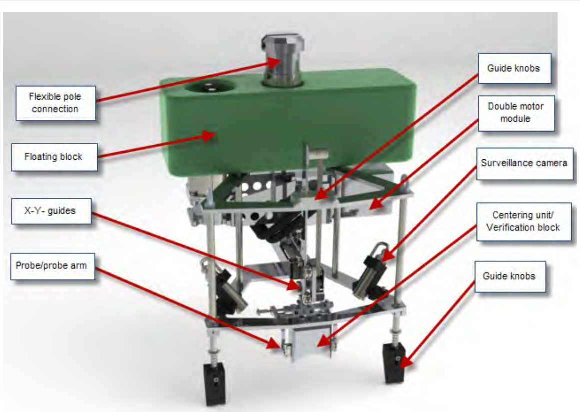
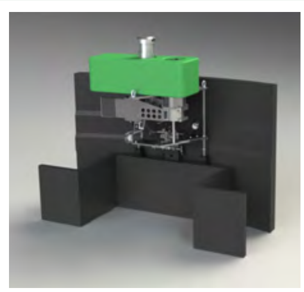
Inspection of stellite cladding on surface of Core Plate Radial Support key





The scanner placed in the mockup

Cracks in the stellite surface

The inspection includes both UT and ET:
•Surface testing using Eddy Current to establish presence of cracks and their positions
•TOFD testing using multiple probe separations in order to exactly measure crack size over varying depth
•TOFD testing to verify stellite layer thickness
•TOFD testing to detect lack of fusion between stellite layer and base material

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DEKRA INSPECTION MATERIAL TESTING

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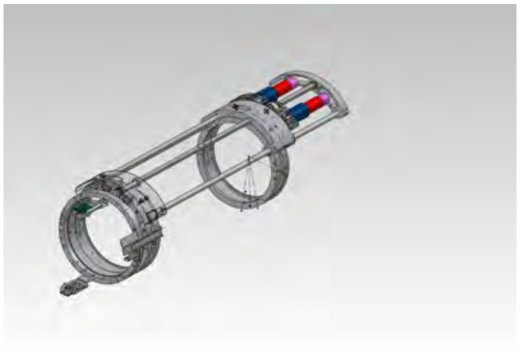
Rimfaxe - Inspection of Piping in confined spaces



- Inspection with ET and UT
- Manipulator can climb
- Two probe holders
- Minimum space 23 mm between pipe and obstacles

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DEKRA INSPECTION MATERIAL TESTING

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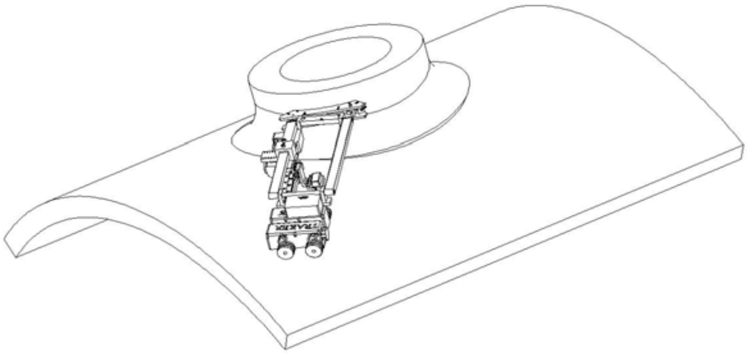
Steam Generator welds

- Qualified technique developed for Ringhals
- Circumferential and longitudinal welds with TOFD technique
- Nozzles with TOFD and pulse echo



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DEKRA INSPECTION MATERIAL TESTING

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Mechanized PT

OD and ID inspection of steam dryer for Oskarshamn

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DEKRA INSPECTION MATERIAL TESTING

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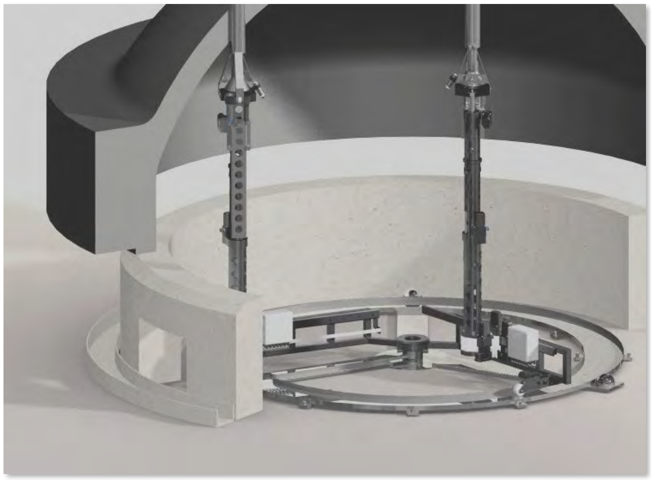
The VHP system in inspection configuration and in service mode



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DEKRA INSPECTION MATERIAL TESTING

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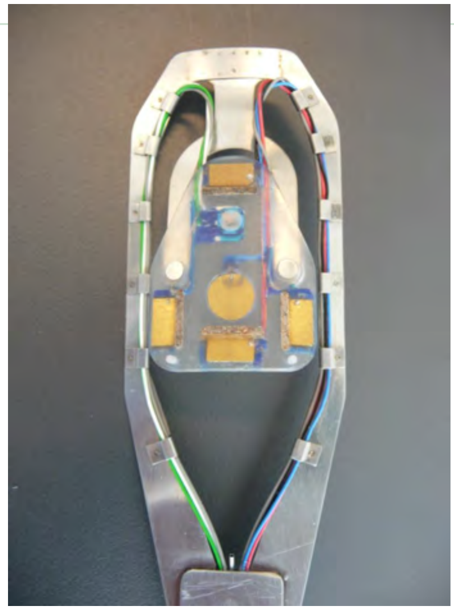
Extra-flat Blade Probe for VHP inspection

Four different functions in the same probe

- TOFD for circumferential defects
- TOFD for axial defects
- ET driver/ pickup
- Transducer at 0° for thickness measurement

  (lack of fusion indications at the interface of the J-groove weld and tubing outside surface)



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DEKRA INSPECTION MATERIAL TESTING

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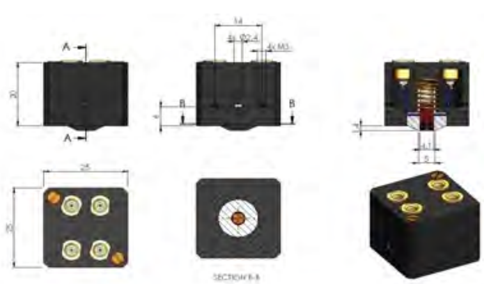
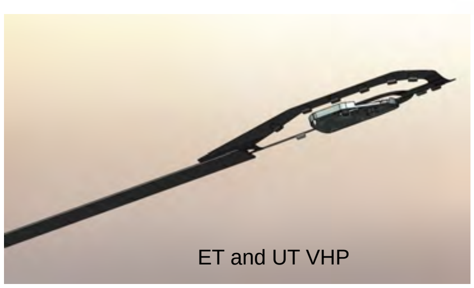
Probe design for special applications

ET and UT BMI Nozzle ID



ET Star probe for defects in all directions



ET and UT VHP

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DEKRA INSPECTION MATERIAL TESTING

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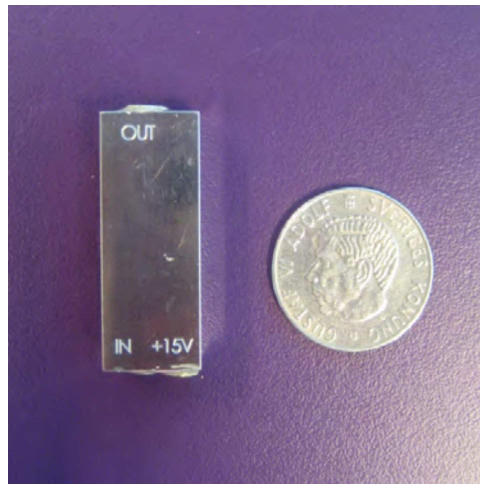
Ultrasonic Preamplifiers

The preamplifier, housed in a water-proof enclosure, is very small and lightweight making it ideally suited for remote applications. This preamplifier provides low noise amplification of ultrasonic signals ranging from 50KHz to 20MHz and is ideal for TOFD scanning.

General Characteristics

- Voltage Gain : 40 dB (Fixed)
- Bandwidth (-3dB) : 50 kHz - 20MHz
- Power : 15V DC input
- Connectors: SUHNER 22_MCX_50
- Dimensions: 12mm x 10mm x 25mm
- Weight: 15 gr.
- Operating Temperature: 0°C to 50°C
- Approved for usage in high radiation environments



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Visual Inspection of Radial Support Welds

- Qualified inspection; Procedure VT01
- Inspection with a camera connected to the rigid pole-system
- Detection target 20µm x 5mm

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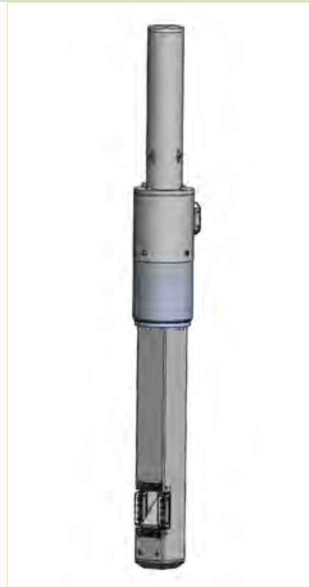
DEKRA INSPECTION MATERIAL TESTING

DEKRA

Visual Inspection Core grid

- Qualified inspection; Procedure VT01
- Inspection with a radiation secure camera connected to the rigid pole-system
- Detection target 20µm x 5mm



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DEKRA INSPECTION MATERIAL TESTING

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Hugin - ROV for visual testing

- Remotely operated
- Pan & tilt camera
- Zoom capability
- Full color
- Reliable thrusters
- Standardized control system
- Compatible with qualified procedures

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DEKRA INSPECTION MATERIAL TESTING

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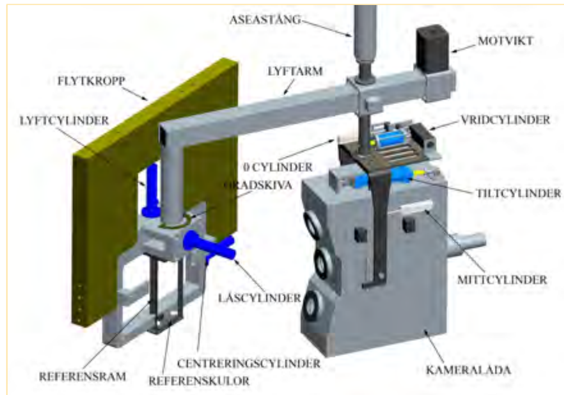
Key support and clevis measurement

- **GOAL**

Measurements of the worn surfaces shall come within an accuracy of ± 0,05 mm depth wise.

On the worn surfaces on the clevis key, the wear shall be reciprocally comparable within an accuracy of ± 0,1 mm.

As a result; cavities in one surface shall be comparable with elevations in the other, this is required in order to determine and show the total play in the application.



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Training and qualification

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DEKRA INSPECTION MATERIAL TESTING

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The DEKRA advantage

- We are one of the largest organizations for manual and mechanized inspections in Europe!
- Independent supplier of all types of inspection
- Experienced engineers, projects in PWR, BWR, VVER and RBMK
- Strong organization to develop new robotics and NDE procedures as well as probes
- Large pool of personnel in France, Germany, Sweden, Finland, Czech Republic, Lithuania and Turkey for manual and mechanized NDT
- QA and QC resources for new plants/upgrade
- Several labs for destructive testing

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Movie from Ringhals PWR!

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On the safe side.

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Timothy J. Griesbach
Sr. Associate

A Proposed Flaw Tolerance Approach for CASS Piping

Presented at 4th Int. Workshop on Inspection of CASS Piping
Seattle, WA
May 24 – 25, 2012

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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
- A flaw tolerance approach is required with some inspections to demonstrate structural margins against fracture

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CASS Piping - ***SLIDE 2***

Objectives

- Provide a methodology for developing acceptable flaw sizes for cast austenitic stainless steel (CASS) piping using a probabilistic fracture mechanics approach
- Establish a technical basis for the acceptable flaw size using the probabilistic fracture mechanics methods and available material properties from existing studies on CF-8M
- Develop a Code methodology for managing aging of CASS materials
  - Propose a flaw tolerance approach that can be used for CASS piping
  - Define the role of inspections for demonstrating piping integrity

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CASS Piping - **SLIDE 3**

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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CASS Piping - **SLIDE 4**

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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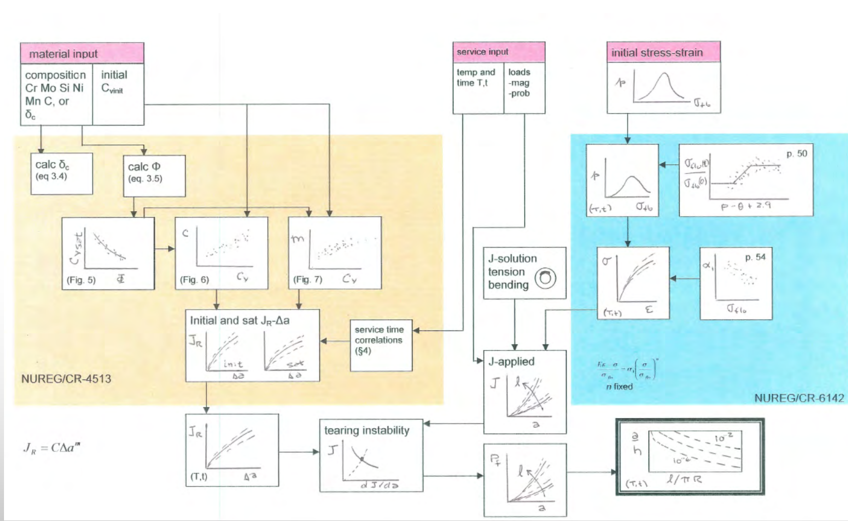
CASS Piping - **SLIDE 5**

Flow Chart of Method to Determine Failure Probability of CASS Piping



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Risk Management of CASS Piping – Slide 6

CASS Piping - **SLIDE 6**

Key Steps in the PFM Process

- Define and Characterize Input Variables
  - Much data from available NUREGs. Make maximum use of data and existing equations for saturated toughness properties.
  - Characterization of scatter in data will describe the material contribution to uncertainty in maximum allowable flaw size predictions.
  - Elastic-plastic tearing instability used for evaluation of crack stability.
- Concentrate on fully saturated CF-8M properties
- Use Monte Carlo simulation to evaluate random variables
- Define the Outcome (i.e., maximum tolerable flaw sizes for a given failure probability) and determine the results

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CASS Piping - **SLIDE 7**

Proposed Flaw Tolerance Approach for Aged CASS Piping Materials

a)Select locations for postulating flaws in susceptible (i.e., high delta ferrite) CASS components (see GALL XI.M12 and the Grimes Letter dated May 19, 2000)

b) Determine stresses on the components and determine maximum allowable flaw depths using the PFM approach (*or from revised Tables C-5310-1, -2, -3, -4, & -5*)

c) Postulate one-quarter thickness reference flaw with a length six times its depth and perform fatigue crack growth analysis for cyclic loading conditions

d) Establish the final flaw depths at the end of the interval and confirm that the assumed initial flaws remain below the maximum allowable flaw depth from step b)

e) Define and implement an inspection program for susceptible CASS component locations using the (proposed) Section XI Code Case for inspection of CASS piping

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CASS Piping - **SLIDE 8**

Select Locations for Postulating Flaws in CASS Piping

The susceptibility of CASS piping to thermal aging is determined as follows*:

•For low-molybdenum content (0.5 wt% max.) steels, only statically cast steels with > 20% delta ferrite are potentially susceptible to thermal embrittlement

•Static-cast low-molybdenum steels with < 20% ferrite and all centrifugal-cast low-molybdenum steels are not susceptible

•For high-molybdenum content (2.0 to 3.0 wt%) steels, static-cast steels with > 14% delta ferrite and centrifugal-cast steels with > 20% delta ferrite are potentially susceptible to thermal embrittlement

•Static-cast high-molybdenum steels with < 14% delta ferrite and centrifugal-cast high-molybdenum steels with < 20% delta ferrite are not susceptible

Note: CASS piping adjacent to dissimilar metal welds that have been mitigated by WOL may be excluded from this list if a flaw tolerance analysis has already been performed and it meets CC N-770-1 and/or the latest revision of CC N-740

* From GALL Report (NUREG-1801, Rev. 1) XI.M12 – Thermal Aging Embrittlement of Cast Austenitic Stainless Steels

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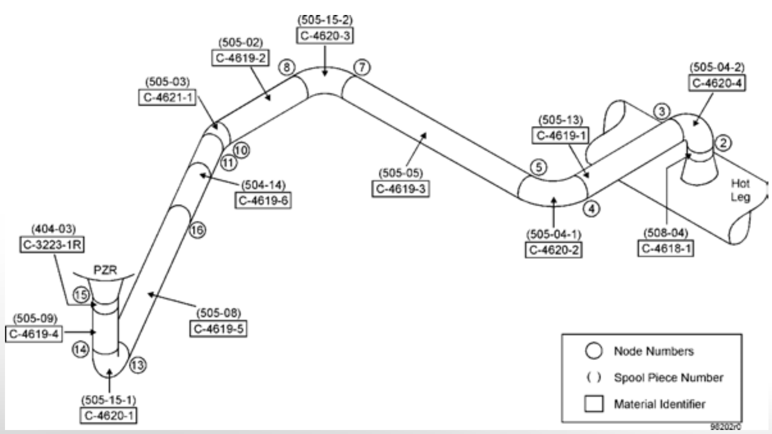
CASS Piping - ***SLIDE 9***

Example of CASS Piping in a Surge Line



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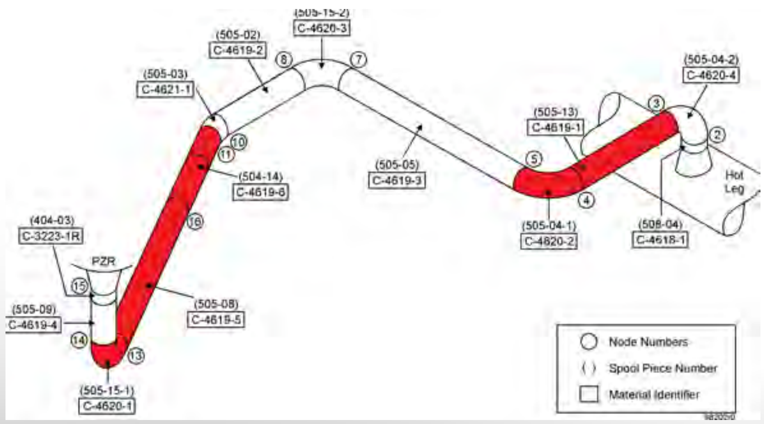
CASS Piping - ***SLIDE 10***

Example Showing Susceptible (High DFN) CASS Components



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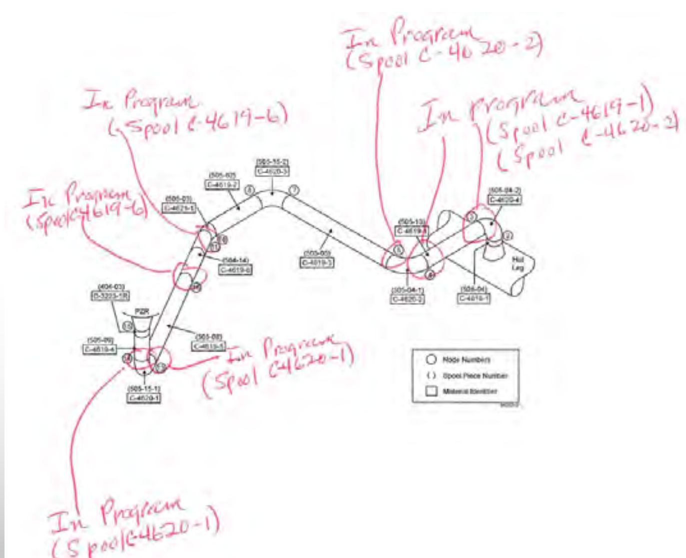
CASS Piping - **SLIDE 11**

Example Showing CASS Piping Locations to be Inspected per the GALL XI.M12



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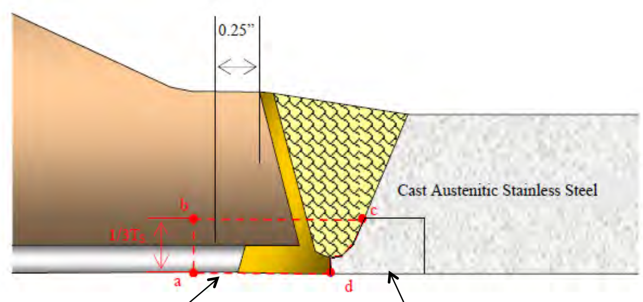
CASS Piping - **SLIDE 12**

CASS Examination Volume Next to a Weld



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

Determine Loading Conditions and Criteria for the CASS Pipe

Level A – Normal Operating Events

Level B – Abnormal or Upset events

Level C – Emergency Conditions

Level D – Faulted Conditions

•For these conditions, consider the appropriate probability of failure criteria for acceptance of stable flaw sizes (thru-wall depth versus length)

•For example, Regulatory Guide 1.174 for Probabilistic Risk Assessment and Risk-Based Approaches states that changes in the plant licensing basis contributing to CDF and LERF will be considered if the calculated increase (i.e., overall probability of failure) is less than 10^{-6} per reactor year

Survey of Normal Operating 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 ksi, and P_b = 10 ksi
- Stress Ratio = $(\sigma_m + \sigma_b)/\sigma_f$ = (8 + 10)/57.1
  ~ .31

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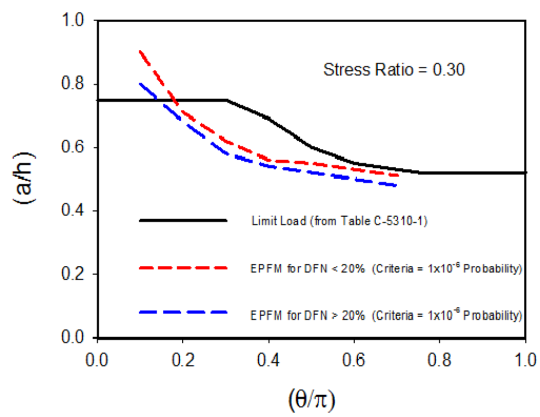
CASS Piping - **SLIDE 15**

Maximum Tolerable Flaw Sizes for Example Problem with P_m = 8 ksi and P_b = 10 ksi for Fully Aged CF-8M

Comparison of Maximum Allowable End-of-Evaluation-Period Depth-to-Thickness Ratio for Circumferential Flaws - Service Level A Conditions



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CASS Piping - **SLIDE 16**

Next Steps in Developing Flaw Tolerance Approach for CASS Piping

- Demonstrate that a one-quarter thickness reference flaw with a length six times its depth is a conservative assumption for the flaw tolerance analysis of CASS piping
- Establish appropriate fatigue crack growth law for calculating the final end-of-interval flaw size
- Determine revised flaw acceptance standards for high DFN CASS components (using PFM methodology and defined failure probability)
- Define an acceptable inspection program for susceptible CASS component locations using the flaw tolerance analysis approach
  - Utilize the (proposed) Section XI Code Case for inspection of CASS piping
  - Show (by demonstration and analysis) that the current inspection techniques are adequate to assure the desired piping reliability

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CASS Piping - **SLIDE 17**

Example of Revisions to Flaw Acceptance Tables in Appendix C (Ferrite ≥ 20%)

Table C-5310-1
Allowable End-of-Evaluation-Period Flaw Depth-to-Thickness Ratio [Note (1)] for Circumferential Flaws — Service Level A Conditions

Stress Ratio [Note (2)]	Ratio of Flaw Length to Pipe Circumference $\ell_f/\pi D$ [Note (3)] 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.75 or Greater
≥ 0.60	0.75	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]	[Note (4)]
0.55	0.75	0.44	0.23	0.16	0.13	0.12	0.11	0.11
0.50	0.75	0.75	0.44	0.31	0.25	0.23	0.21	0.21
0.45	0.75	0.75	0.65	0.46	0.37	0.33	0.31	0.30
0.40	0.75	0.75	0.75	0.59	0.48	0.42	0.39	0.38
0.35	0.75	0.75	0.75	0.73	0.58	0.51	0.47	0.46
0.30	0.75	0.75	0.75	0.75	0.69	0.60	0.55	0.52
0.30	0.75	0.75	0.75	0.75	0.54	0.52	0.50	0.48 *
0.25	0.75	0.75	0.75	0.75	0.75	0.68	0.63	0.59
0.20	0.75	0.75	0.75	0.75	0.75	0.75	0.70	0.65
0.15	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.74
≤ 0.10	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

* Example of PFM results for DFN > 20% (Failure Probability = 10^{-6})

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CASS Piping - **SLIDE 18**

Status of CASS Piping Evaluation Study

- The PFM Code and draft report have been completed for EPRI and the document has been reviewed by several organizations
- Comments were received on the PFM method and report
- The PFM Code can be used to perform probability of failure calculations and sensitivity studies for fully aged CF-8M CASS piping
- The initial results seem to be very encouraging
- The work to date can provide guidance for application of improved analysis and inspection techniques for CASS piping
- The technical basis document still needs to be developed for a proposed flaw tolerance of CASS piping Code Case

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CASS Piping - **SLIDE 19**

David O. Harris
Associate
Structural Integrity Associates, Inc.®

Probabilistic Analysis of Reliability of Cast Austenitic Stainless Steel Piping

Presented at CASS Piping Workshop

Seattle, WA

May 24 – 25, 2012

www.STRUCTINT.com
877-4SI-POWER

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 of concern due to decreased toughness and ductility.
- Many studies and much data available
- Much scatter in toughness and tensile test results

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PRS-12-020- **SLIDE 2**

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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PRS-12-020- **SLIDE 3**

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 developed by NRC to address piping issues
  - seismic events
  - IGSCC in BWRs
  - fatigue initiation
- PFM piping codes being developed by NRC
  - Pro LOCA
  - xLPR (includes EPRI participation)
- The same methods can be applied to CASS piping

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PRS-12-020- **SLIDE 4**

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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PRS-12-020- **SLIDE 5**

Background

- Analysis composed of two parts (first part covered here)
  - 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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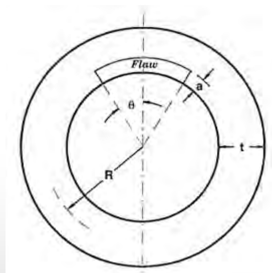
PRS-12-020- **SLIDE 6**

Part I Overview

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



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

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PRS-12-020- **SLIDE 7**

Part 1 Overview

- Deterministic EPFM
- Applied J from Zahoor, EPFM Handbook
  - Tension loading solution available
  - Modified to account for combined tension and bending

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

- CASSPAR performs probabilistic analysis of crack stability in fully aged CF8M piping using Monte Carlo simulation

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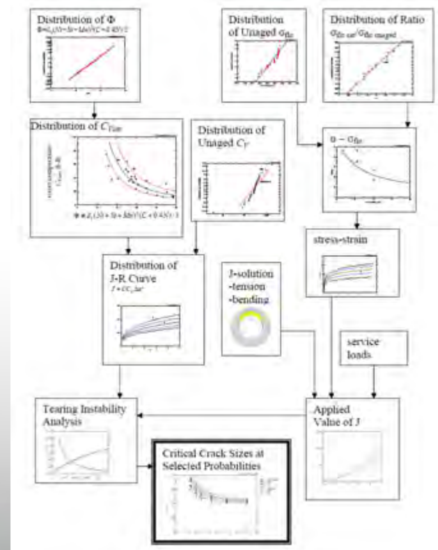
PRS-12-020- **SLIDE 8**

Part I Overview

Probabilistic model



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PRS-12-020- **SLIDE 9**

CASSPAR Random Variable Input

- **Currently included:**
  - Initial Charpy impact energy,
  - Initial flow strength,
  - Ratio of aged flow strength to unaged (initial) flow strength,
  - Material susceptibility, as expressed by the parameter Φ,
  - Fully saturated Charpy impact energy for a given Φ.
- **Recently incorporated:**
  - Correlation between strength and toughness

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PRS-12-020- **SLIDE 10**

Treatment of Material Scatter

- Governing relations drawn primarily from NUREGs
- Charpy energy used for fracture correlations
- Composition and delta ferrite parameter (Φ), used as governing variable $\Phi = \delta_c(Ni+Si+Mn)^2(C+0.4N)/5$

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

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

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

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

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

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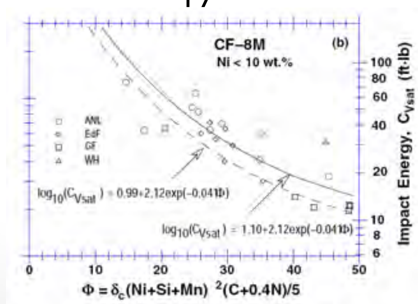
PRS-12-020- **SLIDE 11**

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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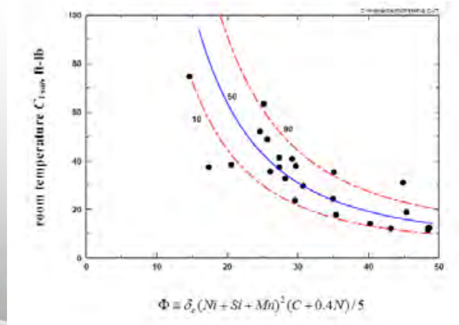
PRS-12-020- **SLIDE 12**

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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PRS-12-020- **SLIDE 13**

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.

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

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

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

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PRS-12-020- **SLIDE 14**

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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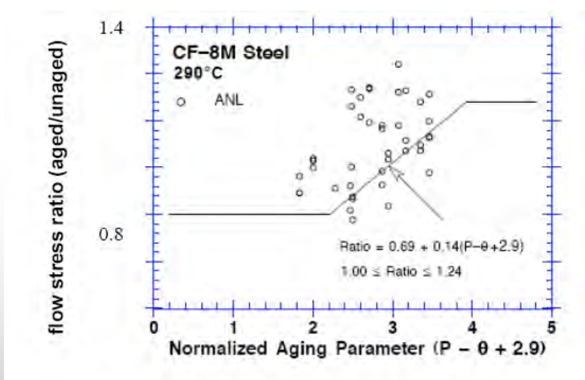
PRS-12-020- **SLIDE 15**

Material Scatter (tensile)

- Saturated flow stress is related to unaged flow stress



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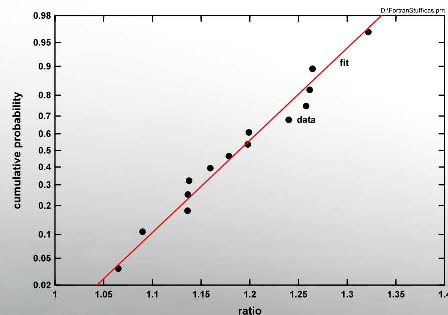
PRS-12-020- **SLIDE 16**

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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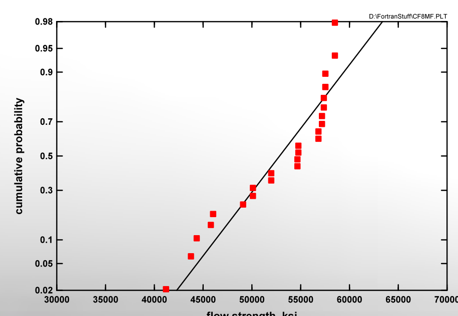
Material Scatter (tensile)

- 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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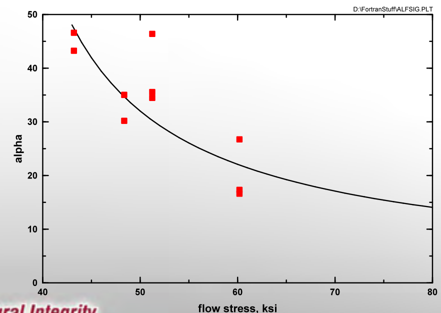
PRS-12-020- **SLIDE 18**

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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*PRS-12-020- **SLIDE 19***

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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*PRS-12-020- **SLIDE 20***

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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PRS-12-020- **SLIDE 21**

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 15 ksi
- Random Φ

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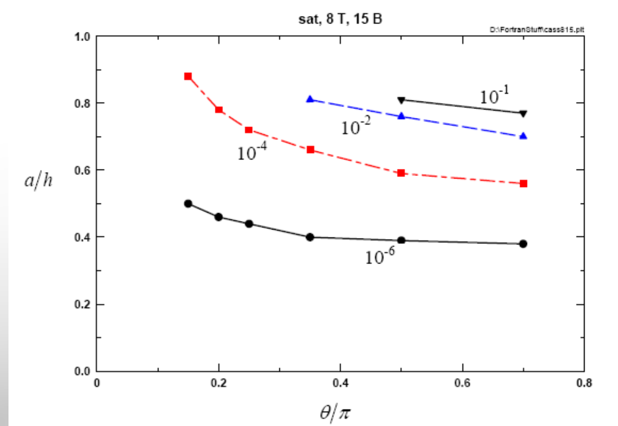
PRS-12-020- **SLIDE 22**

Results of Example Problem

- Crack sizes resulting in a given failure probability (crack instability, fully saturated CF8M)



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Phase I Findings

- Preliminary results predict that tolerable crack sizes (at a given probability) are larger for aged piping 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 exact correlation of strength and toughness

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Concerns and Issues Being Addressed

- Loads
  - Not well characterized (plant-specific).
  - Develop examples for a specific (generic) load case
- Material Properties
  - 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.
- Lack of Data
  - Exchange agreement with NRC research and Omesh Chopra has been completed , but still waiting for EdF data
  - Results are summarized in memo from Gary Stevens

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Recent Improvements to Model

- Possible correlation between strength (high temperature flow strength) and toughness (room temperature CVsat) being investigated
- Consideration of correlation would allow better treatment of effects of aging
- Data very limited. Need CVsat and sigflow for the same heat (CF8M)
  - lots of CVsat data
  - lots of sigflow data
  - very little data available from same heat
  - two heats from ANL NUREGs (74 and 75)
  - two heats from NRC Pipe Fracture Encyclopedia
  - heat 205, sigflo from NUREG, CVsat from Chopra handout
- Need to account for limited data (epistemic uncertainty)

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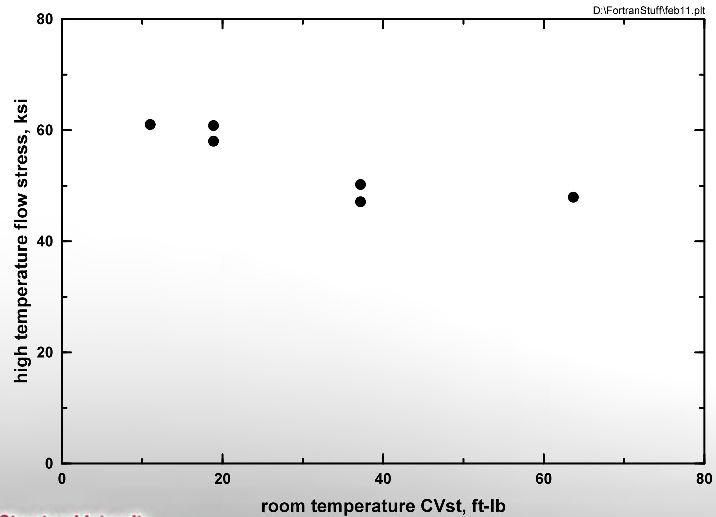
Plot of Data
(Correlation is Apparent)



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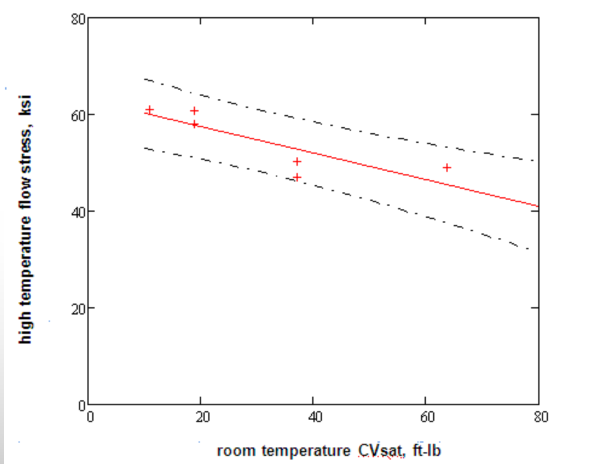
Preliminary Procedures for Estimating Uncertainty in Parameters Developed



Tenth, fiftieth and ninetieth percentiles of distribution of σ_{flo} for a given C_{Vsat} considering small sample size as obtained by Mendenhall procedure.

More data being sought from EDF (also MHI probably has data.)

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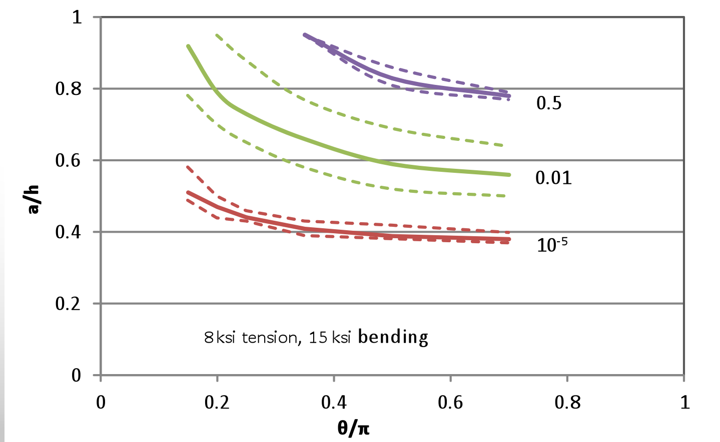
PRS-12-020- **SLIDE 28**

Confidence Levels on Allowable Flaw Sizes: Consideration of Correlation between CVsat and sigflo with limited data (0.1, 0.5, 0.9)



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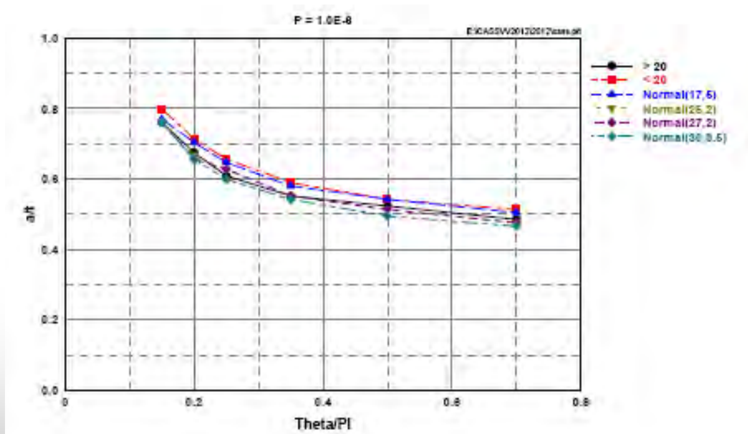
PRS-12-020- SLIDE 29

Effect of delta ferrite



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PRS-12-020- SLIDE 30

Status of Project

- Phase 1 scoping study completed early in 2011
- Preliminary model developed to perform PFM analysis of typical CASS pipe
- Results from scoping analysis were encouraging
- Phase 2 completed at the end of 2012, including
  - More benchmark analyses performed
  - Final report delivered to EPRI on PFM analysis method
  - A proposed ASME Section XI flaw tolerance approach being developed for CASS piping

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PRS-12-020- **SLIDE 31**

What do Utilities Need for License Renewal?

- License renewal commitments must follow procedure in GALL XI.M12 and Christopher Grimes letter dated May 19, 2000
- For susceptible CASS materials (i.e., Hi Mo and Hi DFN), perform UT inspection, or perform a flaw tolerance analysis using aged material properties and EVT-1 exam
- What's the problem?
  - No qualified UT examination methods exist
  - IWB-3640 and App. C not applicable for Hi DFN piping materials
  - Leak-Before-Break not considered a flaw tolerance method
  - Very little data exists for CASS piping materials exceeding 25% DFN
  - Lower bound toughness for (aged) welds may cause welds to become more limiting than base metal (new issue?)

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PRS-12-020- **SLIDE 32**

Keys Areas of Concern

- Loads
  - Increased seismic loads Post-Fukushima
- Materials
  - Thermal aging of welds not well characterized
  - Additional aging mechanism (e.g., SCC of CASS)
- Flaws and Inspectability
  - Very little information exists on flaws in CASS piping
  - What about HAZ and welds?
  - Progress in improved inspection techniques is very slow

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PRS-12-020- **SLIDE 33**

How will these Results be Used?

1. Establish "realistic" flaw acceptance limits for inspection of CASS piping materials
   - Help to develop a qualified CASS piping inspection method
2. Incorporate method into Section XI standards tables for evaluation of flaws in CASS piping (DFN > 20%)
   - See proposed flaw tolerance approach
3. Meet utilities' needs for managing aging of CASS piping to fulfill plant license renewal commitments
   - Work with lead utilities to develop and implement this approach

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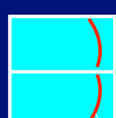
PRS-12-020- **SLIDE 34**

Our Experience of Ultrasonic Inspection for CAST Stainless Steel

May 10, 2012
Yasuo Kurozumi
Institute of Nuclear Safety Systems, Inc.

Automated ultrasonic inspection system with large aperture TRL transducers

1



Large spherical crystal 76mmφ

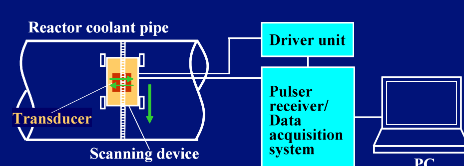
Low frequency (0.5MHz)
Wide band, High SN ratio

Ceramic crystal type

Composite crystal type

Size ; 100L x 100W x 80H(mm)
Weight ; 1.6 kg

Scanning device

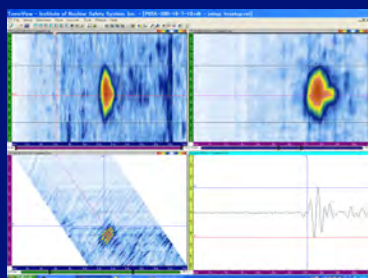


2

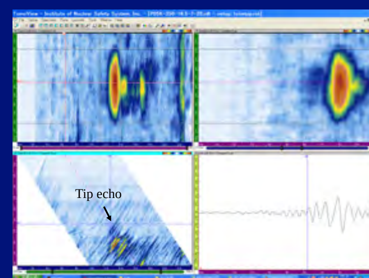
Specifications of probes and data sample

Probe	Type A	Type B	Type C	Type D	Type E
Design	TRL	TRL	TRL	TRL	TRL
Outside Dimensions (mm)	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80	100 x 100 x 80
Frequency	0.5MHz	0.5MHz	0.5MHz	0.5MHz	0.5MHz
Crystal Shape	Spherical surface	Spherical surface	Spherical surface	Spherical surface	Spherical surface
Material of crystal	ceramic / composite	composite	ceramic / composite	composite	composite
Angle of Refraction	40.7°	44°	47.4°	49°	51°
Focal Depth (mm)	65-75	65-75	60-70	55-70	45-65

Specifications of probes used in this method



Data sample (Type B probe, 10%t fatigue crack)
Detection - yes, Depth sizing - no



Data sample (Type C probe, 20%t fatigue crack)
Detection - yes, Depth sizing - yes

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3

Comprehensive results and lessons learned from many examinations

a. We conducted examinations of 76 flaws including fatigue cracks and EDM slits.

b. Detection performance was good. 75 of 76 flaws were detected. Detection rate was 0.986 (75/76).

c. Depth sizing performance was not good. Around 40% of flaws could not be sized.

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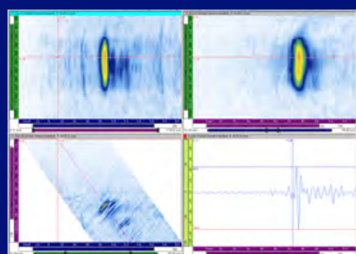
Our recent work : Development of pitch & catch type Phased array probe

4

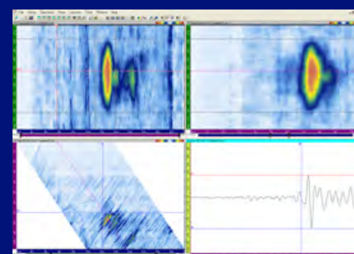
Probe specification

Probe type	Pitch & catch phased array probe
Number of elements	32 × 1
Element size	40.0 × 1.88 (mm)
Element pitch	2.08 (mm)
Outside dimensions	L100 × W45 × H50 (mm)
Frequency	0.5MHz
Angle of refraction	44° (middle refraction angle)

a. Detection performance is the same as conventional TRL probe we developed.
b. Depth sizing performance is a little bit lesser than conventional TRL we developed.
c. PA probe can change refracted angle from 30 to 60 at the same scanning speed of conventional TRL raster scan.



Data sample PA probe (20%t fatigue crack)
Refracted angle : 44°



Data sample TRL probe (20%t fatigue crack)
Refracted angle : 44°

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Lessons learned from on-site verification

5

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

a. We needed much of circulating water for local emersion system. We had to keep all water inside plastic sheet.

b. This system could not access to some welds in the actual plants, since some blanch lines, gratings or other structures interfered scanning device. (This was especially remarkable at the welds of outlet of reactor coolant pump.)

c. At present, our scanning device can not move as required extent at 30% of welds in the actual plant.

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Summary

a. Detection performance of the inspection system is good.

b. Depth sizing performance is not sufficient. Development of depth sizing technique which can surely identify crack tip echoes will be needed.

c. We need to develop smaller scanning system which can access to narrower space in the actual nuclear power plants.

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ELECTRIC POWER RESEARCH INSTITUTE

Cast Stainless Steel Inspection
An Overview of ASME Section XI Activity

Workshop on Cast Austenitic Stainless Steel

Seattle, WA

May, 2012

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

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.

Recent ASME Code Activity on CASS

- While the Appendix VIII, Supplement 9 is "in course of preparation", users are sent to Section XI, Appendix III for examination of cast stainless steel piping
  - Appendix III contains prescriptive requirements for performing non-qualified ultrasonic examination of vessel and piping welds
  - The techniques currently described in Appendix III are not considered the best available UT methods for successful CASS examination
- In 2010, members of the Task Group on Cast Stainless Steel began drafting Code Case N-824 for alternative requirements to Appendix III
  - Calls 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
  - As of last week, this Code Case (N-824) is being considered by the Section XI Standards Committee for approval into Section XI.

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 have developed a Memorandum of Understanding to allow each entity to share information and research results on the topic of CASS
- The industry has also funded a multi-phased flaw evaluation project which is working to determine the critical flaw size(s) are for this material, in order to aid the development of realistic future Appendix VIII UT qualification requirements

Together…Shaping the Future of Electricity