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NUCLEAR ENERGY AGENCY

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BETTER POLICIES FOR BETTER LIVES

Working Group on Codes and Standards
International workshop on In-Service Inspection

11-14 April 2022

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Workshop on In-Service Inspection

Welcome

Day 2 – Tuesday 12 April 2022

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To ask a question, please use the Q&A section.

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Opening remarks

Dr David RUDLAND

Senior Technical Advisor for Nuclear Power Plant Materials

US Nuclear Regulatory Commission

Dr Patrick RAYNAUD

Senior Materials Engineer

US Nuclear Regulatory Commission

Agenda of Day 2

Time*	Topic
11:00-11:15 AM	Opening remarks
11:15-12:35 Session 1	Presentations: - **Ms Tarja NUORANNE** (STUK, Finland): *RPV ISI in Finland* **Mr Emmanuel LEMAIRE** (EDF, France): *EDF Vessel ISI program* - **Mr Taehun LEE** (KHNP, Korea): *KHNP's Experience on Conventional In-Service Inspection for Reactor Vessel* - **Mr Takeo KIMURA and Mr Yasukazu TAKADA** (Japan): *RV-ISI program from Japanese industrial side*
12:35-13:05 (30min)	Panel discussion and questions from the audience
13:05-13:15 (10min)	Break
13:15-14:15 Session 2	Presentation: - **Mr Shiro OTAKE** (Toshiba, Japan*): Inspection technology to reduce non-detectable parts* - **Mr Hajime SHOHJI** (CRIEPI, Japan): *New Technology of inspection method* - **Dr Seiji ASADA** (MHI, Japan): *Applicability of Full Matrix Capture (FMC) / Total Focusing Method (TFM)*
14:15-14:45 (30min)	Panel discussion and questions from the audience
14:45-15:00 (15 min)	Conclusion of day 2

*Paris time

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Session 1
Reactor vessel ISI programmes and additional regulatory requirements - interval, coverage, qualification, etc.

Ms Tarja NUORANNE

STUK, Finland

RPV ISI in FINLAND

WGCS ISI workshop, April 12th 2022

Tarja Nuoranne
Radiation and Nuclear Safety Authority

Regulation for in-service inspection in Finland 1/3

In-service inspections (ISI) are based on the requirements given in the Finnish legislation and the STUK regulations and guidance

- Nuclear Energy Act (990/1987)
  - Section 60a: the licensee shall apply for STUK's approval of the qualification body
- Nuclear Energy Decree (161/1988)
  - Section 35: When applying for a construction license, the applicant shall submit the conceptual plan of in-service inspections for STUK's approval
  - Section 36: when applying for an operating license, the applicant shall provide the summary programme of in-service inspection for STUK's approval
  - Section 113: NDT of a nuclear facility's structures and components relevant to nuclear safety may be carried out only by a testing organisation and personnel approved by STUK and 113b: with inspection system that is qualified by qualification body

Regulation for in-service inspection in Finland 2/3

- STUK Guide YVL E.5 fulfils the requirements in the legislation, gives more detailed ISI instructions and requirements
  - Requirements for PSI / ISI, RI-ISI
  - The basic requirement level and acceptance criteria follows ASME Boiler and Pressure Vessel Code, Section XI, Rules for In-service Inspection of Nuclear Power Plant Components, Division 1
    - Deviations from the code shall be justified and it shall be demonstrated that a corresponding level of safety and reliability can be achieved
  - Requirements for Inspection system qualification

Regulation for in-service inspection in Finland 3/3

- No divergent rules or regulations for examination of primary circuit components at the stage of extended service life, cases are evaluated separately when sending the applications for lifetime extension.
  - 4 operating units with extended lifetime and 1 new unit under the same regulation
- No difference on regulatory requirements for pre-service and in-service inspections of primary circuit components
- The systems used for surface inspections and volumetric inspections during the pre-service and in-service inspections shall be qualified.
  - Qualifications for surface inspections methods requirements since 2019.
- The testing organizations performing non-destructive in-service testing and their testing personnel shall be approved by STUK according to Nuclear Energy Act and STUK Guide YVL E.12
- Preparations for comprehensive reform of the nuclear energy act and nuclear energy decree as well as STUK regulation have been launched this year.
  - Expected at the end of this decade
  - New technologies are emerging in the industry, regulatory framework for nuclear power generation needs to be reformed in the light of the developments

Steps to approve ISI

- Conceptual plan of in-service inspections
  - Before applying for a construction license
  - Updated regularly by licensee
- Summary programme for in-service inspections
  - Before applying for an operational license
- Pre-service inspection plan
- In-service inspection programme for an inspection interval (10 years)
  - For piping - Risk Informed selection process for In-service inspection programme (RI-ISI)
    - The basis of the risk-informed selection process presented in STUK Guide YVL E.5 and ASME Code, Section XI, Nonmandatory appendix R.
    - RI-ISI programme includes all piping, SC 1-3 and non classified
    - It is approved for all five operating plants in Finland
  - For components - According to ASME BPVC section XI (SC1 / 25 %, SC2 / 10 %)
- Inspection plans for operation periods (1 year)
  - Such that, during inspection intervals the required number of inspections are completed (YVL E.5 358)
  - Plan sent to STUK for approval 1 month before the outage of the unit (YVL E.5 359)


stuk

GUIDE YVL E.5

IN-SERVICE INSPECTION OF NUCLEAR FACILITY PRESSURE EQUIPMENT WITH NON-DESTRUCTIVE TESTING METHODS

https://www.stuklex.fi/en/ohje/YVLE-5

Qualification of an NDT inspection system

- YVL E.5 for inspection system qualification follows the guidelines given in European Network for Inspection and Qualification (ENIQ) documents
  - ENIQ report no. 61: The European Methodology for Qualification
  - ENIQ Recommended Practices
- The systems used for surface inspections and volumetric inspections during the PSI and ISI shall be qualified according to the qualification requirements in STUK Guide YVL E.5. Similar principles may also be applied in the qualification of visual inspection systems.
- Qualification assesses for the inspection reliability in advance
- Accredited qualification body holds the most important role in this assessment, STUK approves qualification.
- The inspector also must have a valid level 2 or 3 personal qualification under a qualification system that complies with standard SFS-EN ISO 9712 or equivalent (YVL E.5 692)

Inspection system
=
Inspection procedure, equipment, software and personnel

Each NDT system separately qualified

Loviisa 1 and 2

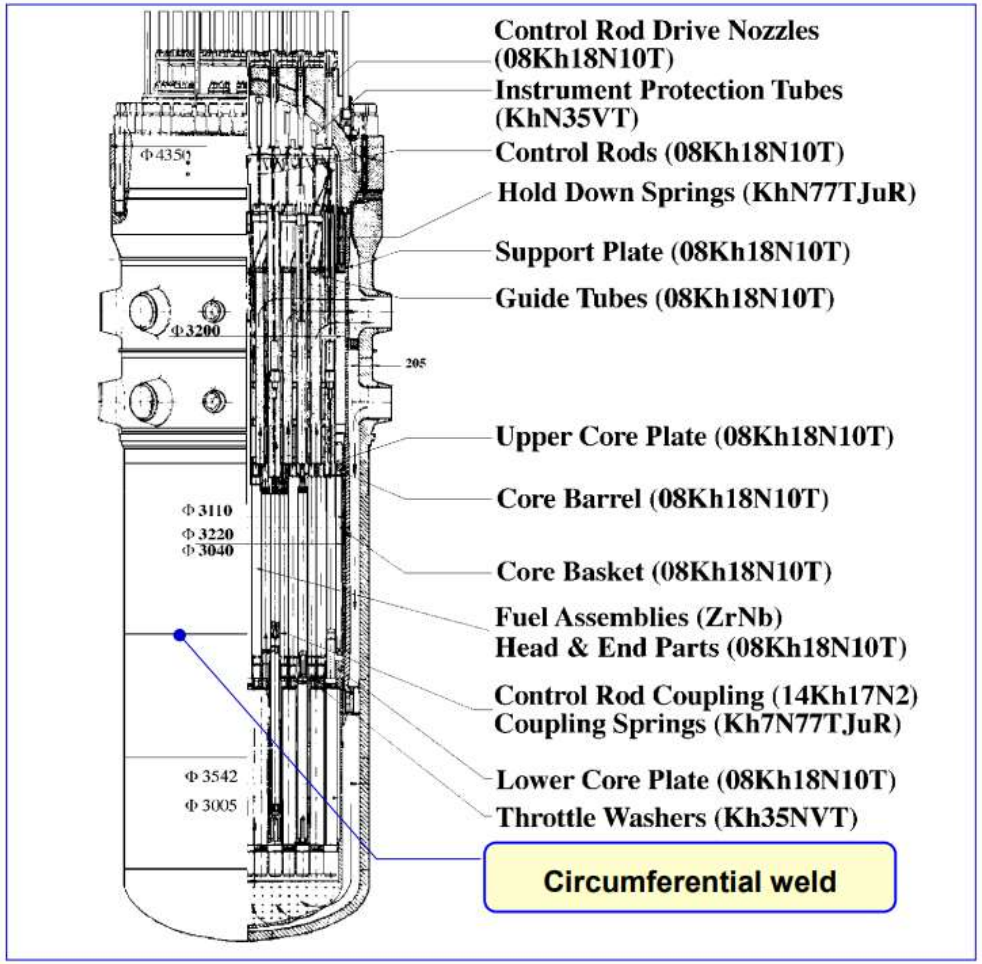
fortum.com

WWER 440
507 MW (electric) / 1500 MW (thermal)
10% Share of Finland’s electricity production
Fortum's Loviisa Unit 1 was the first nuclear power plant in Finland
Commercial use: Unit 1 in 1977, Unit 2 in 1980.
Load factor in 2021 92,9
Operating licences until 2027 and 2030
Fortum applied for new operating licence for both units until the end of 2050.

RPV inside - full inspection in every 8 years

- RPV welds bottom #1 and walls #2-7
- Core area
- RPV nozzle welds
- Nozzle inner radius
- Cladding

- Inspections after hydrostatic testing
  - Pressure test in primary circuit, 178 bar(g) / 17,8 MPa



Plant life management, VTT symposium 227, 2003

Loviisa RPV Inspections

- Inspection of core area outer surface in every 8 years, from 4 years of inner inspections
- RPV sealing surface and RPV head lower surface after every opening
- Control rod drive housing welds with VT, ET and UT
- RPV head housing weld for water leaks, UT
- RPV Internals with Camera aided visual (core basket, core plate)
- Core basket baffle bolts with UT
- PT outer surface of nozzles, first time in 2020

- Extra inspections on RPV core area after indications of hydrogen flakes in Doel 3 and Tihange 2
  - No indications
  - Findings were not probable since the manufacturing method differs from Belgian plants, antiflake treatment

Olkiluoto 1 and 2

Asea Atom BWR
890 MW (electric) / 2500 MW (thermal)
Commercial use: Unit 1 in 1979, Unit 2 in 1982.
Operating licences until 2038

OL1 and OL2 RPV Inspections

Once in every 10 year programme

- RPV inner inspections (ET and UT)
  - Welds in core area, circumferential and horizontal
  - Nozzle inner radius
  - Nozzle safe-end DMW (2 years)
  - Nozzle to shell
  - RPV inner surfaces (VT)
- RPV outer inspections (UT)
  - RPV shell welds, non core area, circumferential and horizontal
  - RPV bottom welds
- Control rod drive housing welds (ET and UT)
- RPV head inspection inside (camera and manipulator aided VT)
- RPV flange and studs threads (ET)
- RPV studs, nuts and washers (VT)

https://www.wesdyne.com/bwr-inspections/

Visual inspection for inner parts (VT-1 and VT-3)

- Control rod guide tube
- Core shroud support
- Core shroud
- Core shroud head
- Core grid
- Feed water sparger – 4 sections
- Core spray
- Boron spray system
- Steam separator
- Steam Dryer
- Reactor instruments mechanical equipment
- Control rods
- Main circulation system

Primary circuit hydrostatic testing

84 bar(g)

First time for
OL2 in 2019 and
OL1 in 2021

Olkiluoto 3

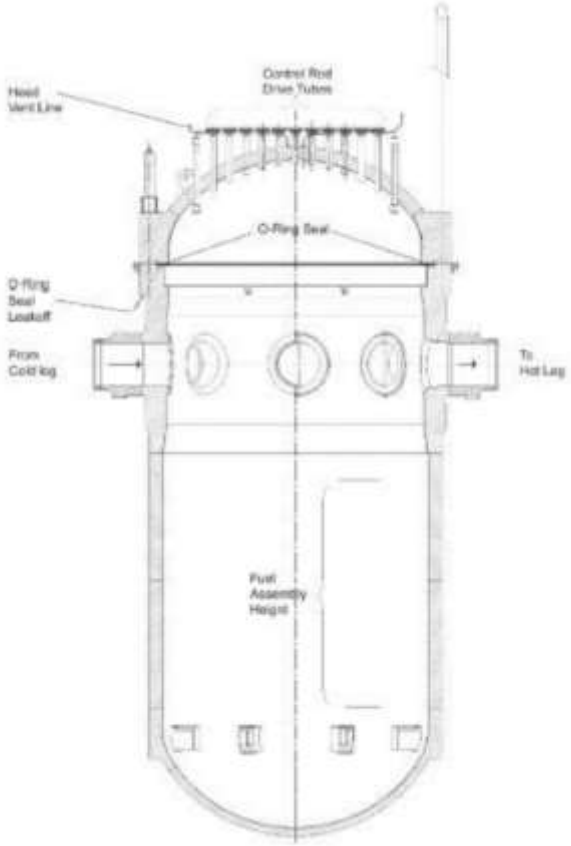
AREVA EPR

- 1600 MW (electric) / 4300 MW (thermal)
- OL1, OL2 and OL3 → 30 % Share of Finland's electricity production
- STUK granted a fuel loading permit in March 2021
- First criticality December 21st 2021.
- Electricity production started March 12th 2022
- Commercial use forecast in July 2022

tvo.fi

OL3 RPV inspection targets

ISI programmes starts at PTO (in 2022) 10 year calendar cycle



📷Status report 78 - The Evolutionary Power Reactor (EPR)
https://aris.iaea.org/PDF/EPR.pdf

- Circumferential shell welds (3 pc), UT inside
- Circumferential bottom head weld, UT inside
- Cover head to flange weld, UT outside + surface
- Nozzle to vessel welds, 4x inlet / 4x outlet, UT inside
- Nozzle inside radius, 4x inlet / 4x outlet, UT inside
- Nozzle to safe-end welds, 4x inlet / 4x outlet, UT inside + surface
- Closure head nuts and washers, (52 pc), VT-1
- Closure studs (52 pc), ET outside
- Threads in flange (52 pc), ET + UT
- Vessel interior, refueling outage accessible areas
- Core support structure, VT-3, accessible welds
- RPV cover head penetrations DMW, UT outside
- Control rod penetrations ligaments, VT-1
- Welded lifting lugs for head, Surface inspection
- Core support, VT-3, when removed from vessel

Mr Emmanuel LEMAIRE

EDF, France

EDF RPV ISI Program

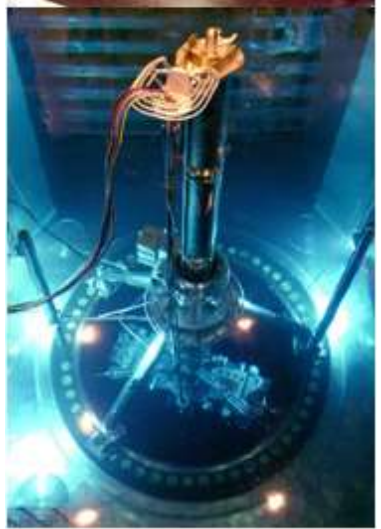
1 - Main Concerns and Regulatory Requirements

2 - Beltline Overview

3 - Vessel Penetrations Overview

Emmanuel LEMAIRE
Corporate Lead, RPV Program, EDF-Nuclear Generation

April 2022 International ISI Workshop
Session 1: Reactor vessel ISI programs and additional regulatory requirements - Interval, coverage and qualification



1 - Main concerns and regulatory requirements

Reactor Pressure Vessel = major component for safety

- RPV is one of two limiting cases for plant LTO
- RPV subjected to neutron flux, leading to a progressive decrease of toughness

Two main safety concerns

- RPV failure not considered
- Boric Acid Corrosion issue if leak due to SCC

In accordance with regulatory requirements, need of

- Integrity demonstration for all operating conditions
- Relevant ISI programs (NDE, periodicity, VOT, dosimetry, operating experience)
- Mitigation of ageing and repair solutions / strategies

1 - Main concerns and regulatory requirements

Requirements	Corresponding actions for RPV
Maintenance program takes into account identified damage / failure modes	Mechanical analysis to identify the most sensitive locations to **fast fracture**, fatigue and **SCC**
Adequate **NDE** are performed on locations deemed relevant by maintenance program	UT performed on **beltline region** and nozzles (search for **underclad defects**), DMW, main body welds, **BMI nozzles**
NDE follow a qualification process demonstrating their performance. Expertise process in case of additional NDE	Qualification of NDE - Locations = beltline region, nozzles, RPV main body welds, DMW, BMI nozzles Hydrogen flakes, manufacturing records
Material ageing phenomena must be considered and suitably followed through by means of specific programs	Irradiation Surveillance Program (ISP) of each RPV (100% / entire beltline region) Experimental mockup tests for CSC (BMI) and thermal ageing (RPV outlet nozzles…)
Safety coefficients must be considered for mechanical analysis	Coefficient applied on loads, depending on fast fracture mode and transient category (1,6 for 10^{-2}>frequency>10^{-4})

2 - Beltline overview

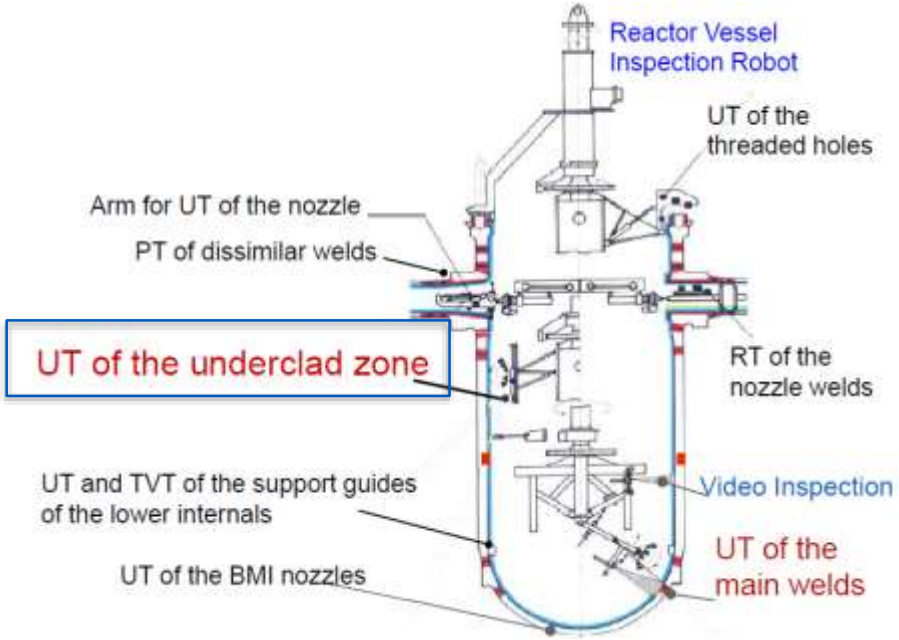
a - Methodology

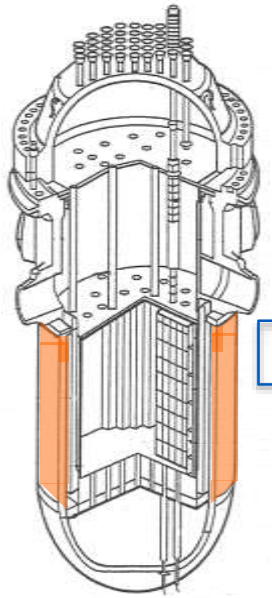
b - Inspection scope

c - Stakes connected to ISI

d - Fluence optimization

e - R&D studies





Beltline region

2a - Beltline overview: methodology

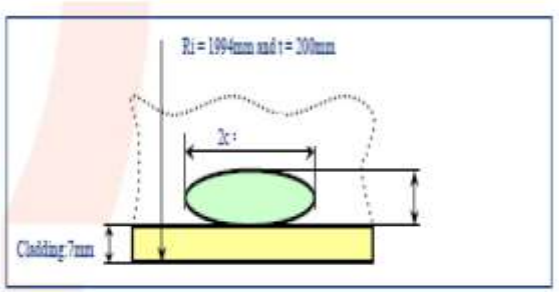
General principles similar to analyses performed in other countries: demonstration mainly based on fast fracture analysis for PTS transients (maximized cold thermal shocks)

Particularities:

- **Deterministic analysis** (probabilistic analysis used as a support study, to illustrate margins - not part of scope reviewed by regulator)
- Requirement = **no crack initiation**, with mandatory margins (regulatory safety coefficients, crack arrest - not part of scope reviewed by regulator)
- Use of conservative assumptions: fluence evaluation, embrittlement prediction, fracture toughness, **severe thermohydraulic input data**, flaw size and/or location

Fast fracture analysis performed on:

- Generic defect: dimensions based on NDE guaranteed detection thresholds, located at most loaded point of most embrittled vessel (covers all RPVs of fleet) → **bounding case for integrity assessment**
- **Defects detected by NDE**



2b - Beltline overview: inspection scope

Inspection of irradiated parts of RPV

- Complete scan of beltline region every 10 years (core shells and welds)
- Inspection performed by In-service Inspection Machine (automated UT)
- Performance demonstrated by qualification process: guaranteed detection of underclad defects > **5x25mm** (dimensions used for FF analysis)
- **Inspection feedback: no in-service evolution of known manufacturing defects (≈ 30 on French fleet)**
- **Additional inspections related to manufacturing files analysis and international feedback (hydrogen flacks)**

→ High level of performance to maintain

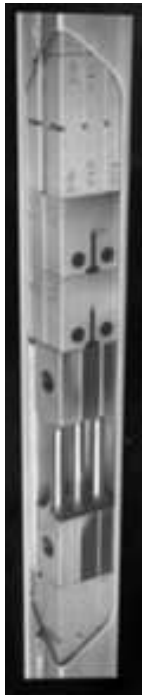
→ Update based on operating experience and mechanical analysis results (mandatory review at least every 10 years)

2b - Beltline overview: inspection scope

Inspection history of irradiated parts of RPV

- 1989: beginning of underclad inspections in core area, on operating vessels in decennial outages,
- 1998: the inspection process VPM is qualified for the detection of 6 mm high and 20 mm long flaws, longitudinal and circumferential,
- 1999: 17 underclad flaws are detected in the core area of a 900 MWe unit,
- 2002: inspections completed for all EDF 900MWe units (34 RPV and inspections of 100% of the core zones),
- 2004: inspections completed for the EDF fleet (58 RPV and inspections of 100% of the core zones),
- 2005: the inspection process is qualified for the detection of 5 mm. high and 25 mm. long flaws,
- 2010: a total of 30 flaws have been detected (58 RPV core areas).

2c - Beltline overview: stakes connected to ISI



Irradiation surveillance program and irradiation prediction

- Capsules inserted in RPV containing selected material for each RPV: base metal, weld, HAZ and reference base metal (Marrel plate)
- Charpy tests performed to evaluate real embrittlement and comparison with embrittlement predictions

→ Additional capsules inserted to cover 60 years of operation

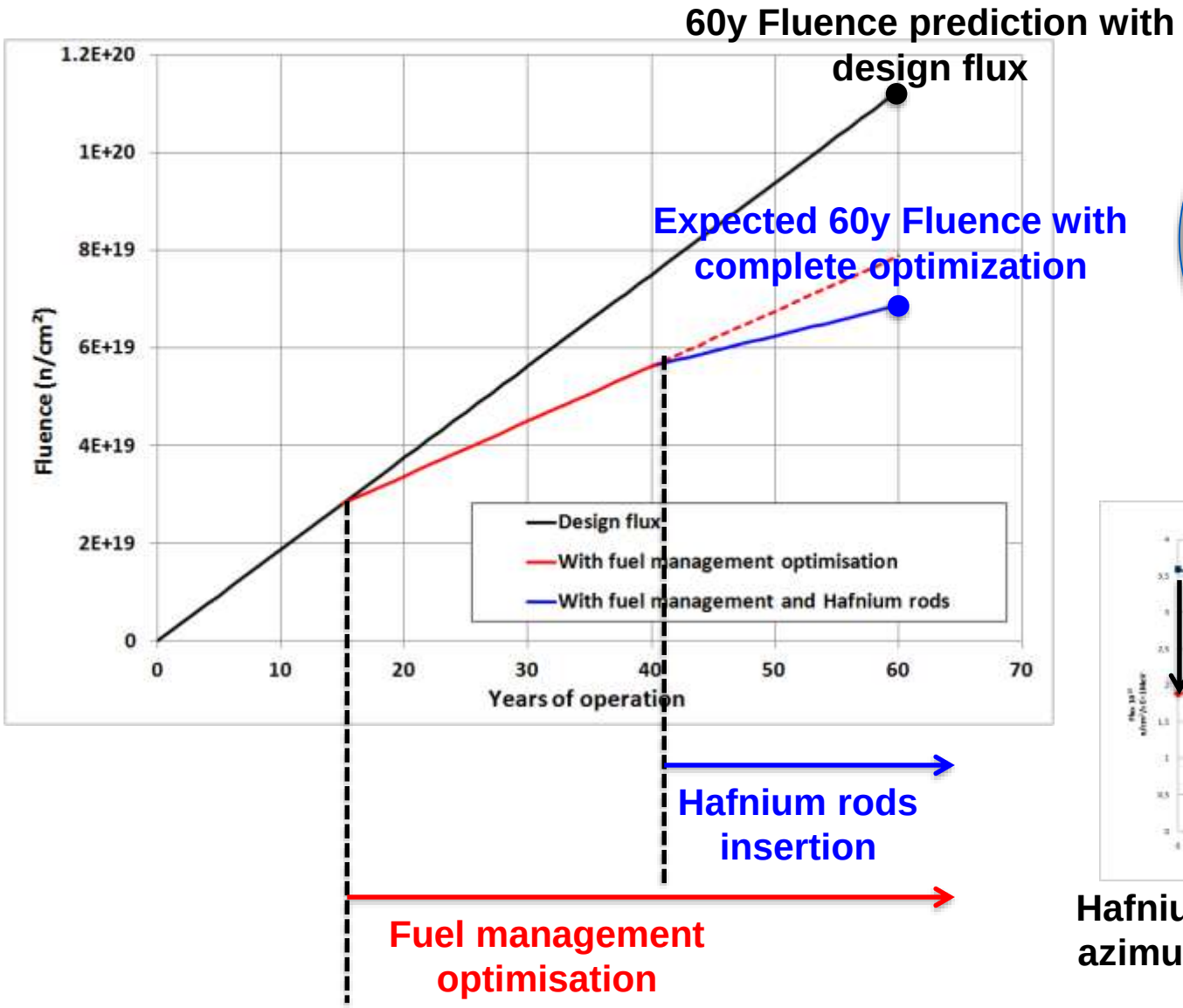
→ Continuous updating of embrittlement formula based on additional available data and additional toughness tests

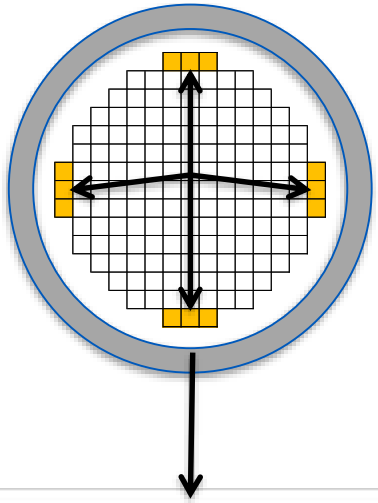
Fuel management optimization

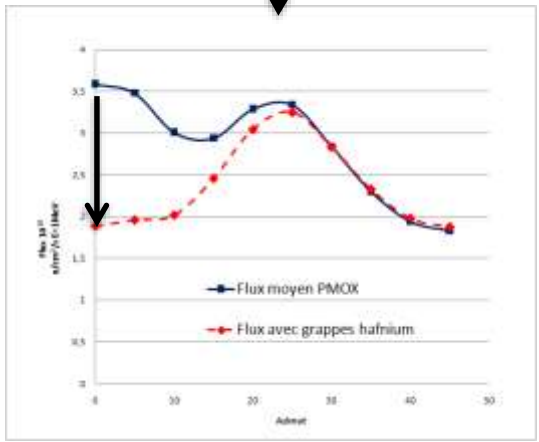
- Starting in early 1990s, emphasis placed on fuel management to limit fluence on RPV walls
- Significant reduction of neutron flux : -30% to -40%

→ Further reduction of flux by inserting Hafnium rods in specific locations of core: ≈ -45% at hot points depending of the plant series (starting in 2019 for the 900 MWe fleet)

2d - Beltline overview: fluence optimization



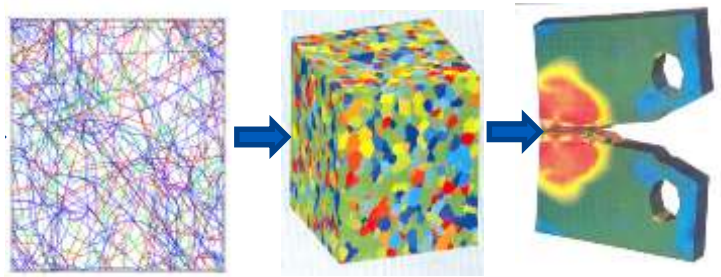


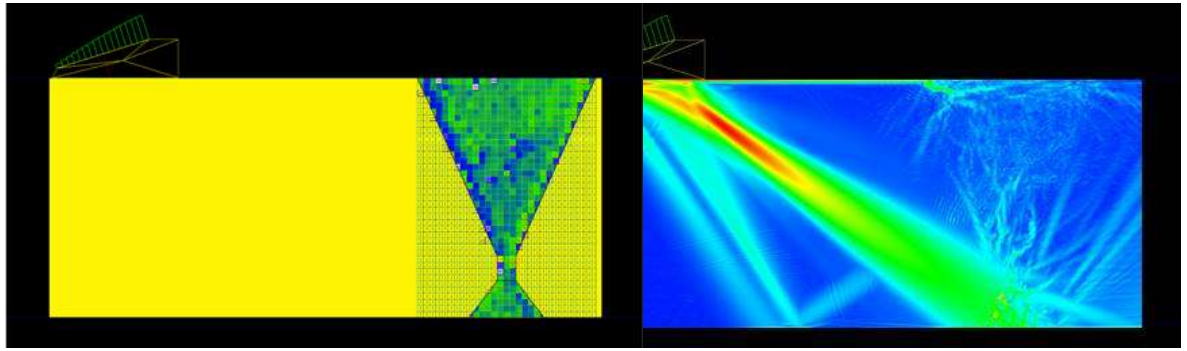


Hafnium rods: local effect on azimuthal distribution of flux

2e - R&D support studies

- Improvement of thermo-hydraulic tools based on mock-up experiments and CFD
- Development of specific criterion « ACE » (AREVA-CEA-EDF), allowing analysis of complex transients - takes into account reloading capacity after maximum pre-load
- State-of-the-art on crack arrest phenomenon
- Atom probe benchmark (EDF-Rouen University, CRIEPI, Kurchatov) and numerical simulation of irradiation effects on microstructure
- Annealing procedure for PWR materials (EDF, Kurchatov) – support to ISP results investigation
- R&D on UT technologies

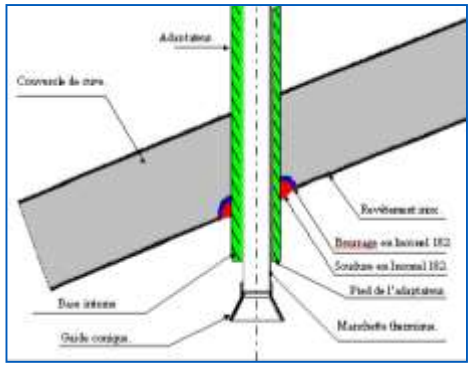




3 - Vessel penetrations overview

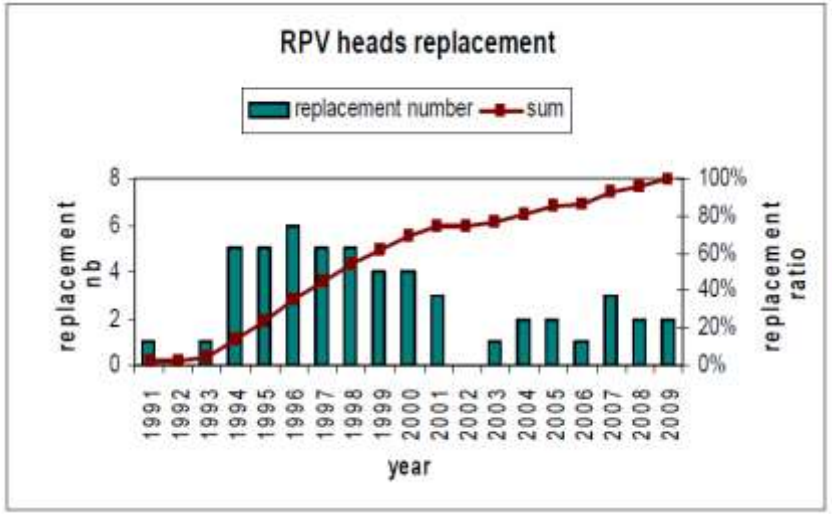
3a - Time scale

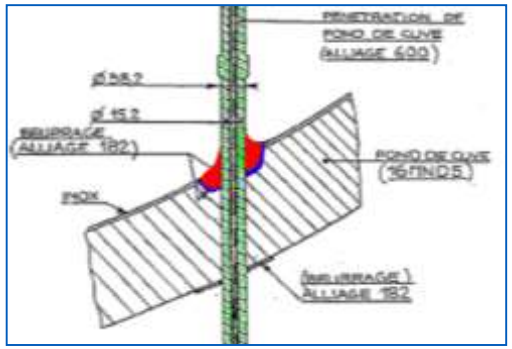
Year	PWSCC of alloy 600	Unit
1981	Steam Generator tubes	Fessenheim 1
1982		Bugey 2
1982	Guide tube pins (alloy X750)	Fessenheim 1 Gravelines 1
1989	Pressurizer nozzles	Cattenom 2 Nogent 1
1991	Vessel head penetrations	Bugey 3
2004	Steam generator partition plates	Chinon B4
2011	BMI Nozzle	Gravelines 1



Leak (during RCS pressure test)

No leak (UT)



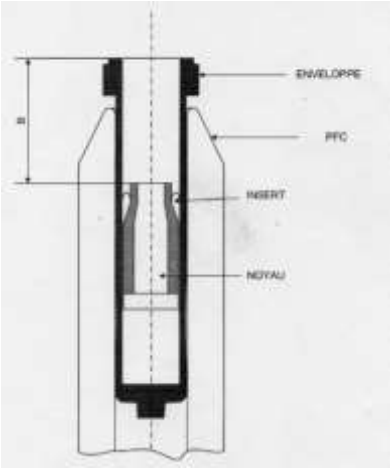


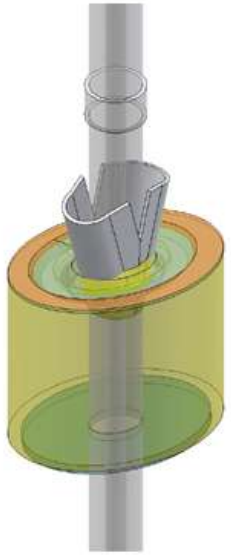
Industrial head replacement program based on ISI results and safety criteria

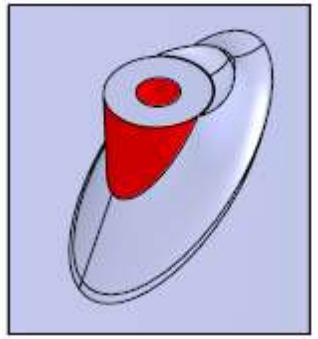
3 - Vessel penetrations overview

3b – Focus on BMI nozzle: inspection strategy following GRA1

- In addition to pit remove TV, moving from UT sampling to extensive ISI (2980 BMI already inspected at least once): extensive characterization needed due to the root cause (presence of stringer, legacy from manufacturing),
- Moving from interim plugging with leak monitoring to removal of defects, with or without permanent plugging.



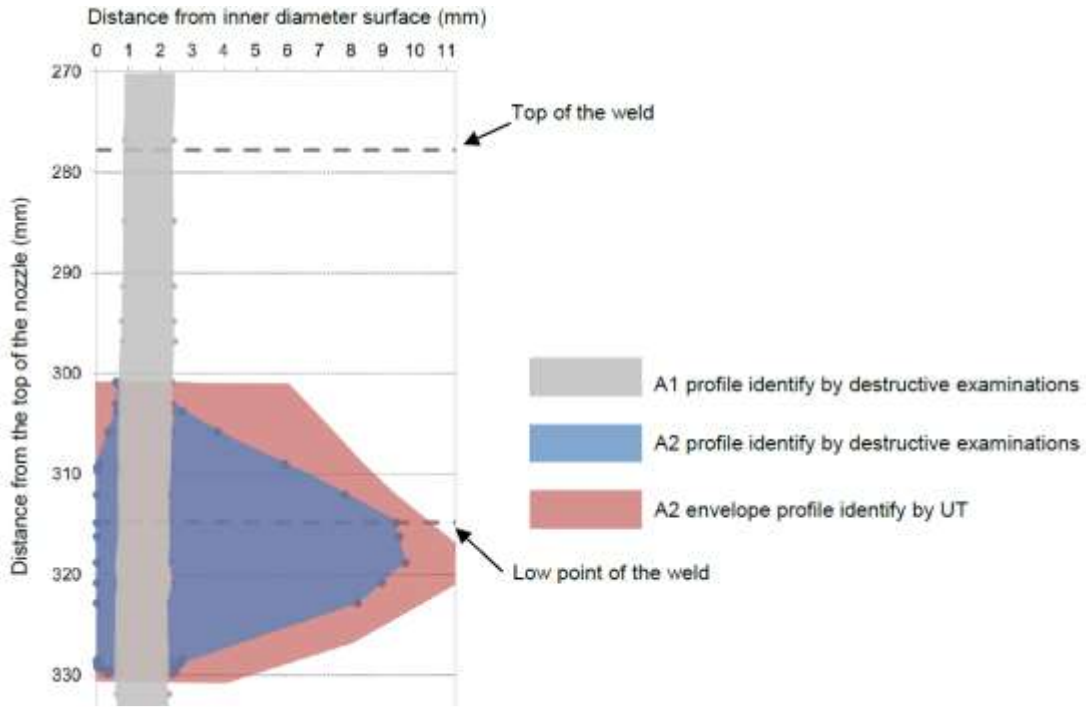


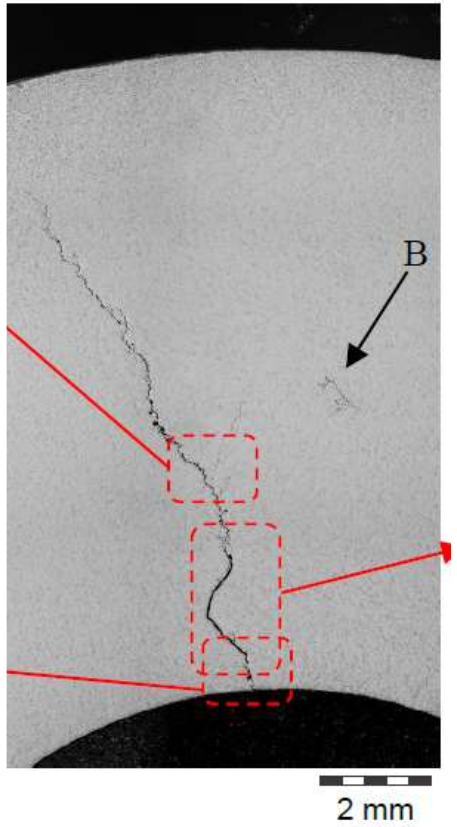


- Strengthening the UT detection capabilities,
- Strengthening the justification of ISI frequency.

3 - Vessel penetrations overview

3b – Focus on BMI nozzle: accuracy and conservatism of UT results proven by destructive exams





FONTEVRAUD 9 | 17 – 20 September 2018 | Avignon, France

Contribution of Materials Investigations and Operating Experience to Light Water NPPs' Safety, Performance and Reliability

Metallurgical examinations results of the bottom mounted instrumentation nozzle #4 of Gravelines 1 nuclear power plant

E. Derniaux[1*], Y. Thébault[1], M-L. Lescoat[2], A. Ledru[2], E. Visse[3]

KEY POINTS (1/2)

RPV ISI is part of a maintenance strategy that incudes mitigation:

- fuel management for the beltline,
- mitigation (peening for the most susceptible BMI nozzles, Zinc injection) for SCC of the sensitive series of Nickel based alloys.

Needs depend on regulatory requirements including integrity assessment studies and operating experience.

For RPV, maintenance programs are based on the following practices:

- detection every 10 years of 5 mm depth for the entire beltline region subjected to under crack defects, with additional ISI following international operating experience or manufacturing record analysis,
- detection of 2 (ID) or 3 mm (OD) for BMI nozzles subjected to longitudinal or circumferential SCC, moving from sampling to extensive after the first event of CSC was detected in 2001,
- detection every 10 years by sampling on 3 reactors following the complete replacement of vessel head with the series 690 (ended in 2009).

KEY POINTS (2/2)

Very few flaws detected, legacy from manufacturing (under crack defects, SCC due to Alloy 600 susceptibly when cold work and stringers).

No evolution of the indications in the beltline. On going ISI program implemented to confirm status planned for 10 year refueling outages.

No leak due to SCC following the event at BUG3 in 1991. Progressive replacement of vessel heads equipped with the series 600 based on ISI results and safety criteria. Target of early detection in BMI nozzles. Two postponed definitive repairs (with laboratory forensic expertise on removed components).

EDF experience has been continuously capitalized starting in the 1980's, based either on field experience or anticipative studies. Combined with an increasing knowledge on material behaviour, adapted and effective ISI. This field experience is of major importance for safety of EDF NPPs fleet both in the mid term and long term.

CONCLUSION

1 - Surveillance policy fully mature and based on OE

2 - Mitigation of fluence for at least 60-year LTO

3 - Proactive replacement of original RPVH

4 - Innovative repairs of BMI nozzle

Mr Taehun LEE

KHNP, Republic of Korea

WGCS International Workshop on Mechanical Codes and Standards: In-Service Inspection
(Virtual, April 11-14, 2022)

KHNP's Experience on Conventional In-Service Inspection for Reactor Vessel in Korea

2022.4.12

Taehun Lee (taehun.lee@khnp.co.kr)
NDE Engineering group
Central Research Institute (CRI)
Korea Hydro & Nuclear Power Co. LTD.

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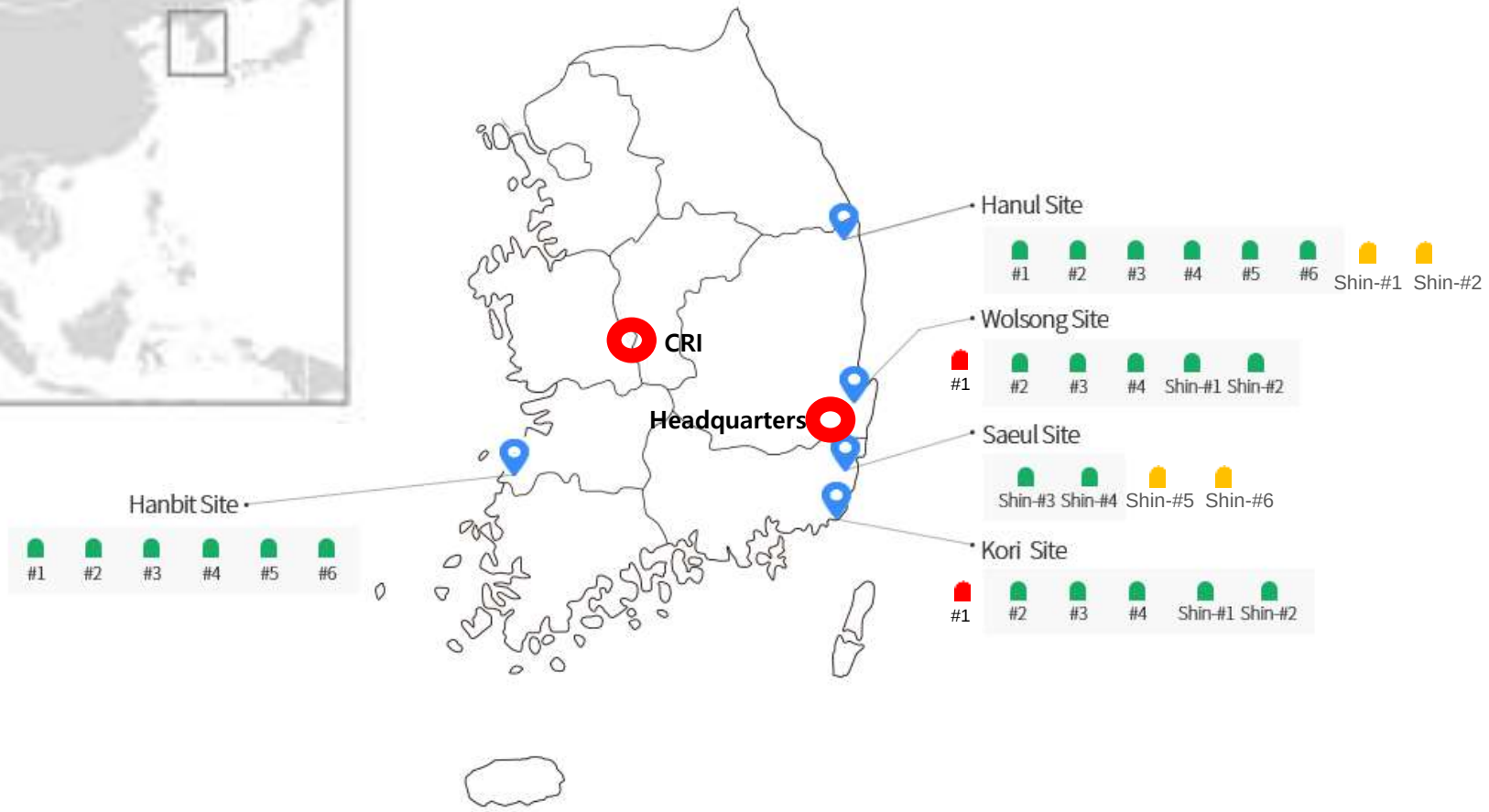
III. Performance Demonstration in Korea

IV. In-service inspection of reactor vessel

V. Summary

Nuclear power plants in Korea



- Nuclear power plants : 24
- Hydroelectric plants : 37
- Pumped-storage power plants : 16
- Renewable power plants : 32

Nuclear power plants in Korea

KHNP

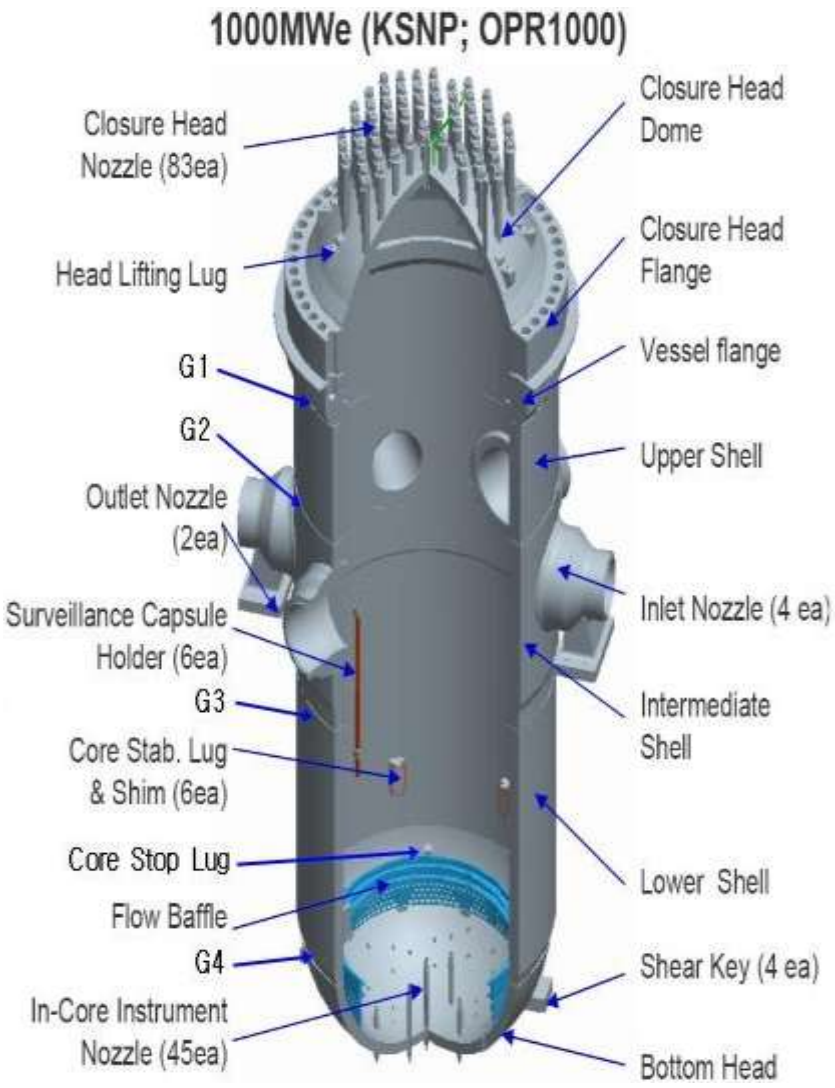
❖ Classification of NPPs in Korea

- Westinghouse Type Reactor: 5 units
  - ✓ Kori#2,3,4 & Hanbit#1,2
- Framatome(France CPI) Type Reactor: 2 units
  - ✓ Hanul#1,2
- **OPR1000(Optimized Power Reactor)**: 12 units
  - ✓ Korean Standard Nuclear Power Plant
  - ✓ Hanbit#3,4,5,6 & Hanul#3,4,5,6
  - ✓ Shin-Kori#1,2 & Shin-Wolsong#1,2
  - ✓ Generation capacity : 1000MW, Design lifetime : 40 yrs.
- **APR1400(Advance Power Reactor)**: 2 units
  - ✓ next-generation nuclear power plant
  - ✓ Shin-Kori#3,4
  - ✓ Generation capacity : 1400MW, Design lifetime : 60 yrs.
  - ❖ Shin-Hanul#1,2 & Shin-Kori#5,6(under construction)
- CANDU type Reactor : 3 units
  - ✓ Wolsong #2,3,4

General Information on Reactor Vessels

❖ OPR1000

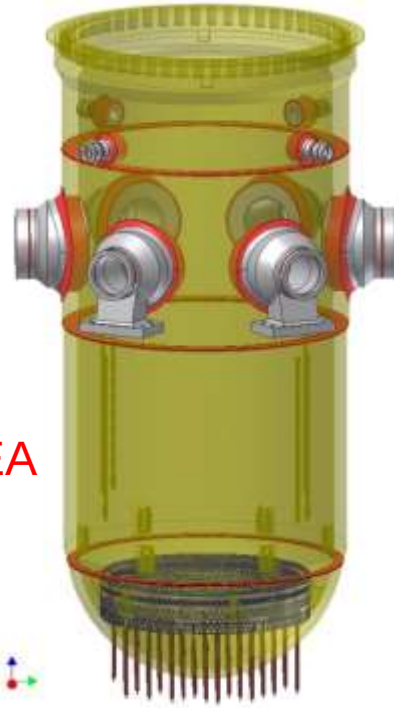
- Reactor Vessel ID: 164 in
- Thickness: 10.5/10.2/6 in
- Clad Thickness: 0.16 in
- Girth Welds: 4 EA
- Inlet nozzles: 4 EA(30 in)
- Outlet nozzles: 2EA(42 in)
- Inlet/Outlet Nozzle to pipe weld: 6 EA

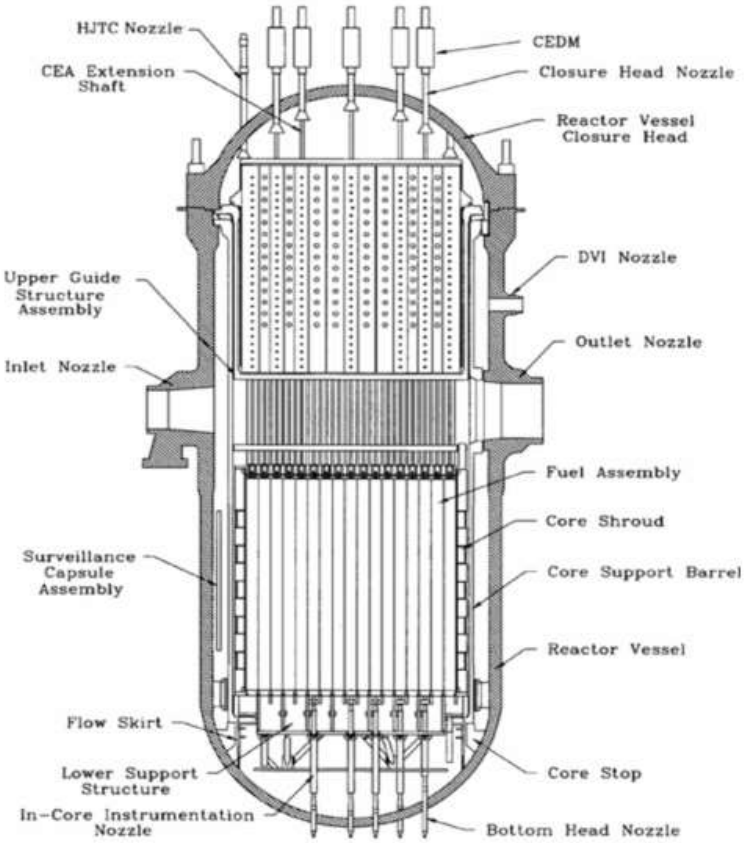


General Information on Reactor Vessels

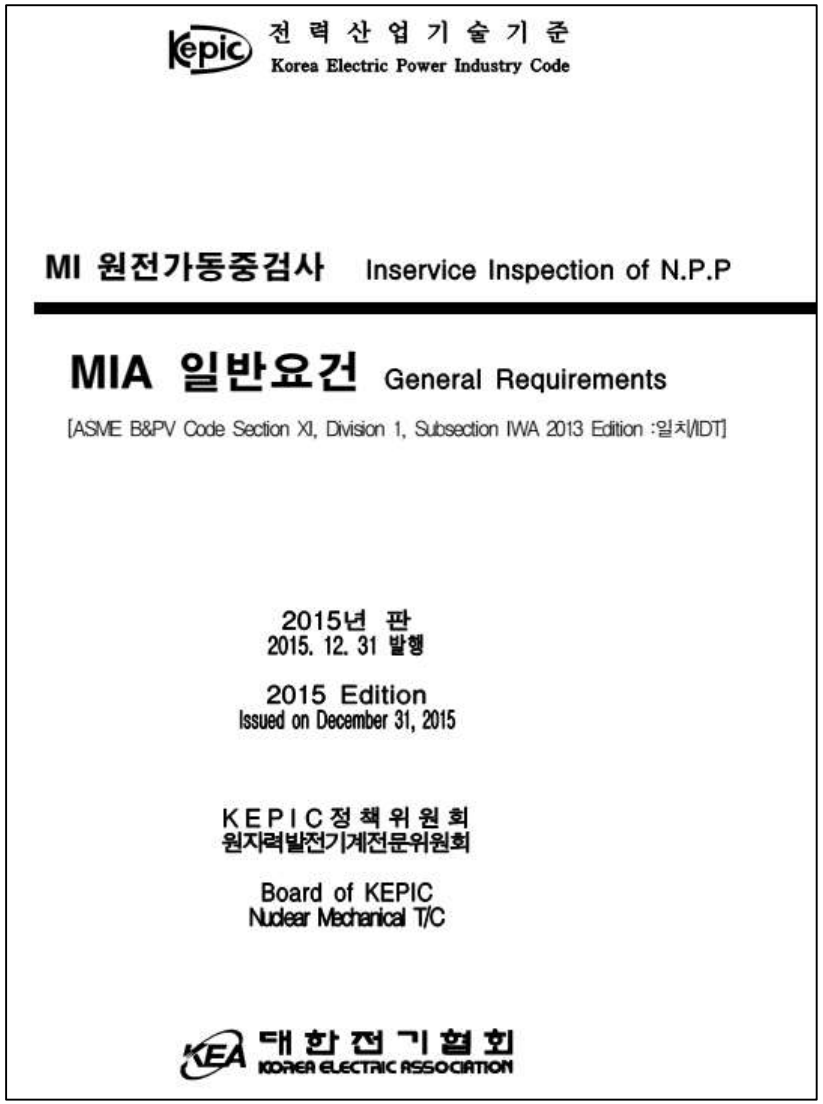
❖ APR1400

- Reactor Vessel ID: 183 in
- Thickness: 11.5/9.37/6.89 in
- Clad Thickness: 0.16 in
- Girth Welds: 3 EA
- Inlet nozzles: 4 EA(30 in)
- Outlet nozzles: 2EA(42 in)
- DVI(Direct vessel Injection) : 4 EA
- Inlet/Outlet Nozzle to pipe weld: 6 EA





KEPIC code for In-service Inspection


전 력 산 업 기 술 기 준
Korea Electric Power Industry Code

MI 원전가동중검사 Inservice Inspection of N.P.P

MIA 일반요건 General Requirements

[ASME B&PV Code Section XI, Division 1, Subsection IWA 2013 Edition :일치/IDT]

2015년 판
2015. 12. 31 발행

2015 Edition
Issued on December 31, 2015

KEPIC정책위원회
원자력발전기계전문위원회

Board of KEPIC
Nuclear Mechanical T/C

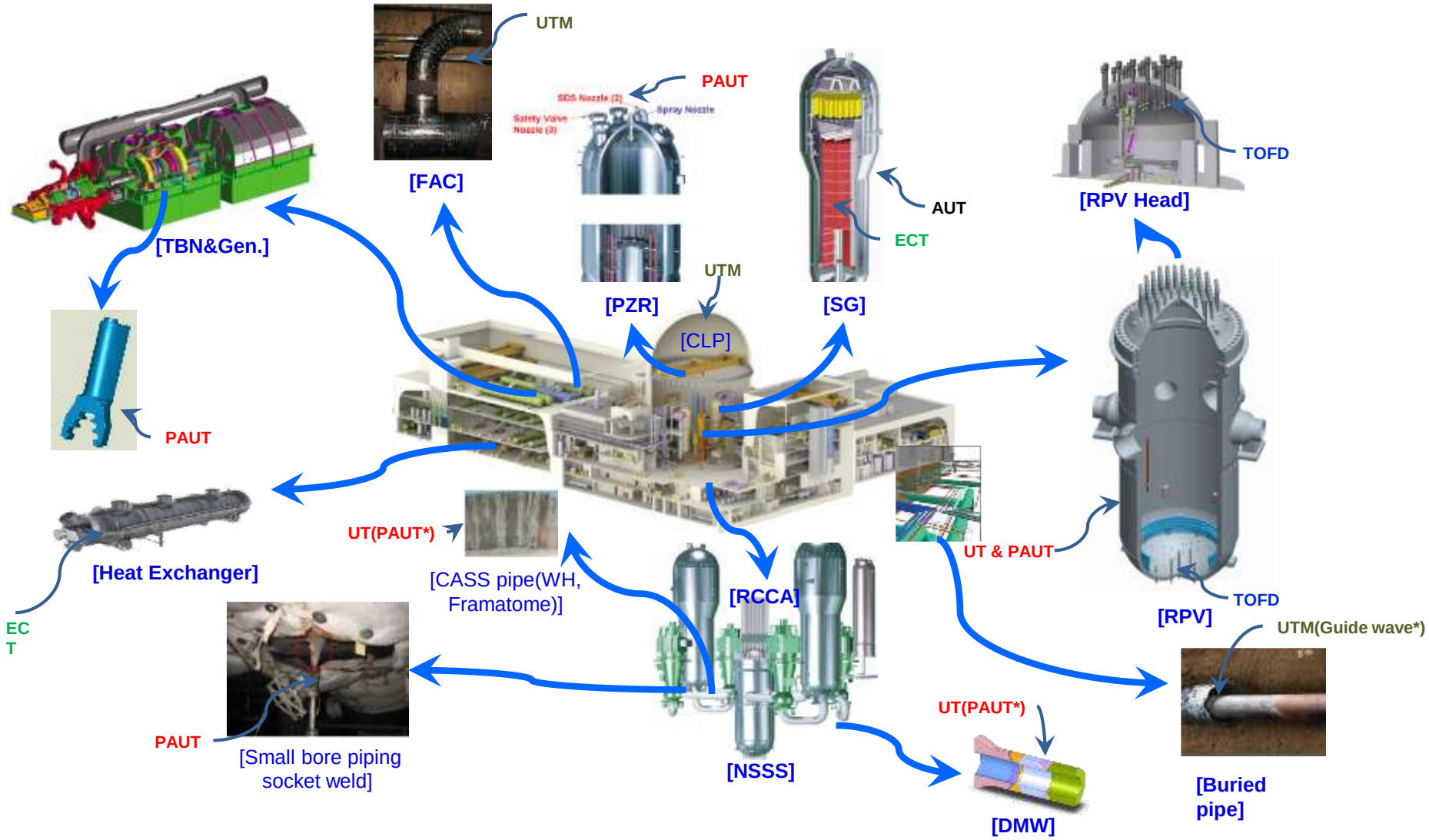
대한전기협회
KOREA ELECTRIC ASSOCIATION

Publication Lists of KEPIC

Tech. Group	Sub-Group
Q Quality	QA(Quality Assurance)
M Mechanical	MN(Nuclear Mechanical), **MI(In-service Inspection),** MW(PHWR ISI), MO(In-service Test), MF(Qualification of Mech. Equipment), MH(Nuclear Air and Gas Treatment), MG(Mechanical General), MB(Boilers), MT(Turbine/ Generater), MC(Crane), MD(Material), ME(Nondestructive Examination), MP(Performance Test), MQ(Welding), MN(Maintance)
E Electrical and I&C	EN(Nuclear Electrical and I&C), EM(Measuring & Control Equipment), EE(Electric Equipment), EC(Cable& Raceways), ET(Transmission, Transformation & Distribution)
S Structural	SN(Nuclear Safety Related Structures), SG(Non-Nuclear Safety Related Structures), ST(General Structural Provisions), SW(Structural Welding)
N Nuclear	ND(Design of NPP), NR(Radiation Protection), NW(Radioactive Waste Control), NF(Nuclear Fuel), NP(PSA)
F Fire	FP(Fire Protection)
G Environmental	GG(Air Pollution),GS(Noise/Vibration),GW(Water Treatment)

Requirement for in-service inspection : KEPIC MI (ASME B&PV code Sec. XI)

Application of Volumetric testing for NPP



- PAUT : Phased Array Ultrasonic Testing
- UTM : Ultrasonic Thickness Measurement
- TOFD : Time of Flight Diffraction

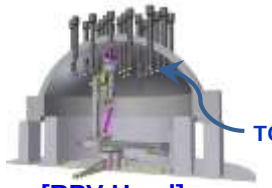
* NDT method planned to be applied in the future

Management program by KHNP

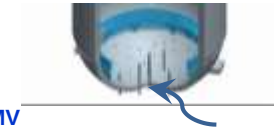
❖ Integrated guidelines for management of alloy 600 components

Location	Method	Inspection Interval		
Reactor Upper Head Penetration Nozzles (CC N-729-4)	BMV	1 outage		3 outages(5 yrs)
		4 units		others
	UT	1 outage	8 yrs	10 yrs.
		4 units	6 unit	others
Reactor Lower Head Penetration (Bottom mounted instrumentation, BMI) Nozzle	BMV (CC N-722-1)	2 outages		
		13 unit		
	UT	one time inspection (not code required)		
		13 unit		
Dissimilar Metal Weld Butt weld (CC N770-1)	BMV	1 outage		10 yrs
		pressurizer, Hot leg		Cold log
	UT	2 outages or 10 ysr 1)	5 yrs	2 period (<7 yrs)
		pressurizer	Hot leg	Cold log
Pressurized heater Sleeve (CC N722-1)	BMV	1 outage		
		6 unit		
Instrument and small diameter nozzle (CC N722-1)	BMV	1 outage	1 outage	10 yrs
		pressurizer	Hot leg	Cold log

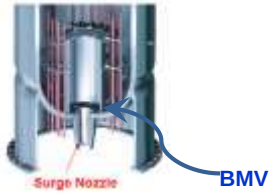
1) Full Structural Weld Overlay for dissimilar metal weld in PZR



[RPV Head]



[DMW]



[PZR]

❖ Management program for small bore piping socket weld within the pressure boundary of RCS

[Inspection Interval and method]

Combination	Group	Inspection period	Inspection Method
Ⅰ+A	①	1 period	PT, UT
Ⅰ+B	②	1 Period	PT, UT
Ⅰ+C	③	6 Period	PT, UT
Ⅱ+A	④	2 Period	PT, UT
Ⅱ+B	⑤	2 Period	PT, UT
Ⅱ+C	⑥	6 Period	PT
Ⅲ+A	⑦	2 Period	PT, UT
Ⅲ+B	⑧	1 Period	PT
Ⅲ+C	⑨	6 Period	VT
Total	-	-	-

[Small bore piping socket weld]

KEPIC Code for Reactor Vessel Inspection

TABLE MIB 2500-1(1) EXAMINATION CATEGORIES

EXAMINATION CATEGORY B-A, PRESSURE RETAINING WELDS IN REACTOR VESSEL							
Item No.	Parts Examined	Examination Requirements/ Fig. No.	Examination Method	Acceptance Standard	Extent and Frequency of Examination		Deferral of Examination to End of Interval
					First Inspection Interval	Successive Inspection Intervals	
B1.10 B1.11 B1.12	Shell welds Circumferential Longitudinal	MIB 2500-1 MIB 2500-2	Volumetric	MIB 3510	All welds<2>	Same as for first interval	Permissible
B1.20 B1.21 B1.22	Head welds Circumferential Meridional	MIB 2500-3	Volumetric	MIB 3510	Accessible length of all welds<2>	Same as for first interval	Permissible
B1.30	Shell-to-flange weld	MIB 2500-4	Volumetric	MIB 3510	Welds<2>	Same as for first interval	Permissible<3><5>
B1.40	Head-to-flange weld	MIB 2500-5	Volumetric and surface	MIB 3510	Welds<2>	Same as for first interval	Permissible<4><5>
B1.50 B1.51	Repair welds<1> Beltline region	MIB 2500-1 and -2	Volumetric	MIB 3510	All weld repair areas	Same as for first interval	Permissible
	Reactor Vessel						
B3.90	Nozzle-to-Vessel Welds	MIB 2500-7<4>	Volumetric	MIB 3512	All nozzles<1>	Same as for 1st Interval	<2><3><5>
B3.100	Nozzle Inside Radius Section	MIB 2500-7<4>	Volumetric	MIB 3512	All nozzles<1>		<2><5>

- **B 3.100 Alternative:**
  ASME Code Case N-648-1 "Alternative Requirements for Inner Radius Examinations of Class 1 Reactor Vessel Nozzles Section XI, Division 1"

Performance Demonstration for UT of RPV

KHNP

- ASME XI Appendix Qualification Requirements Component Qualification Supplements

  - ✓ Supplement 2: Wrought austenitic Piping Welds
  - ✓ Supplement 3: Ferritic Piping Welds
  - ✓ Supplement 4: Clad/base metal interface region of reactor vessel
  - ✓ Supplement 6: Reactor vessel welds other than clad/base metal interface
  - ✓ Supplement 7: Nozzle examinations from the inside surface(nozzle bore side access)
  - ✓ Supplement 10: Dissimilar metal Piping Welds

KPD Organization

Korea Performance Demonstration(KPD)
<All PD works controlled by KHNP-CRI>

Regulatory Body
- NSSC/ KINS

Qualification/Training/Exam Body< KHNP-CRI>

- PD Program Manager
- QA Records Specialist
- UT Project Manager
- ECT Project Manager
- Supervisor Level III (UT)
- Supervisor Level III (ECT)

Oversight & Feedback
- All Works related with PD
- Include just Review annual Training/SSPD results

Certification(Oversight) Body<The 3rd Party(*)>

- Certification Manager
- QA Specialist
- UT in charge
- ECT in charge

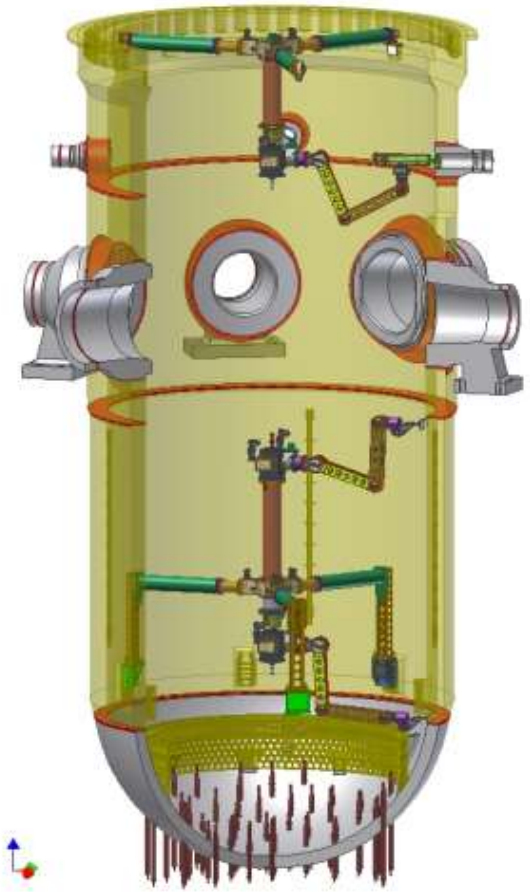
(*) Service Agreement : June.2019 ~ June.2022(3 years)
: KSNT(The Korean Society of Nondestructive Testing

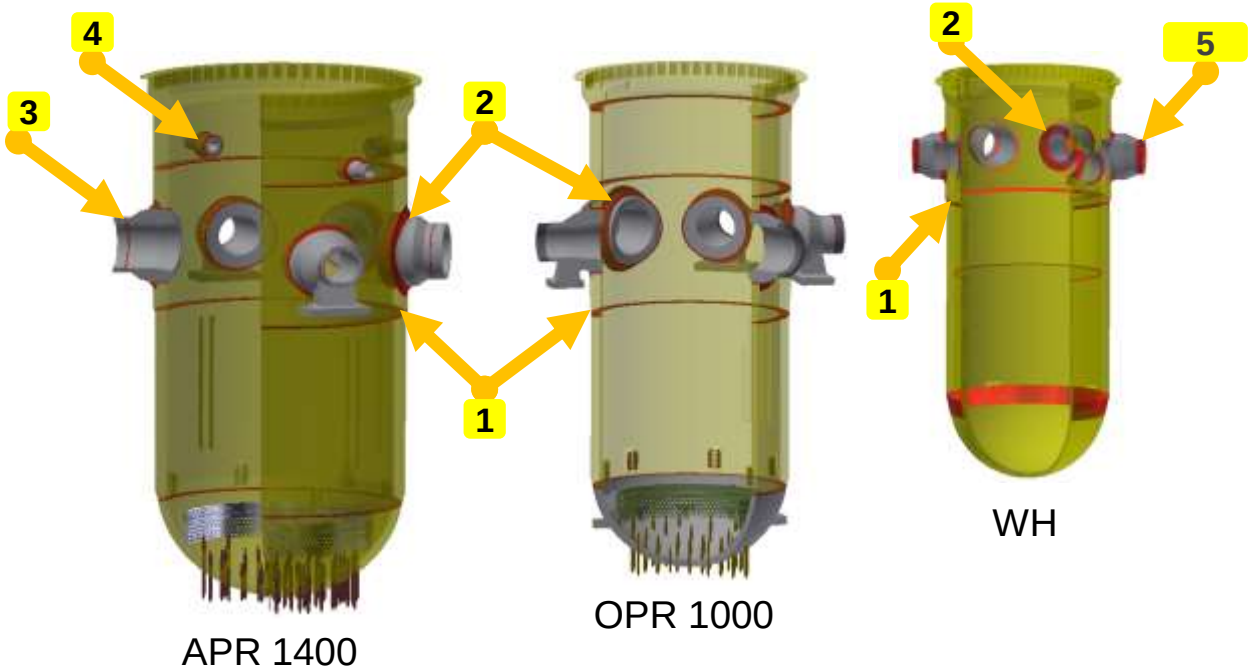
KPD Organization

NDE Method	Component Type	PD System
UT	▪ Wrought Austenitic Piping Welds ▪ Ferritic Piping Welds ▪ Bolts and Stud	KPD KPD KPD
	▪ Weld, IRS & Clad/Base Metal Interface of Reactor Vessel	EPRI(US)
	▪ Overlaid Wrought Austenitic Piping Welds	EPRI(US)
	▪ Dissimilar Metal Piping Welds	KPD
	▪ Reactor Vessel Head Inspection	EPRI ▶ KPD(2018)
ECT	▪ SG ECT Data Analyst(QDA)	KPD
	▪ Site Specific PD(SSPD)	KPD

*** Annual Training for UT Examiner by KPD(KHNP-CRI)**

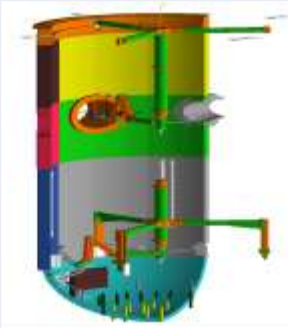
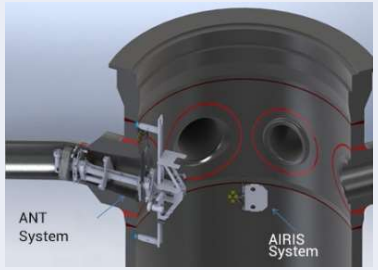
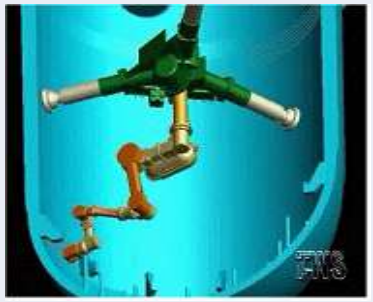
In-service inspection of reactor vessel





No.	Inspection Part	ASME Sec XI App VIII	Plant Type
1	Shell to Shell weld	Sup. 4 & 6	APR, OPR, WH
2	Nozzle to Shell weld	Sup. 4, 5 & 7	APR, OPR, WH
3	Nozzle to Pipe weld	Sup. 3	APR, OPR
4	DVI to Shell weld	Sup. 4, 5 & 7	APR
5	Dissimilar Metal Pipe weld	Sup. 2 & 10	WH

Inspection system of reactor vessel

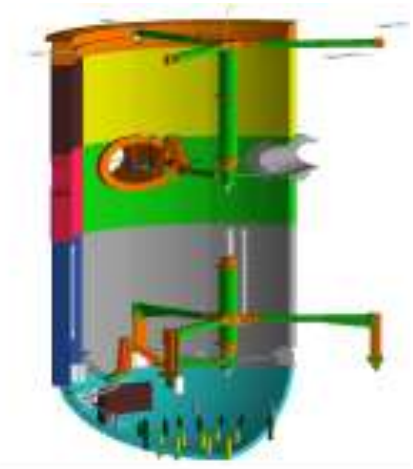
	United States	United States	Japan	France
Manufacturer	**WesDyne**	ISwT→ IIA	**MHI**	**AREVA**
Robot	 SUPREEM	 ANT/AIRIS	 A-UT	 TWS
UT System	PARAGON	DYNARAY	PADAS	SAPHIR
UT Method	Conventional	Phased Array	Conventional	Conventional + Phased Array [4 Channel]

KEPCO KPS **Sae-An**

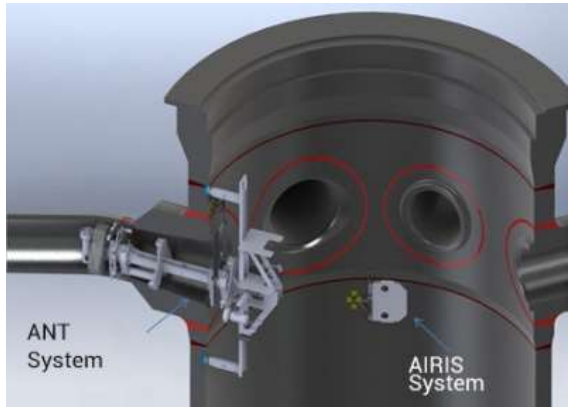
Inspection system of reactor vessel

❖ Service Providers for Reactor Vessel Inspection

- KEPCO KPS: Technology Partner(Westinghouse)
  - ✓ Robot System(SUPREEM)
    - SUPREEM(Submersible Platform with Rosa End Effector Motion)
  - ✓ UT System
    - Paragon System(Conventional UT System)



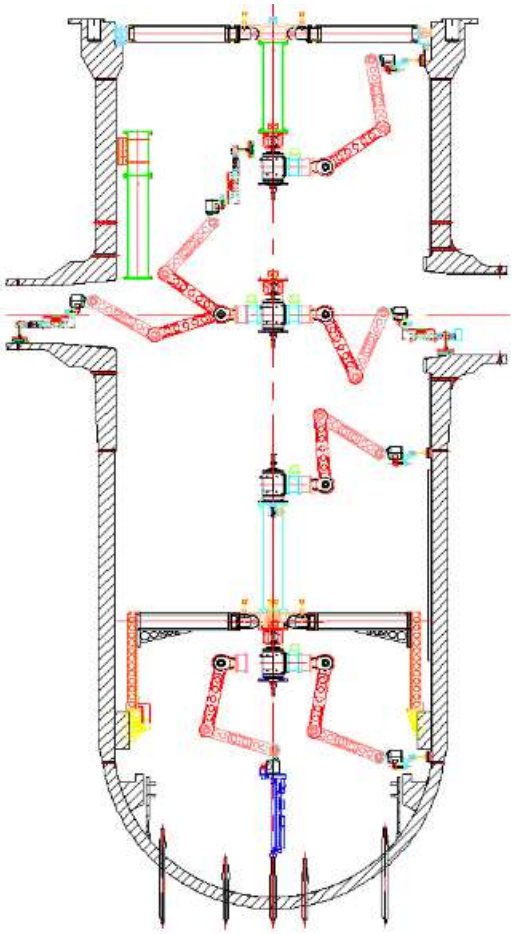
- SAE-AN: Technology Partner (ISwT→ IIA)
  - ✓Robot System: AIRIS, ANTS, ANTS II, SATURNi
  - ✓ UT System: Dynaray & TOMO-III
    (Phased Array UT System)



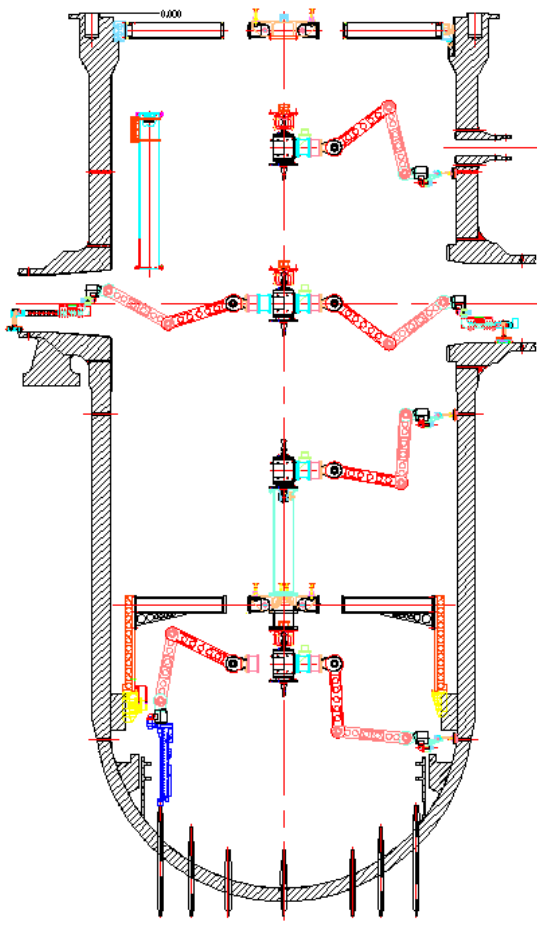
Inspection system of reactor vessel

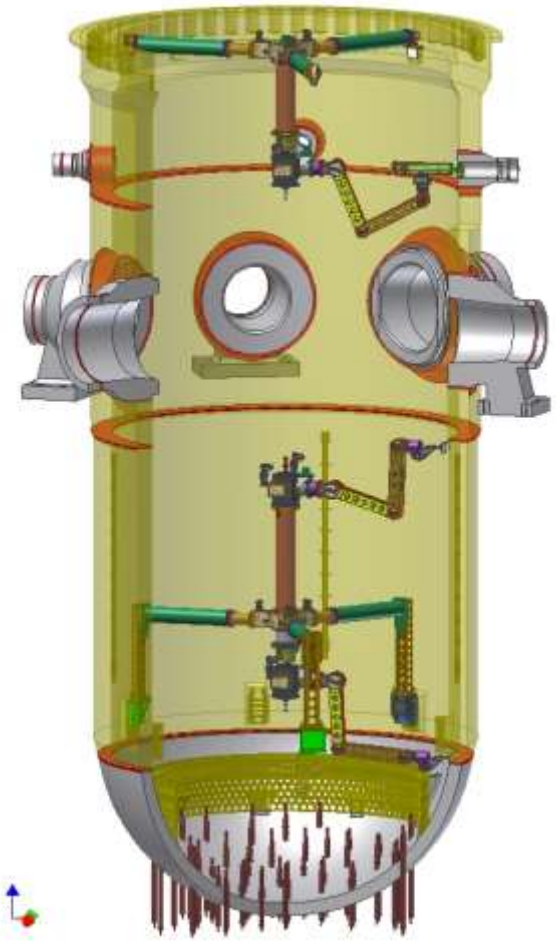
❖ Field inspection (KEPCO KPS, Conventional UT)

OPR1000



APR1400

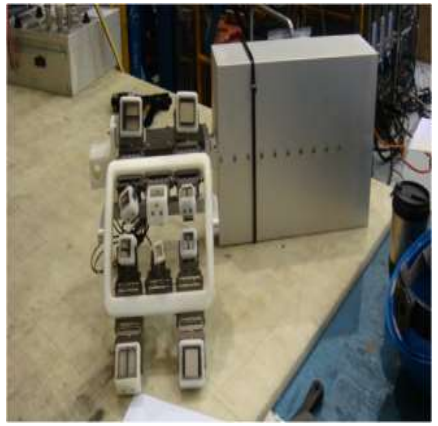




Inspection system of reactor vessel

❖ Field inspection (KEPCO KPS, Conventional UT)

[PARAGON ™]

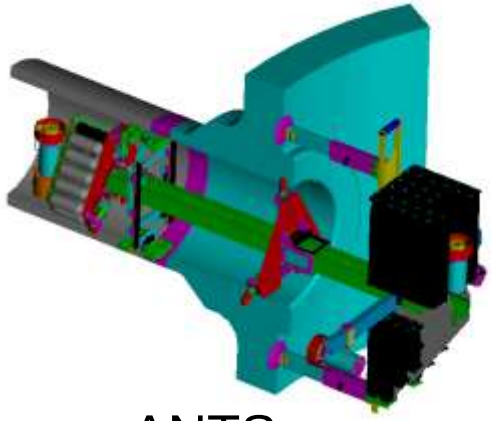


- Shell to Shell(G1,G2,G3)
  : 45°L Dual, 45°L, 45°S
- Shell to Nozzle(Inlet/Outlet/DVI)
  Shell side : 45°L Dual, 45°L, 45°S
  Nozzle bore side : 0°, 30°L, 45°L
- Nozzle to Pipe(Inlet/Outlet)
  : 70°L Dual
- Nozzle to SE, SE to Pipe(DVI)
  : manual inspection(OD side)
- IRS(Inlet/Outlet/DVI) : VT

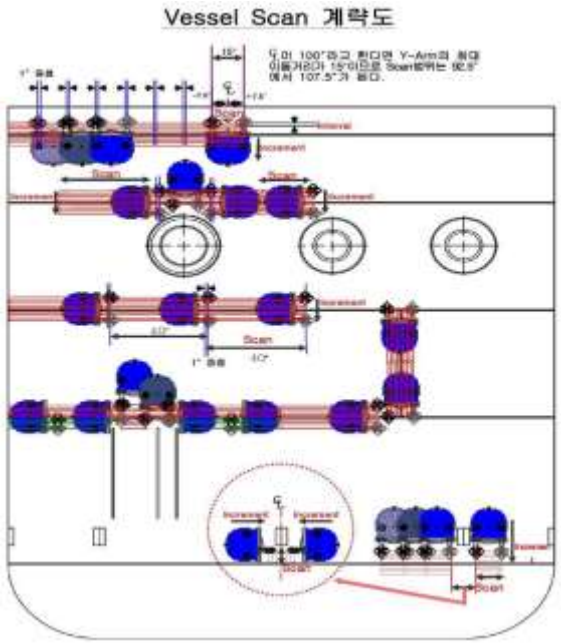
Inspection system of reactor vessel

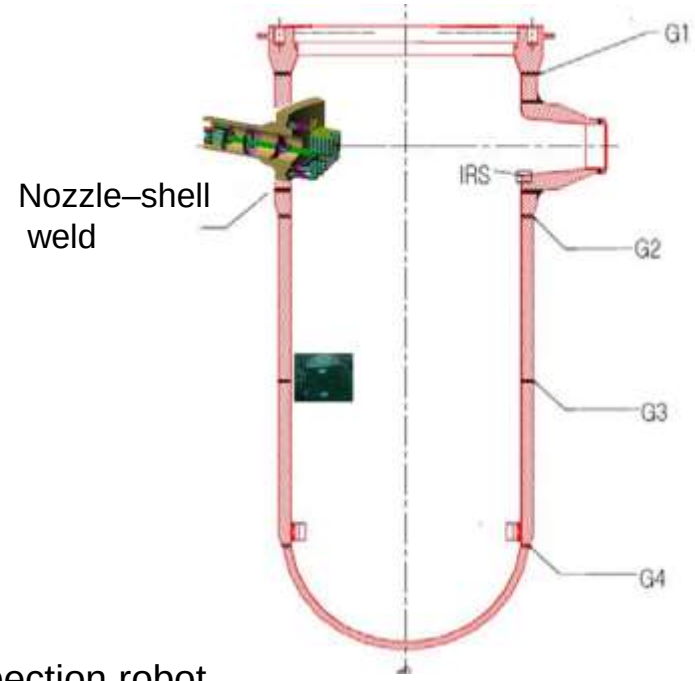
❖ Field inspection (SAE-AN, Phased Array UT)

- AIRIS



- ANTS

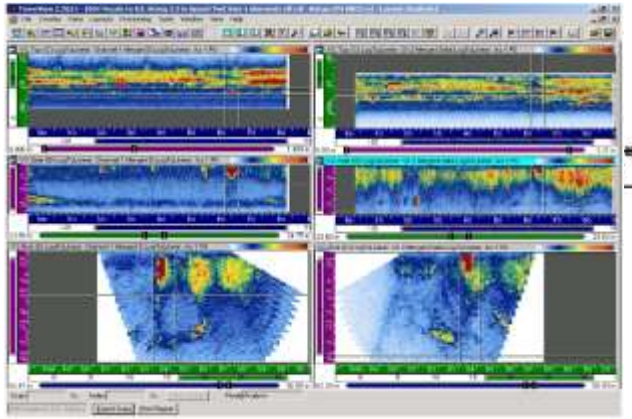


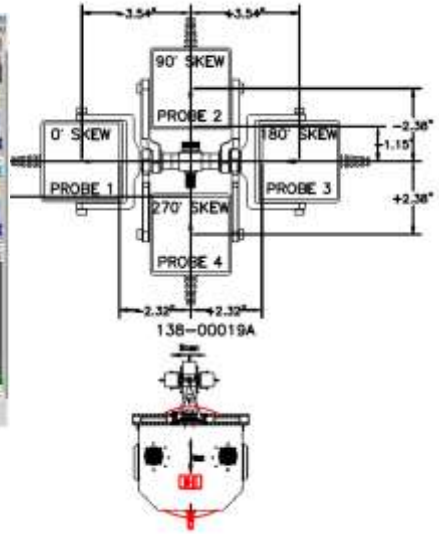


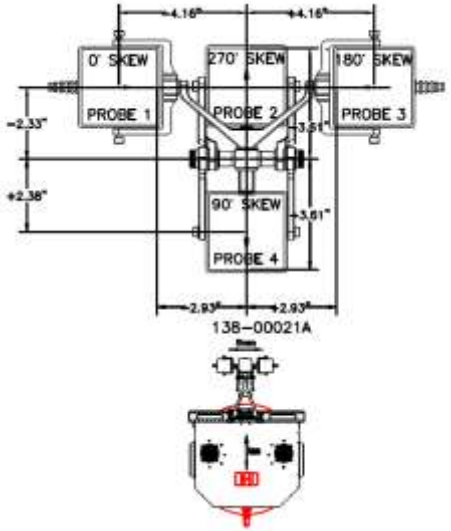
Posture of inspection robot

Inspection system of reactor vessel

❖ Field inspection (SAE-AN, Phased Array UT)

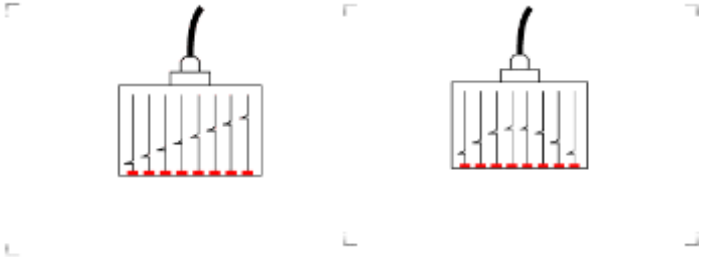






■ Phased Array Ultrasonic Testing

- Phased array ultrasonic technology uses multiple piezoelectric elements
- The characteristics of the ultrasonic beam can be controlled electronically (beam angle, focal depth)
- PAUT can perform beam sweeping sequentially through an angular range, beam scanning at fixed angle, and beam focusing.



ISI for reactor vessel welds

- 1st Period Inspection
  - Parts examined
    - Outlet Nozzle Welds
    - Outlet Nozzle to Pipe Welds
    - Flange Welds
    - Outlet Nozzle IRS(Inside Radius Section) VT-1 or EVT

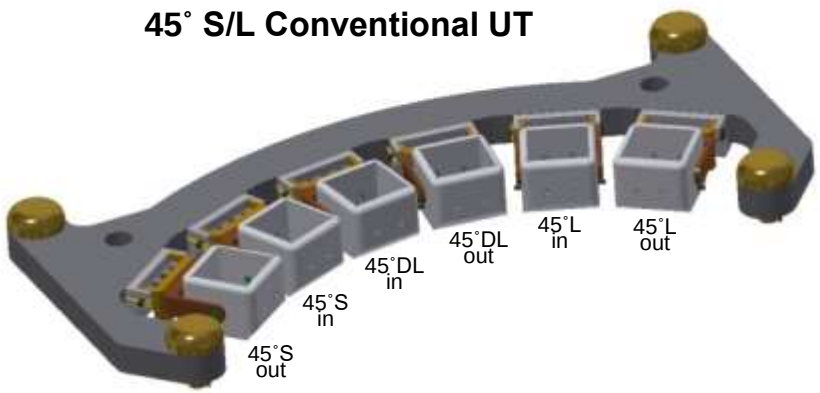
- 3rd Period Inspection
  - Parts examined
    - Inlet/Outlet Nozzle Welds
    - Shell Welds
    - Inlet Nozzle IRS(Inside Radius Section) VT-1 or EVT
    - Interior of Reactor Vessel, etc

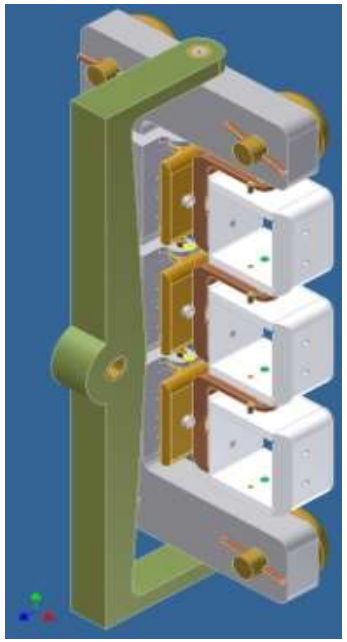
Status of ISI result

History of in-service inspection results																	Sum		Assessme-nt Result	Notes
Unit	1st interval				2nd interval				3rd interval				4th interval				No of Indi.	No of welds		
	Year		No of Indi.		Year		No of Indi.		Year		No of Indi.		Year		No of Indi.					
OO #A	'93		0		'01		0		'12		5		'16		1		6	3	Sound	
OO #B	'94		0		'04		0		'14		2		'19		0		2	2	Sound	
OO #C	'94		0		'04		0		'14	'16	0	8	'19		0		8	6	Sound	
□□ #A	'13		1														1(PSI:7)	1(PSI:4)	Sound	PSI('10)
□□ #B	'15		0														0(PSI:0)	0(PSI:0)	Sound	PSI('11)
□□ #C	'19		0														0(PSI:2)	0(PSI:2)	Sound	PSI('12)
□□ #D																	0(PSI:0)	0(PSI:0)	Sound	PSI('15)
△△ #A	'15	'21	4	3													7	4	Sound	
△△ #B	'17		0														0(PSI:1)	0(PSI:1)	Sound	PSI('15)
▽▽ #A	'95		0		'04		0		'09	'15	0	18					18	8	Sound	
▽▽ #B	'95		0		'05		0		'14	'16	28	27					33	15	Sound	
◇◇ #A	'02		4		'11		4		'16		0						4	3	Sound	
◇◇ #B	'02		3		'12		3		'17		1						3	2	Sound	
◇◇ #C	'09		1		'14	'20	0	1									1	1	Sound	
◇◇ #D	'10		0		'14		1										1	1	Sound	

⋮

Limited access of conventional UT probe





■ Probe sled for conventional UT makes very difficult to perform scanning due to limitation of access by inner structure and geometry

Limited access of conventional UT probe

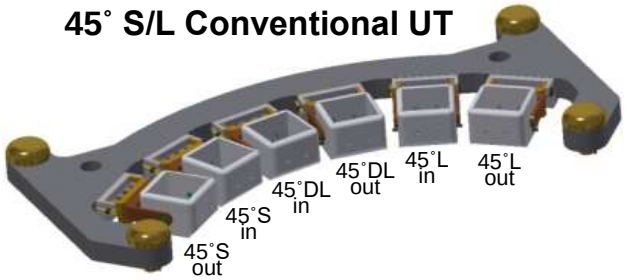
KHNP

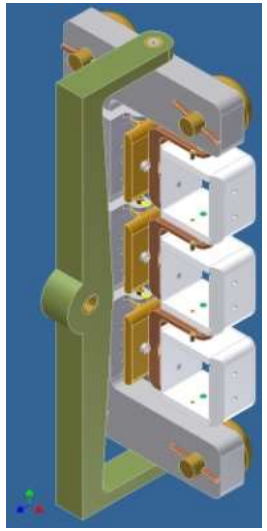
❖ Examination coverage of OO Unit ◇ with conventional UT

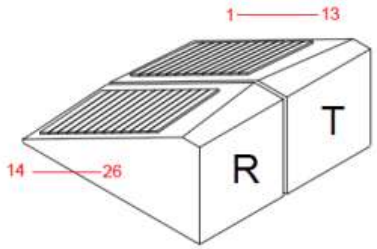
Parts examined	Examination wave and angle	Combined Average of Coverage
G1 Upper shell to Intermediate shell	45°DL,45°L,45°S	100%
G2 Intermediate shell to Lower shell	45°DL,45°L,45°S	100%
G3 Lower shell to Bottom Head	45°DL,45°L,45°S	97.25%
N-1, N-2 Outlet Nozzle to shell	0°, 30°L,45°L 45°DL,45°L,45°S	**74.33%**
N-3, N-4, N-5, N-6 (Inlet Nozzle to Shell)	0°, 30°,45° 45°DL,45°L,45°S	99.73%
N-7, N-8, N-9, N-10 (DVI Nozzle to Shell)	0°, 30°,45° 45°DL,45°L,45°S	91.48%
42-RC-A-1101 #1 (N1-PIPE) 42-RC-B-1102 #1 (N2-PIPE) (Outlet Nozzle to Pipe)	70°DL	100%
30-RC-A-1104 #9 (N3-ELBOW) 30-RC-B-1105 #9 (N4-ELBOW) 30-RC-B-1106 #9 (N5-ELBOW) 30-RC-A-1103 #9 (N6-ELBOW) (Elbow to Inlet Nozzle)	70°DL	100%

Limited access of conventional UT probe

45˚ S/L Conventional UT

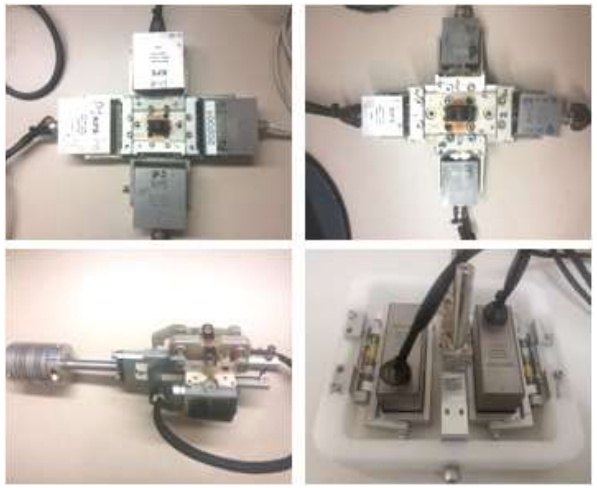






SHELL Sled

Pipe Sled



SI/DVI Sled

Nozzle Sled

30˚~70˚ S/L PAUT

■ One small phased array probe can provide the equivalent of multiple single-transducer probes and cover a wide range of applications

Limited access of phased array UT probe

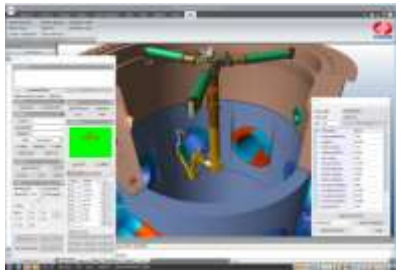
KHNP

❖ Examination coverage of OO Unit △ with phased array UT

Parts examined	Examination method	Combined Average of Coverage
G1 Upper shell to Intermediate shell	PAUT (Mech. UT)	100%
G2 Intermediate shell to Lower shell	PAUT (Mech. UT)	100%
G3 Lower shell to Bottom Head	PAUT (Mech. UT)	95.14
N-1, N-2 Outlet Nozzle to shell	PAUT (Mech. UT)	**74.48%**
N-3, N-4, N-5, N-6 (Inlet Nozzle to Shell)	PAUT (Mech. UT)	95.40%
N-7, N-8, N-9, N-10 (DVI Nozzle to Shell)	PAUT (Mech. UT)	91.37%
42-RC-A-1101 #1 (N1-PIPE) 42-RC-B-1102 #1 (N2-PIPE) (Outlet Nozzle to Pipe)	PAUT (Mech. UT)	100%
30-RC-A-1104 #9 (N3-ELBOW) 30-RC-B-1105 #9 (N4-ELBOW) 30-RC-B-1106 #9 (N5-ELBOW) 30-RC-A-1103 #9 (N6-ELBOW) (Elbow to Inlet Nozzle)	PAUT (Mech. UT)	100%

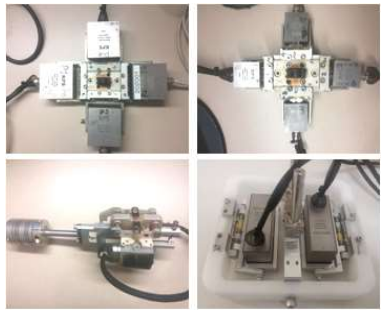
Developed Reactor Inspection System

AURoRA™ Control System

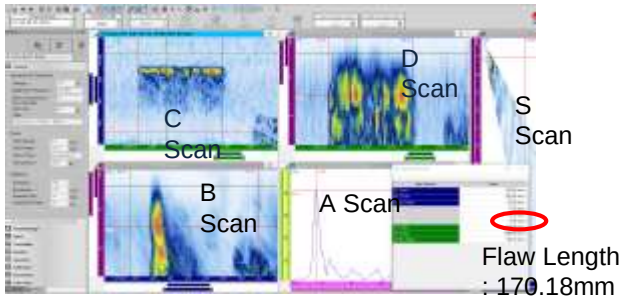


AURoRA™

Control Room outside CV



PAUT Probes



SPAcE™ PAUT system

* AURoRA : Advanced Underwater Robot for Reactor Assessment
* SPAcE : Smart Phased array Acquisition and Evaluation system

Developed Reactor Inspection System

Quali. Date	Company	Instrument	Vesion	method
1994.11.18	GE	GERIS 2000	4.7	Conventional
1995.02.11	SIEMENS	GRST		Phased Array(16/4)
1996.01.07	FRAMATOME	ACCUSONEX	4.6	Conventional
1996.03.08	**SWRI (→IHI SWT)**	**EDAS II**	**1.37**	**Conventional**
1998.01.19	**TECNATOME**	**TECNATOME**		**Conventional**
2001.03.20	WedDyne	PARAGON	3.01	Conventional
2003.09.09	FRAMATOME	ACCUSONEX	6.4	Conventional
2007.08.09	**IHI SWT**	**EDAS II**	**1.37**	**Conventional**
2009.07.29	**IHI SWT**	**DYNARAY**	**3.1r4**	**Phased Array**
2010.04.20	INETEC	DYNARAY	3.1r9	Conventional
2016.01	**TECNATOM**	**Sonia F1**	**1**	**Phased Array**
2016.08.12 2018.05.14	**KEPCO KPS**	**SPAcE**	**1**	**Phased Array**

- Procedure / Equipment / Personnel Qualification
- KEPCO KPS have got the 3rd EPRI PD qualification in the world for PAUT Automatic inspection for reactor vessel division

  - IHI-SwT(2009), Tecnatom(2016), KEPCO KPS(2018)

Summary

- In Korea, in-service inspection program shall comply with KEPIC code edition and addenda

- KHNP CRI has Korea performance demonstration system associated with the PD requirements in code, except components related with reactor vessels and overlaid welds

- Regarding ISI of reactor vessel welds, There is no big issue for inspection indications in Korea

- It was considered that phased array UT enable to address the issue associated with examination coverage, but that have no significant effect

- KPS(inspection vendor) have developed phased array UT system and probes for ISI of reactor vessel and completed a EPRI PD qualification

THANK YOU

KHNP

Mr Takeo KIMURA

Tokyo Electric Power Company Holdings,Inc

Mr Yasukazu TAKADA

The Kansai Electric Power Co., Inc

RV-ISI Program from Japanese Industrial Side

Yasukazu TAKADA
The Kansai Electric Power Co., Inc

Takeo KIMURA
Tokyo Electric Power Company Holdings,Inc

OECD/NEA/US NRC WGCS International Workshop on Mechanical Codes and Standards: In-Service Inspection
11-14 April 2022

Contents

1. JSME Fitness-for-Service Code

2. Technical Evaluation of JSME FFS Code by NRA

3. Response of Utilities

1. JSME Fitness-for-Service Code

- Policy of Inspection Rules of JSME FFS Code
- JSME FFS Code Requirements for Inspection of RV
- Examination Categories for RV in JSME FFS Code

Policy of Inspection Rules of JSME FFS Code

Examination Extent

- The examination extents of JSME Fitness-for-Service Code were determined by the following.
  - The components classification
  - Probabilities of losing structural integrity and influence
- The examination extents were classified into the following three grades depending on the importance of components or parts examined, considering probabilities of losing structural integrity and influence on the plant.
  - Inspection Level A 100% / 10 years* : the most important
  - Inspection Level B 25% / 10 years* : next important to A
  - Inspection Level C 7.5% / 10 years* : next important to B

*7years from 4th inspection interval

Components	RPV(RV)		Vessel		Piping
Parts	DMW**/ SD***	Others	DMW/SD	Others	DMW/SD
Class 1	A	C	B	C	B
Class 2	----		C	---	C

**DMW : Dissimilar Metal Weld, ***SD : Structural Discontinuities

JSME FFS Code Requirements for Inspection of RV

- Dissimilar Metal Welds / Structural Discontinuities
  - High stress, High potential damage than General Part

    ⇒ Inspection Level A : 100% / 10 years

- General Part of Reactor Vessel
  - No damage cases in the past
    The stress distribution is relatively loose.
    -> Low potential damage
  - Factors that make a difference for each part are also small.
  - Structural integrity can be represented by the inspection of structural discontinuities.

    ⇒ Inspection Level C : 7.5% / 10 years

  - Considering the increased risk due to irradiation embrittlement, if that received high neutron fluence all weld is required to be inspected.

Examination Categories for RV in JSME FFS Code

Examination Categories for Reactor Vessel

Part	Examination Category	Parts Examined	Examination Method	Examination Extent
General Part	B-A	Shell welds – Circumferential (Beltline)	Volumetric	7.5%
				100%*
		Shell welds – Longitudinal (Beltline)	Volumetric	7.5%
				100%*
	B-B	Shell welds – Circumferential	Volumetric	7.5%
		Shell welds – Longitudinal	Volumetric	7.5%
		Head welds – Circumferential	Volumetric	7.5%
		Head welds – Longitudinal	Volumetric	7.5%
Dissimilar Metal Welds / Structural Discontinuities	B-C	Welds between Shell and Flange	Volumetric	All welds
		Welds between Vessel Head and Flange	Volumetric	All welds
	B-D	Nozzle-to-Vessel Welds	Volumetric	All nozzles
		Nozzle Inside Radius Section	Volumetric	All nozzles
	B-F	100A or Larger Nozzle-to-Safe End Butt Welds	Volumetric and Surface	All welds
		Less Than 100A Nozzle-to-Safe End Butt Welds	Surface	All welds
		Nozzle-to-Safe End Socket Welds	Surface	All welds

* : All accessible welds ; if that received neutron fluence exceeding $1x10^{23}n/m^2$

2. Technical Evaluation of JSME FFS Code by NRA

- NRA Staff's Indication
- JSME's Position
- Comments of Utilities in NRA Hearings
- Additional Requirements on RV Inspection

NRA Staff's Indication

In the technical evaluation of JSME FFS Code 2012ed. for endorsement by NRA, the NRA staff indicated that the examination extent of the general part of RV should be essentially 100%.

Examination Requirements for Reactor Vessel

Part	Parts Examined	Examination Method	Examination Extent
General Part	Shell welds – Circumferential (Beltline)	Volumetric	7.5%
			100%*
	Shell welds – Longitudinal (Beltline)	Volumetric	7.5%
			100%*
	Shell welds – Circumferential	Volumetric	7.5%
	Shell welds – Longitudinal	Volumetric	7.5%
	Head welds – Circumferential	Volumetric	7.5%
	Head welds – Longitudinal	Volumetric	7.5%
Dissimilar Metal Welds / Structural Discontinuities	Welds between Shell and Flange	Volumetric	All welds
	Welds between Vessel Head and Flange	Volumetric	All welds
	Nozzle-to-Vessel Welds	Volumetric	All nozzles
	Nozzle Inside Radius Section	Volumetric	All nozzles
	100A or Larger Nozzle-to-Safe End Butt Welds	Volumetric and Surface	All welds
	Less Than 100A Nozzle-to-Safe End Butt Welds	Surface	All welds
	Nozzle-to-Safe End Socket Welds	Surface	All welds

should be essentially 100%

* : All accessible welds ; if that received neutron fluence exceeding $1x10^{23}n/m^2$

JSME's Position

- At the time of the technical evaluation* of JSME FFS Code 2002ed.**, the following discussions were held on the situation in Japan regarding the technical basis of 100% inspection requirements in the United States. As a result, JSME requirements were judged to be appropriate.

* : conducted by Nuclear and Industrial Safety Agency
** : Examination requirements for RV are the same as 2012ed..

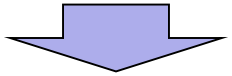
1. An embrittlement concern which shows that certain reactor vessel materials undergo greater radiation damage than previously expected
   -> There is no case of irradiation embrittlement progressing compared to the evaluation results of the surveillance material tests.

2. A concern that SCC of BWR reactor vessels is more probable than previously thought
   -> No stress corrosion cracking has been detected in the reactor vessel so far.

3. A concern regarding significant cracking that has occurred in large vessels (e.g, pressurizer, SG) designed and fabricated to the ASME code
   -> There is no past failure to the pressure retaining weld of the Class 1 vessels.

JSME's Position (contd.)

- After the endorsement of JSME FFS Code 2002ed., inspections have been carried out on all plants in Japan, and no flaws have been found.
- Furthermore, in the special inspection for application for extension of operation period*, 100% UT has been applied to the base metal in addition to the weld for the beltline, no flaws have been found.
  * : Extension of operation period from 40 to 60 years
- The damage cases reported so far in other countries are caused by manufacturing process, and it is not necessary to change the examination extent based on these problems.



- From the situation after the endorsement of 2002ed., it is considered that there is no technical need to immediately review the examination extent.
- However, JSME will continue to investigate the latest findings and inspection status in Japan and overseas, and consider whether it is necessary to review the code requirements.

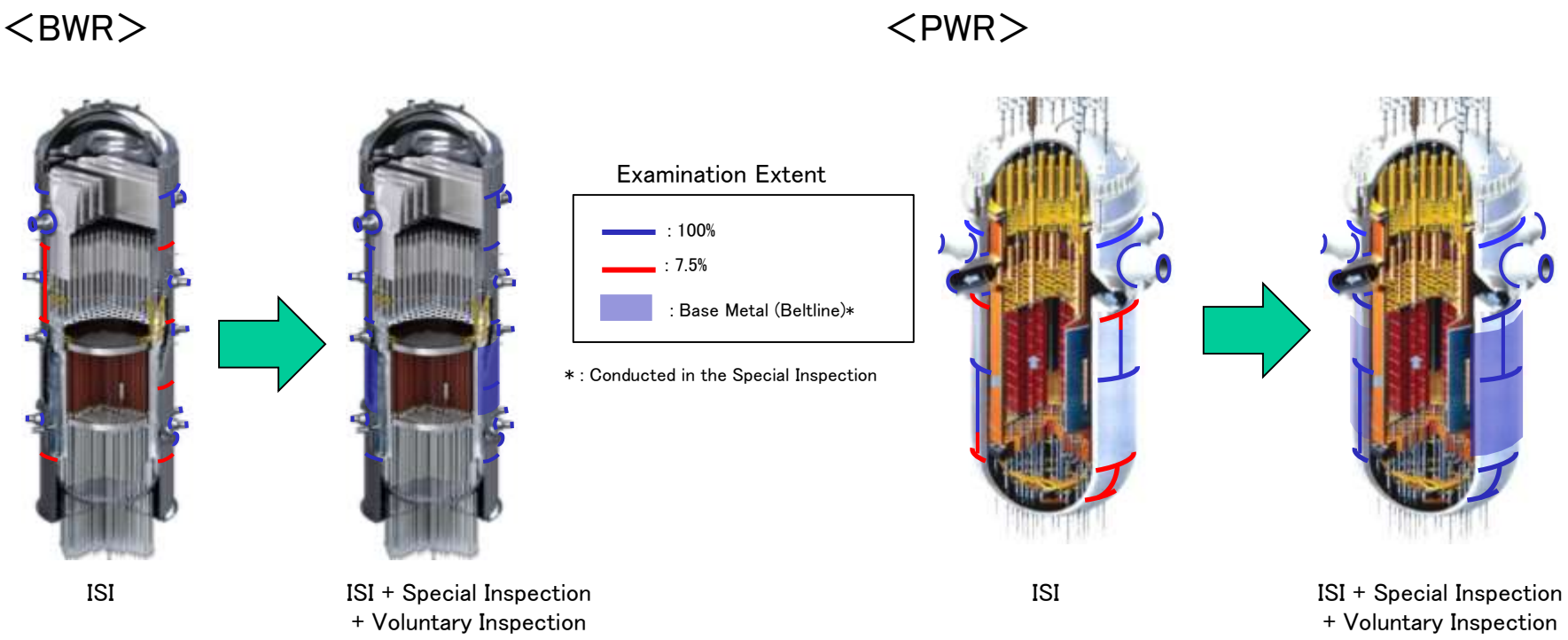
Comments of Utilities in NRA Hearings

- Utilities considers that the examination extent of JSME FFS code is appropriate, since the inspections have been carried out based on the importance of components and probabilities of losing structural integrity.
- In the United States, the regulatory requirement is 100% / 10years, but examination extent has been reduced by the relief request system. The actual condition of the examination extent in Japan is virtually the same as in the United States.

	Japan	United States	
Regulatory Requirements	JSME FFS Code : ➢ 100%/10yrs. Dissimilar Metal Welds / Structural Discontinuities ➢ 7.5%/10yrs. General Part	ASME Sec. XI : 100%/10yrs. Relief request system available	
Actual Condition of Exam. Extent (Ratio to the Whole Welds of RV)	(BWR) Substantially about 50%/10yrs. (PWR) Substantially about 70%/10yrs. or more ➢ Extent and frequency of exam. based on JSME FFS code	BWR	PWR
		Substantially about 50%/10yrs. ➢ Reduction of exam. extent by the relief request based on probabilistic evaluation	Substantially about 100%/20yrs. ➢ Extension of inspection interval by the relief request based on probabilistic evaluation

Comments of Utilities in NRA Hearings (contd.)

- If the examination extent is extended, there is concern that the exposure dose of inspectors will increase due to the increase in work in the high dose area.
- However, utilities decided to examine all welds of RV for the purpose of further safety improvement.



Additional Requirements on RV Inspection

As a result of the technical evaluation, NRA endorsed the JSME FFS code 2012ed. with additional requirements.

- Examination Extent for General Part of RV : 7.5% -> essentially 100%

Examination Requirements for Reactor Vessel

Part	Parts Examined	Examination Method	Examination Extent	
			before	after
General Part	Shell welds – Circumferential (Beltline)	Volumetric	7.5% 100%*	100%
	Shell welds – Longitudinal (Beltline)	Volumetric	7.5% 100%*	100%
	Shell welds – Circumferential	Volumetric	7.5%	100%
	Shell welds – Longitudinal	Volumetric	7.5%	100%
	Head welds – Circumferential	Volumetric	7.5%	100%
	Head welds – Longitudinal	Volumetric	7.5%	100%
Dissimilar Metal Welds / Structural Discontinuities	Welds between Shell and Flange	Volumetric	All welds	All welds
	Welds between Vessel Head and Flange	Volumetric	All welds	All welds
	Nozzle-to-Vessel Welds	Volumetric	All nozzles	All nozzles
	Nozzle Inside Radius Section	Volumetric	All nozzles	All nozzles
	100A or Larger Nozzle-to-Safe End Butt Welds	Volumetric and Surface	All welds	All welds
	Less Than 100A Nozzle-to-Safe End Butt Welds	Surface	All welds	All welds
	Nozzle-to-Safe End Socket Welds	Surface	All welds	All welds

* : All accessible welds ; if that received neutron fluence exceeding $1x10^{23}n/m^2$

3. Response of Utilities

- Response of BWR Owners
- Response of PWR Owners

Response of Utilities (BWR Owners)

Changing the examination extent of RPV

●Examination extent of RPV welds was changed by the additional requirements from the NRA technical evaluation.

●Utilities (BWR owners) reflected it in their inspection programs,and inspections for additional part are expected to be completed by the end of 2029 for all in-service BWR plants in Japan.

●In Onagawa-2 and Tokai-daini , inspections for additional part were conducted except for top head welds of Onagawa-2,and top and bottom head welds of Tokai-daini.

Response of Utilities (BWR Owners) (contd.)

Efforts to optimize inspection range

- There is a concern that the exposure dose of inspectors will increase due to the expansion of examination extent of RPV welds.

- As in the U.S , utilities are considering optimization of the examination extent using PFM evaluation.

- Utilities are preparing for analysis using FAVOR code used in the U.S. A trial analysis has been carried out for Kashiwazaki-kariwa unit1 and 7 ,and it has been confirmed that CPF value is small enough for the criterion in the U.S.

- Utilities are also promoting acquisition of initial crack and residual stress data using archive materials of Kashiwazaki-kariwa NPP.

- From 2022,utilities plan to conduct a benchmark evaluation of PFM with EPRI, and confirm the validity of PFM evaluations conducted by Japanese BWR utilities.

Response of Utilities (PWR Owners)

Changing the examination extent of RV

- Examination extent of RV welds was changed by the additional requirements from the NRA technical evaluation.
- Utilities (PWR owners) reflected it in their inspection programs.

➢ Shell welds

It was changed from 7.5% to essentially 100%.

Since utilities (PWR owners) have been voluntarily conducting 100% inspections, there was almost no impact.

–> No indication of flaws

➢ Head welds

It was changed from 7.5% to essentially 100%.

Most plants have no welds on lower head shell of RV, so there was no impact.
Only 3 plants have welds on lower head shell. Inspections were conducted on those plants with adding examination extent.

–> No indication of flaws

Response of Utilities (PWR Owners) (contd.)

Impact of changing the examination extent of RV lower head shell welds

- Inspection of RV lower head shell welds is performed by manual ultrasonic testing. Therefore, the increase in the exposure dose of inspectors due to the expansion of examination extent is a big problem.

- Owner of the 3 plants (Kansai ; Mihama-3, Takahama-1 and 2) was able to carry out the inspection during the plant shutdown to comply with the new regulations. Since these plants had been stopped for a long time, the radiation dose around the inspection area (under the lower head of RV) was somewhat low.

- However, these plants will be in operation at the next inspection interval. So radiation dose around the inspection area is expected to be high.

- Utilities are trying the evaluation of the failure probability using PFM evaluation, in order to determine if it is possible to change the examination extent or interval for RV lower head shell welds.

Summary

- The examination extents JSME FFS Code were classified into the three grades depending on the importance of components or parts (including RV) examined, considering probabilities of losing structural integrity and influence on the plant.

- It is considered that there is no technical need to immediately review the examination extent, but JSME continue to consider whether the code requirements should be reviewed.

- Utilities reflected the additional requirement from the NRA technical evaluation in their inspection programs, and inspection of additional part is being conducted.

- Since there is concern about increase in the exposure dose of inspectors, utilities conduct the evaluation using probabilistic evaluation, in order to determine if it is possible to change the extent or interval of examination for RV.

- Efforts to optimize inspection rules / programs by using evaluation methods such as PFM will be promoted.

Panel discussion and Q/A from the audience

Dr Patrick RAYNAUD

Senior Materials Engineer

US Nuclear Regulatory Commission

NEA
NUCLEAR ENERGY AGENCY

OECD
BETTER POLICIES FOR BETTER LIVES

Working Group on Codes and Standards

Workshop on In-Service Inspection

Break

Workshop will resume in 10 minutes

Day 2 – Tuesday 12 April 2022

NEA
NUCLEAR ENERGY AGENCY

OECD
BETTER POLICIES FOR BETTER LIVES

Session 2
Evolution of NDE techniques

Mr Shiro OTAKE

Toshiba, Japan

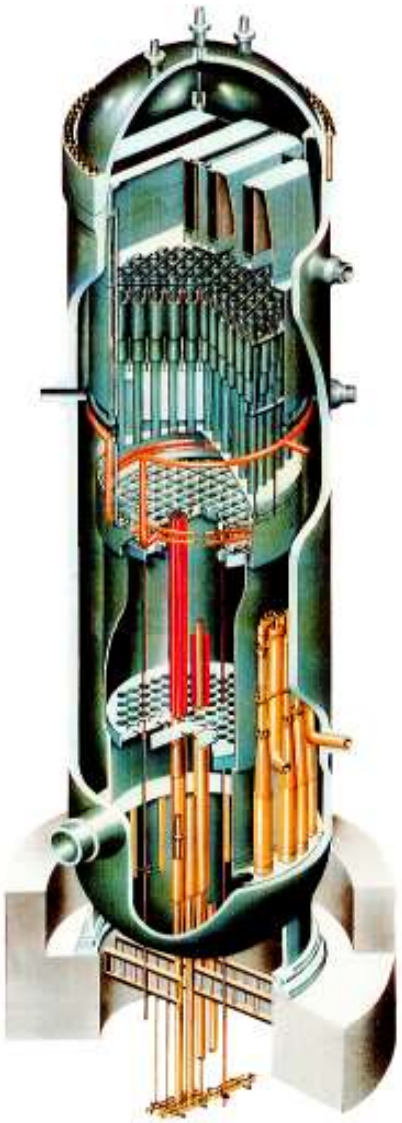
TOSHIBA

ISI workshop

Inspection technology to reduce non-detectable parts

Toshiba Energy Systems & Solutions Corporation
Shiro Otake
12 April 2022

Motivation of the NDI technique development



1 Voluntary Efforts & Continuous Improvement of Nuclear Safety

Configurations

- Nozzle
- Grinder finishing
- Reducer
- Saddle joints

Materials

- Valve / Piping joint
- Dissimilar metal weld
- Cast Austenitic Stainless Steel (CASS)

2 Special Inspection for Plant Life Extension

Unexperienced part of ISI

- Riser brace arm / RPV weld
- RPV base metal
- Feed water nozzle corner
- As Built surfaces

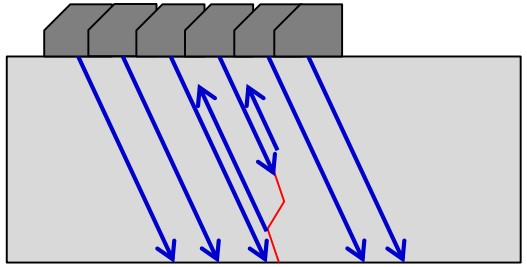
⋮

In order to overcome the uninspectable parts, enhancement of NDI technique is needed

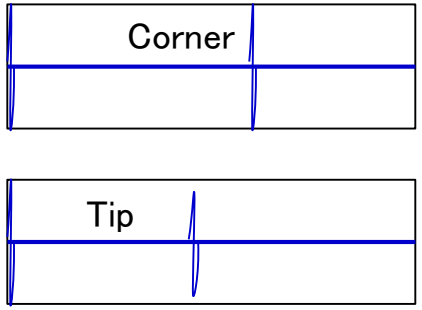
Principle of PAUT and application to BWR

In order to evaluate the soundness of plant structural materials, ultrasonic testing (UT) have been performing important role

Mono probe UT

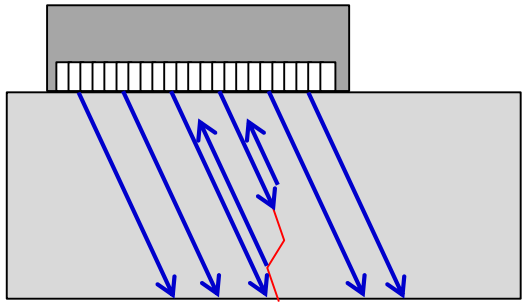


Result (waveform)

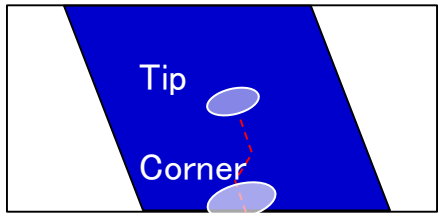


- Mechanical scanning
- Defect was measured by only waveform

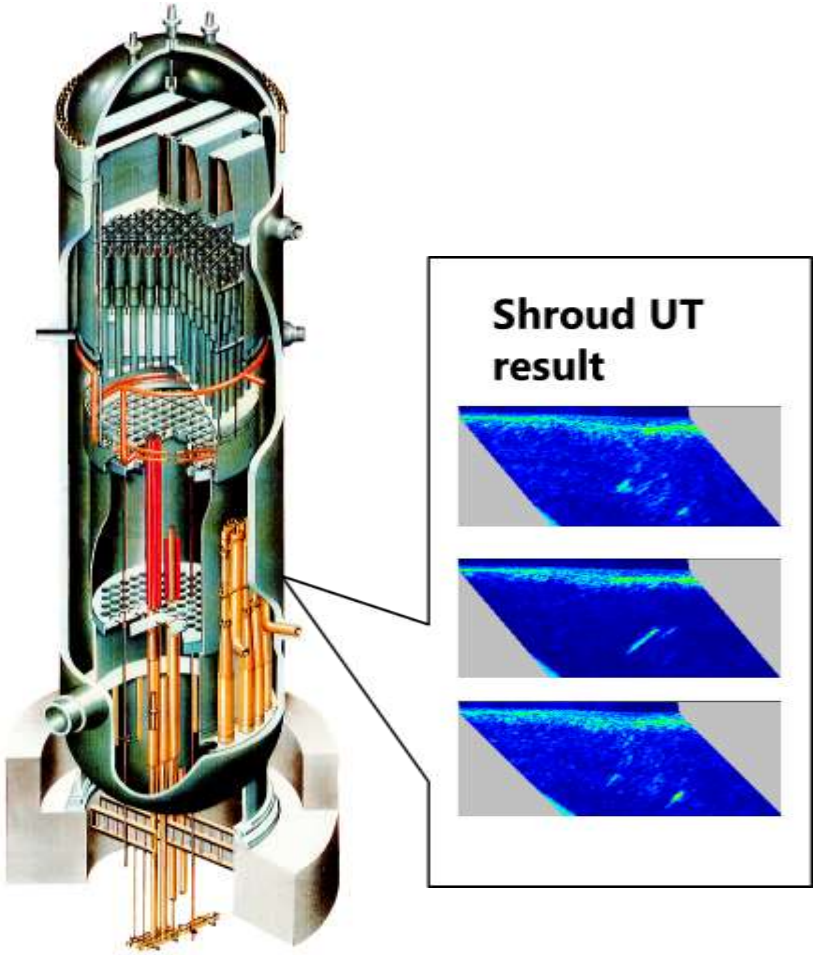
Phased Array UT (PAUT)



Result (image)

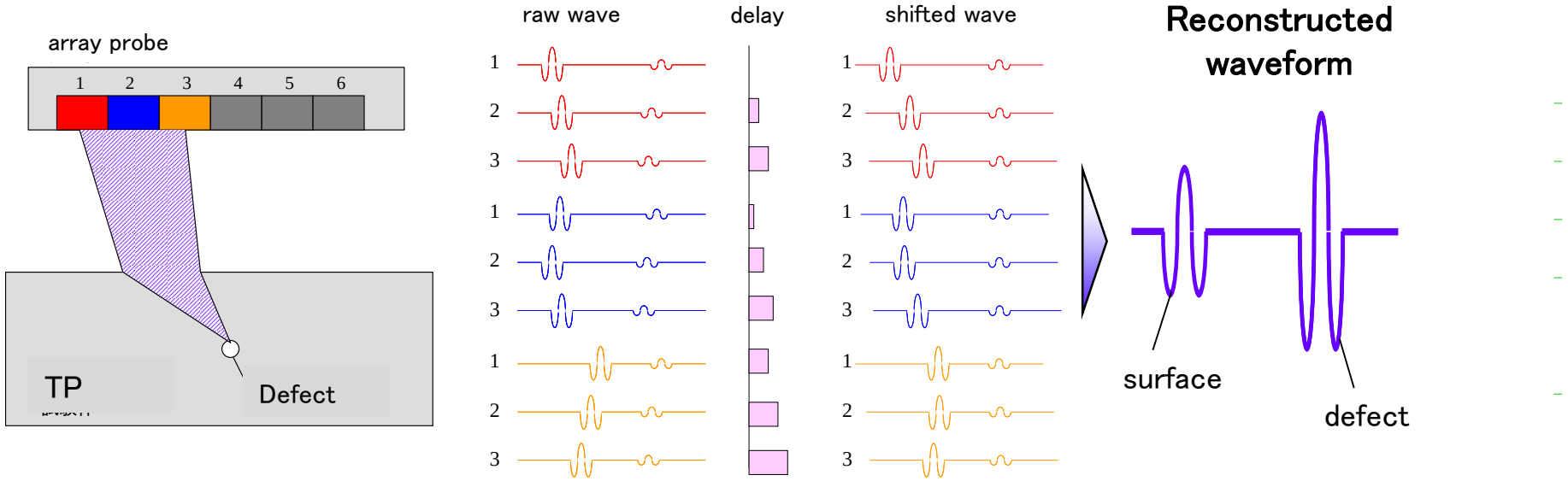


- Electrical scanning
- Defect was measured by image and waveform



In Japan, PAUT have been applied to BWR shroud inspection since about 2000s.

Principle of FMC and wave reconstruction



Trans. / Receive	EL. 1	EL. 2	EL. 3	…	EL. N
EL. 1	✓	✓	✓	…	✓
EL. 2	✓	✓	✓	…	✓
EL. 3	✓	✓	✓	…	✓
…	⋮	⋮	⋮		⋮
EL. N	✓	✓	✓	…	✓

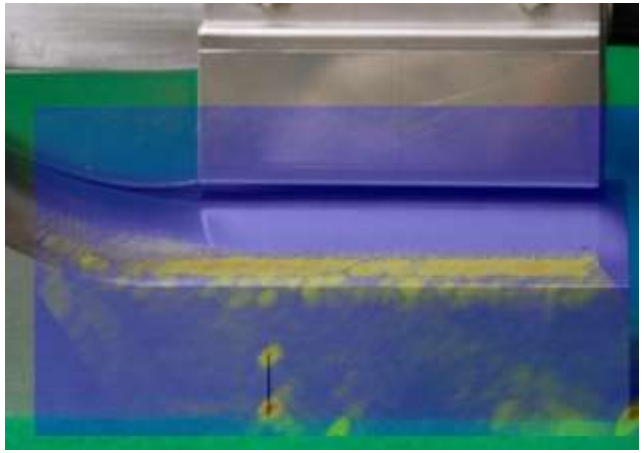
[1] M. Komai, et al.; Development of Under Sodium Inspection Techniques for FBR(3), Proceedings of ICON 6, ICONE6-6122 (1997)

[2] C. Holmes, et al.; The post-processing of ultrasonic array data using the total focusing method, Insight: Non-Destructive Testing and Condition Monitoring 64(11) pp.677-680 (2004)

Waveform reconstruction according to delay law [2]

Typical uninspectable parts

Complicated surface



- Probe mismatching

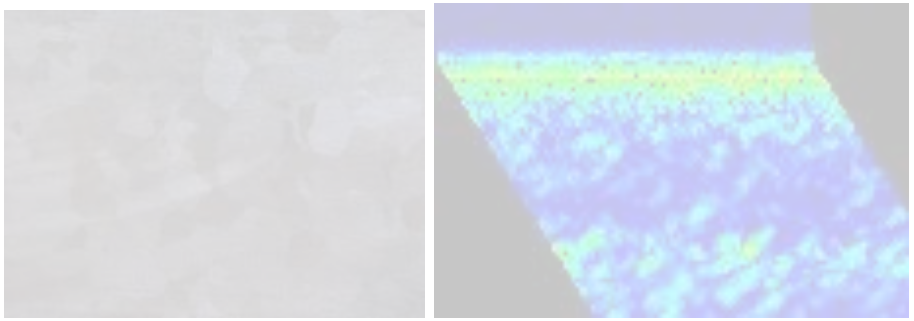
  Conventional rigid array probe will not match curved surfaces like RPV nozzles, valves.

- Incident wave distortion

  Curved surfaces will induce the wave distortion.
  Appropriate sound beam will not be formed.

Shape adaptive beam steering + soft shoe

Cast Austenitic Stainless Steel (CASS)



- Noise from large grains

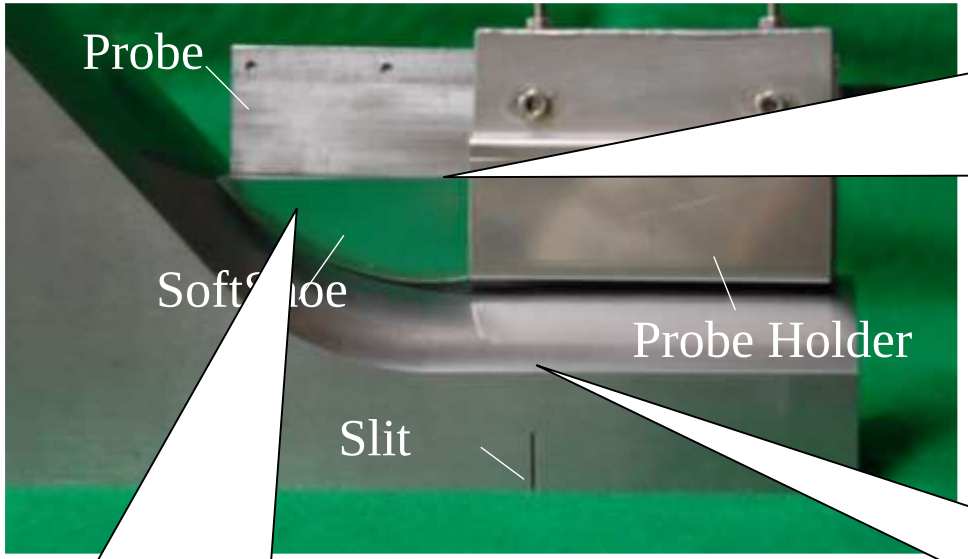
  Large noises will cause a misjudging of cracks.

- High damping

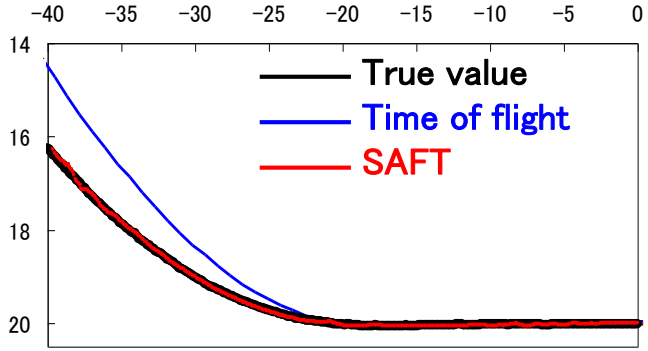
  Signal to noise ratio (SNR) of defect echoes will be declined by large grains and anisotropic medium.

Comprehensive UT + Improved firing method

Three technical components

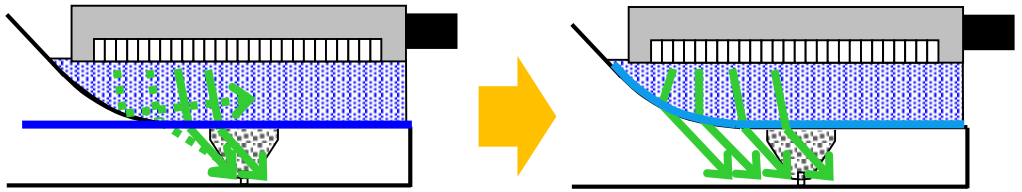


1. Surface shape measurement



Accurate measurement of as built surface

2. Shape adaptive delay calculation



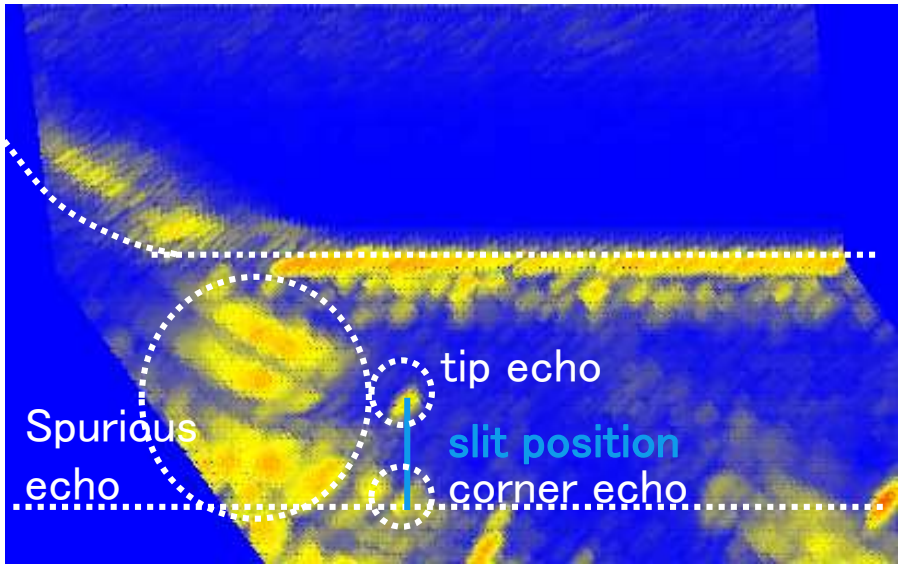
Taking into account the measured surface, optimized delay law would be obtained.

3. Soft shoe

Soft shoe which made of hydro gel, enables enough probe matching such as immersion condition.

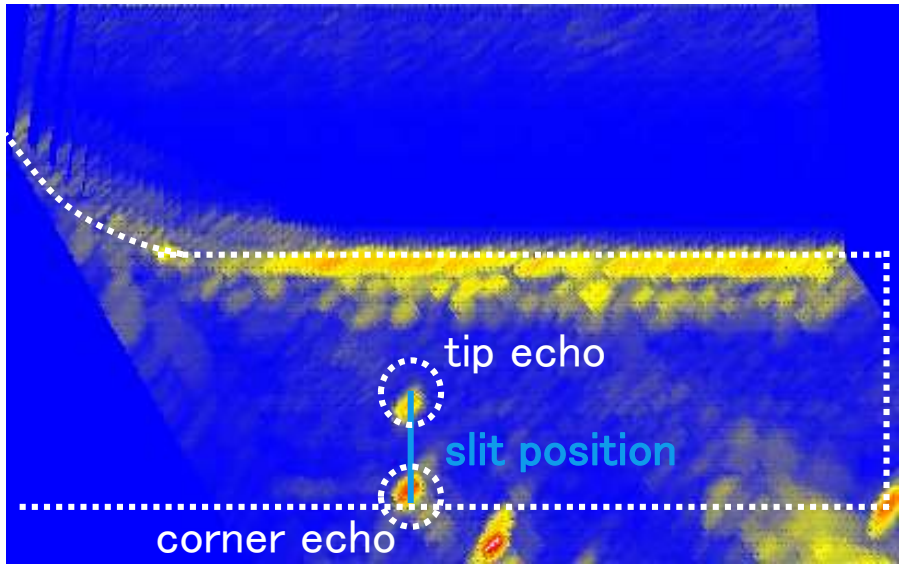
Application result – Nozzle specimen

Conventional PAUT



- A lot of spurious echoes
- Unclear corner echo

Developed PAUT

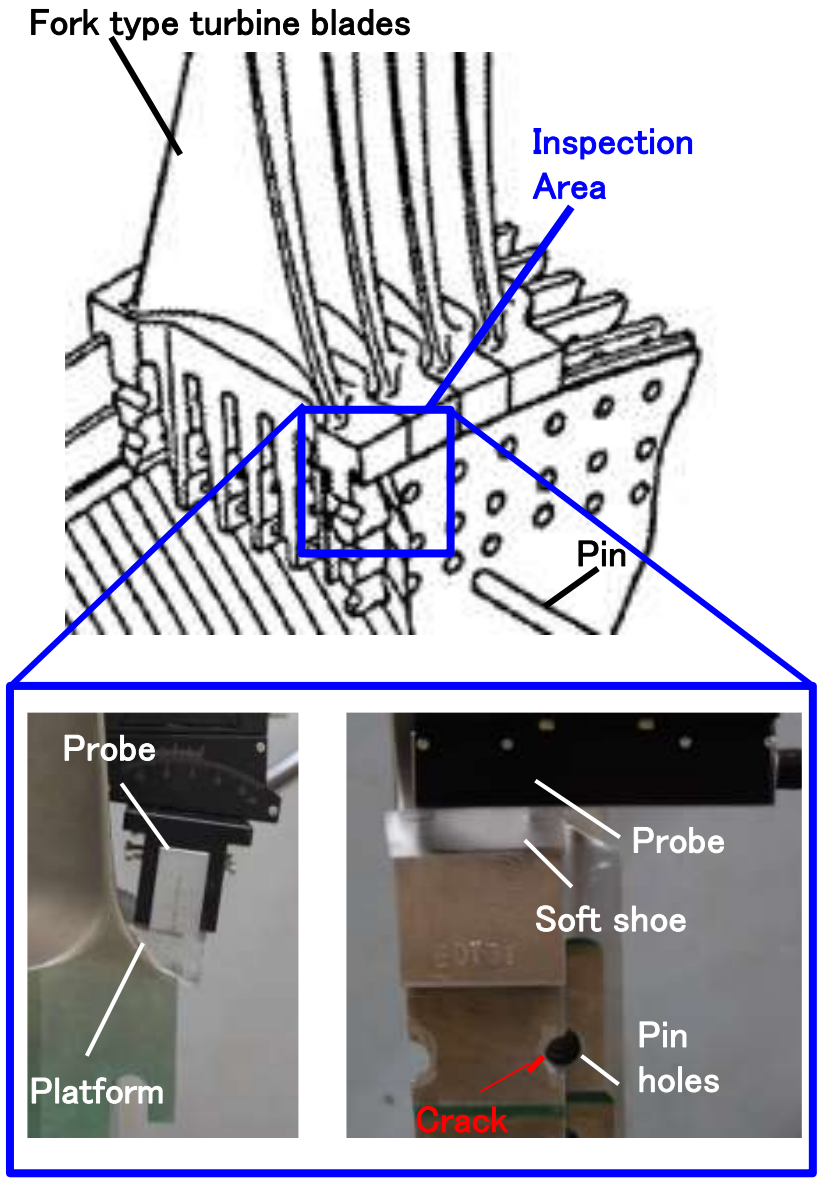


- Declined spurious echoes
- Localized corner echo

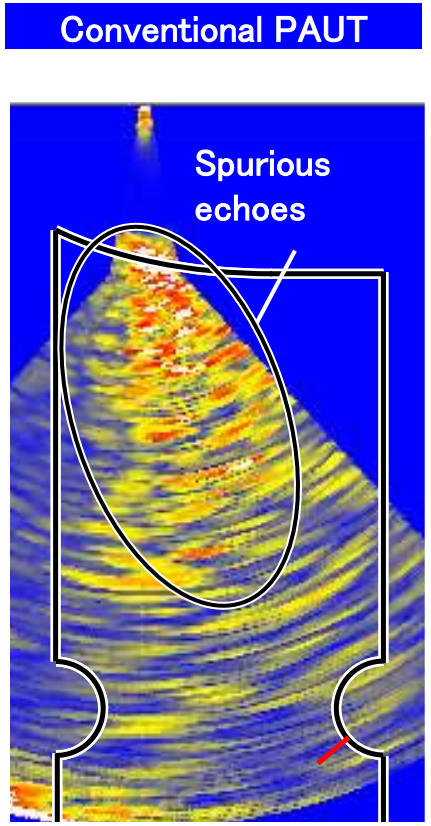
Shape adaptive beam steering overcomes complicated surfaces

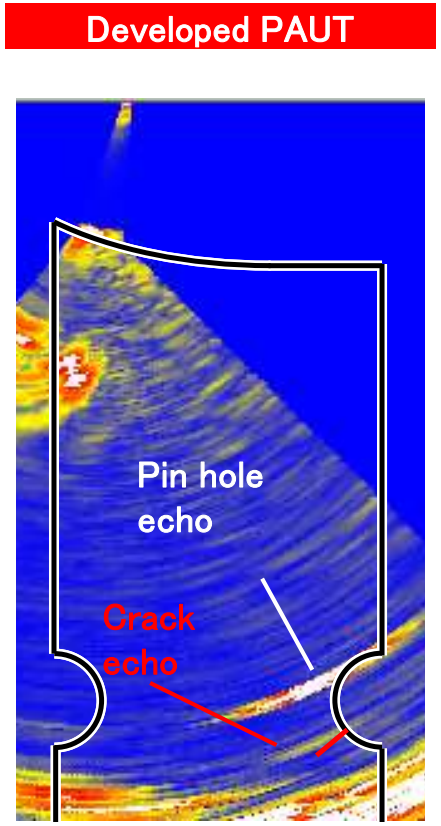
[3] Toshiba corporation; Phased array ultrasonic testing for components with complex surface geometry, EJAM vol.5 No.1, 2013, NT55

Application result – Turbine blade specimen



To detect fatigue cracks near the pin holes, probe only can be accessed by platform of the blade

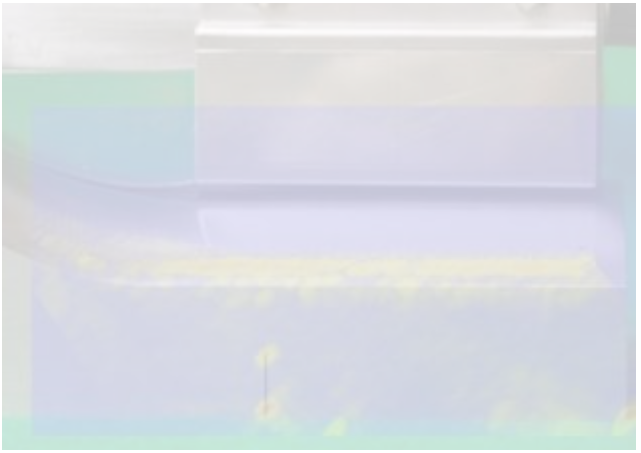




Turbine blades would be inspected without removing from turbine rotor.

Typical uninspectable parts

Complicated surface



- Probe mismatching

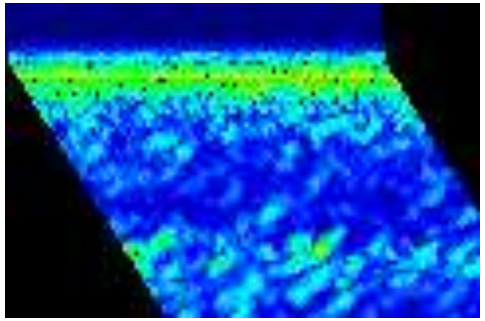
  Conventional rigid array probe will not match curved surfaces like valves.

- Incident wave distortion

  Curved surfaces will induce the wave distortion.
  Appropriate sound beam will not be formed.

Shape adaptive beam steering + soft shoe

Cast Austenitic Stainless Steel (CASS)



- Noise from large grains

  Large noises will cause a misjudging of cracks.

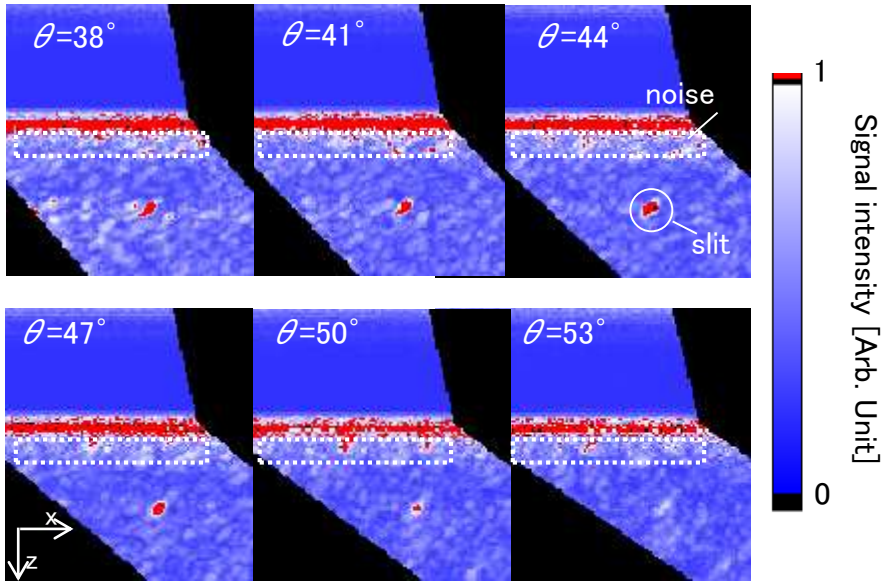
- High damping

  Signal to noise ratio (SNR) of defect echoes will be declined by large grains and anisotropic medium.

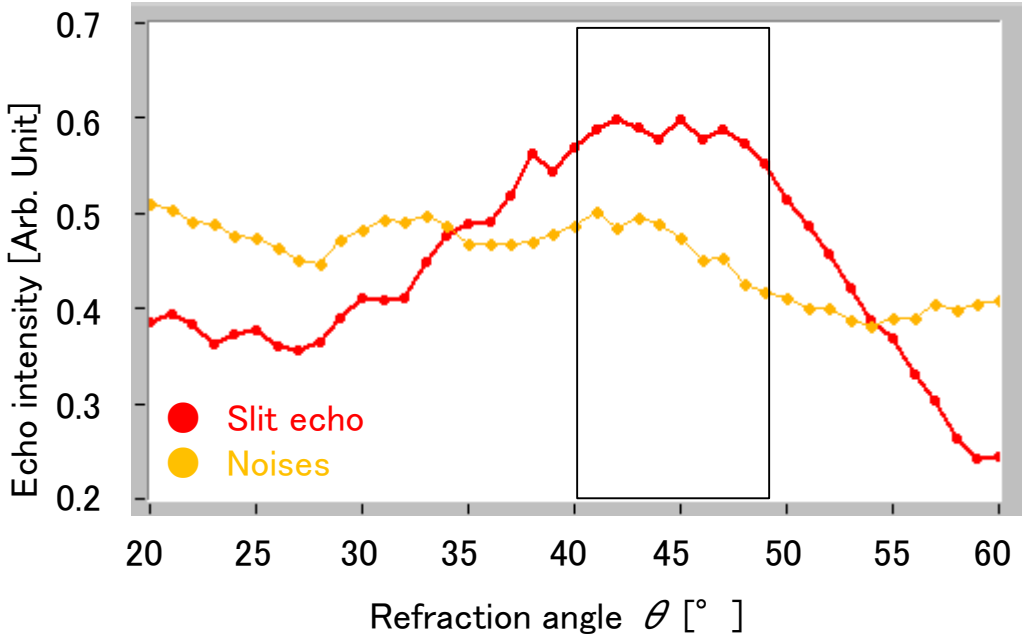
Comprehensive UT + Improved firing method

Comprehensive PAUT

Linear scan images



Refraction angle dependency

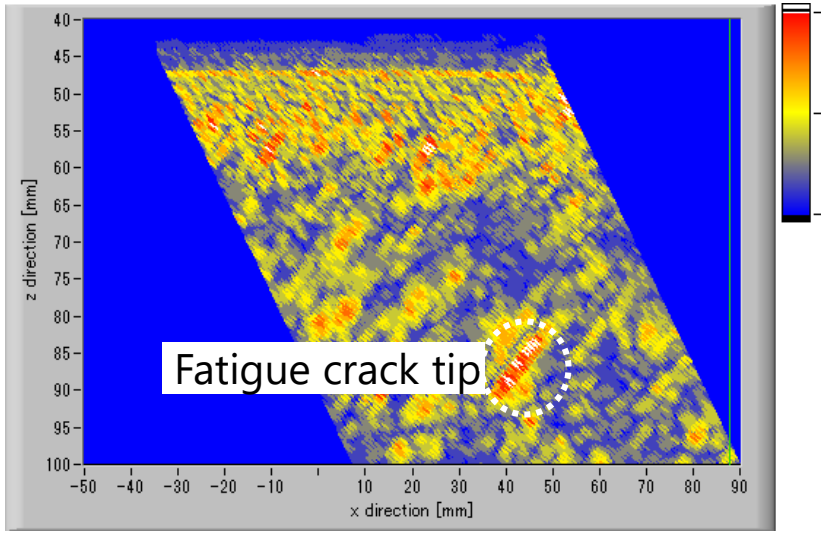


CASS has large grains which generate high intensity back scattering noises.
However, refraction angle dependency of defect echoes and noises are different.
Comprehensive linear scan supports distinction of noises and defects[4].

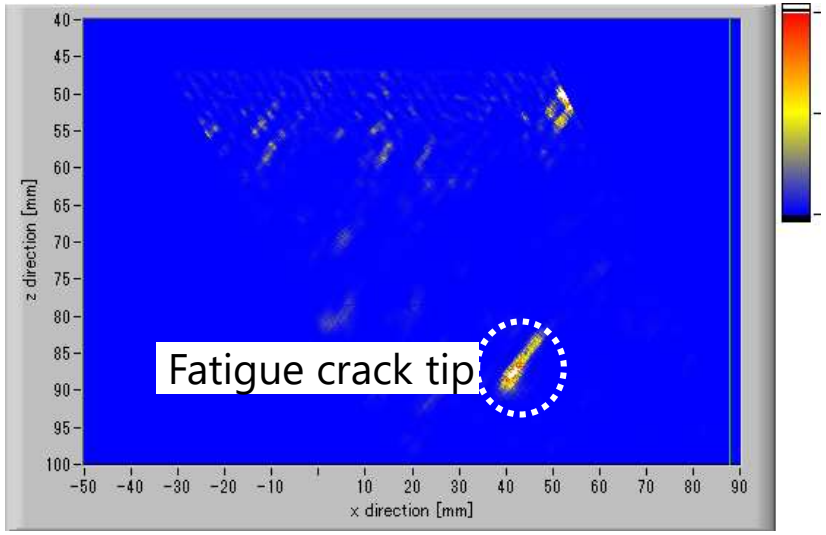
[4] S. Yamamoto J. Semboshi, A. Sugawara, M. Ochiai, K. Tsuchihashi, H Adachi and K. Higuma; Phased array ultrasonic inspection technique for cast austenitic stainless steel parts of nuclear power plant, Proceedings of ICONE 24, 2016, ICONE24-60256

Merging filter

Conventional PAUT



Developed PAUT



Spatial filter which realized by merged several image of linear scan supports the identification of feeble crack echoes from noises.

Experimental result - slits

Detection result of 1.5mm slits

SNR: Signal to Noise Ratio

Thickness [mm]	Conventional PAUT		Developed PAUT	
	θ [°]	SNR	$\theta_s \sim \theta_e$ [°]	SNR
35	45	1.2	42~47	4.4
51	35	1.4	32~37	6.5
70	23	1.2	20~26	2.5

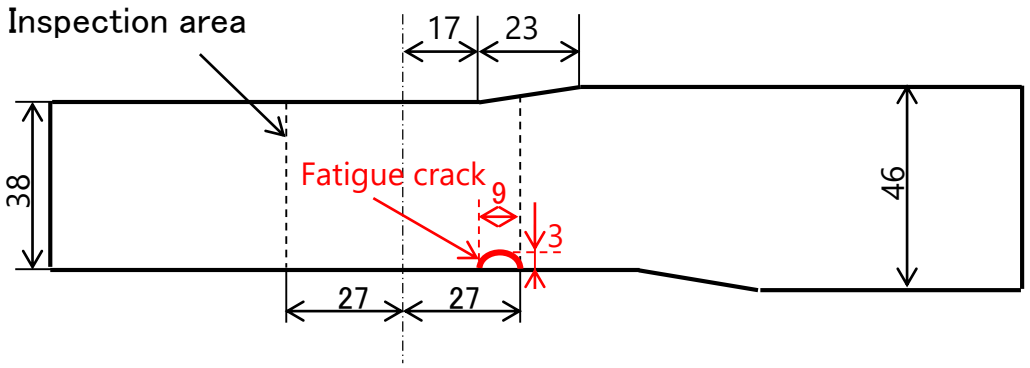
Sizing result of slits

Thickness [mm]	Nominal slit depth [mm]	Measured slit depth [mm]	Measurement error [mm]
51	8.5	8.1	-0.4
	17.0	15.8	-1.2
70	11.7	12.1	+0.4
	23.3	22.7	-0.6

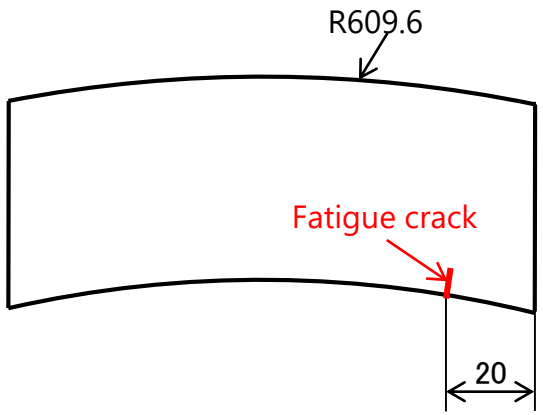
Several slits were clearly observed and measurement error was not so large

Specimen design for verification of merged system

In order to verify the performance of merged system, 3D complicated surface specimen which is made of CASS was designed.
The design is based on the pump/elbow joint of actual plant.



Center of weld



Material of specimen：SCS16A

Shape of fatigue crack
Crack length：9mm
Crack depth：3mm

Fabrication of specimen and fatigue crack

Photo (Side view)

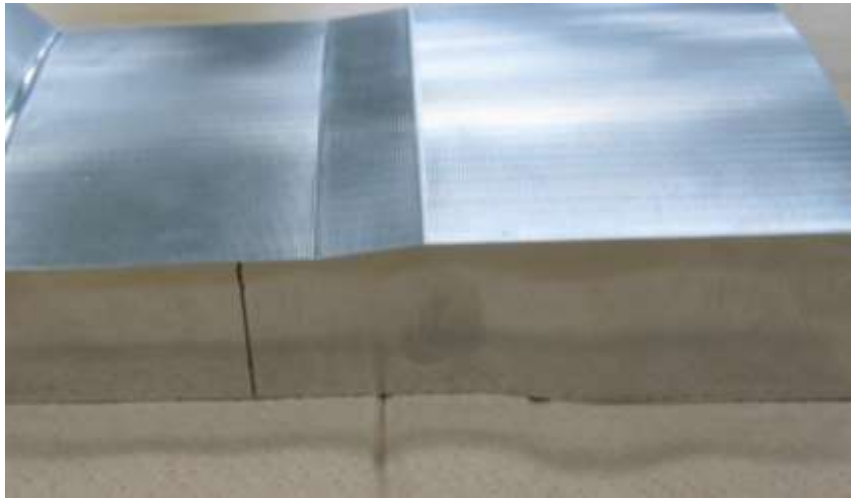
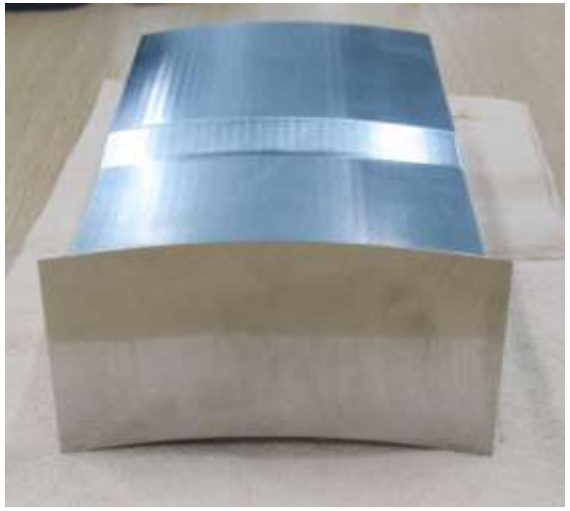
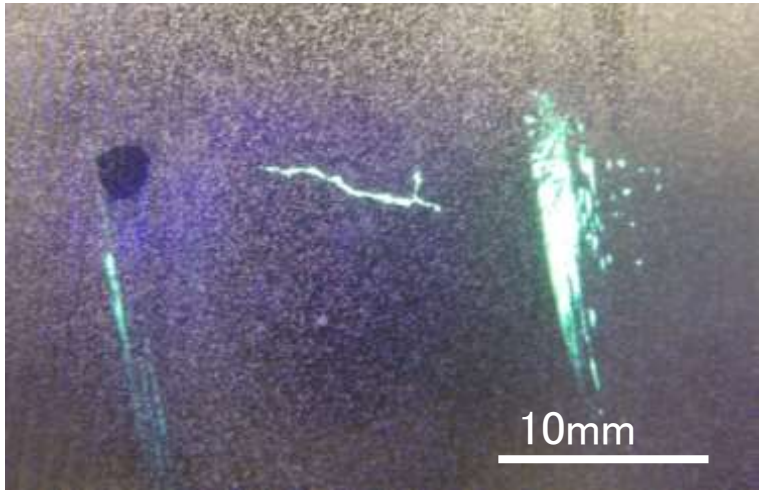


Photo (Pump side cross-section)



Fluorescence penetrant testing (FTP) image



Shape of fatigue crack

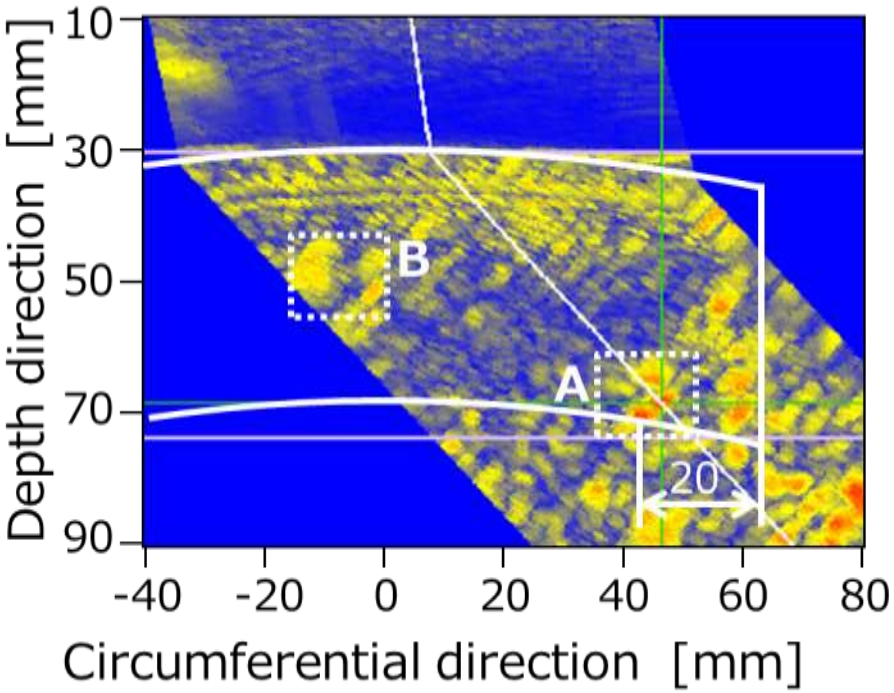
Crack length：9mm

Crack depth：3mm

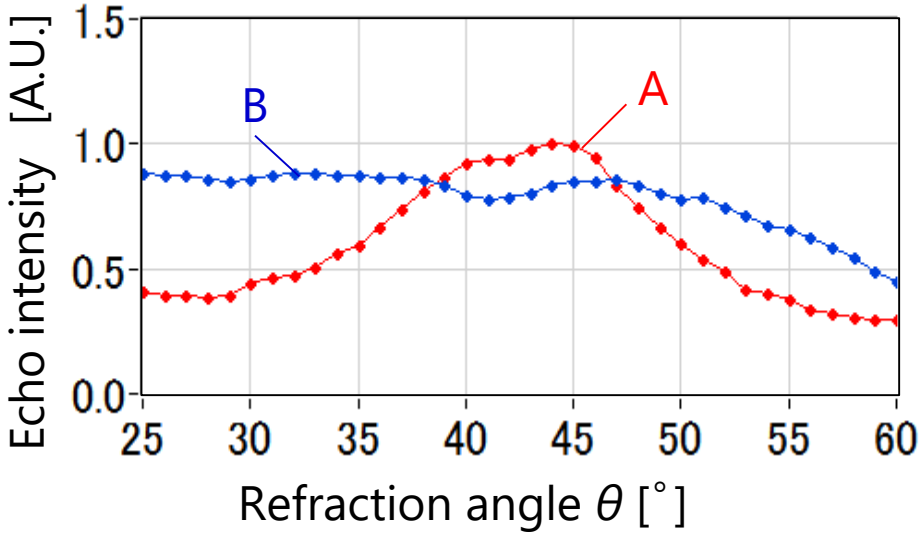
＊Crack depth is estimated value of aspect ratio management

Fabrication of specimen and fatigue crack

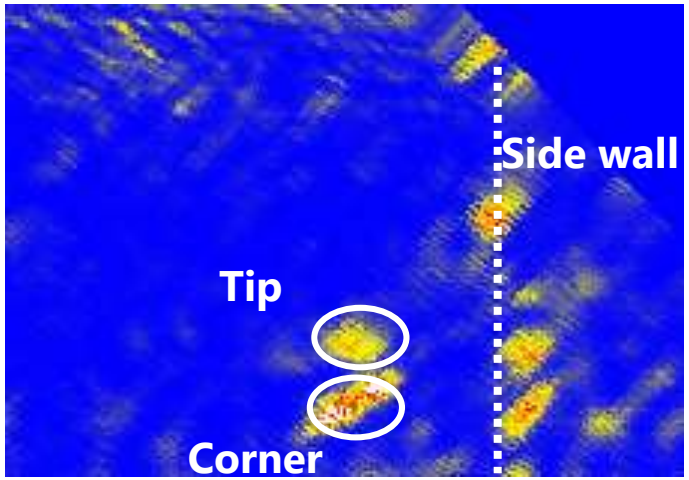
One shot linear scan image



Refraction angle dependency



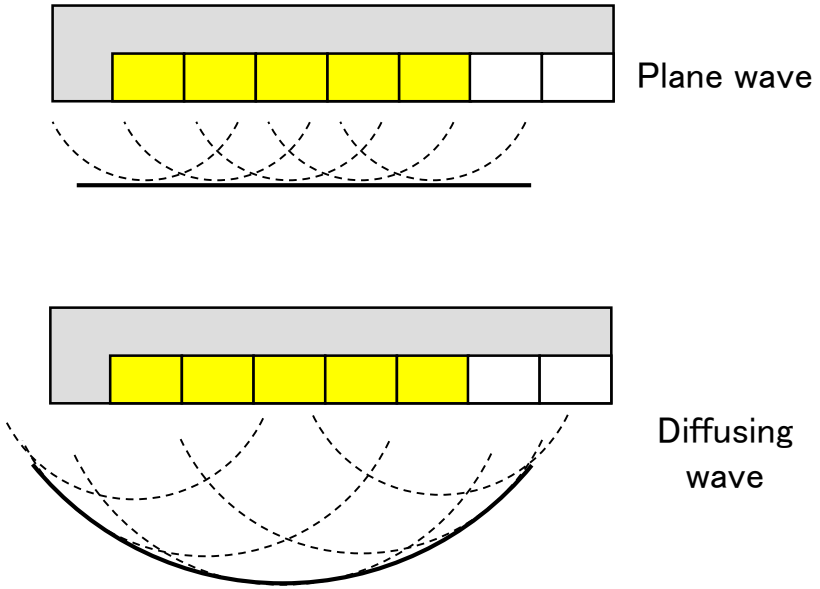
Merged image



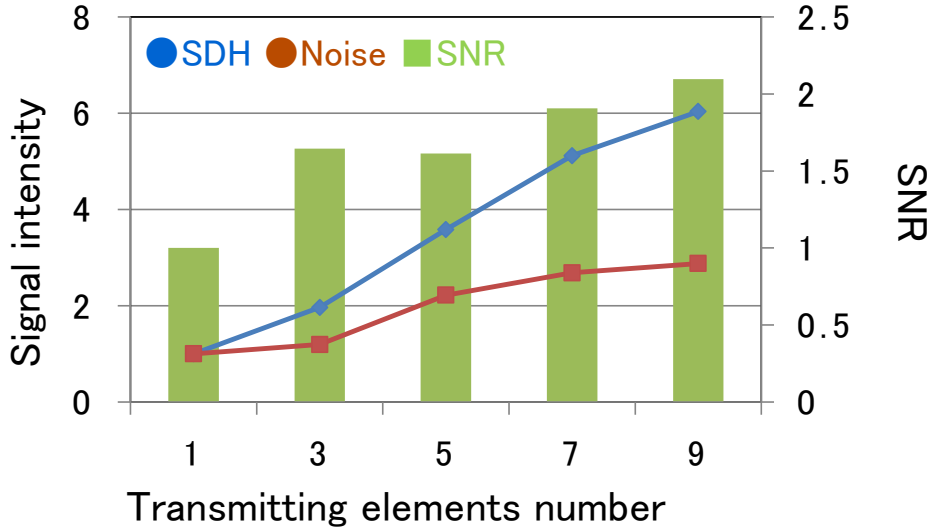
Crack echoes were clearly separated from the others
(grain noises, void echoes and so on…)
Depth measurement result coincided with estimated crack depth

Improvement of firing method for CASS

Plural elements firing in FMC procedure [5]



Fundamental confirmation of SNR improvement



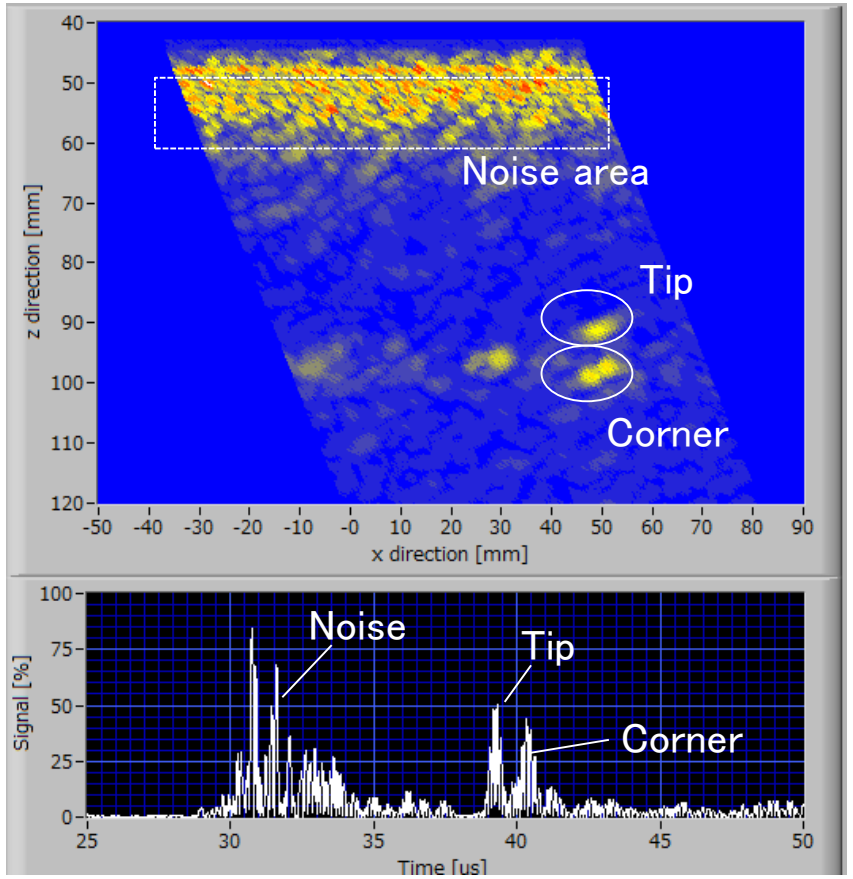
[5] H. Karasawa, T. Ikeda, S. Matsumoto, T. Hamajima and H. Isobe; 3D-SAFT ULTRASONIC INSPECTION EQUIPMENT "MatrixeyeTM", JRC-NDE 2009, 2010

SNR: Signal to Noise Ratio
SDH: Side Drilled Hole

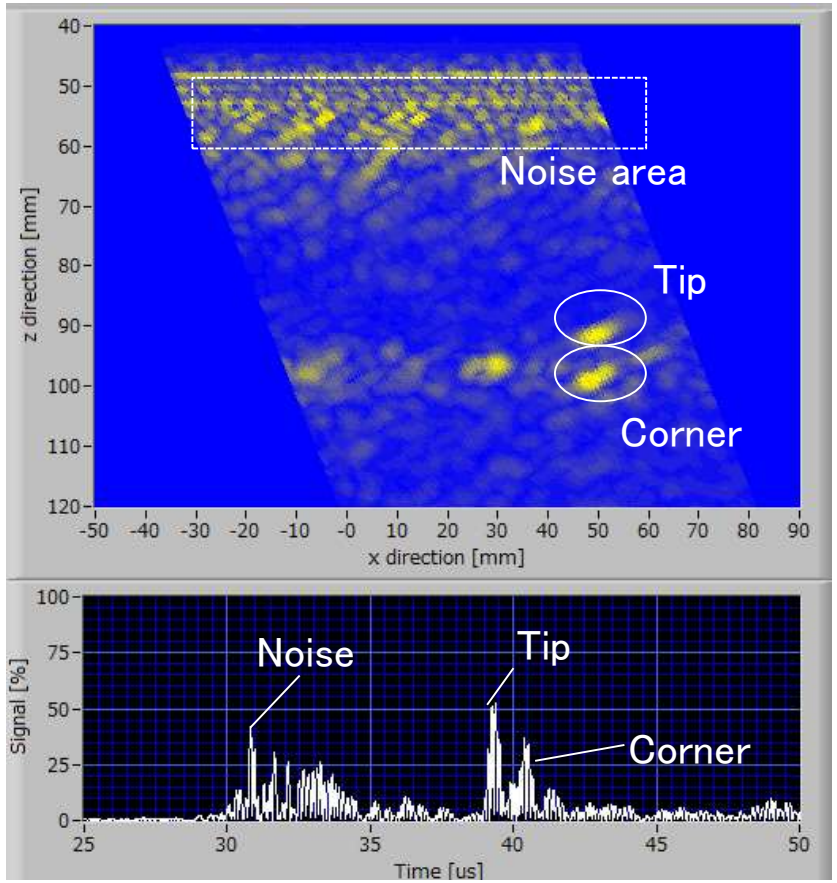
As number of transmitting elements increased, SNR was improved

Experimental result - slits

1ch firing



3ch firing



SNR of slit tip in the CASS specimen (t51mm) was clearly increased

Conclusions

Shape adaptive beam steering＋Soft shoe

Performance verification have been conducted under complicated surface. This technique is in the application phase and applied to several actual Japanese plants.

Comprehensive PAUT for CASS

This technique is in the development phase. Today, Toshiba showed the several experimental results.

Combined two technique have a potential to realize a inspection of complex shaped components and CASS

TOSHIBA

Mr Hajime SHOHJI

CRIEPI, Japan

New Technology of Inspection Method

Energy Transformation Research Laboratory
Central Research Institute of Electric Power Industry
Senior Research Scientist Hajime SHOHJI

International workshop on In-service Inspection Examination Frequency
April 12, 2022

About CRIEPI [1]

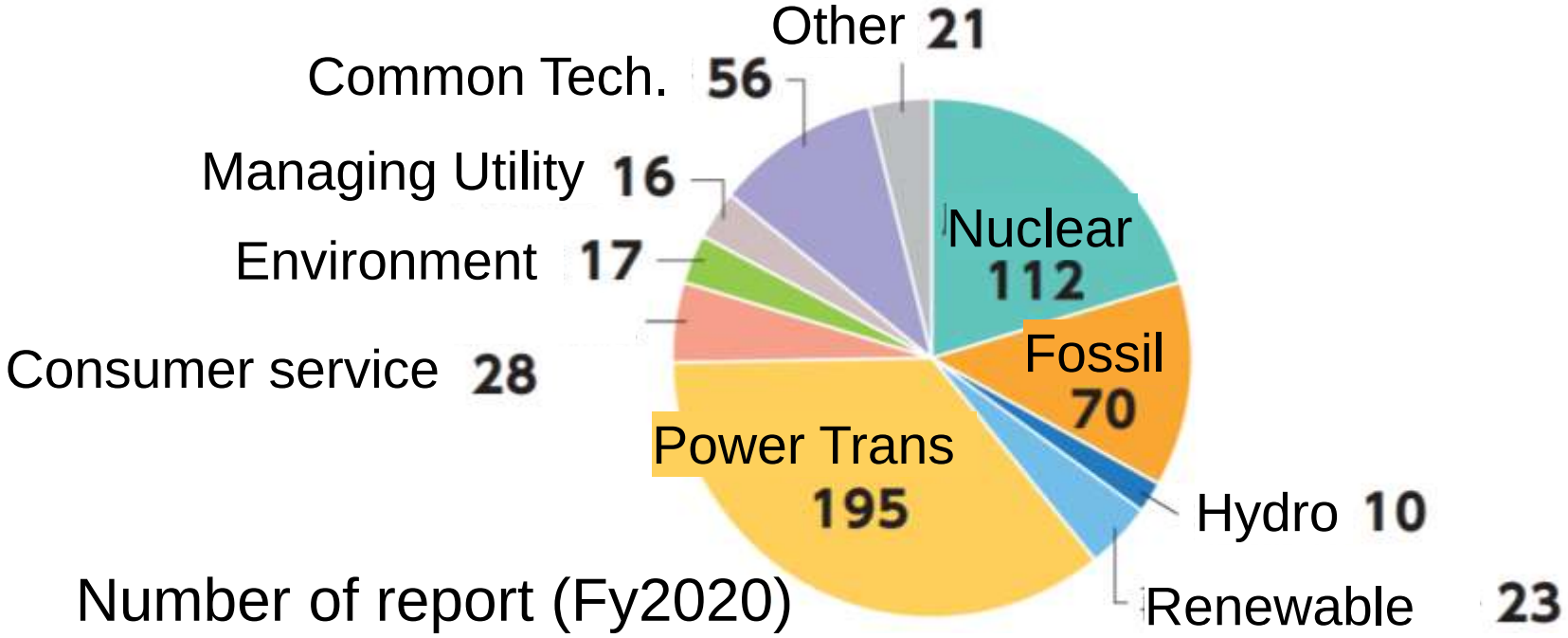
Name : Central Research Institute of Electric Power Industry

President : Masanori Matsuura

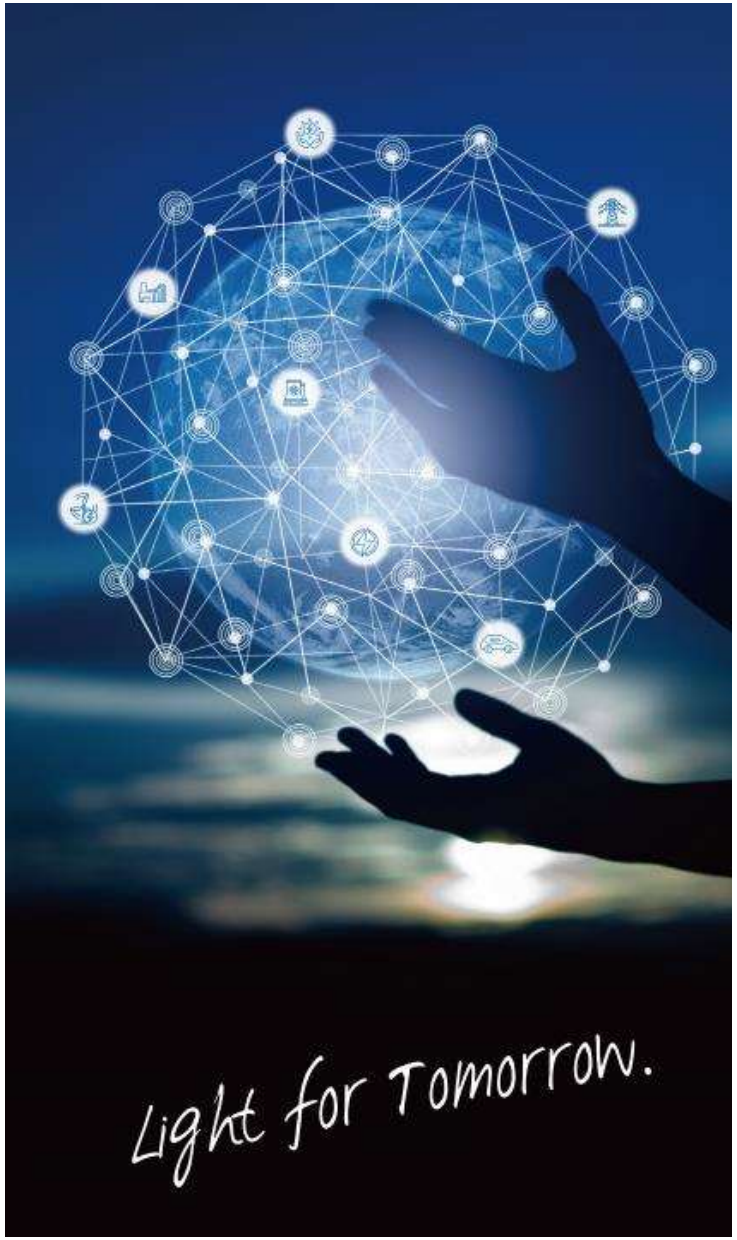
Date Established : Nov. 7, 1951

Operational Budget : 30.1 Billion yen (FY2021) ≃ 246 Million $

Personnel : Research : 697 Office work : 90 Total : 787



Number of report (Fy2020)



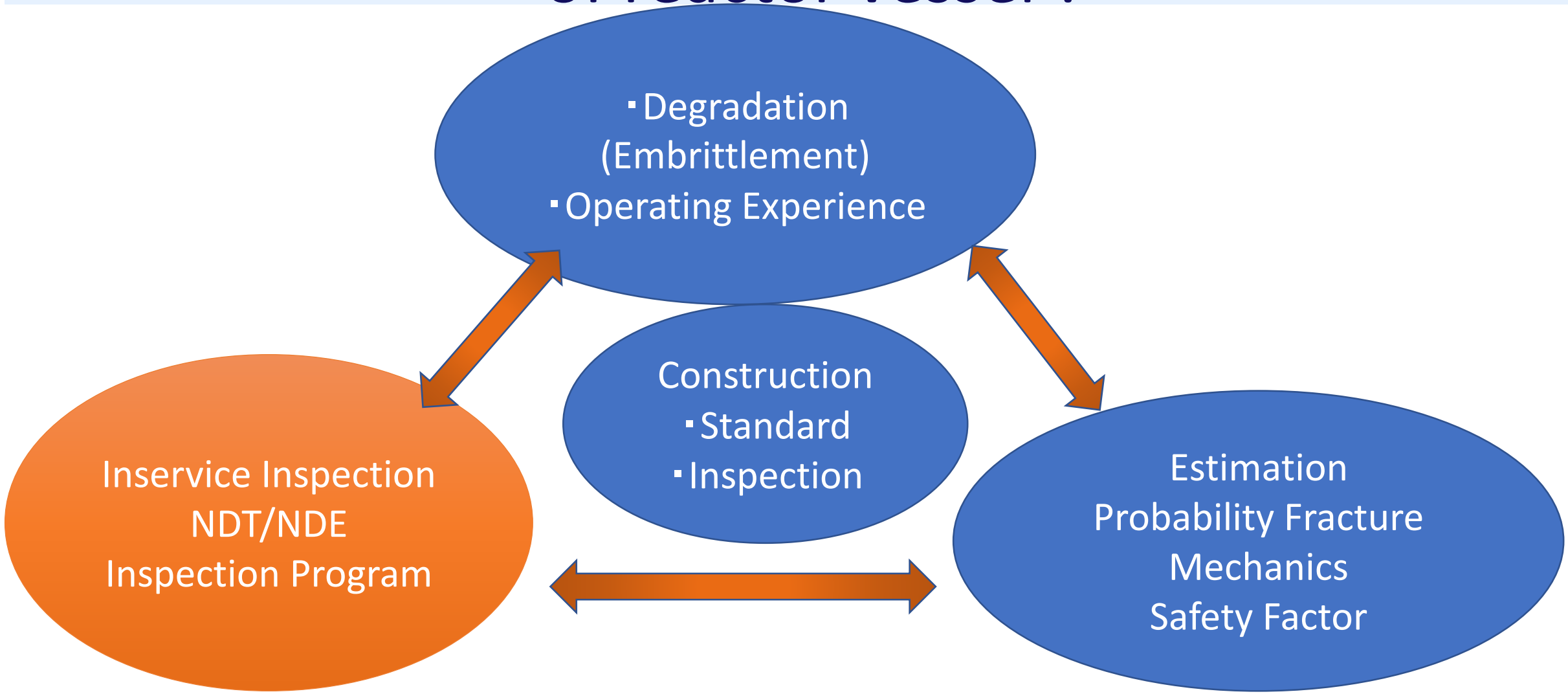
About CRIEPI

CRIEPI

- Board of Directors
  President
  - Socio-Economic Research Center
  - Nuclear Risk Research Center
  - Energy Trasformation Research Lab.
    - Plant Systems Engineering Division
    - Material Science Division
      - Performance Demonstration Center
    - Energy Chemistry Division
    - .....
  - Grid Innovation Research Lab.
  - Sustainable System Research Lab.
  - .....
  - .....

- High Temp. Material
- NDE unit
- Micro Structure
- .....

What is the structural integrity evaluation of reactor vessel ?



Background

- Our NDE research projects (On Going)
  - Ultrasonic testing for Cast stainless steel piping[2]
  - Ultrasonic testing for austenitic weld
  - Guided wave
  - Modeling
  - Training system using UT simulator[3]
  - Flaw sizing technique
  - Concrete
  - POD analysis for Probabilistic Fracture Mechanics
  - ....

- At this workshop, we focused on just NDE and "Inspection Intervals".

Inservice Inspection

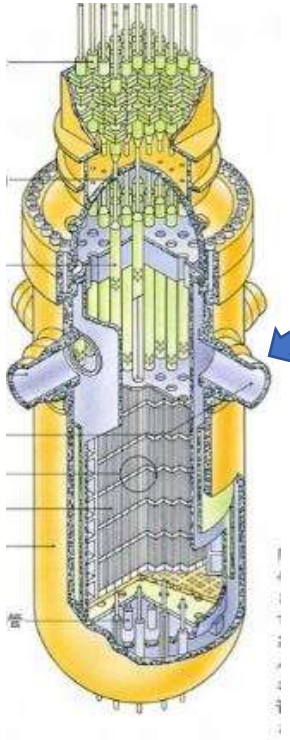
- Nozzle to safe end weld
- Nozzle Inside radius (UT)
- Nozzle Inside radius (ECT)
- Other approach

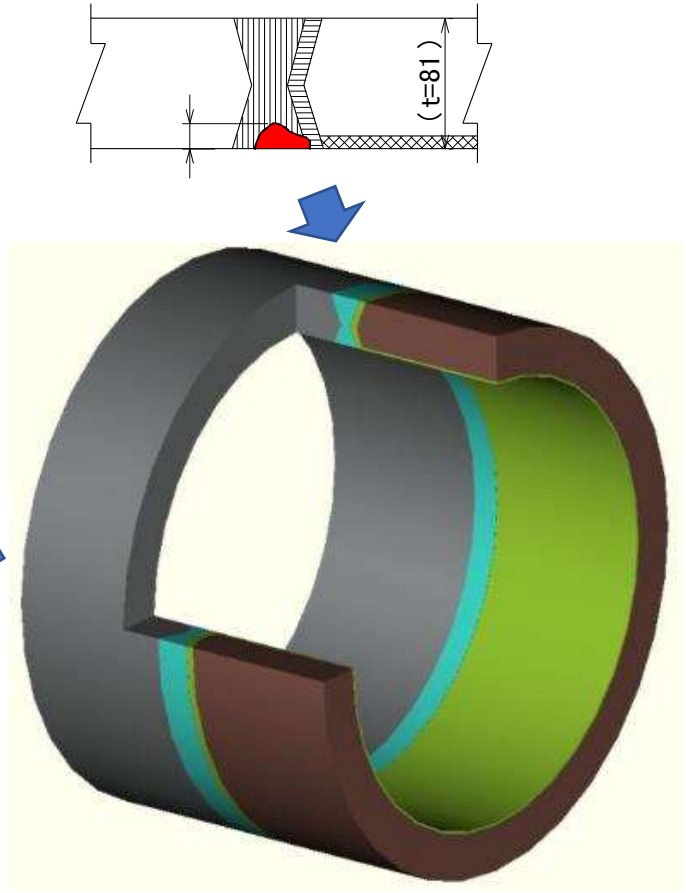
Nozzle to safe end weld

- Nozzle to safe end section is an important part of the pressure retaining boundary
- Nickel-based alloy welds have been detected crack
- It is difficult to ultrasonic testing due to its high attenuation and

✓ Japanese PWR plant :

Its surface flushing smoothly inside and outside.



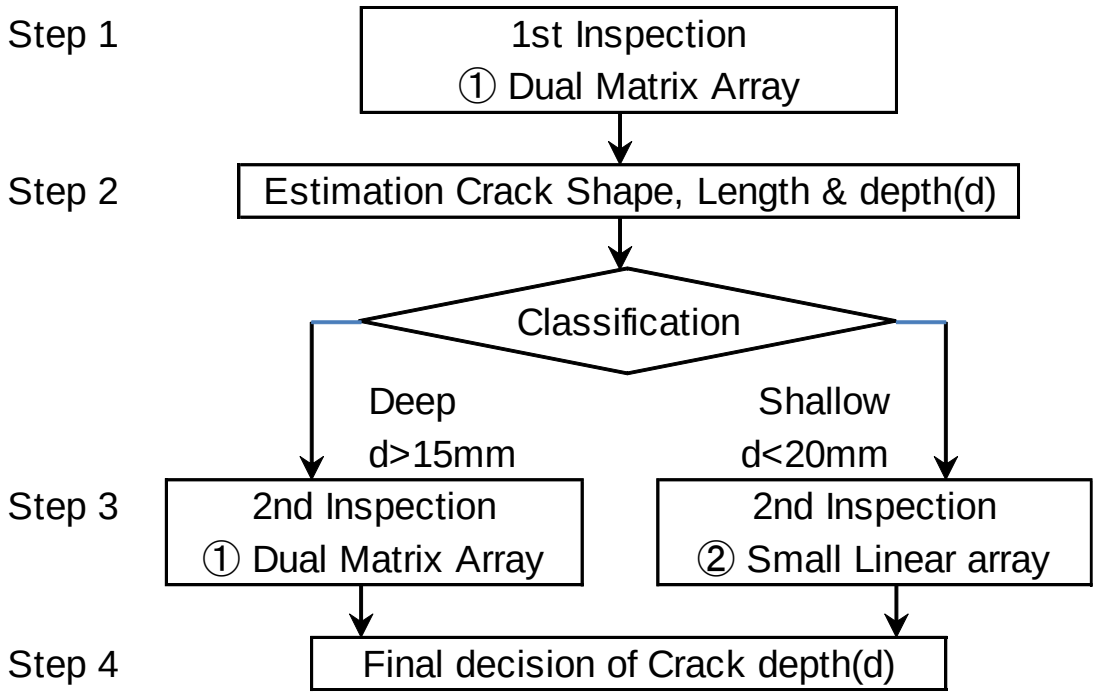


Nozzle to safe end weld (Inside)[3] (1/3)

- We developed a new procedure for crack through wall depth sizing.

UT Probe

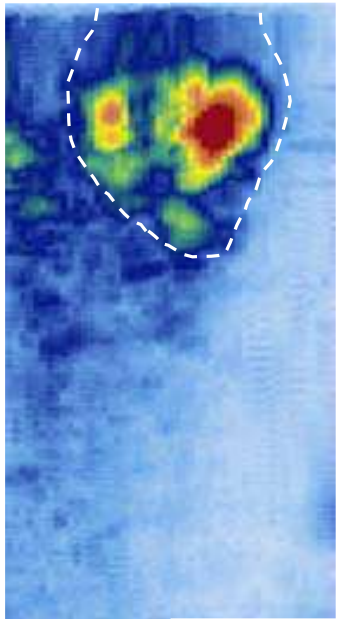
- 200 ch. matrix array (pitch/catch)
- 128 ch. linear array

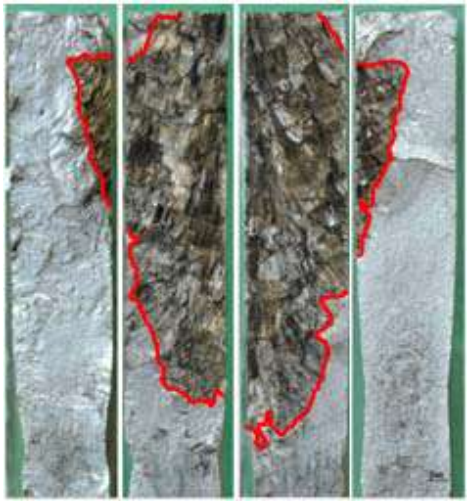


Nozzle to safe end weld (Inside) (2/3)

- The shape of the crack can be estimated by using developed procedure with fine pitch scan.

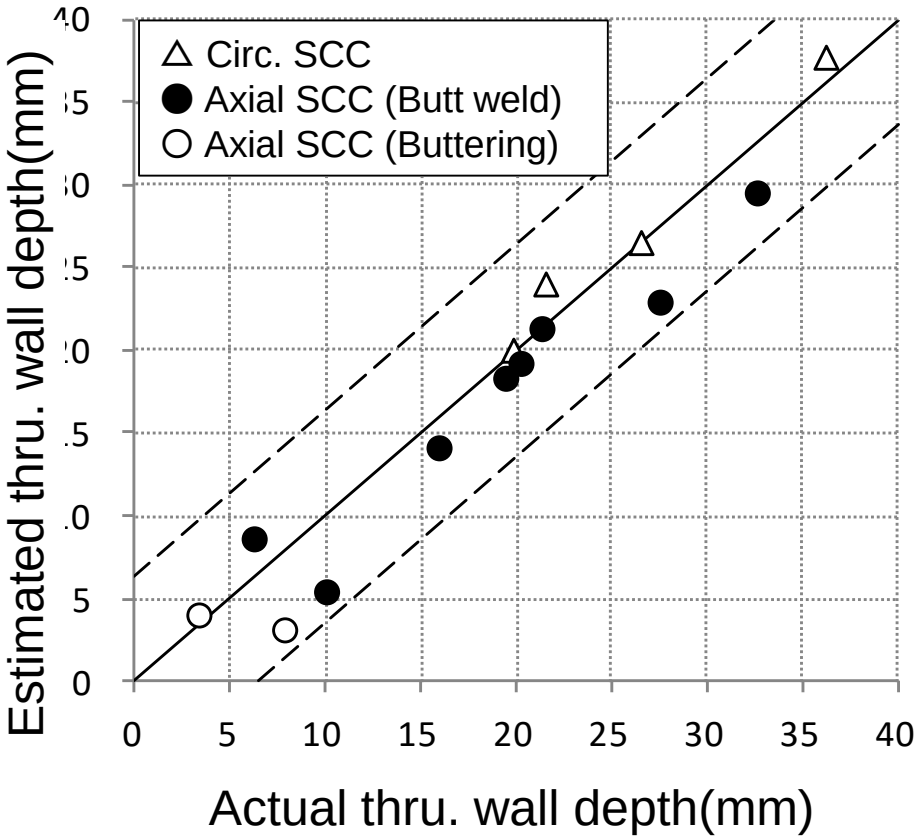
  Some cases of cracks in nickel-based alloy have short crack opening length and spread inside. Therefore, it is important technique for identifying the length of the crack.





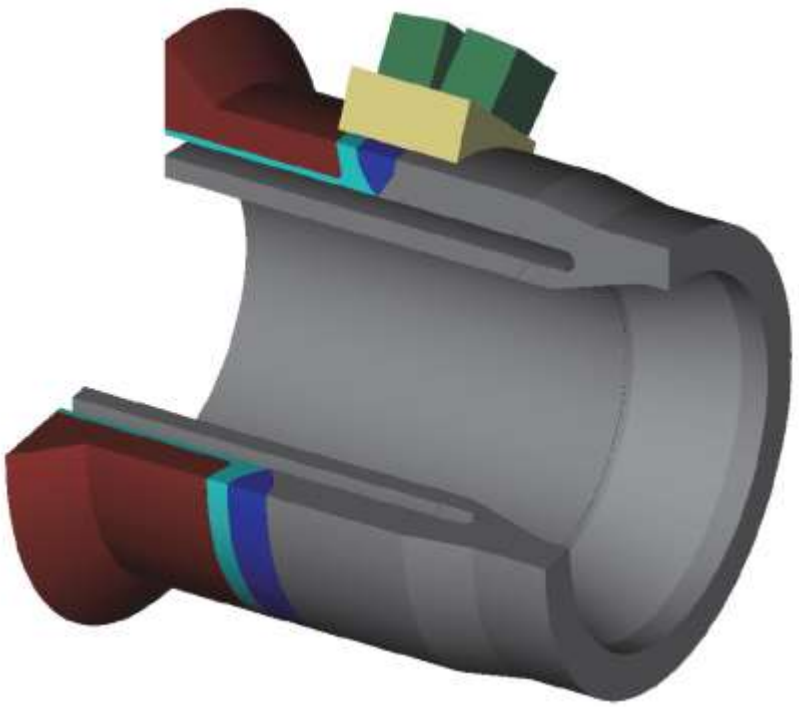
Nozzle to safe end weld (Inside) (3/3)

- From Inside Inspection
- Crack Detection and through wall depth sizing accuracy



Nozzle to safe end weld (Outside)[5] (1/4)

- From outside Inspection
- Crack Detection and through wall depth sizing accuracy



Nozzle to safe end weld (Outside) (2/4)

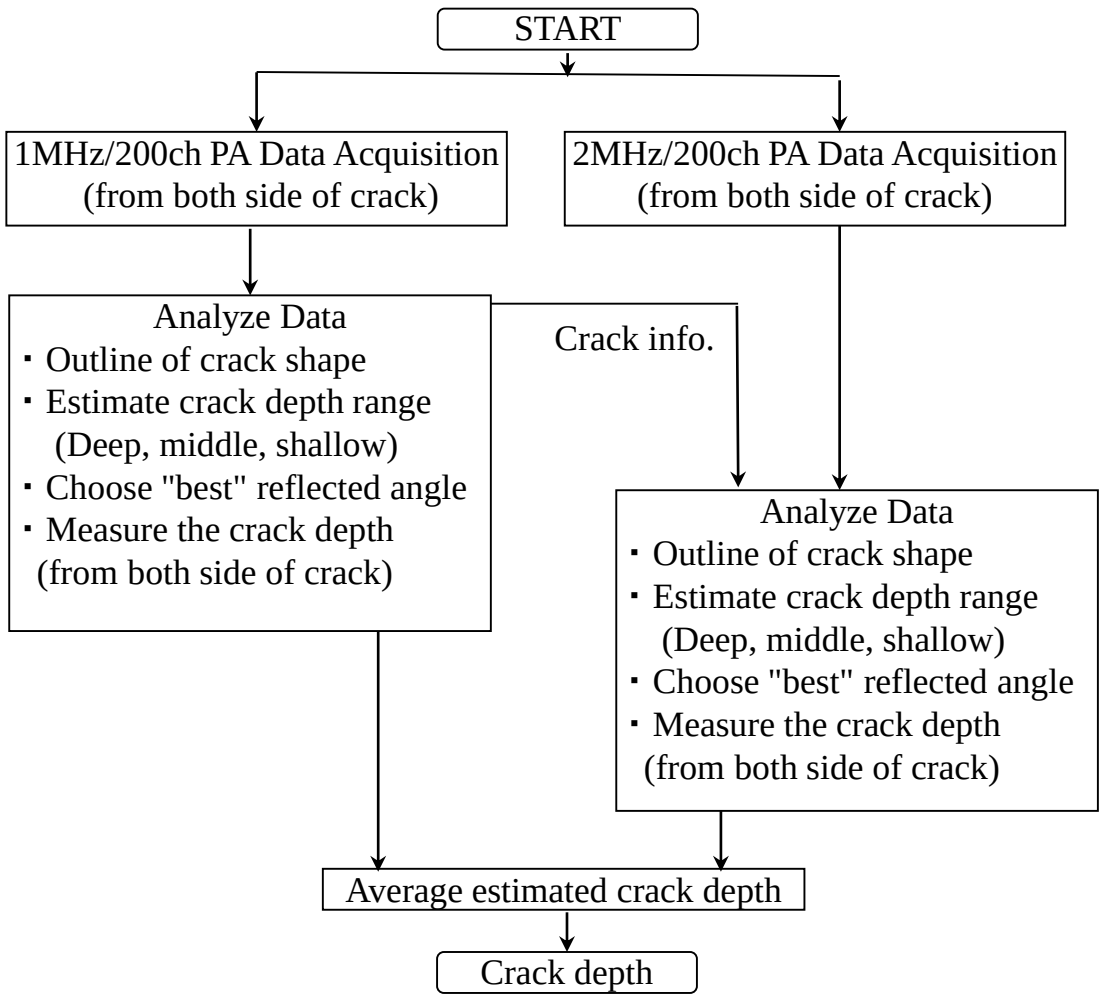
- From outside Inspection
- High power Phased array technique

Nozzle to safe end weld (Outside) (3/4)

- We developed new procedure for crack through wall depth sizing.

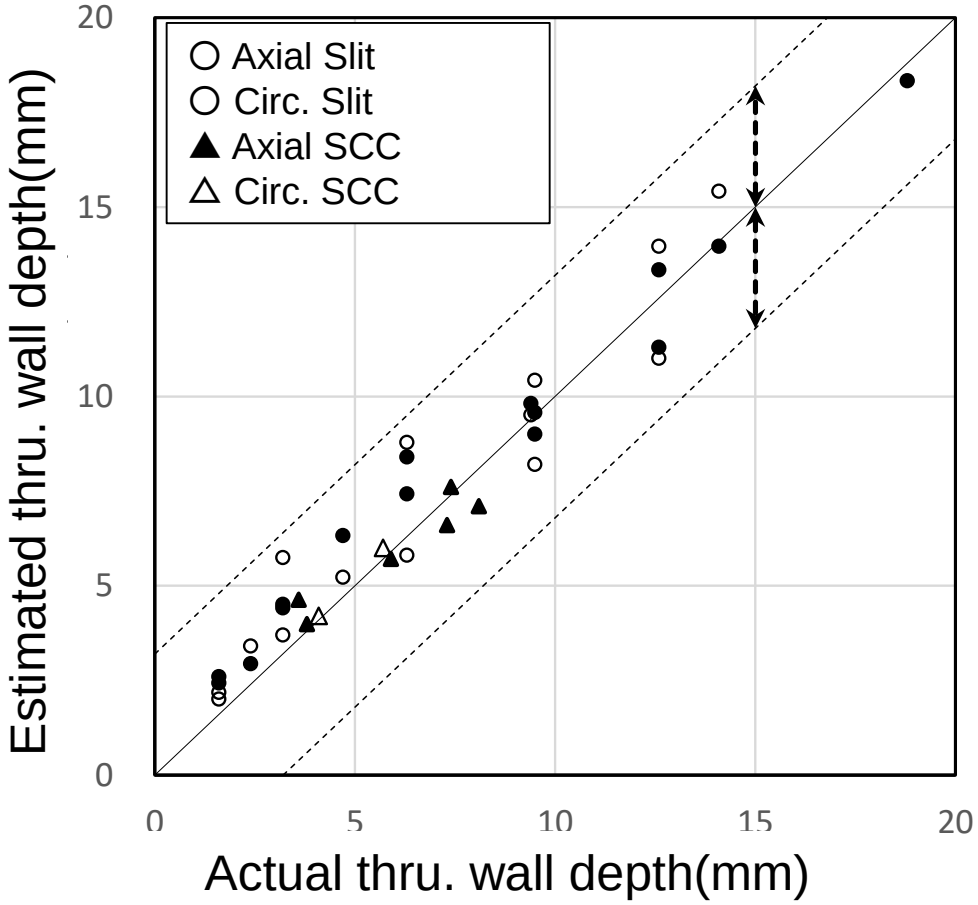
UT Probe

- 200 ch. matrix array (pitch/catch)
- 1MHz "and" 2MHz



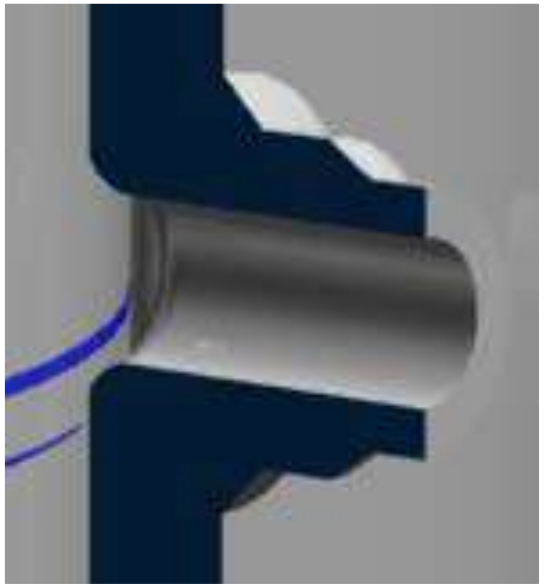
Nozzle to safe end weld (Outside) (4/4)

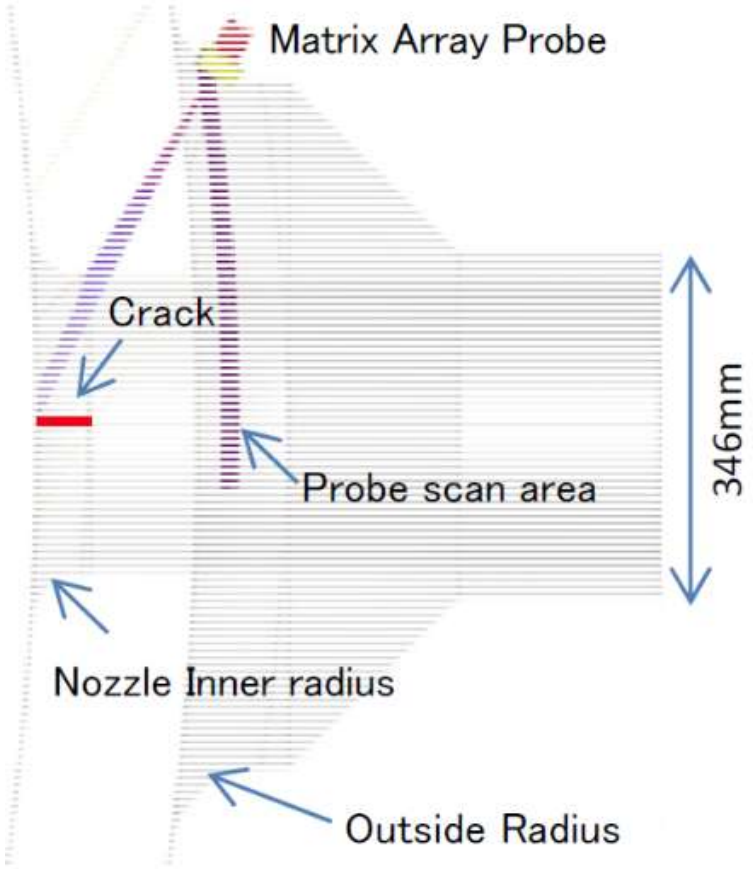
- From outside Inspection
- Crack Detection and through wall depth sizing accuracy



Nozzle inside radius UT (1/3)

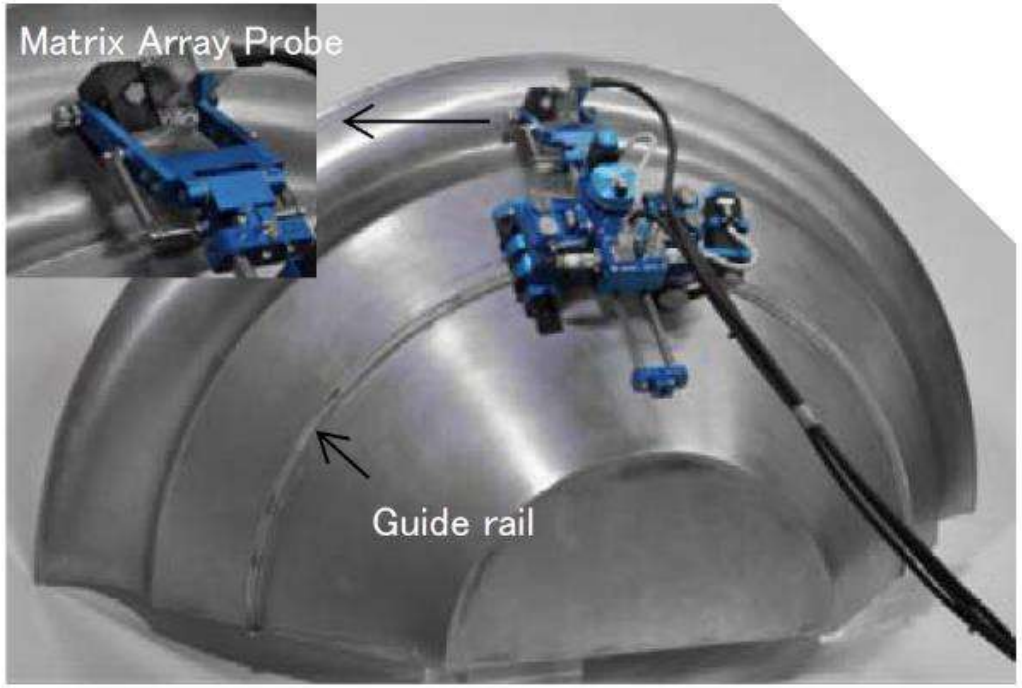
- From outside Inspection
- Matrix type Phased array UT technique





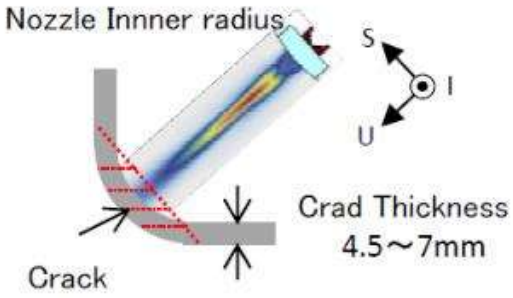
Nozzle inside radius UT (2/3)

- It is possible to detect even shallow crack within the cladding, using new developed phased array technique.
- Crack depth can be measured with high accuracy.
- The accuracy of flaw length measurement is low

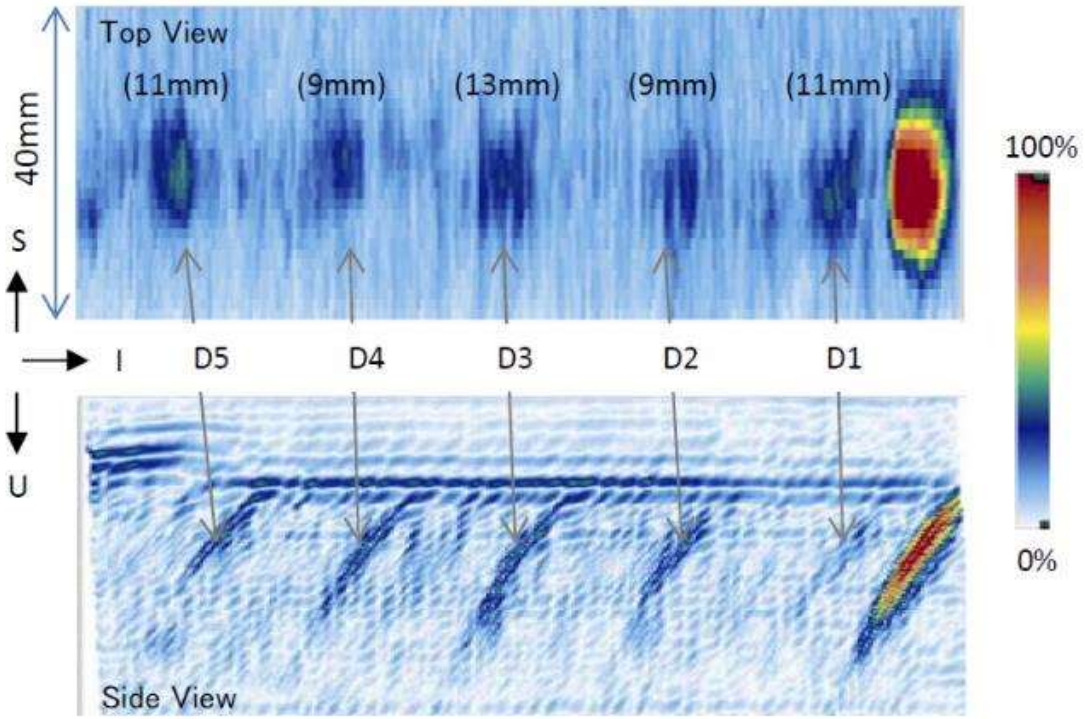


Nozzle inside radius UT (3/3)

- It is possible to detect even shallow crack within the cladding, using new developed phased array technique.
- Crack depth can be measured with high accuracy.

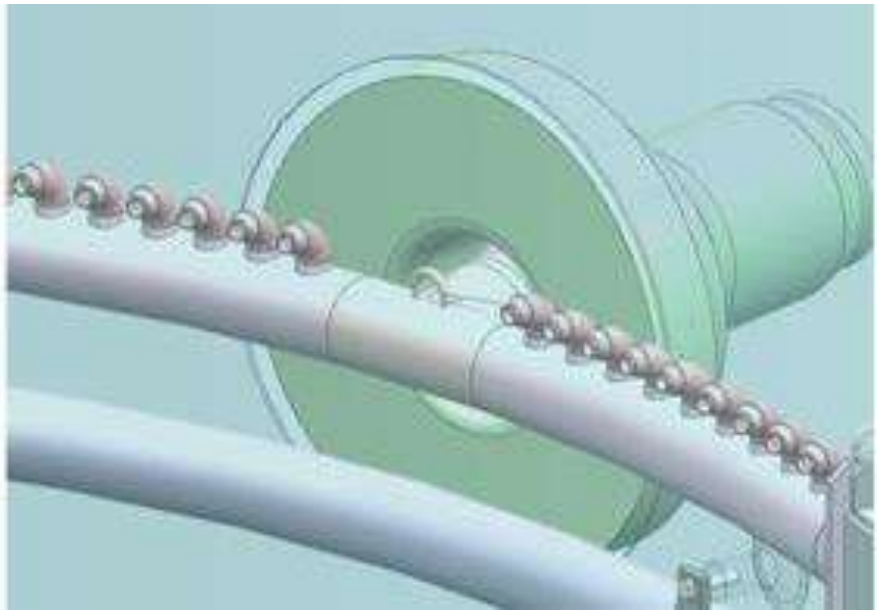


Crack ID	Depth (mm)	Est. Length (mm)
D1	2	34
D2	4	44
D3	6	53
D4	8	60
D5	10	71



Nozzle inside radius ECT[1] (1/5)

- NRAJ (Japanese regulator) has requested LPT, MT or ECT for the inside radius of the nozzle for license extend more than 40 years.
- Feed water nozzles of BWR are not cladding.
- ECT for low alloy steel is generally difficult due to its ferromagnetism.



[1] EJAM, Vol.8 No.4 "Development of the Eddy Current Testing (ECT) technique for the feedwater nozzles of Nuclear Power Plant Reactor Pressure Vessel", 2017

Nozzle inside radius ECT (2/5)

- The problem with ferromagnets is ;
  - the B-H curve has hysteresis.
  - False signal is detected in the magnetized area.
- There is no standard or code for surface inspection standard using ECT of ferromagnet

⇒ Joint research project has been performed by;

Japanese utility operating BWR,

Japanese BWR plant manufacturer

and CRIEPI

Nozzle inside radius ECT (3/5)

- Detectability tests were performed with several probes and frequencies ;
  - T-R Pancake coil
  - Cross coil & pancake coil
  - Uniformization
  - Cross-induced / Self-comparative
- Test specimen ;
  - Flat Plate / 2D shape / 3D Shape
  - Notch, Mechanical fatigue crack, Thermal fatigue crack,
  - Magnetized / Un-magnetized

Nozzle inside radius ECT (4/5)

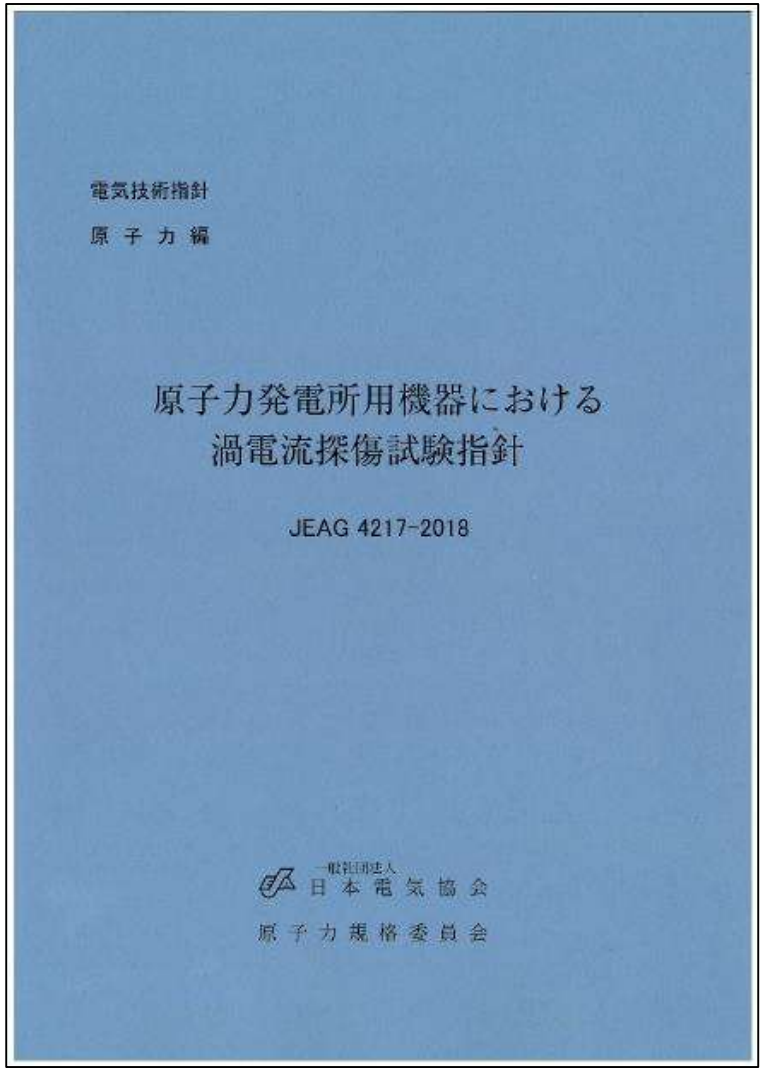
- Confirm the detectability for each crack through detection test.
- Also, the detectability did not decrease with a 3D-Shape.
- False signal from magnetization and crack signal can be discriminated by signal Phase.

probes / ID. Specimens	Signal source	TR pancake	Cross coil & pancake	Uniformization	Mutual·Induction Self-comparative
1. plates (average roughness Ra=3μm, machining)No.1*1	notch (1mm depth,11.8mm length)	◎	◎	◎	○*
2. plates(average roughness Ra=9μm) No.1*1	notch (1mm depth,11.8mm length)	◎	◎	◎	○*
3. plates (oxide film) No.1*1	notch (1mm depth,11.8mm length)	◎	◎	◎	○*
4. plates (cladding) No.1*1	notch (1mm depth,11.8mm length)	○*	◎	×*2	○*
5. plates (machining) No.1*1	notch (0.5mm depth,8.4mm length)	◎	◎	◎	◎
6. plates (machining) No.2*1	thermal fatigue flaw (0.5mm depth,2.3mm length)	△*2	◎	×*2	○*
7. 2-dimension (machining) No.3*1	notch (0.5mm depth,8.4mm length)	◎	◎	◎	◎
8. 2-dimension (machining) No.4*1	mechanical fatigue flaw (1.4mm depth,13.8mm length)	◎	◎	△*2	◎
9. 3-dimension (actual plant machining) No.5*1	notch (1mm depth,11.8mm length)	◎	◎	◎	◎
10. 2-dimension (machining) No.3*1	notch (1mm depth,11.8mm length)	◎	◎	◎	◎

Nozzle inside radius ECT (5/5)

- Extend ECT guide to Low alloy Steel for surface inspection of NPP. And it was endorsed by NRAJ.
- Apply to actual plant.

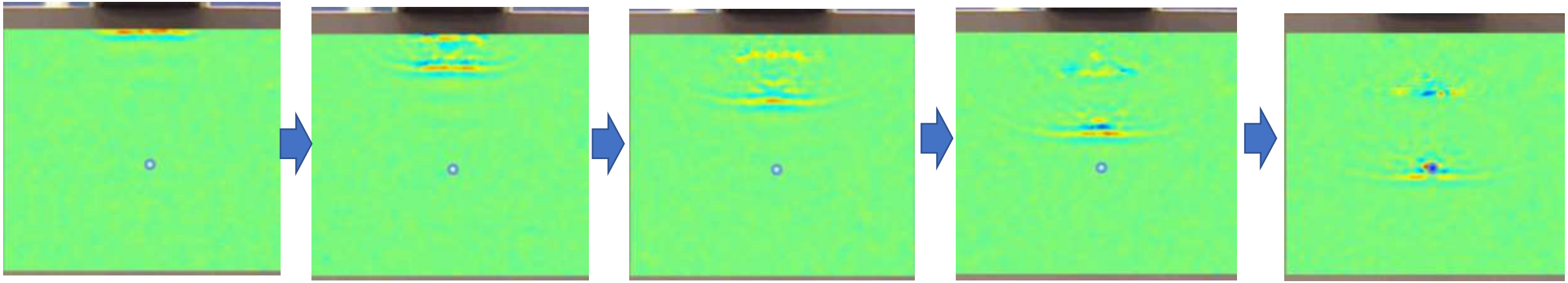
item		contents
probe	specification	single or array probe
	method	upper coil applicable for the flaw detector specification
	frequency	above 2 kinds frequency from 10 kHz to 1 MHz
reference block	shape	plate or specimen simulating actual corner curvature
	material	same as actual test part
	calibration flaw	1 mm depth notch
reference sensitivity		set to the prescribed sensitivity using calibration flaw
phase angle		appropriate angle for detection (ex. 90° or 250°)
probe scan direction		orthogonal or parallel to the nozzle axial direction
detection threshold		above 20% of reference sensitivity
length measurement		recommend the length measured by 12dB drop (length measured by the vanishing point is available depending on the characteristic of the coil)



Other Technology

Ultrasonic propagation measurement technology

- We developed new technology for observing ultrasonic vibration using 3D LASER doppler system
- This technology is very useful for optimization of UT process



Conclusion

- CRIEPI is performing research projects about structural integrity evaluation of pressure vessels from multiple perspectives, including non-destructive inspection.
- We have developed an effective technology for detecting/sizing cracks in the nozzle to safe end of the pressure vessel.
- We have developed a phased array technique and eddy current testing technique that can detect flaws in the nozzle inside radius.
- Going forward, we will continue to develop technology.

Acknowledgments

These research projects are supported by Japanese Utilities, Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku, Kyusyu, J-Power and JAPC.

The research project about nozzle inside corner ECT technique is the result of joint research project with Tokyo, Tohoku, Chubu, Hokuriku, Cyugoku, J-Power, JAPC, Toshiba and Hitachi-GE.

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[7] EJAM, Vol.8 No.4 "Development of the Eddy Current Testing (ECT) technique for the feedwater nozzles of Nuclear Power Plant Reactor Pressure Vessel", 2017

Mr Seiji ASADA

MHI, Japan

ISI workshop - April 11-14

Session 2: Evolution of NDE Techniques

Applicability of Full Matrix Capture (FMC) /Total Focusing Method (TFM)

April 12, 2022

Mitsubishi Heavy Industries, Ltd.

Seiji Asada, Isao Seki, Keisuke Kajikawa

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2. Basis of FMC/TFM

3. Adaptive processing

4. Verification of FMC/TFM

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4.2 SDH imaging of stainless steel piping weld

4.3 LOF imaging of stainless steel piping weld

4.4 Fatigue crack imaging of stainless steel piping weld

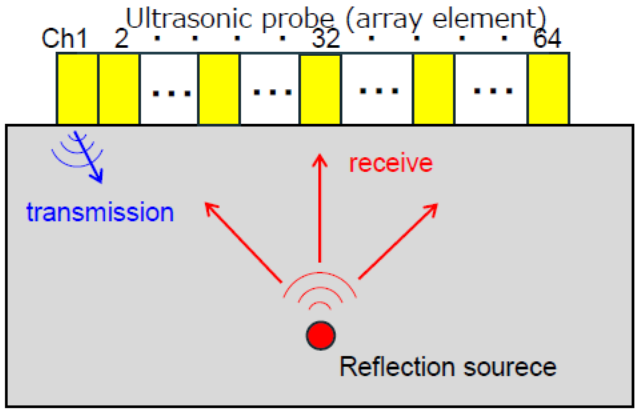
4.5 SCC of imaging stainless steel piping – elbow weld

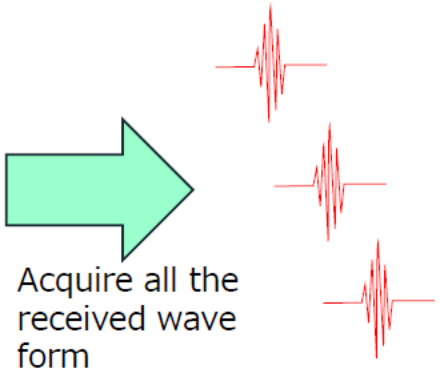
5. Conclusion

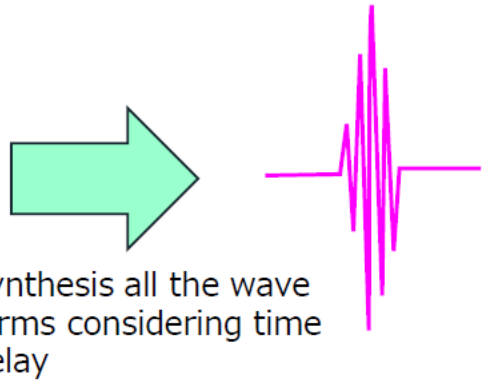
1. Background

- Ultrasonic Testing (UT) method in lieu of Radiographic testing (RT) for ferrite steel and austenitic stainless steel is specified in ASME Section XI, Code Case N-831-1.
- If UT method is applied in lieu of RT during manufacturing stage, that is useful to achieve transition from construction stage to operating stage in view of inspection.
- Full Matrix Capture and Total Focusing Method (FMC/TFM) is one of the candidate.
- FMC/TFM is recent UT technology using phased array probe with synthetic aperture method.
- This presentation introduces our activities for FMC/TFM.

2. Basis of FMC/TFM





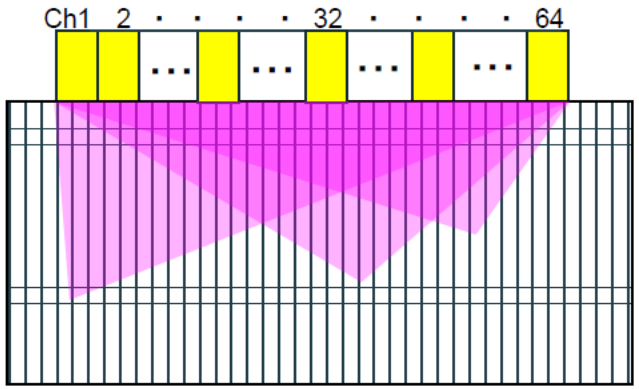


Full Matrix Capture (FMC)

- One element transmits an ultrasonic wave, and all element receive the reflected wave form.
- This process is repeated for each element, and all the received wave forms are acquired. (*)

(*) In case of 64ch, In case of 64ch, 64×64＝4096 wave forms are acquired.

Plot the amplitude corresponding to the beam path length.



Total Focusing Method (TFM)

Using the wave forms acquired by the FMC, echoes are superimposed on an arbitrary grid and an UT image is developed.
(This process is equivalent to focusing on each grid.)

<Feature of FMC/TFM>

The FMC/TFM method is different from the conventional PA technique that focuses UT beam on a specific location.
This method can generate UT images for all area that have high lateral resolution and high S/N ratio for all ranges and analyze flaws.

→ This method is effective to flaw detection and sizing.

In addition, this method produces the results of straight beam and angle beam technique in one inspection, so it is possible to shorten the time and reduce radiation exposure.

FMC/TFM imaging sample of stainless steel base metal with Side-Drilled Hole (SDH)

Probe spec

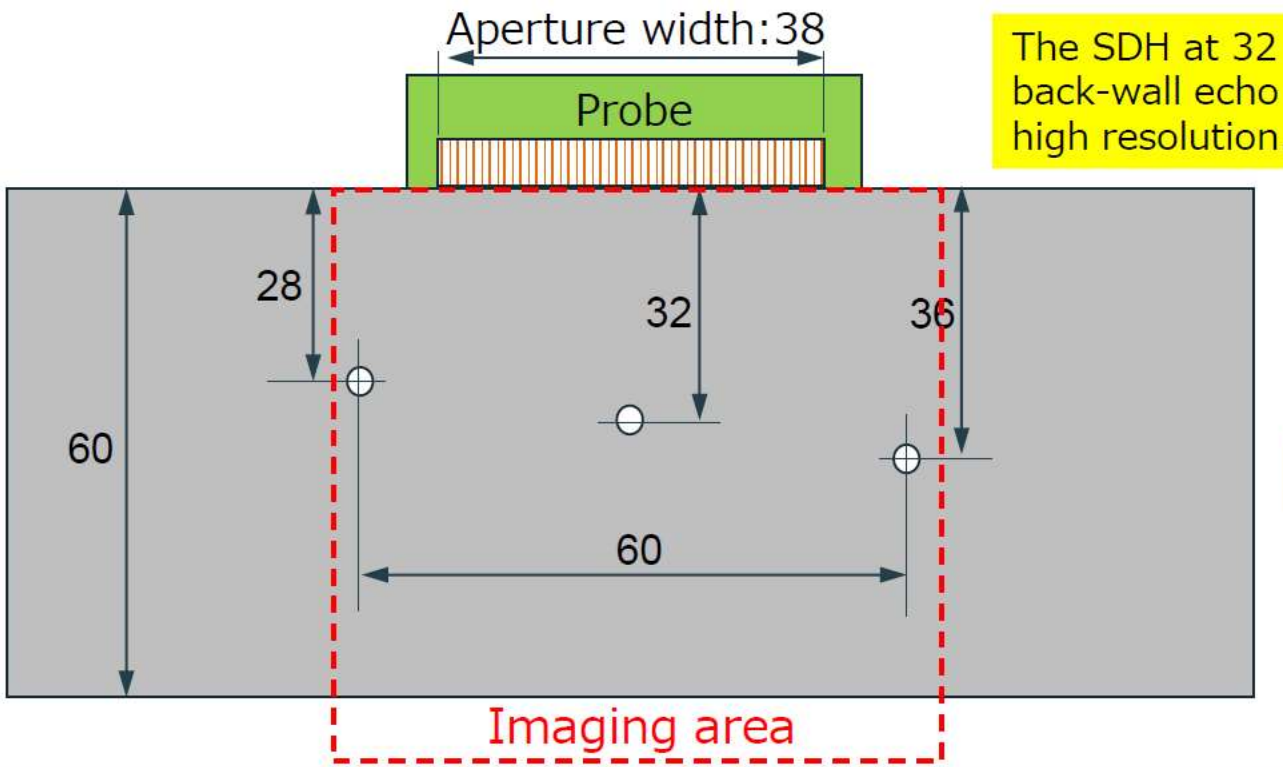
Aperture width	Number of element	Element pitch	Element location
38mm	64ch	0.6mm	Linear array

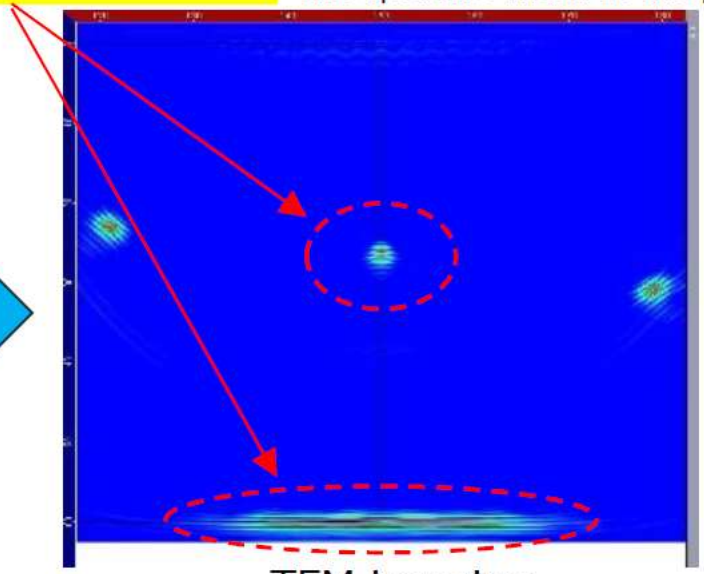
Specification

Material	Wall thickness	Size of SDH
SUS 304	60mm	Φ3.2mm

The SDH at 32 mm depth and the back-wall echo could be identified with high resolution.

Remark:
The resolution of the SDHs on both sides is lower than that of the center SDH because the SDHs on both sides are located outside the aperture width of the prove.





TFM imaging

3. Adaptive processing

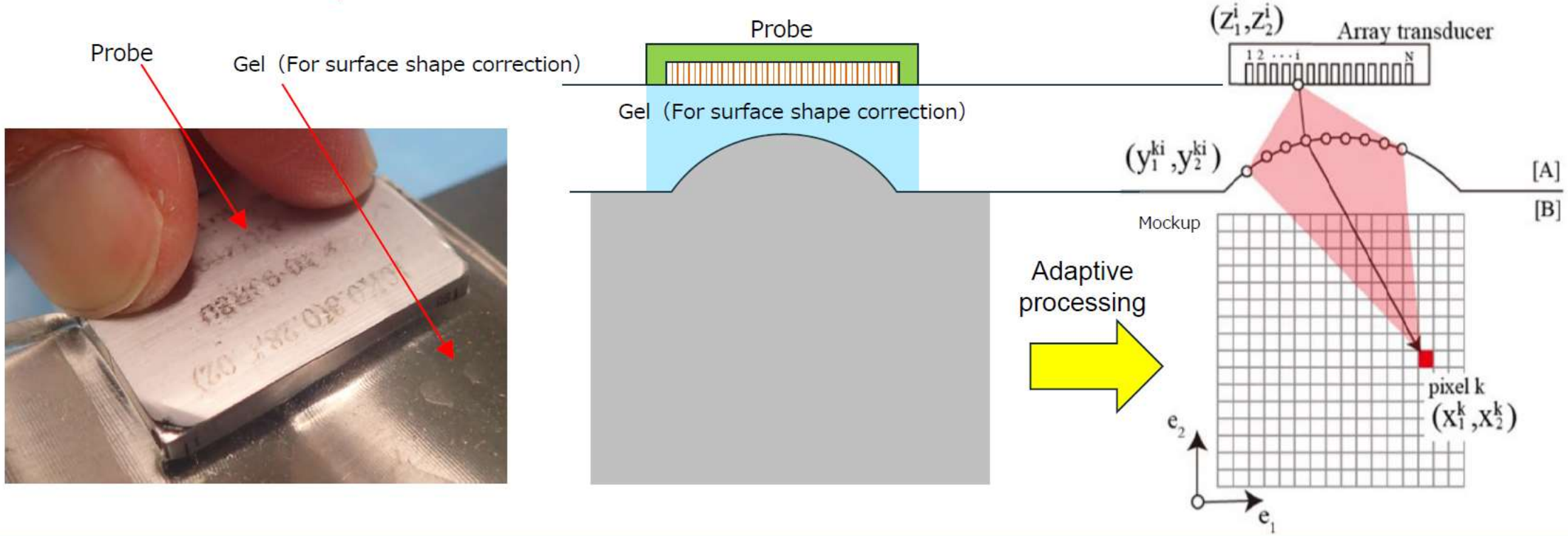
Issue of TFM

An imaging process of TFM relies on the shape of surface applied a probe. When the surface is uneven or curvature, the surface condition will give an influence on an ultrasonic wave because of the gap between the prove and the surface, and it may be difficult to achieve high resolution and high S/N ratio.

Countermeasure

The effect of the complicated surface shape is corrected by performing adaptive processing (*).

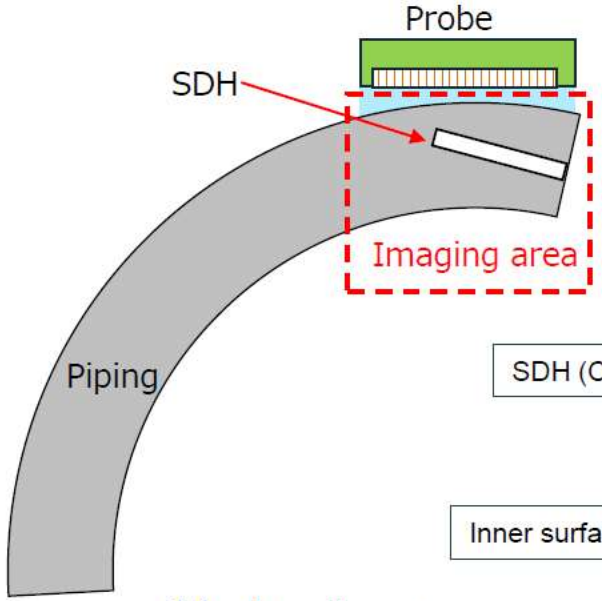
(*)Adaptive processing: First, the surface shape is acquired, and the refraction of the ultrasound due to the effect of the surface shape is corrected on the data.



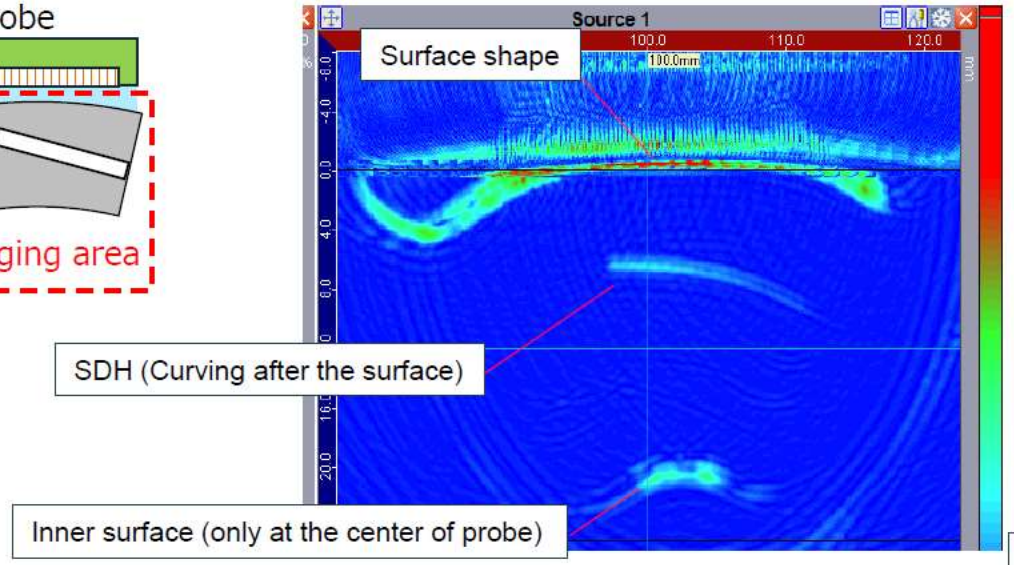
Verification of adaptive processing

Mockup spec :SUS piping with SDH (circumferential direction)

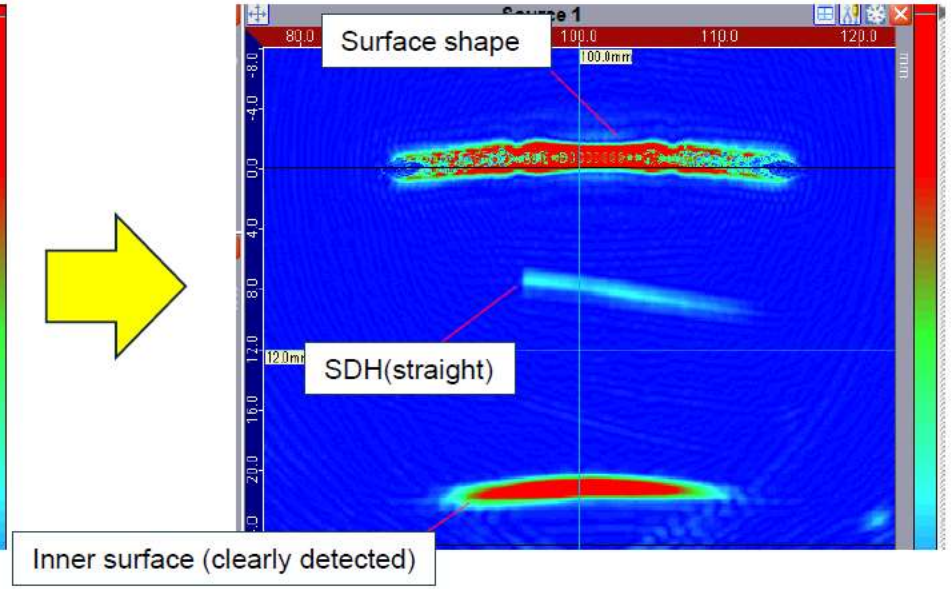
Result :
【Before adaptive processing】
SDH : The SDH image is curved along the curvature of the outer surface of the piping.
Back-wall echo : This reflection echo from inner surface of the piping can be detected only at the center of probe.
【After adaptive processing】
SDH : The SDH image of a straight hole can be obtained.
Back-wall echo : The reflection echo from the inner surface of piping can be clearly detected.



Mockup image



Before adaptive processing



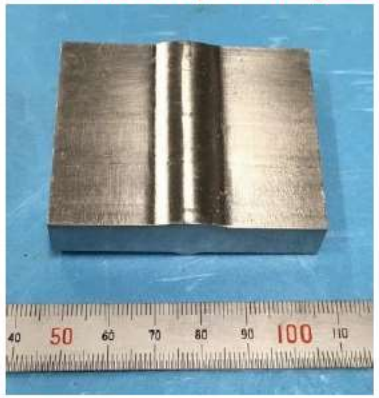
After adaptive processing

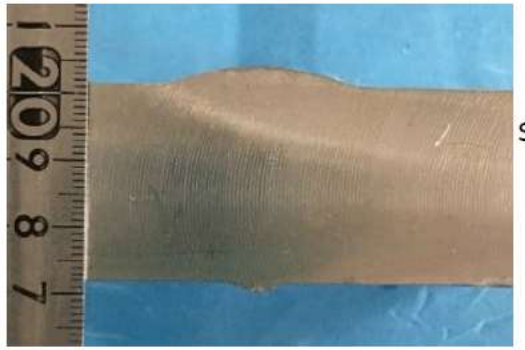
3. Adaptive processing

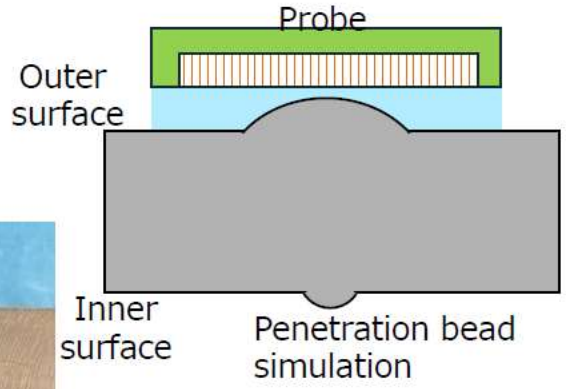
Verification of adaptive processing

Mockup specification :Stainless steel plat of 30 mm thickness with machined weld crown and penetration bead shape (no weld metal)

Result :
【Before adaptive processing】
Shape of inner surface can not be imaged
【After adaptive processing】
Clearly imaged the shape of penetration bead

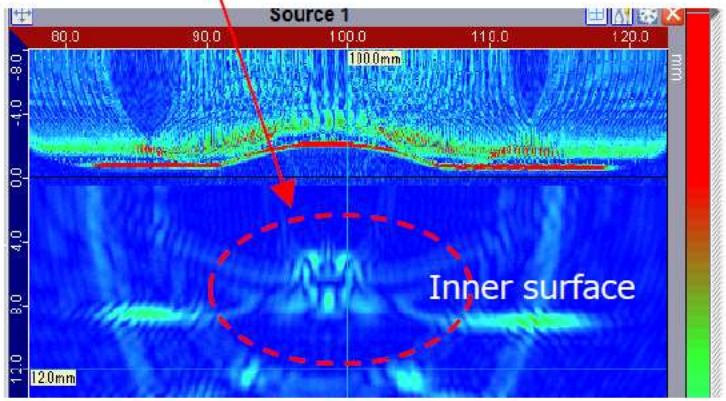




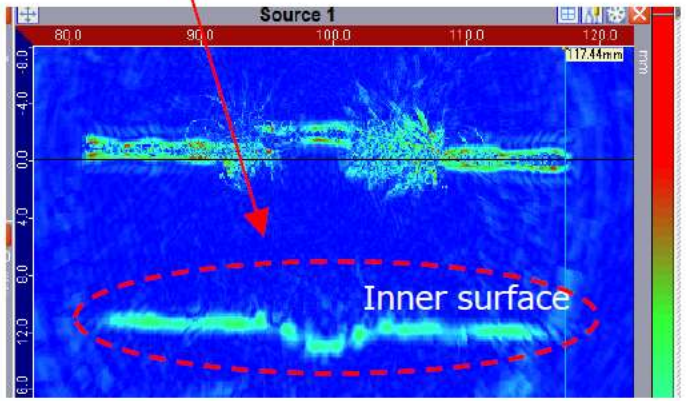


The effect of weld crown, inner surface shape is not imaged.
(the shape of penetration bead is not imaged)

Inner surface shape is imaged
(the shape of penetration bead)



Before adaptive processing



After adaptive processing

Complicated shape can be appropriately imaged by performing adaptive processing.

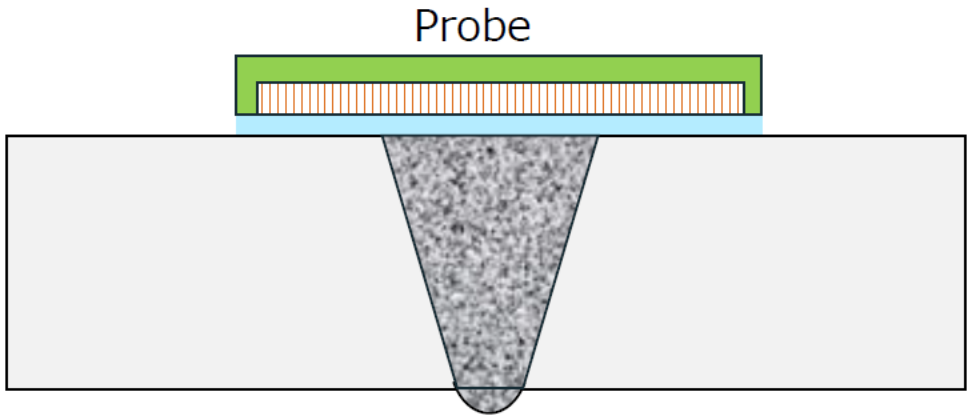
4.1 Penetration bead shape imaging of stainless steel piping weld

When indication is detected at inner surface by ISI- UT for a stainless steel weld joint, the inner shape of piping (penetration bead, center line of welded part, taper location and so on) shall be identified to analyze and evaluate UT signal.

This verification demonstrates FMC/TFM imaging ability of the inner shape of piping (penetration bead) for 3 case of wall thickness

Piping mockup with penetration bead spec

Size	Wall thickness	Material	Weld crown
8B (200A)	23.0mm	304SS	Not exist
10B (250A)	28.6mm	304SS	Not exist
12B (300A)	33.3mm	304SS	Not exist



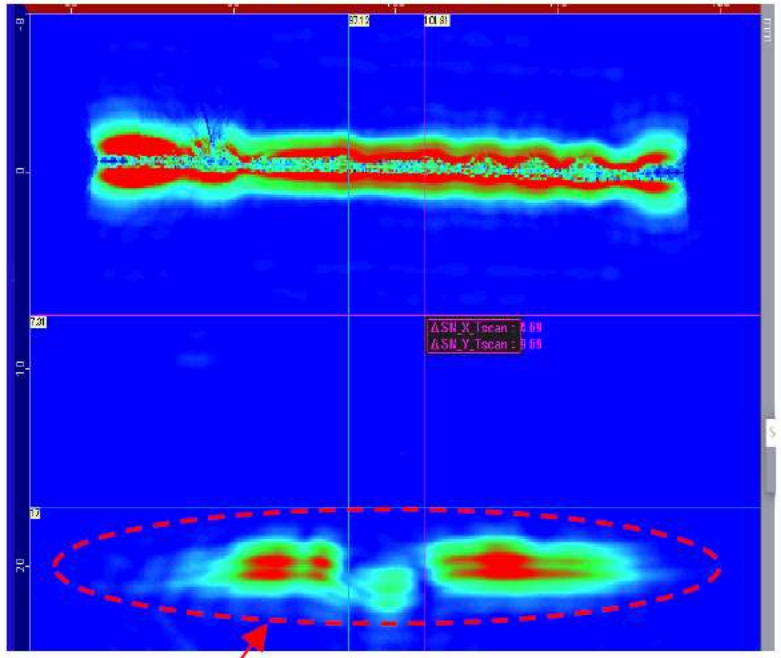
Piping mockup with penetration bead

4.1 Penetration bead shape imaging of stainless steel piping weld

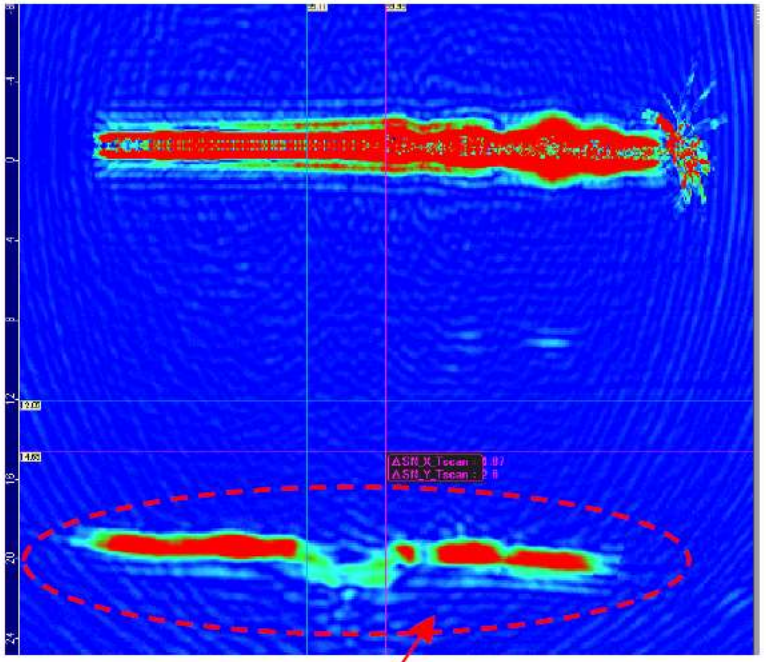
Result of FMC/TFM for 8B(200A) piping mockup with penetration bead

8B piping mockup
(Inner surface penetration bead)

2MHz Probe



5MHz Probe



The inner shape can be imaged, but the resolution is lower than the image by 5 MHz.

The inner shape can be imaged, and the penetration bead shape can be clearly identified.

MITSUBISHI HEAVY INDUSTRIES

4.1 Penetration bead shape imaging of stainless steel piping weld

Result of FMC/TFM for mockup with penetration bead

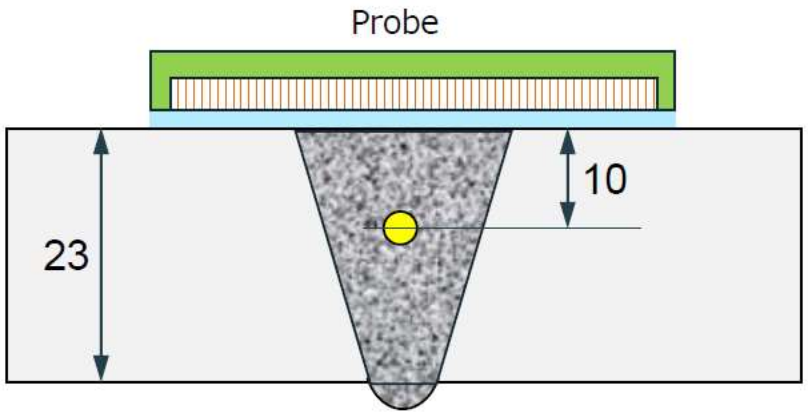
Size	Wall thickness	Result of 2MHz probe	Result of 5MHz probe
8B (200A)	23.0mm	Identified	Clearly identified
10B (250A)	28.6mm	Partially identified	Partially identified
12B (300A)	33.3mm	Not identified	Not identified

In case of 23 mm wall thickness, the piping inner penetration bead could be imaged, while the visibility was significantly reduced for the case of 28.6 mm wall thickness.

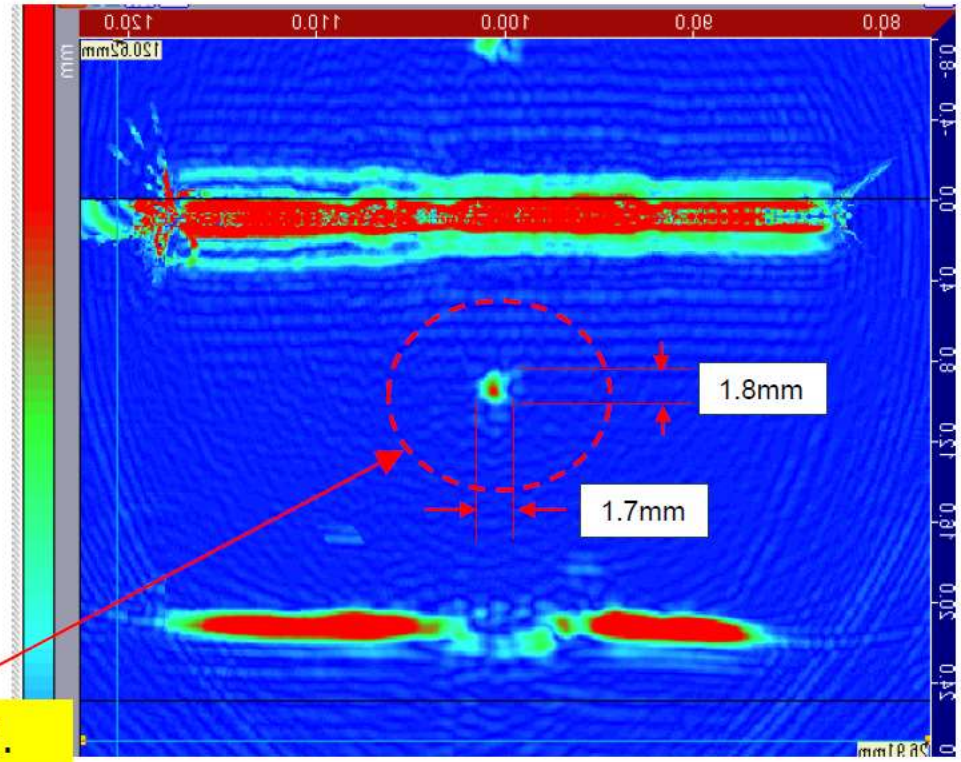
At this point in time, the FMC/TFM can be applicable to stainless steel weld of which thickness is less than around 25 mm.

4.2 SDH imaging of stainless steel piping weld

The FMC/TFM method has been applied to the mockup of stainless steel weld with a SDH of φ1.6mm diameter that located from 10 mm from the surface.



Detection of φ1.6mm side drilled hole

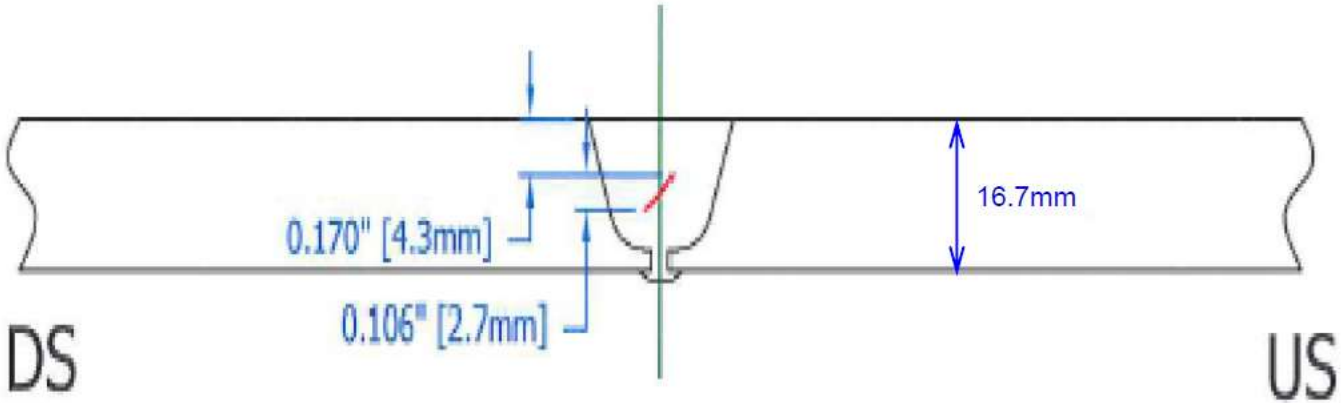


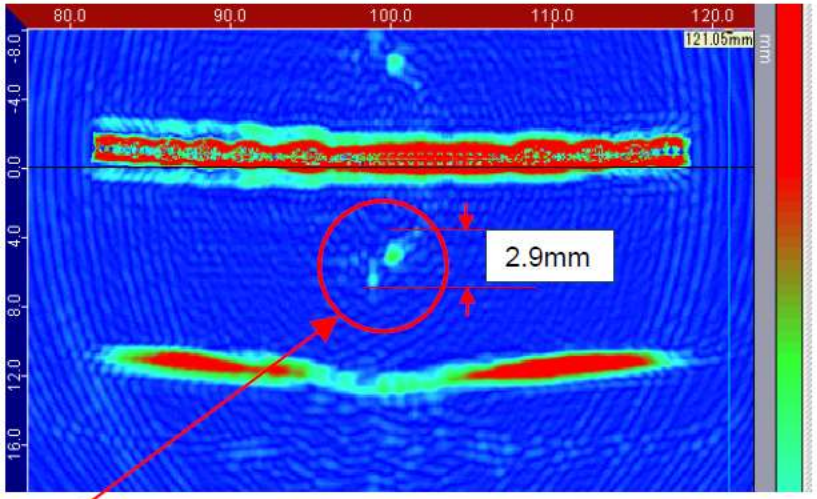
The SDH could be clearly imaged.

4.3 LOF imaging of stainless steel piping weld

The FMC/TFM method has been applied to the mockup of stainless steel weld with lack of fusion (LOF) with the height of 2.7 mm that located from 4.3 mm from the surface.

The height of LOF was estimated as 2.9 mm by imaging.



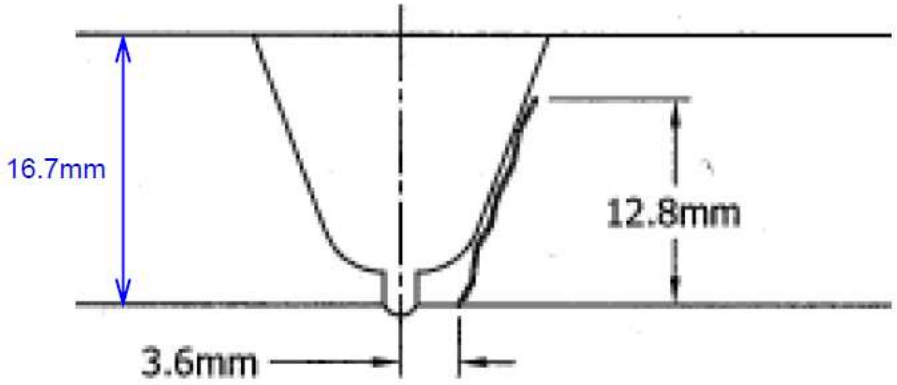


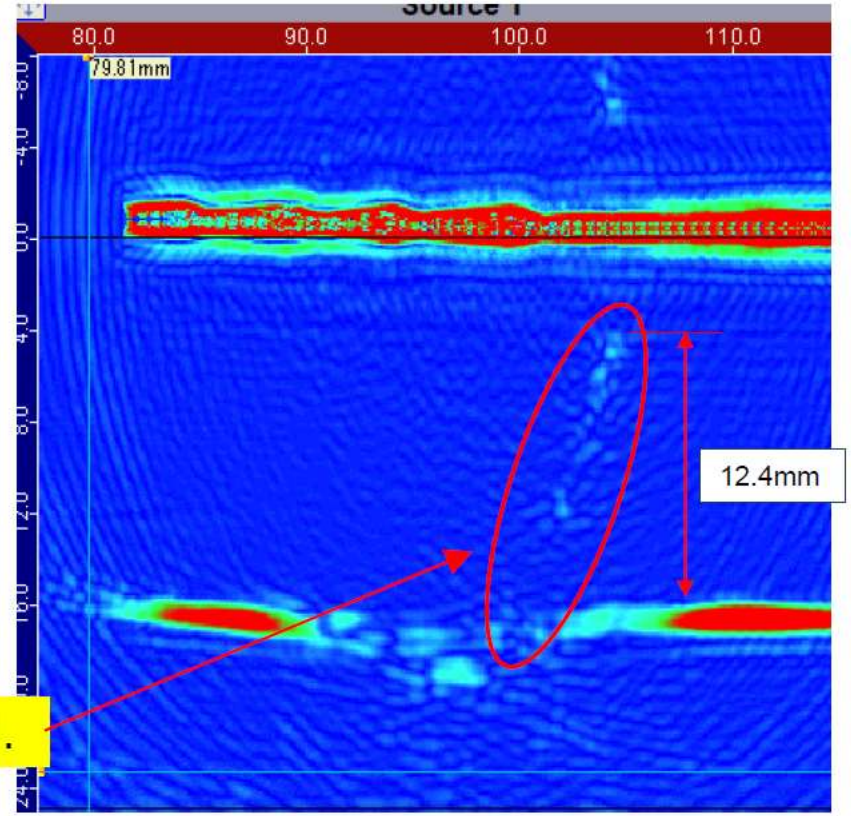
The LOF could be clearly imaged.

4.4 Fatigue crack imaging of stainless steel piping weld

The FMC/TFM method has been applied to the mockup of stainless steel weld with a fatigue crack of which height was 12.8 mm.

The height of fatigue crack was estimated as 12.4 mm by imaging.



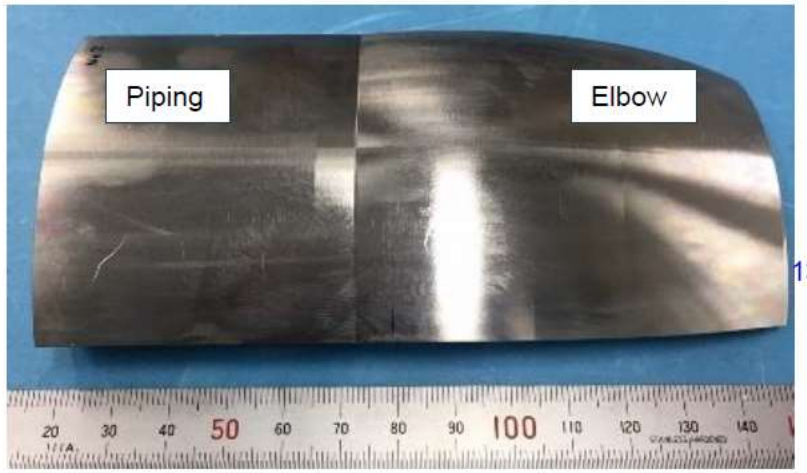


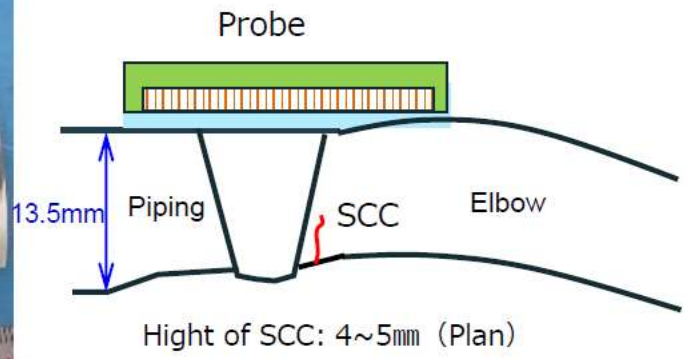
The fatigue crack could be clearly imaged.

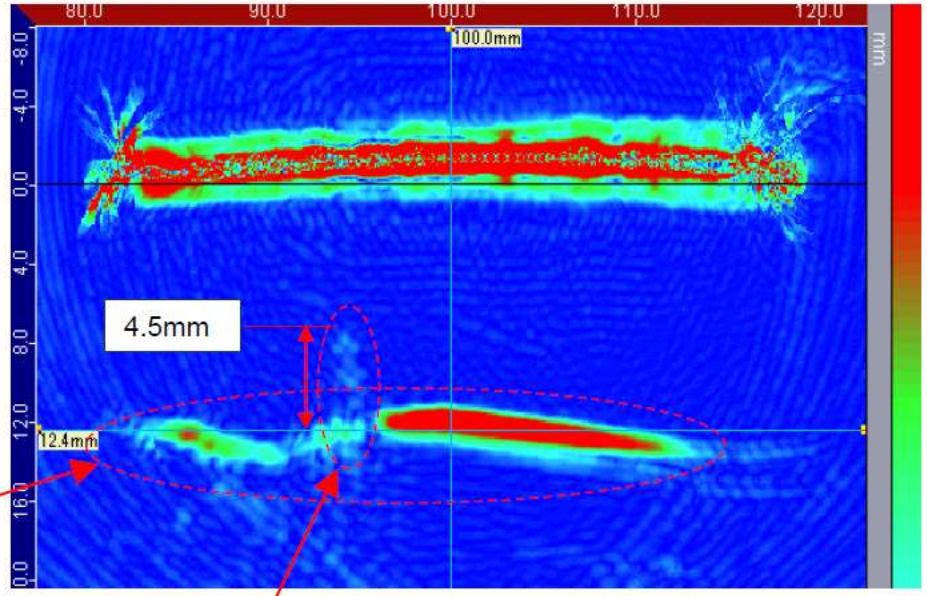
4.5 SCC of imaging stainless steel piping – elbow weld

The FMC/TFM method has been applied to the mockup of stainless steel weld between piping and elbow with a SCC.

The SCC could be detected. Also, the shapes of elbow part, penetration bead and SCC could be identifed.







The shape of penetration bead and elbow could be clearly imaged.

The SCC could be clearly imaged.

5. Conclusion

- FMC/TFM is a candidate for UT technique in lieu of RT, A series of verification tests for FMC/TFM have been performed and confirmed the applicability for stainless steel piping weld.

- The adaptive processing could improve scanning on complicated surface.

- At this point in time, the FMC/TFM technique can be applicable to stainless steel weld of which thickness is less than around 25 mm.

- The FMC/TFM technique could identify flaws such as LOF, fatigue crack and SCC in the stainless steel piping weld
→ This emergent technology is promising for application to UT in ISI for stainless steel piping weld.

- The FMC/TFM technique has achieved high resolution to analyze flaw morphology in the weld and can be expected as UT technique in lieu of RT.
→ If the FMC/TFM technique is applied in lieu of RT during manufacturing state, that is useful to achieve transition from construction stage to operating stage in view of inspection.

- We have performed basic tests for the FMC/TFM technique. In the next step, study for practical application level is required. The world wide collaboration to develop the FMC/TFM technology is desired.

MITSUBISHI
HEAVY INDUSTRIES

Panel discussion and Q/A from the audience

Dr Patrick RAYNAUD

Senior Materials Engineer

US Nuclear Regulatory Commission

Conclusion of day 2

NEA
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BETTER POLICIES FOR BETTER LIVES

Working Group on Codes and Standards
Workshop on In-Service Inspection

Thank you for your participation today and see you all tomorrow @2PM (CET)!