Welding Technology for Advanced BWR
- Potential Cooperation with Polish Companies for first Nuclear Power Plant in Poland -

October 17, 2018
Yu Kuwada
Hitachi-GE Nuclear Energy, Ltd.
Today’s Main Topics

1. Introduction
   1-1 Hitachi Construction Experience
   1-2 Outline of ABWR Building

2. Fabrication Technologies of Reactor Internals (RIN)
   2-1 Outline of Reactor Internals (RIN)
   2-2 Applicable Codes and Standards for RIN
   2-3 Fabrication Sequence of RIN (Core Shroud)
   2-4 Key Technologies for RIN Fabrication

3. Welding Quality Control
   3-1 Potential Cooperation in Poland
   3-2 Quality Control for Welding
   3-3 Supply Chain Establishment
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   3-3 Supply Chain Establishment
1. Instruction
1-1 Hitachi Construction Experience

- More than 40 years of continuous experience
- Almost achieved 20,000 MWe of total power

Domestic Production Phase  Improvement and Standardization Phase  Advanced BWR(ABWR) Phase

- Under Construction
  - OHMA - 1*
  - SHIMANE - 3
  - SHIKA - 2
  - HAMAOKA - 5*
  - ONAGAWA - 3*

- Domestic Production
  - KASHIWAZAKI-KARIWA 7*
  - KASHIWAZAKI-KARIWA 6*
  - KASHIWAZAKI-KARIWA 4
  - KASHIWAZAKI-KARIWA 6*
  - KASHIWAZAKI-KARIWA 5
  - SHIMANE - 2
  - HAMAOKA - 4*
  - KASHIWAZAKI-KARIWA - 5
  - HAMAOKA - 3*
  - FUKUSHIMA II - 4
  - FUKUSHIMA II - 2
  - HAMAOKA - 1*
  - HAMAOKA - 2*
  - TOKAI - 2*
  - FUKUSHIMA I - 4
  - FUKUSHIMA I - 1*
  - SHIMANE - 1
  - FUKUSHIMA I - 1*
  - TSURUGA - 1*

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1. Instruction
1-2 Outline of ABWR Building

Cross-sectional Model of ABWR Building

① Reinforced Concrete Containment Vessel
② Reactor Pressure Vessel
③ Steam Dryer
④ Steam Separator
⑤ High Pressure Core Flooder Sparger
⑥ Fuel Assembly
⑦ Control Rod
⑧ Reactor Internal Pump
⑨ Fine Motion Control Rod Drive System
⑩ Control Rod Drive Mechanism Handling Machine
⑪ Main Steam Piping
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3. Welding Quality Control
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Since RIN has the important roles such as **dehumidifying water vapor**, **supporting fuel** and **forming reactor coolant flow channels in RPV**, its required high quality and high precision fabrication.
(1) Applicable standard for RIN:
ASME Section Ⅲ – Division 1 Subsection NG “Core Support Structures”
(JSME S-NC1 for Japanese domestic plant)

Abstract of Applicable ASME Code for RIN

<table>
<thead>
<tr>
<th>Article</th>
<th>Content</th>
<th>Related Section</th>
</tr>
</thead>
</table>
| NG-2000  | Material
          Especially important sub - article
          NG-2400 : Welding Material                                               | Section II Materials Part C                    |
| NG-3000  | Design                                                                  |                                               |
| NG-4000  | Fabrication and Installation
          Especially important sub - article
          NG-4200 : Forming, Fitting and Aligning
          NG-4300 : Welding Qualifications
          NG-4400 : Rules Governing Marking, Examination and Repairing Welds
          HG-4600 : Heat Treatment                                                 | Section IX Welding and Brazing Qualification |
| NG-5000  | Examination                                                             | Section V                                     |
| NG-8000  | Nameplate, Stamping with Certification Mark and Report                   |                                               |

Note: Hitachi-GE holds the N-type certificate to comply with above ASME codes.
## (2) Qualification of Welding Procedures for RIN (Austenitic stainless steel)

<table>
<thead>
<tr>
<th>Requirements</th>
<th>ASME Sec. III NG-4300 ASME Sec. IX</th>
<th>EN ISO 15607 ISO 15614-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Butt joint with full penetration</td>
<td>Specified</td>
<td>Specified</td>
</tr>
<tr>
<td>② Fillet weld</td>
<td>Specified for nonpressure-retaining fillet welds, but not mandatory (① qualify ②)</td>
<td>Specified</td>
</tr>
<tr>
<td>③ T-joint with full penetration</td>
<td>③ is included in ①</td>
<td>Specified</td>
</tr>
<tr>
<td>④ Branch connection with full penetration</td>
<td>④ is included in ①</td>
<td>Specified</td>
</tr>
</tbody>
</table>
(3) Qualification of Welders for RIN

<table>
<thead>
<tr>
<th>Requirements</th>
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<td>Specified (① qualify ②)</td>
<td>Specified</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(① do not qualify ② or vice versa)</td>
</tr>
<tr>
<td>③ Branch connection</td>
<td>—</td>
<td>(a) For angle $\geq 60^\circ$, qualified by butt welds in pipes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(b) For angle $&lt; 60^\circ$, qualified by product standard</td>
</tr>
</tbody>
</table>
2. Fabrication Technologies of RIN

2-3 Fabrication Sequence of RIN

Upper Shroud

Lower Shroud

Upper Flange (SUS316L)

Lower Flange (SUS316L)

Lower Shell (Ⅰ) (SUS316L)

Lower Shell (Ⅱ) (SUS316L)

CUTTING → WELDING → MACHINING → WELDING → DHT → MACHINING

NDI: Nondestructive Inspection
DHT: Dimensional Stability Heat Treatment
WITNESS: Witness Inspection
(1) Mitigation of Stress Corrosion Crack (SCC) Risk
(a) Specifying welding materials:
   • Low carbon material (Stainless steel)
(b) Specifying cold work process:
   • Managing strain ratio and surface hardness
   • Polishing after grinding work (Removing hardened layer)
(c) Mitigating residual tensile stress caused by welding:
   • Water Jet Peening

(2) High Quality and High Productivity
Applying narrow groove welding joint:
   • Lower welding heat input
   • Mitigate residual stress

(3) Dimensional Stability
Preventing in-service deformation caused by residual stress releasing:
   • Low temperature dimensional stabilizing heat treatment

Items (1)(a) and (2) would be detailed on the following pages.
### (1) Mitigation of SCC Risk

#### (a) Specifying Welding Materials for Low Carbon Material (Stainless Steel)

Typical welding materials specification (for Japanese ABWR plant)

1. Chemical component: \( C \leq 0.020 \% \) (Hitachi Spec. to prevent sensitization)
2. Mechanical property: Equal to or greater than the base material spec.

#### Specification of Chemical Component of Stainless Steel Welding Materials

<table>
<thead>
<tr>
<th>Japanese Industrial Standards</th>
<th>Chemical Component (Mass Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C*</td>
<td>Si</td>
</tr>
<tr>
<td>GTAW JIS Z 3321 YS 316L **</td>
<td>( \leq 0.020 )</td>
</tr>
<tr>
<td>SMAW JIS Z 3221 ES 316L ***</td>
<td>( \leq 0.020 )</td>
</tr>
<tr>
<td>SAW JIS Z 3324 S 316L ***</td>
<td>( \leq 0.020 )</td>
</tr>
</tbody>
</table>

GTAW: Gas Metal Arc Welding
SMAW: Shielded Metal Arc Welding (Manual metal-arc welding)
SAW: Submerged Arc Welding

*: Hitachi’s specification
**: Filler metal
***: Deposited metal
2. Fabrication Technologies of RIN
2-4 Key Technologies for RIN Fabrication

(1) Mitigation of SCC Risk
   (a) Specifying Welding Materials for Low Carbon Material (Stainless Steel)

   ASME Sec.III  NG-2400 “Welding Material” requirement

   ① Chemical analysis test
      Analyzed elements for Chromium and Cr-Ni stainless material
      C, Cr, Mo, Ni, Mn, Si, P, S, V, Cb+Ta, Ti, Cu
      (No specific elements, only report)

   ② Delta Ferrite Determination
      (i) Method
         • Magnetic measuring instrument
         and
         • Chemical analysis
         (WRC-1992 Diagram)
      (ii) Acceptance standards
         Minimum 5 FN
# 2-4 Key Technologies for RIN Fabrication (2) High Quality and High Productivity

## Application of Narrow Groove Welding Joint

### Table: Available welding method

<table>
<thead>
<tr>
<th>Welding Method</th>
<th>Example of Application Joint</th>
<th>Welding position</th>
<th>Deposition efficiency (1&gt;2 &gt;3 &gt;4)</th>
<th>Total Welding activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LASER welding (Super Narrow groove)</td>
<td>Longitudinal joint and Circumferential joint of shell</td>
<td>Flat, Horizontal &amp; Vertical position</td>
<td>1 High Efficiency due to narrow groove</td>
<td>© Dedicated facility</td>
</tr>
<tr>
<td>Submerged arc welding (SAW)</td>
<td>Welding of parts such as lag block</td>
<td>Flat position</td>
<td>2 High current (high heat input)</td>
<td>△ Setup of shell that are tailored to flat position</td>
</tr>
<tr>
<td>Fully mechanized GTAW welding (Narrow groove)</td>
<td></td>
<td>All position</td>
<td>3 High Efficiency due to narrow groove</td>
<td>× Setting of welding head rail</td>
</tr>
<tr>
<td>Manual metal-arc welding (SMAW)</td>
<td></td>
<td>All position</td>
<td></td>
<td>△△ △△</td>
</tr>
<tr>
<td>Manual GTAW welding</td>
<td></td>
<td></td>
<td></td>
<td>×</td>
</tr>
</tbody>
</table>

**Deposition efficiency (1>2 >3 >4):**
1. High Efficiency due to narrow groove
2. High current (high heat input)
3. High Efficiency due to narrow groove
4.  
5.  

**Total Welding activity:**
- Good (©)
- Setup of shell that are tailored to flat position (△)
- Setting of welding head rail (△△)
- Dedicated facility (©)
- Flat position (○)
Application of Narrow Groove Welding Joint

Historical Trend of Narrow Groove Welding for Thick Material

- Material thickness of 50 mm

Note:
- SAW: Submerged Arc Welding
- GTAW: Gas Tungsten Arc Welding
- GMAW: Gas Metal Arc Welding
- LBW: Laser Beam Welding

- V-shape groove
- Narrow groove (GTAW, GMAW)
- Super narrow groove (LBW)
- Narrower V-shape groove (SAW, GTAW)

- Efficiency Upgrade
- Number of Weld Pass

- 1970: SAW
- 1980: GTAW, GMAW
- 1990: Narrow groove (GTAW, GMAW)
- 2000: Super narrow groove (LBW)
- 2010: Narrower V-shape groove (SAW, GTAW)

Mitigation of Welding Distortion

Groove Cross Section

Wide

Narrow

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2-4 Key Technologies for RIN Fabrication
(2) High Quality and High Productivity

◆ Application of Narrow Groove Welding Joint
Improvement of fabrication sequence

(before improvement) Longitudinal joint welding procedure by **SAW**
Turn over the product for each step in order to reduce weld deformation

![Diagram illustrating the welding process](image)

**Weld (1)** in flat position

**Weld (2)** in flat position

**Weld (3)** in flat position

Grinding & Polishing

Rolling

Outside welding

Re-Rolling

Modification of welding deformation

Repeating weld(1)~(3) setting of weld equipment and shell rotation

Opposite side fully

Remaining fully

Half depth

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2-4 Key Technologies for RIN Fabrication
(2) High Quality and High Productivity

◆ Application of Narrow Groove Welding Joint

Improvement of fabrication sequence

➢ To achieve Narrow Groove → Mechanized GTAW / LASER welding → Vertical Position

(after improvement)

Longitudinal joint welding procedure by Mechanized GTAW or LASER welding

Fit Up

Weld in Vertical position

Re-Rolling

Assembled in vertical placement

Inside/outside alternately

Modification of welding deformation

Fig. LASER welding (outside)

Improvement History of fabrication sequence

<table>
<thead>
<tr>
<th>Welding method transition</th>
<th>Submerged arc welding (SAW)</th>
<th>Mechanized TIG welding (narrow groove joint)</th>
<th>LASER welding (super narrow groove joint)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved points</td>
<td>1. Reduce welding distortion by narrow groove and alternately build-up</td>
<td>2. Save setup time by assembling and welding in vertical placement</td>
<td></td>
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Feature of NPP Construction

What’s Demanded for NPP

<table>
<thead>
<tr>
<th>Safety</th>
<th>Reliability</th>
<th>Profitability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Safety Culture</td>
<td>Quality Control</td>
<td></td>
</tr>
</tbody>
</table>

“Construction” is a key matter of the NPP business.

What’s the feature of NPP construction?

- Long Period Work
- Large Work Volume
- Many Documents & Record
- Traceability
- Many Interfaces with Project Participants

Cooperation with Polish Companies for the First NPP in Poland

- Quality Control required for NNP
- Highest standards of Nuclear Safety Culture
Quality of welding depends on following:

- Establishment of Quality Management System for welding and relevant process
- Adequacy of Welding Process Specification (WPS) based on Welding Procedure Qualification (PQR)
- Adequate assignment of **Welding personnel** who have necessary capabilities
  - Welder and Welding Operator
  - Welding Engineer
  - Examiner and Inspector
  - Welding Supervisor
- Adequate test and inspection

(1) ISO 9000 family “Quality Management Systems”
(2) ISO 3834 “Quality Requirements for Fusion Welding of Metallic Materials”
3-2 Quality Control for Welding
(2) QC in accordance with Codes and Standards

(a) Quality Control Required for NPP

**QA Grade** of Item

Item : Product, Equipment, Piping etc.

* QA Grade is identified by Hitachi’s Customer dependent on factors including, but not limited to, the Nuclear Safety Classification, engineering complexity, supply chain performance and project schedule.

Code, Standard, Guideline etc. : ISO, PED, ASME etc.

Quality Control is required in accordance with these applicable Code, Standard, Guideline etc.

Certificate

- ISO Certificate (ex. ISO 9000)
- PED Certificate**
- ASME Certificate

** PED Certificate is required for pressure equipment other than items specially designed for nuclear use.
### (2) QC in accordance with Codes and Standards

#### (b) Quality Management System Requirement to Supplier

<table>
<thead>
<tr>
<th>Degree of QA Grade</th>
<th>QA Grade</th>
<th>ASME NQA-1</th>
<th>IAEA GSR Part 2</th>
<th>ISO 9001</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>A</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>C</td>
<td>-</td>
<td>X*1</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>If specified in a Contract, comply with the Contract</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) **ASME NQA-1 (Nuclear Quality Assurance -1)**
- "Quality Assurance Requirements for Nuclear Facility Applications"
- Regulatory standard issued and maintained by ASME.
- For QA Grade A and B, Suppliers shall comply with the applicable element of the requirement of NQA-1 for quality assurance arrangements.
- Maintaining ASME N-Type Certification is acceptable.

(2) **IAEA GSR Part 2 (General Safety Requirements Part 2)**
- "Leadership and Management for Safety"
- For QA Grade A and B, and Grade C if required in Contract, Supplier shall also comply with the requirements of IAEA GSR Part 2.
- The suppliers shall be assessed by Hitachi for compliance with IAEA GSR Part 2.

(3) **ISO 9001**
- For QA Grade C, Suppliers have the option to comply with either NAQ-1 or ISO 9001.

*1 If required in a Contract.
(2) QC in accordance with Codes and Standards

(b) Supplier Program Requirements for Welding

<table>
<thead>
<tr>
<th>QA Grade</th>
<th>ASME Code Sec. III and IX</th>
<th>ISO 15609, ISO 15614 ISO 9606-1</th>
<th>Test Lab. for PQR and WPQR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>B</td>
<td>X</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>X</td>
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<tr>
<td>D</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

(1) **ASME Code Sec.III and IX**

- For QA Grade A and B, Supplier who perform welding shall comply with the applicable subsection requirements of ASME Code Sec.III and Sec.IX for welding.
- Where agreed with Hitachi, ISO standard specified in (2) may be applied as alternatives.

(2) **ISO 15609, ISO 15614 and ISO 9606-1**

- For QA Grade C, Supplier who perform welding shall comply with the requirements of ISO 15609, ISO 15614 (ex-EN288) for welding procedure specification (WPS) qualification, and EN ISO 9606-1 for welder qualification.
- Where agreed with Hitachi, ASME Code Sec.III and Sec.IX specified in (1) may be applied as alternatives.

(3) **Test Laboratory for PQR and WPQR**

- For QA Grade A and B, all associated tests for PQR and WPQR shall be performed by a test laboratory within the scope of its accreditation in accordance with ISO 17025.
(b) Supplier Program Requirements for NDE

<table>
<thead>
<tr>
<th>QA Grade</th>
<th>SNT-TC-1A</th>
<th>ISO 9712 (EN 473)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>X</td>
<td>-</td>
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<tr>
<td>C</td>
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</table>

(1) **SNT-TC-1A**

- Recommended Practice “Personnel Qualification and Certification in Nondestructive Testing” issued and maintained by the American Society for Nondestructive Testing (ASNT).
- SNT-TC-1A provides guidelines for employers to establish in-house certification programs for the qualification and certification of NDE personnel.
- For QA Grade A and B, Suppliers whose personnel perform NDE shall be qualified in accordance with the recommended guidelines of SNT-TC-1A for the qualification of NDE personnel.
- When agreed with Hitachi, ISO standards (e.g. ISO 9712) may be applied as alternatives.

(2) **ISO 9712**

- For QA Grade C, Suppliers shall qualify NDE personnel in accordance with an accredited national scheme in accordance with ISO 9712.
- When agreed with Hitachi, SNT-TC-1A may by applied as alternatives.
"Hitachi-GE Nuclear Energy, Ltd. and its partner company GE-Hitachi Nuclear Energy, Ltd. have already engaged with potential Polish companies in terms of engineering, procurement and construction of new nuclear build, and will continue to engage and develop a Polish Supply Chain to maximize the involvement of Polish suppliers for the new nuclear build in Poland."
Thank you for your listening.