Aspects of Operational Life Management of NPPs

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Tecnatom S.A.
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- Nuclear Power Background
- NPP Lifetime
- Degradation of the RPV and Internals
  - Master Curve Approach
  - IASCC Research
  - Baffle Bolts Inspection and Replacement
- Conclusions
Of a total of 436 reactors, 327 have more than 20 years

Data from the IAEA Nuclear Power Newsletter, Vol. 4, No. 3, September 2007

- Plant operational life assurance
- Operational life extension
- Newer candidate materials
Nuclear Power Plant Life

- Design life
- Operational or service life
- Plant operational life assurance
- Amortisation life
- Life extension
- Long term operation

Choice of plant
Financing arrangements
Obtaining permissions,
Design, Construction

START UP
DESIGN LIFE
OPERATIONAL LIFE
De-fuel,
Decommission
Dismantle
CLOSURE

PLANT LIFE
Pressure vessel replacement from the top

With its oldest reactors nearing their 30-year mark, Japan has been undertaking a significant effort to investigate the possibility of managing the life of its nuclear plants to last some 60 years, including the feasibility of replacing the reactor pressure vessel (RPV). A team from one of the country's main utilities and its three suppliers came up with an inventive plan to replace the old reactor vessel at a BWR without closing its interior. The scheme does not require developing any new techniques and the needed lifting equipment is already available for the job.

FEASIBILITY OF RPV REPLACEMENT

Extending the life of a nuclear plant can be an expensive business, requiring costly plant upgrading. Historically, the replacement of the reactor pressure vessel had been excluded as being unrealistic. Today, however, when considering extending the life of a plant to over 60 years, the possibility of replacing the RPV must be examined, as it can significantly affect such a prospect.

With this in mind, Tokyo Electric Power Co., Hitachi, and Toshiba began a feasibility study to examine the techniques, time, and costs involved in such a venture.

The team came up with a solution which involves replacing the old reactor vessel with a new one while leaving the reactor internals, providing substantial cost savings.

Lifting of the reactor pressure vessel with shield in all with large-size crawler cranes.

The calculated weight of the load is about 3300 t. As devised, the opening is about 10 m by 10 m, an accordion curtain is used as a temporary cover. During the construction, exhaust fans are operated to avoid air leakage.

June 1999

30
Pressurized Thermal Shock

The risk of PTS failure of the RPV is very low.

Over 80% of the operating US PWRs have estimated through-wall cracking frequency values below $1 \times 10^{-8}$ reactor-year after 60 years of operation.
Radiation embrittlement
- Open issues

Fatigue
- RPV closure studs

PWSCC
- Alloy 600/82/182 & Alloy 690/52/152

Boric acid corrosion
- A consequence of Alloy 600 cracking
# PWR Pressure Vessel Internals

<table>
<thead>
<tr>
<th>SECTION</th>
<th>Embrittlement</th>
<th>Fatigue</th>
<th>Corrosion</th>
<th>Wear</th>
<th>Irradiation creep and swelling</th>
<th>Handling incident</th>
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</thead>
<tbody>
<tr>
<td>Upper internals</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Control rods guide tubes</td>
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<td>X</td>
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<tr>
<td>Guide</td>
<td></td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Guide tube support split pins</td>
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<tr>
<td>Thermocouple columns</td>
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<tr>
<td>Upper core plate fuel alignment pins</td>
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<tr>
<td>Lower internals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Baffles (bolts, plates)</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Thermal Shield Fasteners or welds</td>
<td></td>
<td>X</td>
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<tr>
<td>Locating Systems (Radials Keys, etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Lower instrumentation guide columns</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Bottom instrumentation thimble</td>
<td></td>
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<td></td>
<td></td>
<td>X</td>
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</tr>
</tbody>
</table>

- **Flexure**
- **Guide Card**
- **C Tube and Sheath**
- **Guide Tube Support Pin**
- **Baffle-Edge Bolts**
- **Baffle-Former Bolts**
- **Baffle-Former Bolts**
- **Lower Core Plate**
  (XL Lower Core Plate - not shown in this design)
- **Lower Core Barrel**
- **Flux Thimble Tube**
Industry’s Top Ten R&D Priorities (from MRP-205)

1. Inspection & Evaluation (I&E) Guidelines: Reactor Internals
2. NDE Technology: Dissimilar Metal (DM) Butt Welds
3. PWSCC Mitigation: Environmental Controls
4. I&E Guidelines: Bottom Mounted Nozzles
5. Vibration Fatigue: Small Bore Piping
7. NDE Qualification Program: Ni-Alloy Penetrations
8. NDE Accessibility: Reactor Internals
9. PWSCC Mitigation: Stress Improvement (SI) of Butt Welds
10. Thermal & Irradiation Embrittlement: Synergistic Effects on CASS & SS Welds - Internals
Some Open Issues (from AMES)

- Embrittlement trend curve based on Master Curve concept
- High Cu & fluence rate
- Si-Mn/Ni effects
- Re-embrittlement rates & residual shifts
- P segregation open issues
- IASCC
Fracture Toughness. ASME

\[ K_{IC} = 36.5 + 3.1 \cdot \exp[0.036 \cdot (T - RT_{NDT} + 55.5)] \]

\[ K_{IR} = 29.43 + 1.355 \cdot \exp[0.0261 \cdot (T - RT_{NDT} + 88.9)] \]
Fracture Toughness. Master Curve

\[ K_{jc}(\text{med}) = 30 + 70 \cdot \exp[0.019 \cdot (T - T_0)] \]
Reconstitution of Surveillance Specimens

Reconstitution of Charpy specimens

CT specimens reconstituted
Comparison between values of $RT_{To}$ and $RT_{NDT}$ (°C) at different thicknesses in the RPVs of Garoña and Ascó II NPPS

### 40 years (32 EFPY)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garoña Base</td>
<td>16.0</td>
<td>-32.9</td>
<td>16.0</td>
<td>-35.2</td>
<td>16.0</td>
<td>-40.9</td>
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<tr>
<td>Garoña weld</td>
<td>43.5</td>
<td>-9.0</td>
<td>34.7</td>
<td>-12.6</td>
<td>18.7</td>
<td>-22.5</td>
</tr>
<tr>
<td>Ascó 2 Base</td>
<td>41.5</td>
<td>-20.5</td>
<td>39.3</td>
<td>-26.1</td>
<td>34.2</td>
<td>-33.7</td>
</tr>
</tbody>
</table>

### 60 years (54 EFPY)

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
<th>$RT_{NDT}$</th>
<th>$RT_{To}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garoña Base</td>
<td>16.0</td>
<td>-29.2</td>
<td>16.0</td>
<td>-31.9</td>
<td>16.0</td>
<td>-38.0</td>
</tr>
<tr>
<td>Garoña weld</td>
<td>54.7</td>
<td>-1.9</td>
<td>45.3</td>
<td>-5.5</td>
<td>28.1</td>
<td>-14.4</td>
</tr>
<tr>
<td>Ascó 2 Base</td>
<td>43.7</td>
<td>-11.8</td>
<td>42.0</td>
<td>-19.0</td>
<td>37.5</td>
<td>-29.4</td>
</tr>
</tbody>
</table>
Research on RPV internals

Proposal for a “Cooperative research project on ex plant materials from José Cabrera NPP”
## Candidate Zorita Materials for IASCC Research

<table>
<thead>
<tr>
<th>Material</th>
<th>Value to Future Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 Baffle/Former Bolts</td>
<td>Degradation of 304 needed for all PWR plant internals issues – Zorita has high fluence in 304 material</td>
</tr>
<tr>
<td>304 Baffle/Former Bolts</td>
<td>Swelling of 316 baffle bolts in all operating plants is a life continuing</td>
</tr>
<tr>
<td>347 Baffle/Former Bolts</td>
<td>5-10% of operating plants have 347 baffle/former bolts</td>
</tr>
<tr>
<td>308/309 Core Barrel Weld Metal</td>
<td>Opportunity to properly evaluate Ferrite containing weld metal response after high dose exposure</td>
</tr>
</tbody>
</table>
Defective bolts found in France (CP0), Tihange 1, Doel 1 y 2, Loviisa 1 y 2, and in several plants in US and Japan.

The analyses performed on defective bolts confirm that, in general, the degradation mechanism is IASCC.

It is not a problem of safety if there is only a limited number of defective bolts.

There are not reliable model for prediction of bolt cracking.

Recommended studies: Neutron fluence calculations, thermal-stress analysis, microstructural analysis.
Baffle Bolts Inspection and Replacement at Loviisa NPP Unit 2

- Visual and ultrasonic inspection of all 312 locking bolts (Tecnatom)
- Removal of defective locking bolts (Westinghouse)
- Assembly of the new fixing system (Westinghouse)
- Internals TV-inspection of the core basket (Tecnatom)
SUPREEM superstructure + ROSA robotic arm.

MIDAS acquisition system
Bolts Replacement

- First core baffle bolt replacement campaign in VVER type NPP
- Adaptation of the existing manipulator to the specific Loviisa Design
- Different design of the fixing system
Inspection and Replacement of Baffle Bolts. Results

- 312 baffle bolts inspected (UT + TV)
- 3 defective baffle bolts found
- 4 baffle bolts replaced
- 3 baffle bolts will be sent to the VTT hot lab for metallurgical investigation and failure analysis

**OLD**

**NEW**
Conclusions

- The decrease in the number of plants coming into operation during the past twenty years has focussed attention onto plant operational life assurance/operational life extension.

- The Master Curve approach is today the prefer methodology to reduce unnecessary conservatism in estimates of RPV material degradation.

- The adoption of a preventive maintenance programme for the RPV internals with the capability of detecting system degradations will enhance the safety as well as the efficiency of plant operation.

- The state-of-the-art of the technology allows a certain level of control and mitigation of IASCC, but today several factors contributing to the degradation are not well known.
Thank You!

谢谢