Barsebäck RPV material used for true evaluation of embrittlement – SAFIR2018 BRUTE

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25/03/2019  VTT – beyond the obvious
Background

6 BWRs, 2 PWRs and 2 WWERs are preparing for / evaluating operation beyond the original licensing period (LTO) in the Nordic countries.

Necessary to distinguish the operational limiting factors.

Can be assessed by a number of methodologies:
- IAEA Safety Report 57 presenting one such methodology (Safe Long Term Operation of NPPs).
- Identification of Time Limited Ageing Analysis (TLAA) through a gross list suggested in IAEA International Generic Ageing Lessons Learned (iGALL), Safety report 82.
Reactor Pressure Vessel (RPV)

The RPV was early on identified as an area that need special attention.

Ageing of the component is caused by both thermal and neutron irradiation induced embrittlement.

Mechanical properties are monitored by means of a surveillance program consisting of a number of capsules installed in the RPV to be irradiated in a somewhat accelerated manner.

From "Barsebäcks Kärnkraftverk, Dokumentation", rapport 2006:57
Irradiation induced ageing and degradation

During service, the RPV is subjected to thermal and neutron induced ageing.

The end-result is microstructural changes leading to hardening and a shift in a measure called Ductile to Brittle Transition Temperature (DBTT).

DBTT is a measure of the temperature region where the material exhibits a ductile behavior and thus prevents the onset of brittle fracture.

Has been measured at the NPPs since the beginning of operation and is to high extent regulated nationally.

![DBTT change for BWR weld metal](image)
Specifics of the Uddcomb-RPVs

Weld-metal contains relatively high Ni- and Mn-content

   Excellent beginning of life (BOL) properties

   All Uddcomb RPVs are (more of less) manufactured to the same specifications (B1&2, O2&3, Ol1&2, F1,2&3, R3&4)

Can be considered a sub-group of RPVs

   Possibility for an integrated surveillance program allowing for optimized capsule withdrawal

Hanhikivi 1 weld metal composition if also high in Ni
Current state of the art knowledge

All Uddcomb RPVs appear to follow similar trend curves with respect to neutron dose

Negligible influence of thermal ageing on the resulting shift in mechanical properties

The number of remaining surveillance capsules for some plants are in the low end of the acceptance band for operation beyond 60 years

   International situation can be worse
BREDA Barsebäck R&D arena and BRUTE main objectives

Investigating the comparability between the fracture toughness properties of the RPV and the surveillance test specimens

Understanding the effect of flux and fluence on the shift in ductile-to-brittle (DBTT) transition temperature

Understanding the effect of irradiation embrittlement on the fracture mechanical crack tip constraint

Identifying the factors affecting the fracture toughness properties in thickness direction

Determining the shift in DBTT due to thermal embrittlement versus the shift due to the combined effect of thermal embrittlement and irradiation

BRUTE: pioneer CNS hot cell infrastructure
BRUTE stands on two legs

Pioneer CNS hot cell infrastructure
- Optimise and validate test procedures for mechanical and microstructural investigations

Fulfil BRUTE scientific goals
- Perform mechanical and microstructural investigations on RPV and surveillance materials

SAFIR2018 BRUTE & SAFIR2022 BRUTE
SAFIR2022 BRUTE
Extraction of trepans

More than 10 trepans extracted from Barsebäck 2 RPV
Eight trepans will be delivered to VTT, 4 from the head area and 4 from the beltline welds
Overview and drill with harvested sample
Testing of trepan, surveillance and additionally irradiated materials

Non-irradiated trepans
Irradiated trepans

Surveillance material
Accelerated irradiated material

Miniature C(T) testing is a relatively new technique
Working in the new hot cell environment

Working with hot cells and manipulators require a new mind set

   Everything shall be planned in advance, as equipment shall not be accessed during normal operation

   Handling is done using manipulators, which require planning, training and validation

The infrastructure has been created in RADLAB and REHOT (SAFIR), and BRUTE is the pioneering project
Cutting, mechanical testing and analysis

**Electric discharge cutting machine, EDM**
- Cutting of trepans, slices, specimens
  - FANUC Robocut

**Electromechanical testing machine**
- Tensile, SE(B), C(T)
  - Zwick Z250SW
  - Environmental chamber
  - Laser extensometer, Clip-on gauges
  - Load cells 10, 50 kN

**Pendulum impact tester**
- Impact tests
  - Zwick HIT50, instrumented
  - Tempering furnace
  - Semiautomatic feeding unit RoboTest I
  - Tools 3x4x27, 5x5x27 mm

**Servohydraulic testing machine**
- Precracking for fracture mechanical tests
  - MTS310.10
  - Load cell 10, 100 kN
  - Extensometers, Clip-on gauges
  - Tensile, SE(B), C(T)

**Digital microscope**
- SE(B), C(T), impact
  - Leica DSM300
    - Fracture surface documentation
    - Crack length software

**Dimensional measuring device**
- C(T), impact, SE(B)
  - OPG SmartScope Flash CNC200
  - Objective, touch probe
  - Area 200x200 mm, height 150 mm
    - Overall specimen dimensions
    - Notch, lateral expansion, reduction of area etc.
Metallographic investigations

Grinding / polishing
- Preparation of cross-sections for metallographic investigations
  - Struers Tegrapol-15
  - Struers TegraForce-1
  - Struers TegraDoser5
  - Buehler VibroMet-2

Light optical microscope
- Microstructure
  - Struers Axio Observer 7

Hardness tester
- Hardness
  - Struers DuraScan-80
  - Automatic
  - Force 0,098 – 98,1 N
  - Area 280x140 mm, height 260 mm

Digital stereo microscope
- Leica DMS300

Electropolishing / thinning
- Preparation of TEM-specimens
  - Struers LectroPol-5
  - Struers TenuPol-5
  - Lauda Proline RP855

Accessories
- Specimen preparation
  - US washer, magnetic stirrer, hot plate, air dryer, vacuum chamber, puncher, etc.
Can CNS handle Ø200mm á 40kg trepans? – Yes we can

The design basis for CNS is based on smaller maximum size than the trepans.

The capabilities to move and cut the trepans were evaluated and concluded to be OK.

A jig for moving the trepan in the electric discharge cutting machine designed, manufactured, assembles and tested.
Validation of mechanical test methods

ается target to receive acceptance for accredited testing for tensile, impact and fracture mechanical testing (in Spring 2019)

Requires validation of

• Specimen manufacturing (dimension and straightness tolerances, surface roughness)
• Testing procedure
• Analysis of results

• Small specimen sizes and manipulators add to challenge
Validation of microstructural methods

- Development and verification of methods using in-cell device with as small amount of waste as possible
  - How big cross-sections can be prepared with high quality?
    - Full plates are 60mm x 150mm, and too big. Cutting into three needed. DONE
  - How to polish, clean, etch
    - dipping or swabbing? TBD, taking into account waste handling. PENDING
  - Evaluation of minimum surface requirement for hardness measurements
    - Polishing needed, DONE
  - Hardness measurements OK and method accreditation in final phase. DONE
  - Preparation of TEM-specimens (Ø3 mm x nm) using glove-box. PENDING
Development of preliminary test matrix

In total more than 1500 specimens possible, and optimisation needed to make the most of the available resources

<table>
<thead>
<tr>
<th>Test method</th>
<th>Nominal location of the slice from the RPV/cladding interface</th>
<th>Specimen type</th>
<th>Maximum number of specimens per slice</th>
<th>Test temperature</th>
<th>Orientation of the specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0 ASTM E1921</td>
<td>13 mm, ¼ thickness, ¾ thickness, possibly &lt; 13 mm</td>
<td>C(T)</td>
<td>Weld: 20</td>
<td>Base: 20</td>
<td>T-S (circumferential welds) L-S (longitudinal welds)</td>
</tr>
<tr>
<td>Constraint effects on fracture toughness</td>
<td>Close to ¾ thickness</td>
<td>SEN(B)</td>
<td>Weld: 40</td>
<td>Base: 40</td>
<td>T-S (circumferential welds) L-S (longitudinal welds)</td>
</tr>
<tr>
<td>Impact</td>
<td>1/4T = 130 mm/4 = 32.5 mm, this position is found in the second slice which is at a depth of 25 mm from the cladding interface</td>
<td>Charpy-V 10×10×55 mm</td>
<td>Weld: 15</td>
<td>Base: 15</td>
<td>T-S (circumferential welds) L-S (longitudinal welds)</td>
</tr>
<tr>
<td>Tensile according to ISO 6892-1</td>
<td>13 mm, ¼ thickness, ¾ thickness</td>
<td>Flat B = 1 mm W = 2 mm L = 20 mm</td>
<td>Weld: 4 x 3</td>
<td>Base: 4 x 3</td>
<td>Multiple: 1. same test temperature as for constraint, 2. 300 °C, 3: room temperature</td>
</tr>
</tbody>
</table>
BRUTE2018 started the journey which continues in SAFIR2020 BRUTE

Harmony Goal: nuclear supplies 25% of global electricity demand

Ref: Agneta Rising, WNA, Kärnteknik 2018, Stockholm