TREPANING PROCEDURE APPLIED AT THE RPV OF THE FORMER GREIFSWALD NUCLEAR POWER PLANT

Hans-Werner Viehrig, Udo Rindelhardt, and Werner Keller

1. Introduction

The integrity assessment procedure for the reactor pressure vessels (RPV) of nuclear power plants (NPP) is based upon fracture mechanics methodologies. The fracture toughness parameters of the RPV steels after long-term service irradiation are determined in surveillance programs using so-called surveillance specimens. Radiation loading, metallurgical and environmental histories, however, can differ between the surveillance specimens and the steel of the operated RPV. Therefore, the investigation of RPV steels from decommissioned NPPs offers the unique opportunity to evaluate the real fracture toughness values. A chance is given now through the investigation of material from the former Greifswald NPP (VVER-440/230; shutdown in 1990) to evaluate the material states of a standard RPV design (including annealed material states) and to assess the quality of prediction rules and assessment tools. The well documented different irradiation/annealing states of the four Greifswald RPVs are very useful for an integrated approach to study the embrittlement phenomena. This approach includes:

- Neutron and gamma fluence calculations,
- Niobium based experimental dosimetry and
- comprehensive material investigation program.

In autumn 2005 the first trepans (diameter 120 mm) were gained from unit 1 of the Greifswald NPP. The paper describes some details about the trepanning procedure.

2. Characteristics of the Greifswald NPP

Between 1973 and 1979, four units (unit power 440 MW\textsubscript{el}) of the Russian Pressurized Water Reactor line VVER-440/230 were put into operation in Greifswald. Design, material production and operation conditions are identical or almost identical for more than 30 similar units in Russia and Eastern Europe.

*Table 1: Radiation characteristics of the Greifswald reactor units 1 – 4*

<table>
<thead>
<tr>
<th>unit</th>
<th>cycles</th>
<th>effective days</th>
<th>annealed in</th>
<th>azimuthal maximum of $\phi_{E&gt;1\text{MeV}}$ in units of $10^{19}$\text{ n/cm}^{2}</th>
<th>inner wall axial maximum</th>
<th>inner wall weld 4</th>
<th>outer wall axial maximum</th>
<th>outer wall weld 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>4215.0</td>
<td>1988</td>
<td>4.4</td>
<td>3.3</td>
<td>0.69</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>1*</td>
<td>2</td>
<td>627.4</td>
<td>-</td>
<td>0.40</td>
<td>0.29</td>
<td>0.058</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td>4067.4</td>
<td>1990</td>
<td>5.3</td>
<td>4.1</td>
<td>0.83</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>3581.8</td>
<td>1990</td>
<td>4.4</td>
<td>3.4</td>
<td>0.68</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>11</td>
<td>3207.9</td>
<td>not</td>
<td>4.0</td>
<td>3.1</td>
<td>0.62</td>
<td>0.45</td>
<td></td>
</tr>
</tbody>
</table>

*after annealing

$\phi_{E>1\text{MeV}}$ - neutron fluence (E>1MeV)

---

1 Studsvik IFM GmbH&Co.KG, Karlsruher Str. 20, 75179 Pforzheim
The neutron flux is very high (small water gap: 16 cm), the operation temperature is low (270 °C) and the material is sensitive to neutron embrittlement (Cu content > 0.12 %, high P content in the weld). Therefore, the accepted embrittlement limits had already been reached after about 12 cycles, and the units had to be annealed around the most loaded core weld to continue their operation. In 1990, after the German reunification all units were shut down.

The operation time, radiation characteristics and annealing states of the four Greifswald units are given in Table 1.

3. The trepanning procedure

The trepanning process had to be integrated in the dismantling procedure of the Greifswald NPP. The originally planned procedure was based on a complete cutting of the RPV. In this case the trepans could easily be taken using the normal dismantling equipment. In 2004 the strategy was changed. Now, it is intended to store the complete RPV in an interim storage near the NPP. Therefore, a special trepaning machine had to be designed. The trepaning machine shown in Fig. 1 allows the following remote controlled actions:

- labeling the position and orientation of the trepan,
- drilling the trepan and ejection of the trepan into the RPV and
- closing the hole in the RPV with a lead plug.

This trepaning machine was mounted outside of the RPV in the height of the coolant loops on the top of the annular water tank. This water tank has a shielding function and acts additionally as support construction of the RPV. To drill the trepans from the predefined positions, the whole RPV was lifted and rotated by crane. Before the drilling process was started, the selected position was marked and numbered. The trepan was drilled using an air
A cooled hollow milling tool. The generated waste was collected by an extractor fan. The trepan was finally kicked into the RPV.

The drilled hole in the RPV was than closed by a lead plug. The plug was first cooled down by depressuration of CO₂-gas and pressed into the hole and fixed during the warming up phase. All the described actions are remote controlled.

The function of the drilling machine was tested in summer 2005. By thermographic measurement was proved, that the maximum temperature in the RPV material does not exceed 190°C direct in the drilling region and 80 °C within the body of the trepan, respectively. A negative influence on the material properties could so excluded. After transferring the machine to the NPP, a total of five trepans were gained from unit 1 end of 2005.

4. Location of the trepans in the RPV

Fig. 3 shows the location of the trepans taken from the RPV of Greifswald Unit 1. Trepans were taken from the welding seam SN0.1.4., and the base metal ring 0.3.1. Table 2 provides the location, the estimated neutron fluences (E > 1 MeV) of the trepans, and the maximum temperatures during the annealing procedure at the location of the trepans.

<table>
<thead>
<tr>
<th>code</th>
<th>RPV material</th>
<th>axial location in mm</th>
<th>azimuthal location in grd</th>
<th>condition</th>
<th>inner wall fluence in 10^{18} n/cm²</th>
<th>annealing temperature in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>weld metal SN0.1.4</td>
<td>-6850</td>
<td>330</td>
<td>IAI</td>
<td>29.4</td>
<td>475</td>
</tr>
<tr>
<td>A2</td>
<td>weld metal SN0.1.4</td>
<td>-6850</td>
<td>270</td>
<td>IAI</td>
<td>29.4</td>
<td>475</td>
</tr>
<tr>
<td>A3</td>
<td>weld metal SN0.1.4</td>
<td>-6850</td>
<td>90</td>
<td>IAI</td>
<td>29.4</td>
<td>475</td>
</tr>
<tr>
<td>B</td>
<td>base metal ring 0.3.1.</td>
<td>-6430</td>
<td>330</td>
<td>IAI</td>
<td>&gt;29.4</td>
<td>475</td>
</tr>
<tr>
<td>C</td>
<td>base metal ring 0.3.1.</td>
<td>-4440</td>
<td>300</td>
<td>U</td>
<td>&lt;0.07</td>
<td>&lt;300</td>
</tr>
</tbody>
</table>

IAI  irradiated, annealed, irradiated after annealing
U    unirradiated
The trepans were transported to the Hot Cell laboratory of the Institute for Safety Research for the planned investigations.

5. Running research program

A comprehensive research program was started in 2006 around the gained trepans. The aim of these investigations is to evaluate the material state of a standard RPV design and to assess the quality of prediction rules and of the state of the art assessment tools, as well as of the advanced RPV integrity assessment codes.

The program includes the following main parts:

- Calculation of the received neutron/gamma fluence in a fine grid. These calculations will be performed using the Monte Carlo code TRAMO [1].
- Verification of the calculated fluence with measured Niobium activities. Nb is a well suited monitor to measure the fast fluence of reactor pressure vessels [2]. The low Nb content in the material will be a special challenge, because Nb is only contained as trace metal in base as well as weld material.
- Investigation of microstructure [3] and chemical composition, i.e.:
  - chemistry profiles
  - metallographic characterization
  - SANS investigations
- Investigation of the mechanical properties [4] of the weld and the base metal, i.e.:
  - cleavage fracture toughness values and Master Curve based reference temperatures,
  - J-Δa curves and ductile initiation fracture toughness values,
  - full Charpy-V transition curves,
  - tensile properties,
  - hardness HV10 properties.
References


