Corrosion monitoring system in the Slovak Republic nuclear power plants

Martin Březina - Ľudovít Kupča
Corrosion aspects of NPP ageing

- Corrosion is one of the most important degradation and aging mechanisms of all structural materials.
- Among others it is required to have knowledge about real corrosion situation of all important components and their structural materials.
- From the operational experience and from the demands of the national regulatory bodies follows that it is necessary to have monitoring possibilities of corrosion behaviour of the structural materials. ¹)
- As the response to this requirement, several technical solutions have been prepared for the long-term monitoring of corrosion processes of NPPs materials.
- Monitoring of corrosion stability of WWER-440 NPPs safety related components are in VUJE Inc. one of the main objects of interest.

¹) requirements of NRA SR given in the guide BNS II.3.4/2005: Corrosion monitoring of the NPP’s safety related components.
Examples of corrosion failures

1. Stress corrosion cracking of primary collector bolts
Examples of corrosion failures

2. Stress corrosion cracking of primary collector flange
Examples of corrosion failures

- Stress corrosion cracking of the auxiliary circuit pipeline
Main features of the corrosion monitoring systems

- All monitoring systems are based on the principle of surveillance samples

- The main advantages of these systems are:
  - simple construction
  - the same operational history
  - original environment
  - practically zero operational cost

- Disadvantages follow from operational conditions:
  - limited access to the samples
  - surface contamination
  - no possibility to change working environment, etc.
Test samples

- “Standard” corrosion coupons
- U-bend specimens (single or double, reverse)
- Circular bead weldment specimens
- Pre-stressed CT specimens
- Crevice bent beam (CBB)
- Pre-stressed tension specimens
- Specimens for the crevice corrosion monitoring by ASTM G-48
- Special types of samples
  - for analysis of corrosion layers
  - for a metallographical evaluation
  - for decontamination purposes
  - etc.
Corrosion monitoring systems

- Corrosion loop in the primary circuit at
  - Bohunice Unit-3
  - Mochove Unit-1
- Monitoring system in RPVs water shielding tank
- Monitoring system situated on the primary flange of the steamgenerator collector
- Monitoring system in spent fuel interim storage pools
Corrosion loops in primary circuit

Technical principle

- Corrosion chamber with samples is placed between the outlet and the inlet of the main coolant pump.
- The water flow through the chamber - result of pressure difference on the main coolant pump.
- The main parts are:
  - corrosion chamber(s) with support construction
  - feeding piping
  - cut-off valves
  - drainage piping
## Corrosion loops - Basic technical parameters

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BOHUNICE – UNIT #3</strong></td>
<td><strong>MOCHOVCE – UNIT #1</strong></td>
</tr>
<tr>
<td>operational temperature</td>
<td>270°C</td>
</tr>
<tr>
<td>operational pressure</td>
<td>12.3 MPa</td>
</tr>
<tr>
<td>number of chambers in the loop</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>dimensions of the chamber</td>
<td>Ø 168x12-600 mm</td>
</tr>
<tr>
<td></td>
<td>Ø 160x14-600 mm</td>
</tr>
<tr>
<td>volume of the chamber</td>
<td>8.8 dm³</td>
</tr>
<tr>
<td></td>
<td>7.4 dm³</td>
</tr>
<tr>
<td>weight of the filled chamber</td>
<td>cca 65 kg</td>
</tr>
<tr>
<td>feeding piping</td>
<td>Ø 22 x 2,5 mm</td>
</tr>
<tr>
<td></td>
<td>Ø 18x2,5 mm</td>
</tr>
<tr>
<td>construction material</td>
<td>08Ch18N10T</td>
</tr>
<tr>
<td></td>
<td>steel STN 17 247.4</td>
</tr>
<tr>
<td>corrosion medium</td>
<td>primary coolant</td>
</tr>
<tr>
<td>flow rate</td>
<td>cca 57 dm³/min</td>
</tr>
<tr>
<td></td>
<td>cca 45 dm³/min</td>
</tr>
<tr>
<td>decrease of temperature</td>
<td>&lt; 1°C</td>
</tr>
<tr>
<td></td>
<td>&lt; 1.5°C</td>
</tr>
</tbody>
</table>
Corrosion loops – inner construction
Corrosion loops - Main results

- No significant corrosion attack was observed on the samples prepared from the original structural materials without special sensitization.
- Small corrosion cracks were found on circular bead weldment specimens prepared from the sheet.
- Corrosion cracks were observed on CBB specimens made of a special heat with high contents of Ti inclusions.
- Small intergranular corrosion cracks were found on pre-stressed tension specimens in base metal – only on electrochemically polished specimens.
Corrosion loops - main results of evaluation

*CBB samples*

Transverse cracks in 2 samples made from Kola NPP primary piping.
Material with high contents of Ti inclusions.
Corrosion loops - main results of evaluation

*CBB samples*

Transverse cracks in 2 samples prepared from Kola NPP primary piping.
Material with high contents of Ti inclusions.
Corrosion loops - main results of evaluation

Circular bead weldment specimens

Surface cracks near to the weld
Corrosion loops - main results of evaluation

Circular bead weldment specimens

Surface cracks near to the weld
Corrosion loops - main results of evaluation

Pre-stressed CT specimens

final crack

fatigue pre-crack
Corrosion loops - main results of evaluation

_Pre-stressed tensile specimens_
Corrosion loops – new “module” conception
Corrosion loops – time schedules

Bohunice #3

Mochovce #1
Corrosion monitoring in the water-shielding tank

- Ring form barrels are placed around the RPV's of V-1 NPP
- Dimensions ø 6100/4140 mm, height 4500 mm
- Tank capacity – 68 m³
- Material - carbon steel 11 375 by STN (S325JRG2 by EN 10025-94)
- Medium – demineralized water with addition of 2g/l K₂CrO₄ (inhibitor)
- Maximal working temperature is 60°C.
- Experimental materials:
  - Original material from the tank
  - Equivalent steel with weld joint
Water-shielding tank – scheme
Water-shielding tank – sample holders
Water-shielding tank– main results of evaluation

- Mass lost of the corrosion coupons was minimal in every sample sets
- U-bend samples – no corrosion cracks were found
- There are no differences between results obtained from original and equivalent materials
- Corrosion situation of the tank is long-time stabilized
Corrosion monitoring system in steam generators

- A simple equipment enables a long-term exposition of various samples inside the steam generator above the primary collector flange.
- The samples are placed on a special holder into secondary circuit conditions.
- The first charge contained two sets of CBB type specimens. All test samples were prepared from the primary collector material with the aim to assess the influence of different repairing technologies on corrosion stability.
Current monitoring program

- Experimental material – steel ChN35VT-VD from failed primary collector bolts

- Test samples
  - pre-stressed tension specimens 7 ps
  - pre-stressed tension specimens with notch 7 ps
  - ½ C(T) pre-stressed specimens with fatigue crack 14 ps
  - ½ C(T) pre-stressed specimens with electrodischarge crack 14 ps

- CBB samples from the previous program
  - weld „A“ 1 ps
  - weld „B“ 1 ps
  - weld „C“ 1 ps
Scheme of holder placement on collector flange
Monitoring results – CBB samples
Monitoring results – pre-stressed samples

tensile

CT
Corrosion monitoring in the spent fuel interim storage

- The spent fuel interim storage in the nuclear power plant Jaslovske Bohunice makes use a wet storing
- Principally the spent fuel assemblies, which are placed in racks, are stored in large water pools
- This way of storing makes heavy demands on a long-term corrosion stability of used structural materials
- From this point of view, it is necessary to have monitoring possibilities of corrosion behavior of the structural materials
Scheme of the spent fuel interim storage – ground plan
Scheme of the spent fuel interim storage – ground plan
Scheme of the spent fuel interim storage in profile
Experimental materials

Resources of the experimental materials:
- Stainless steel plates, grade 08Ch18N10T – base metal and weld joint
- Old parts of the SFIS equipment – details removed during the reconstruction – preserved original surface without decontamination
- Stainless steel plates, grade ATABOR – base metal and original weld joint of hexagonal tubes from the compact racks
Samples holder

- Monitoring systems are placed in each storage pool
- Sets of samples are fixed in a special holder
- The holder in the form of a “basket” has to conform to the next requirements:
  - simple and flexible construction
  - easy mounting and dismantling of samples
  - fixing of samples in their right positions
  - free access of the corrosion medium to all samples
  - not disturbing the regular operation of the SFIS
  - possibility to add new set of samples
- Samples location in the holder – two basic positions:
  - samples submerged all time beneath the water surface
  - samples placed in the water level fluctuation
Set of samples #1
Sets of samples #2 and #3
Time schedule of samples evaluation

- Basic evaluation interval of samples from each pool is 4 years
- Every year is evaluated one set of samples
- After finishing adding new samples and if the results are favourable the evaluation interval will be extended
- If the operation conditions change, then it will be possible to evaluate an extra set of samples to estimate the influence of these changes on corrosion stability of structural materials

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>116/1</td>
<td>Inst.</td>
<td>E+A</td>
<td>E+A</td>
<td>E+A</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>116/2</td>
<td>Inst.</td>
<td>E+A</td>
<td>E+A</td>
<td>E+A</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>116/3</td>
<td>Inst.</td>
<td>E+A</td>
<td>E+A</td>
<td>E+A</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>117</td>
<td>Inst.</td>
<td>E+A</td>
<td>E+A</td>
<td>E+A</td>
<td>E</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Inst. – installing of the system with initial set of samples
- E – evaluation of the samples
- A – adding new samples from new compact racks

- done
- prepared
- planned
Monitoring results

- Up to now 6 sets of samples have been evaluated
- At the same time new sample sets were inserted into holders
- Average mass loss of all samples < 0.8 g.m\(^{-2}\).y\(^{-1}\)
- Main results from the evaluation of all sets – no corrosion attack was observed

CBB sample
Monitoring results – circular bead weldment
Monitoring results – metallographical specimens
Conclusions

- Corrosion monitoring provides important information about corrosion situation of both materials and equipments
- All presented monitoring systems are based on the principle of surveillance samples
- From the results of evaluation follows that no significant corrosion attack was found
- From the corrosion point of view – used structural material is stable in given standard condition and makes possible to extend the life of NPPs
Test samples

double U-bend specimen

circular bead weldment specimens
Test samples

crevince bent beam (CBB) specimen

pre-stressed CT specimen
Test samples

pre-stressed tension specimen

specimens for the crevice corrosion monitoring