The radiation life time of reactor pressure vessel (RPV) is the most important limiting factor for the term of exploitation of the whole power unit. The main degradation mechanism of RPV metal is the neutron induced embrittlement. Processes of radiation aging running in RPV metal lead to fracture toughness decrease and to increased probability of brittle fracture of the vessel under thermal shocks. This explains the importance of RPV integrity assessment and rest life time management.

1. Base information on NPP Kozloduy Unit 3 and Unit 4 RPVs
Reactor pressure vessels of NPP Kozloduy Unit 3 (KNPP3) and Unit 4 (KNPP4) are second generation WWER440/230. Unit 3 was put in operation in 1980, Unit 4 – in 1982. Both reactors have anticorrosion cladding. The chemical composition and mechanical properties of reactor shells have been determined by the manufacturer. The content of phosphorous and copper in KNPP3 RPV weld 4 is typical for WWER440/230 model and in KNPP4 they are similar to WWER440/213 model.

Low leakage core zone charging scheme was applied in both units in order to reduce the neutron loading on RPV wall. Additionally 36 dummy cassettes were inserted in core zone periphery of KNPP3.

Recovery annealing was applied to KNPP3 RPV weld 4 metal in 1989.

2. Rest life time assessment
No surveillance specimens for monitoring of RPV metal aging are available for both KNPP Units. Cutting of templates from RPV wall is not recommended because of the presence of cladding. So KNPP3 and KNPP4 RPV metal current status can not be experimentally evaluated.

The existing information on impurity elements concentration and on initial critical temperature of embrittlement ensure the possibility to predict the rest life time by empirical methods provided that embrittlement and re-embrittlement laws are reliably confirmed. The experience and results gathered from other WWER440/230 RPVs should be used for this purpose.

2.1. KNPP3
The method for life time assessment of annealed RPVs accepted in Russian standards is based on the conservative approach of reembrittlement. The analysis of KNPP1, KNPP2, Novovoronej 3 and 4 weld metal re-irradiation data shows that the rate of re-embrittlement of WWER440/230 RPVs weld 4 metal is lower than predicted by this approach and the lateral law is valid in this case [1, 2, 3]. The lateral re-embrittlement law should be applied for KNPP3 RPV radiation life time assessment also because of the similar chemical composition of KNPP3 weld 4 metal.

Tkf calculations made according lateral embrittlement law show that the KNPP3 RPV integrity is proved practically up to 28th fuel cycle, i.e. to the end of design life time. The application of elasto-plastic fracture mechanics methods for Tkf calculation permits the rest life time to be extended beyond designed one.
2.2. KNPP4

The prognostic calculations of Tkf shift of KNPP4 weld 4 metal during operation were performed. It was shown that the exploitation of Unit 4 will be safe beyond the design lifetime.

3. Surveillance program development

A Surveillance program for KNPP3 and KNPP4 RPV metal is under development at the moment. As no archive RPV material for specimens manufacturing is available, RPV materials of similar composition, manufactured by identical technology like Unit 3 and Unit 4 materials will be used for Charpy and tensile specimens manufacturing (Table 1).

<table>
<thead>
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<th>Unit</th>
<th>Material</th>
<th>P</th>
<th>Cu</th>
</tr>
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<tbody>
<tr>
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</tr>
<tr>
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<td>0.035</td>
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<td>KNPP4</td>
<td>BM</td>
<td>0.023</td>
<td>0.03</td>
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</tbody>
</table>

Containers with surveillance specimens, arranged in chains, will be inserted in surveillance channels of NPP Rovno 1 (low flux) and 2 (high flux) for irradiation. Investigation of weld metal behavior after initial irradiation, annealing and re-irradiation is planned in KNPP3 Surveillance program. Flux effect for KNPP3 specimens will be studied. For this purpose irradiation and re-irradiation at high and low neutron flux will be performed parallelly.

KNPP4 Surveillance program foresees investigation of base and weld metal behavior under irradiation. Initial accelerated irradiation up to fluence $8 \times 10^{19}$ cm$^{-2}$ is foreseen followed by two irradiations at low flux to fluence $11 \times 10^{19}$ cm$^{-2}$ and to $14 \times 10^{19}$ cm$^{-2}$.

References
1. Siemens AG, Evaluation of rate and degree of irradiation embrittlement of KNPP1 weld4 metal during re-irradiation
2. Siemens AG, Evaluation of rate and degree of irradiation embrittlement of KNPP2 weld4 metal during re-irradiation