Effect of lead on SCC susceptibility of steam generator body material under PWR secondary side crevice conditions

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INTRODUCTION
Lead (Pb) is known to cause lead induced stress corrosion cracking (PbSCC) of nickel based materials normally used in steam generator (SG) tubing, i.e. alloy 600 and alloy 690. Lead is found in almost all deposit samples taken from SGs, the source being impurities in the structural materials, chemicals used or, in extreme cases, lead blankets used for radioactive protection during outage periods. In some PWRs, wall through cracks have been found in SG body at locations of dissimilar (low alloy steel to stainless steel) welds. During boiling operation, impurities in the SG water accumulate in crevices formed under deposits, since the impurities are mainly non-volatile. Depending on the nature of the impurities, the crevice chemistry thus formed may become strongly acidic or alkaline. Very little is known about the susceptibility of low alloy steels to PbSCC, and thus a study was made to the role of Pb in this respect.

MATERIAL & METHOD
Carbon steel 22K, the body material of VVER SGs was studied under secondary side crevice conditions. A combination of mechanical tests (slow strain rate, SSRT), electrochemical tests (voltammetry and electrochemical impedance spectroscopy, EIS) and post-test examination of exposed surfaces with scanning electron microscopy (SEM) and glow discharge optical emission spectroscopy (GDOES) techniques was used in this work. Carbon steel 22K was studied in a SG crevice environment (both acidic and alkaline) with chloride and sulphate, with and without 100 ppm Pb, at the temperature of $T = 278^\circ$C.

During SG operation, deposits (mainly magnetite from feed water line) form within the SG, and since impurities in the water are not volatile, they concentrate within and under the deposits. Depending on the impurities in the bulk water, the crevice chemistry can end up acidic or alkaline. The crevice conditions studied in this work are shown in Table 1.

Table 1. The crevice environments studied in this work.

<table>
<thead>
<tr>
<th>Crevice condition</th>
<th>NaCl (wppm)</th>
<th>Na$_2$SO$_4$ (wppm)</th>
<th>Pb (wppm)</th>
<th>H$_2$SO$_4$ (wppm)</th>
<th>pH at T = 278°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic</td>
<td>330</td>
<td>740</td>
<td>0 and 100</td>
<td>98</td>
<td>5.5</td>
</tr>
<tr>
<td>Alkaline</td>
<td>330</td>
<td>740</td>
<td>0 and 100</td>
<td>0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Slow strain rate testing (SSRT)
In slow strain rate testing, a tensile specimen is slowly pulled into fracture (strain rate of $10^{-6}$ s$^{-1}$ or less, resulting in testing times of days or weeks), allowing enough time for corrosion processes to take place. The susceptibility to SCC is judged from reduction in the strain to fracture (in comparison to that in air at the same temperature), and from fracture surface appearance. Figure 2 shows the results from SSRT for air and both the acidic and alkaline crevice conditions.

Conclusions
Steam generator body material (low alloy steel 22K) is susceptible to stress corrosion cracking (SCC) in both acidic and alkaline crevice conditions at $T = 278^\circ$C. Under alkaline crevice conditions, the susceptibility is, however, less evident. Addition of 100 ppm Pb reduces the susceptibility to SCC under both types of crevice conditions. Increasing the potential, as in a simulated oxygen inleakage to the steam generator, dramatically increases the susceptibility to SCC.

Based on the results, in relation to PWR secondary side chemistry control, avoiding impurities in the bulk chemistry leading to acidic crevice conditions is recommended. With regard to SCC of SG body material (carbon steel), Pb is not a problem.