Update on BWR Water Chemistry

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ECP and Pt Loading Trends in OLNC Plants
ECP Measurements in Plants

- ECP measurements in the vessel and reactor recirculation loop showed excellent response during and after OLNC applications.
- ECP decreased below -230 mV(SHE) at which IGSCC is mitigated, in less than 24 hours and to -450 to 500 mV(SHE at the end of application.
- ECP stayed below -230 mV for the rest of the cycle and until the next OLNC application in following cycle.
- The ECP measurements showed that effective OLNC mitigation was achieved with annual applications.
Noble Metal Loadings

- Internal surfaces and surveillance capsule artifacts near the core shroud OD showed substantially higher noble metal loading than on coupons retrieved from external (MMS) sampling systems.

- Noble metals mass loading found on sampled reactor internal surfaces and artifacts in regions where IGSCC mitigation is desired indicate adequate levels of noble metals.

- The MMS is a very conservative location to monitor platinum mass deposition from OLNC, and may not be indicative of substantially higher particle density or catalytic activity on reactor surfaces.
Mitigation Performance Indicator
### OLNC Mitigation Performance Indicator Criteria

<table>
<thead>
<tr>
<th></th>
<th>Green</th>
<th>White</th>
<th>Yellow</th>
<th>Red</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWC Availability</td>
<td>≥95%</td>
<td>≥93%, &lt;95%</td>
<td>≥90%, &lt;93%</td>
<td>&lt;90%</td>
</tr>
<tr>
<td>ECP</td>
<td>At least 1 functioning probe or availability of 2 validated secondary parameters</td>
<td>not applicable</td>
<td>not applicable</td>
<td>No functioning probes and no validated secondary parameters.</td>
</tr>
<tr>
<td>MMS Availability</td>
<td>≥90%</td>
<td>≥80%, &lt;90%</td>
<td>&lt;80%</td>
<td>not applicable</td>
</tr>
<tr>
<td>Availability of 2 Secondary Parameters</td>
<td>≥95%</td>
<td>≥90%, &lt;95%</td>
<td>≥80%, &lt;95%</td>
<td>&lt;80%</td>
</tr>
<tr>
<td>OLNC Catalyst Injected</td>
<td>Injection amounts per vendor recommendation</td>
<td>not applicable</td>
<td>not applicable</td>
<td>Injection amounts less than vendor recommendation</td>
</tr>
<tr>
<td>OLNC Reapplication Frequency</td>
<td>≤16 operating months</td>
<td>not applicable</td>
<td>not applicable</td>
<td>&gt;16 operating months</td>
</tr>
</tbody>
</table>

- **How do the Individual PIs determine Overall MPI Status?**
  - **Green**: All Individual PIs must be Green.
  - **White**: If any one PI is White, the overall MPI is White.
  - **Yellow**: If any one PI is Yellow, the overall MPI is Yellow.
  - **Red**: If any one PI is Red or two PIs or more are Yellow, the overall MPI is Red.
Yellow indicator driven by HWC availability on one HWC-M from a hydrogen supply shortage in the Northeast. Currently on track to be Green during the current cycle.

No U.S. Plants are implementing NMCA now. One transitioned back to HWC-M in 2014.
HWC Performance for Last Completed U.S. BWR
Cycles with OLNC

![Bar graph showing HWC Availability (%) by year of cycle start](image)

- HWC Availability (%): Range, Average, Good Practice

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A higher percentage of the BWR Fleet (including Non-U.S.) is obtaining greater than 95% HWC availability.

Improvements driven by:
- Reducing system trips and vulnerabilities
- Starting hydrogen at lower power levels during plant startup (most start at 5% power)
- With OLNC, reductions or isolation of HWC injection have essentially been eliminated to support dose reduction during balance of plant maintenance
- Increased industry awareness
Effect of Chloride Transients on SCC of Low Alloy Steel
SCC of LAS in BWR Operating Environments

- More than two decades ago, MnS, $\text{SO}_4^{2-}$ and HS effects on SCC and corrosion fatigue were identified. Greater concern in US BWRs due to high-S% LAS used in US:
  - 2% > 0.030% S, 63% > 0.015% S, 96% > 0.010% S

- Recent laboratory data indicate significant effects on SCC CGR in LAS when chloride is 5 ppb or greater.

- More recent studies indicate similar effects of chloride at even lower concentration (< 5 ppb) below Action Level 1.

- BWRVIP initiated a project to study effects of low level chloride concentration on SCC of LAS.
Summary of Low Chloride Effects on LAS in NWC

Chloride level as low as ~3 ppb may enhance the SCC crack growth rate of LAS

Effect of Chlorides on in HWC

No SCC growth was observed in HWC under constant load up to 200 ppb chloride

Beneficial Effect of HWC on SCC Crack Growth in LAS

- There was no SCC growth in HWC for all three heats with chloride up to 200 ppb under constant load with $K \sim 49.5 - 55$ MPa√m.

- Higher CGRs observed under cyclic loading conditions, but again there was no evidence of chloride effects in HWC.

- *Results demonstrate that HWC is highly effective in mitigating SCC of low alloys steel even with chloride ingress.*

- Mitigated regions of the vessel will not be affected by HWC.

- Non-mitigated regions above the core will be affected.

- BWRVIP-62 Rv1 identifies the vessel internal components that are mitigated with HWC-M, NMCA and OLNC.
Implications for BWR Water Chemistry Guidelines (BWRVIP-190 Revision1)

- The results this work as well other reported studies show that for some heats SCC CGR in LAS can be accelerated by chloride transients down to 3 ppb at stress intensity $K \geq 50 \text{ MPa} \sqrt{\text{m}}$
- These results support a lower limit for Action Level 1, from current 5 ppb to 3 ppb
Interim Guidance on Chloride Action Level and Excess DH
Reactor Water Chloride Action Level 1 Value

▪ Laboratory tests showed that the SCC crack growth rate of pressure vessel low alloy steel can be accelerated in 288 °C oxygenated BWR water with a chloride level as low as 3 - 5 ppb.

▪ Cracking can be mitigated with HWC, but some reactor pressure vessel surfaces are exposed to oxidizing liquid and are not mitigated.

▪ Result: Interim Guidance Issued to lower Action Level 1 value for reactor water chloride at power operating conditions from ≥5 ppb to ≥3 ppb.

▪ Applies to all chemistry regimes.
Interim Guidance for Mitigation Monitoring

- Industry Initiatives to measure noble metal, catalytic activity.
  - External coupons and specimens, internal component scrapes and artifacts, mass loading, SEM particle density.

- New Needed and Good Practice Monitoring Guidance:
  - Hydrogen flow confirmation
  - Reactor coolant hydrogen and oxygen measurement
  - ECP
  - HWC Benchmark
Interim Guidance for Mitigation Monitoring

- Key Chemistry Guidance: Monitor Reactor coolant Excess Dissolved Hydrogen (Excess DH).
- The measured Excess DH is the $H_2$ concentration above that required for a $H_2:O_2$ molar ratio of 2.
  - Reactor coolant sample Excess DH is equal to Excess DH in the reactor coolant.
  - Excess DH is not affected by $H_2 + O_2$ recombination in the catalytic sample line, while measured molar ratio is affected (biased high when coolant $H_2:O_2$ molar ratio is >2).
- Measured Excess DH can be correlated with the BWRVIA radiolysis model predictions.
Relationship between Excess DH and Molar Ratio

Upper Downcomer Excess O2, Excess H2 and Molar Ratio versus Feedwater H2

Feedwater Hydrogen, ppm

RW Excess H2 or O2, ppb

Excess H2, ppb
Excess TOX, ppb
MOLRAT

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