Cobalt Reduction Sourcebook

1021103

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Update of Previous Guidelines (TR-103296)

• Previous Positives
  – Good background motivation (elemental cobalt issues)
  – Strong materials background
  – Incentives for cobalt reduction
  – Code requirements documented

• Areas of Improvement
  – Discussion of results
  – Expand beyond hardfacing focus to cross-discipline approach
  – Updated results with respect to materials properties
  – Expanded Discussions
    • PWRs in general
    • BWR turbines, condensers and piping
    • Chemistry/surface preconditioning
    • Industrial experience
Overview of the Sourcebook

- Divided into 7 chapters discussing
  1. Historical cobalt reduction efforts and summary of performance measures (CRE)
  2. Management responsibilities and program ownership emphasizing a team approach
  3. Material replacement strategies
     Table of material properties, valve replacement logic tree, summary of industrial sampling techniques
  4. BWR Co reduction strategies
  5. PWR Co reduction strategies
  6. Valuation of Co reduction strategies (Tables and Flowcharts)
  7. Summary of recommendations
Objectives of Cobalt Reduction Sourcebook (1021103)

- Define dominant sources of elemental cobalt in BWRs and PWRs
- Assess key radiation field mitigation technologies and their expected effectiveness
- Provide a generalized cobalt reduction strategy and identify program owners

Generalized Valuation Strategy

1. Tabulated lists of
   - Available Co reduction methods
   - Expected time to observe benefits
   - Approximate costs
2. A series of flowcharts for implementing a Co reduction strategy for BWR and PWR plants
# PWR Co Reduction Summary Table (excerpts*)

<table>
<thead>
<tr>
<th>Technology/Strategy</th>
<th>Benefits</th>
<th>Concerns</th>
<th>Expected Time Required Before Dose Rate Reduction</th>
<th>Approximate Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Elemental Cobalt Sources</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved valve maintenance monitoring with XRF</td>
<td>Reduce Stellite particles to core</td>
<td>None</td>
<td>2-3 cycles for core fuel replacement needed before expected reduction in RW 60Co concentrations. Best case 60Co decay curve after core replacement.</td>
<td>~$80K plus training and maintenance</td>
</tr>
<tr>
<td><strong>Activity Removal Methods</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Local system chemical decontamination</td>
<td>High decontamination factors on piping</td>
<td>Waste and critical path.</td>
<td>Immediate reduction of dose rates.</td>
<td>~ $1 million, depends on system</td>
</tr>
<tr>
<td>In-vessel vacuuming</td>
<td>Removes particulate activity</td>
<td>Filters must be handled and stored</td>
<td>Immediate reduction of local particulate radiation fields.</td>
<td>~$50K</td>
</tr>
<tr>
<td><strong>Out-of-Core Surface Incorporation Prevention</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc injection</td>
<td>Proven results, large experience base</td>
<td>Fuel concerns for high duty cores</td>
<td>60Co decay curve due to no new cobalt incorporation into oxide films. Faster decay curves possible if other gamma emitters are also mitigated.</td>
<td>~$300K/unit if no fuel exams or fuel cleaning required</td>
</tr>
<tr>
<td>Electropolishing</td>
<td>Significantly lower dose rates, reduced contamination levels</td>
<td>Must be performed with replacement components</td>
<td>Immediate results with newly installed equipment, contamination rates are 50% or greater slower.</td>
<td>~$10K with small components, more for SG Channel heads</td>
</tr>
</tbody>
</table>

*Full table evaluates 14 PWR technologies and strategies*
### BWR Co Reduction Summary Table (excerpts*)

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<tr>
<td>Elemental Cobalt Sources</td>
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<tr>
<td>OEM Blades</td>
<td>OEM Blades Reduce In-vessel elemental cobalt and Co-60 sources</td>
<td>Cost, disposal, outage critical path</td>
<td>Reactor Water Co-60 concentrations should decrease quickly, Cobalt-60 decay curve expected in best case</td>
<td>$200k per CRB (an estimate from a plant in 2010; includes disposal)</td>
</tr>
<tr>
<td>Activity Removal Methods</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Submersible Treatment Equipment</td>
<td>Remove soluble activated corrosion products</td>
<td>Accessibility, vessel dose rates</td>
<td>Immediate impact in local dose rates during refueling.</td>
<td>~$50,000 (plant estimate, includes vessel and other hardware)</td>
</tr>
<tr>
<td>Out-of-Core Surface Incorporation Prevention</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HWC-M; NMCA-HWC; OLNC-HWC</td>
<td>Required for IGSCC mitigation. Need to achieve low ECP, &lt; - 400 mV SHE for minimal Co-60 incorporation into corrosion films.</td>
<td>DZO at least 6 months before reducing conditions are established. $^{16}$N issues with HWC-M; Soluble Co-60 increases following NM applications. NM must be reapplied. HWC must be initiated with NM technology</td>
<td>Immediate impact in maintaining current levels (or dropping along cobalt-60 decay curve) when combined with zinc.</td>
<td>$1-2 million for first OLNC (includes skid purchase). Annual noble metal purchase/license fee afterwards (~$300,000). HWC-M hydrogen annual H$_2$ cost $500,000 to $1 million.</td>
</tr>
<tr>
<td>Electropolishing/ Pre-oxidation/ Stabilized Chrome</td>
<td>Reduced Co-60 incorporation into corrosion films</td>
<td>None significant</td>
<td>Immediate impact, new equipment will contaminate to radiation fields 50% or less than similar untreated equipment.</td>
<td>&lt;$10,000 for small components</td>
</tr>
</tbody>
</table>

*Full table evaluates 17 BWR technologies and strategies*
Optimizing Effectiveness and Managing Expectations

• First consider station specific source term reduction/radiation issues
  – Historical BRAC/SRMP vs. Outage CRE changes
• Before implementation – characterize overall cobalt source term
  – Elemental transport to core
  – Activated transport to out-of-core surfaces
• Elemental cobalt reduction requires a long time for benefit realization
• After Co Reduction Program Implementation
  – Full core change out may be required for optimized reductions
BWR Co Reduction Flowchart (Fig. 6-2)

- BWR Elemental Cobalt Reduction
  - Is cobalt source term low?
    - Yes: Aggressive cobalt reduction measures may not be effective
    - No: Perform NP-2263 evaluation to identify sources (valves, RPV internals, LP Turbine Buckets)
      - Establish elemental cobalt sampling program (CDI, COE, FPO, FW)
      - Reconcile NP-2263 List with Elemental Cobalt Sampling Program
        - Evaluate cobalt sources from non-condensate/FW sources (e.g. PWCU, RRS, HH-SDC, ECCS). Some systems are normally not in service, so source may not be significant.

- Feedwater Sources
  - Seltite valves present between CDI and FFW?
    - Yes: Perform cost benefit for valve replacement using flowchart
    - No: End Feedwater Sources
  - Turbine/Condensate Sources
    - Seltite present in low pressure turbine blades?
      - Yes: Evaluate cobalt sources from non-condensate/FW sources (e.g. PWCU, RRS, HH-SDC, ECCS). Some systems are normally not in service, so source may not be significant.
      - No: In-core/Vessel Sources
        - DEM COE exceeds 20% of Core?
          - Yes: Evaluate cobalt sources from non-condensate/FW sources (e.g. PWCU, RRS, HH-SDC, ECCS). Some systems are normally not in service, so source may not be significant.
          - No: Evaluate cobalt sources from non-condensate/FW sources (e.g. PWCU, RRS, HH-SDC, ECCS). Some systems are normally not in service, so source may not be significant.
Valve Replacement Logic Tree

1. Identify valves that contact RCS
   - Estimate Co release from maintenance records and EPRI reports
   - Identify candidate valves for replacement or refurbishment
   - Prioritize candidate valves for replacement
     - Does valve have HF?
       - Yes
         - Is HF Co-based alloy?
           - Yes
             - Is valve to be replaced?
               - Yes
                 - Co-based HF to be used?
                   - No
                     - Identify valve design, operating conditions, duty cycle
                       - Gate, globe or other valve
                         - Is 
                           - 15 ksi
                           - Select high performance HF
                             - Is Co-free HF selected?
                               - Yes
                                 - Perform safety evaluation if needed
                                 - Identify valve vendor or service organization that can supply selected HF
                               - No
                                 - Isolating control valve
                                   - Check valve
                                     - Non-isolation control valve
                       - No
                         - Calculate (disc/seat) contact stress
                           - Pivot bushing
                             - Seat
                               - Eliminate HF
     - No
       - Is HF Co-based alloy?
         - Yes
           - Is valve to be replaced?
             - Yes
               - Co-based HF to be used?
                 - No
                   - Identify valve design, operating conditions, duty cycle
                     - Gate, globe or other valve
                       - Is 
                         - 15 ksi
                         - Select high performance HF
                           - Is Co-free HF selected?
                             - Yes
                               - Perform safety evaluation if needed
                               - Identify valve vendor or service organization that can supply selected HF
                             - No
                               - Isolating control valve
                                 - Check valve
                                   - Non-isolation control valve
                       - No
                         - Calculate (disc/seat) contact stress
                           - Pivot bushing
                             - Seat
                               - Eliminate HF
             - No
               - Do not change HF/Trim
                 - No
                   - Identify valve design, operating conditions, duty cycle
                     - Gate, globe or other valve
                       - Is 
                         - 15 ksi
                         - Select high performance HF
                           - Is Co-free HF selected?
                             - Yes
                               - Perform safety evaluation if needed
                               - Identify valve vendor or service organization that can supply selected HF
                             - No
                               - Isolating control valve
                                 - Check valve
                                   - Non-isolation control valve
                       - No
                         - Calculate (disc/seat) contact stress
                           - Pivot bushing
                             - Seat
                               - Eliminate HF
                 - Yes
                   - Identify valve design, operating conditions, duty cycle
                     - Gate, globe or other valve
                       - Is 
                         - 15 ksi
                         - Select high performance HF
                           - Is Co-free HF selected?
                             - Yes
                               - Perform safety evaluation if needed
                               - Identify valve vendor or service organization that can supply selected HF
                             - No
                               - Isolating control valve
                                 - Check valve
                                   - Non-isolation control valve
                       - No
                         - Calculate (disc/seat) contact stress
                           - Pivot bushing
                             - Seat
                               - Eliminate HF

Logic Tree carry over from 2004 Radiation Field Control Manual (1003390)
## Industrial Experience

<table>
<thead>
<tr>
<th>Plant*</th>
<th>Technology/ Strategy</th>
<th>Dose Rate Reduction Benefit</th>
<th>Time Required to Observe Benefit</th>
<th>Comments</th>
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<td><strong>BWR Dose Rate Reductions</strong></td>
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</tr>
<tr>
<td>Plant A</td>
<td>OEM CRB replacement; LPT Stellite® Replacement</td>
<td>From 270-470 mR/hr to 70 mR/hr</td>
<td>About 2-4 years, (complete core replacement needed).</td>
<td>Chemical Decontamination and LTNC performed at same 2004 outage as Stellite Reduction.</td>
</tr>
<tr>
<td>Plant B</td>
<td>DZO Implementation</td>
<td>BRAC at time of implementation (2/98) about 400 mR/hr. BRAC in 2008 about 110 mR/hr</td>
<td>About 10 years</td>
<td>HWC initiated in 1999, Moderate HWC in 2007. No chemical decontamination performed.</td>
</tr>
<tr>
<td><strong>PWR Dose Rate Reductions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant C</td>
<td>Zinc injection two cycles before replacement, electropolished steam generator channel heads, constant pH, low core duty</td>
<td>Very low radiation fields</td>
<td>Immediate impact on channel heads, approximate Co-60 decay curve (50% every 5 years)</td>
<td></td>
</tr>
<tr>
<td>Plant D</td>
<td>Electropolished steam generator channel heads, recent zinc injection.</td>
<td>Very low radiation fields for channel heads.</td>
<td>Immediate channel head dose rate reduction.</td>
<td></td>
</tr>
</tbody>
</table>

*Full table contains actual plant references and 13 cases.
Key Aspects of the Cobalt Reduction Sourcebook (1021103)

- Generalized valuation strategies for BWR and PWR
  - Tables including key technologies, benefits, concerns, estimated time before observable results, and cost
  - Flowcharts explaining steps to implementation
- Includes actual industrial experience
- Focuses on cross-discipline cobalt reduction program
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