IN USE: DRIVING COBALT1 TOWARD ZERO - DEVELOPING A STRATEGY FOR RADIATION FIELD SOURCE TERM CONTROL

ISSUE STATEMENT

The global nuclear industry continues to be challenged by radiation field control. Commonly, nuclear plant operators attempt to implement source-term reduction technologies that have shown significant benefits at other plants. This approach may not be optimal because of the variety of plant designs, the variety of materials of construction, the various operational practices, and the many design changes implemented at any given time. Sites are left to decipher a maze of source term reduction and control options to meet radiation reduction goals such as collective radiation exposure (CRE). The purpose of this roadmap is to close gaps in the application of source-term reduction tools, thereby enabling the development of tailored approaches that contribute to reduced dose exposure.

DRIVERS

Regulatory

Worldwide, nuclear plant operators are required to maintain occupational radiation exposures as low as reasonably achievable. Non-U.S. plant administrative limits are as low as 1.0-1.5 rem/year (10-15 mSv/yr) to ensure conservative margin for maintaining regulatory limit compliance. While in the U.S. the current total effective does equivalent (TEDE) limits are 5 rem/year (50 mSv/year), U.S. plants strive to achieve the international dose limit of 2 rem/year (20 mSv/year). Moreover, a lower limit for lens of the eye dose will go into effect internationally in February 2018.

Performance

The global industry (through the Institute of Nuclear Power Operators and the World Association of Nuclear Operators) has committed to CRE dose goals (normalized total cycle person-rem) of 110 person-rem for boiling water reactors (1.1 person-Sv) and 40 person-rem for pressurized water reactors (0.4 person-Sv) by the end of 2015. These CRE goals are best met through integrated strategies of reducing radiation fields (source term control) and time spent in radiation fields (ALARA/work planning). The industry is currently meeting the CRE goals, however, about half of the BWR units are challenged to achieve the CRE goal.

Long-Term Operational

Outage scope continues to increase because of the combined effects of long-term operation, Alloy 600 mitigation, component upgrades or replacements, equipment reliability, maintenance and inspection requirements. The increasing scope to support life-extension challenges control and reduction of worker dose highlighting the need of reducing radiation fields through source term reduction.

Short-Term Operational

Current strategies, e.g., power uprates and flexible operations, may increase the transport of activated corrosion products from the core to out-of-core surfaces, and therefore, increase plant radiation fields, and/or results in unexpected shutdown releases, impacting critical path and possibly radiation field.

Asset Protection

Chemistry is a key factor in preventing or mitigating corrosion, maintaining components and systems integrity, and improving equipment reliability. The same chemical control methods that protect the asset often also affect the generation of corrosion products, their activation and transport through the system.

New Build

Proactive source-term reduction and control measures such as surface passivation prior to operation could enable a new build to avoid the radiation field challenges experienced by the current fleet. Lower radiation fields can also translate to substantial operational cost savings (radiation protection, mitigation measures, shielding and associated retroactive engineering, waste, and releases).

1 Note: While is a major focus, “Cobalt” is used as synonym for all major isotopes causing radiation fields.
RESULTS IMPLEMENTATION

Driving source term toward zero is challenging. This roadmap focuses on creating an integrated, living strategy for source term control and reduction by leveraging plant operational data, advanced tools and technologies, and new and advanced data processing tools such as multivariate pattern recognition and predictive analytics.

• Final Products:
  – Source Term Control and Reduction Implementation Decision Logic, a tool that considers plant-specific conditions and constraints and provides a prioritized source term technology selection and implementation sequence. This logic will be refined as new insights are gained in the continuous improvement process.
  – Results of source term reduction technology demonstrations.
  – Recommendations, guidance, and sourcebooks on available/developed source-term control and reduction operating strategies, technologies, and industry operating experience.

Utility members can work with EPRI, consultants, and licensed vendors to determine and implement appropriate strategies and technologies. Utility members also should provide input into related EPRI databases to enhance data analysis, including BWR/PWR Chemistry Monitoring and Assessment (CMA), Standard Radiation Field Monitoring and Characterization (SRMC), Fuel Reliability (FRED), and Steam Generator Degradation Database (SGDD); continue Stellite® reduction efforts; consider hosting in-plant testing and demonstration of source-term reduction technologies; and evaluate alpha and beta versions of EPRI’s decision logic.

PROJECT PLAN

The overall objective of this project is to develop a strategy for source term control and reduction that can be adapted to the needs of any particular site, current or new built – contributing to reduced personnel exposure.

Execute Source Term R&D and Leverage/Expand Data Set

This focus area will leverage current and future base, supplemental and Technology Innovation Program funded research that explores and improves source-term mitigation technologies. Plant demonstrations and technology transfers are vital to successful implementation, such as HE-UFC demonstrations and plant demonstrations using CoSeq® to reduce coolant cobalt concentration to near zero during outages.

Another crucial component of this project is data collection and analysis. Focused population and analysis of the four core databases (PWR/BWR CMAs, SRMC, FRED, SGDD) can support improved assessment of source-term reduction tactics. Additionally, plant materials of construction and operating experiences will be paired with the monitoring information collected in the databases.

Advanced Data Processing and Assessment

This focus area will analyze available datasets with new and more advanced data processing and analysis tools such as multivariate pattern recognition and predictive analytics. These newly available software tools capture global, detailed, and fine-grained structures in the data and will likely reveal important relationships hidden to typical human deduction approaches, enabling users to draw reliable conclusions about current conditions and future events. The new software tools exploit relationships found in the data to identify potential risks and opportunities.

Source-Term Control Decision Logic

The decision logic will help inform decisions regarding the most effective source-term control and dose reduction technologies, replacing selection solely based on collective global fleet operating experience with an approach tailored to plant-specific conditions and constraints. The logic utilizes plant-specific design parameters, historic and current operation experience, as well as global experiences and integrates this data set with available source term control and reduction technologies and tools to develop a station-specific prioritized selection and implementation sequence.

Plant trials and demonstrations will test, verify, and validate the feasibility and functionality of the developed logic.

RISKS

External Stakeholder Endorsement

Many projects require support from external stakeholders, including nuclear steam supply system, fuel, and/or vendors. In some cases, identified radiation field reduction technologies may require extended testing or more representative laboratory testing to meet nuclear plant design or fuel requirements.

Design and Monitoring Data Collection

The success of this roadmap depends largely on available plant design and monitoring data collected in the EPRI databases. Incorrect and incomplete datasets may result in unreliable data assessments and invalid conclusions. Significant effort shall be placed on data verification and validation prior to utilization.
Technology Implementation Constraint

Some of the identified radiation field reduction technologies may require plant participation and could be too resource intensive to implement. Competing priorities with work groups outside of chemistry and radiation protection – including fuels, materials, and shutdown/outage planning – may add complexity even to the most optimal implementation proposed.

**ROADMAP INTERFACES**

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<th>Roadmap or Task</th>
<th>Owner Organization</th>
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<td>Water Chemistry Guidelines for Advanced Light Water Reactors</td>
<td>Chemistry and Radiation Safety</td>
<td>Expanded Data Set, Decision Logic</td>
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<td>5-Year Plan “Chemistry”</td>
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<tr>
<td>Materials Degradation and Aging Roadmaps</td>
<td>Materials Reliability Program</td>
<td>Expanded Data Set, Data Assessment, Decision Logic</td>
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**OUTPUTS FROM ROADMAP**

| Decision Logic, Recommendations, guidance, and source books | Chemistry and Radiation Safety | 5-Year Plan “Reducing Worker Radiation Exposure” |

**RECORD OF REVISION**

<table>
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<tr>
<th>Revision</th>
<th>Description of Change</th>
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| 0        | Original Issue: December 2014  
Roadmap Owner: Carola Gregorich |
| 1        | Revision Issued: December 2015  
Roadmap Owner: Carola Gregorich  
Changes: Add specific projects to Map  
[Silver and Antimony Influence on Radiation Fields, Development for optimizing zinc injection, Radiation Field Generation Sourcebook] |
| 2        | Revision Issued: August 2016  
Roadmap Owner: Carola Gregorich  
Changes: General revision to reflect current status of research work and results and address current industry developments. |
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Utilities

- Provide Information and Data to EPRI’s Chemistry Monitoring & Assessment and Standard Radiation Field & Characterization Databases
- Implement Available Source Term Reduction Strategies & Provide Operating Experiences (for instance, CoSeq®, UFC)
- New Plant Startups

Chemistry, Low Level Waste and Radiation Management

- Source Term Data Collection and R&D - Understanding Fundamental Processes & Advancing Tools and Technologies
  - Cobalt/Source Term Speciation in Primary Coolant MicroClimates (f(T,p)), core crud, out-of-core oxides, incorporation, release (prompt vs delayed), limited volume SD, colloidal phases, interaction wizinc
  - Sequestration Resin Development for other Contaminants
  - Hydrophobic Coating for PCE and dose Control
  - Surface Passivation
  - IEP and Zeta Potential Effects
  - Mid-Cycle SD Practices
  - PWR SD Rel.
  - Rad Field Gen under Flex Ops
  - Radiation Field Generation/Reduction Sourcebook
  - Optimizing Zinc Addition
  - Decontamination Sourcebook
  - Ultra-low Iron/Reducing Coolant Infl. on Cr-51 as PCE risk
- Collect and Assess Chemistry and Radiation Field Monitoring Data - PWR CMA, BWR CMA; SRMC (SRMP/BRAC)

Chemistry & Radiation Safety

- Extend Data Collection, Advance Data Processing and Assessment Capabilities
  - Database
  - CMA’s – (1) Explore and implement advanced data transfer options, (2) Convert BWR CMA to SQL database, SRMC – (3) Integrate SRMP and BRAC into SQL SMRC database, (4) Link SRMC and CMA, and (5) Enhance data accessibility
  - Plant Demo of At-Power Isotopic Rad Fld Monitoring
  - Remote Isotopic Rad Fld Monitoring
  - Leveraging Data Smartly: Building Intelligent & Learning Data Lakes
  - Maintenance and Development of Supporting/Input Codes (MultEQ, BOA, CORAL,....)

- Development of Decision Logic for Source Term Control & Reduction Technology Implementation
  - Activity Transport Modeling GAP Analysis
  - Decision Logic Development, Testing, Verification & Validation, Demo
  - Plant Demo (New Built / Operating Fleet)
  - Plant Demo – Near Zero Cobalt Removal from Coolant by CoSeq®

Milestones:
1. 3002006956 – Data Science Use in EPRI & its Members
2. 3002008175 – Rad Flld Generation Modeling Review
3. 3002008033 – HFT practices
4. 3002008188 – Review of Adv. Surface Treatments
5. 3002008177 – PWR SD Release – 2016 Update
6. 3002008183 – Optimizing RCP Practices
7. 3002008182 – Rad Flld Micro-Environment OE Review
8. Antimony paper at 2016 NPE, Brighton, UK
9. 3002008181 – BWR Dose – 2016 Update
3002008180 – PWR Dose – 2016 Update

Future Milestone:
- a. OE review and experimental results of durability
- b. Surface treatment feasibility/process
- c. results of surface treatment performance
- d. review of flex ops OE and identification of gaps
- e. zinc program update and injection optimization
- f. OE review – sources and speculation in LWRs
- g. experimental validation of rad flld generation hypothesis
- h. benchmarking graphs for PWR control parameter online
- BWR CMA in SQL

LEGEND
- Key Milestone
- Complete Milestone
- Chem & RS Funded Work
- Chem & RS Unfunded Work
- Proposed Work to Techn. Innov.
- Funded by TSGs, FRP or others in collaboration w/ Chem&RS

Vendors

- INPO/NEI
- Top Ten ALARA Practices

- Surface Passivation Implementation