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PWR Zinc Program Overview

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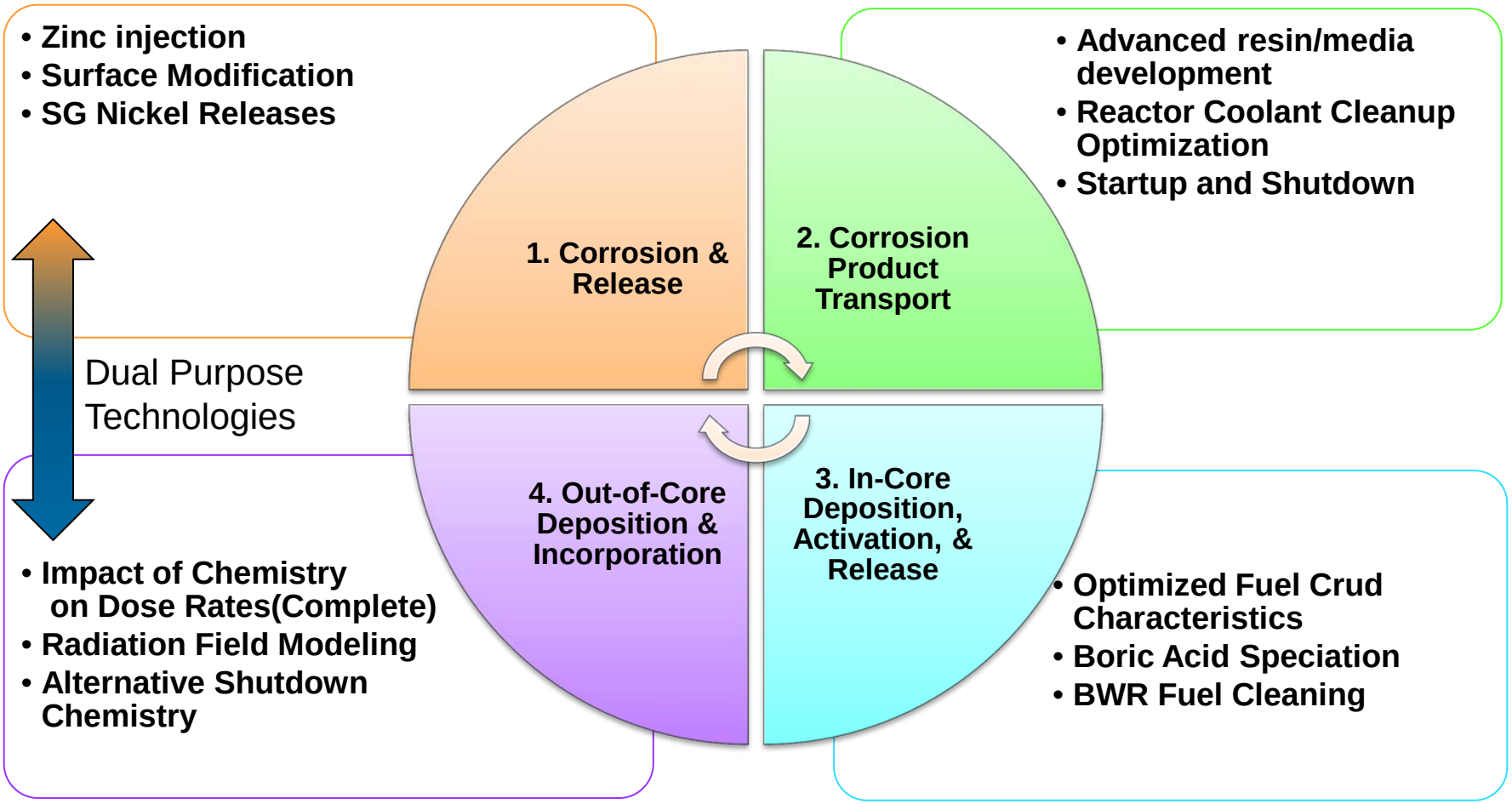
International Symposium on Occupational Exposure
North America
January, 2014

Source Term – A Process



✓ 2014 Fundamental Activity: SRMP/BRAC (Continuing)

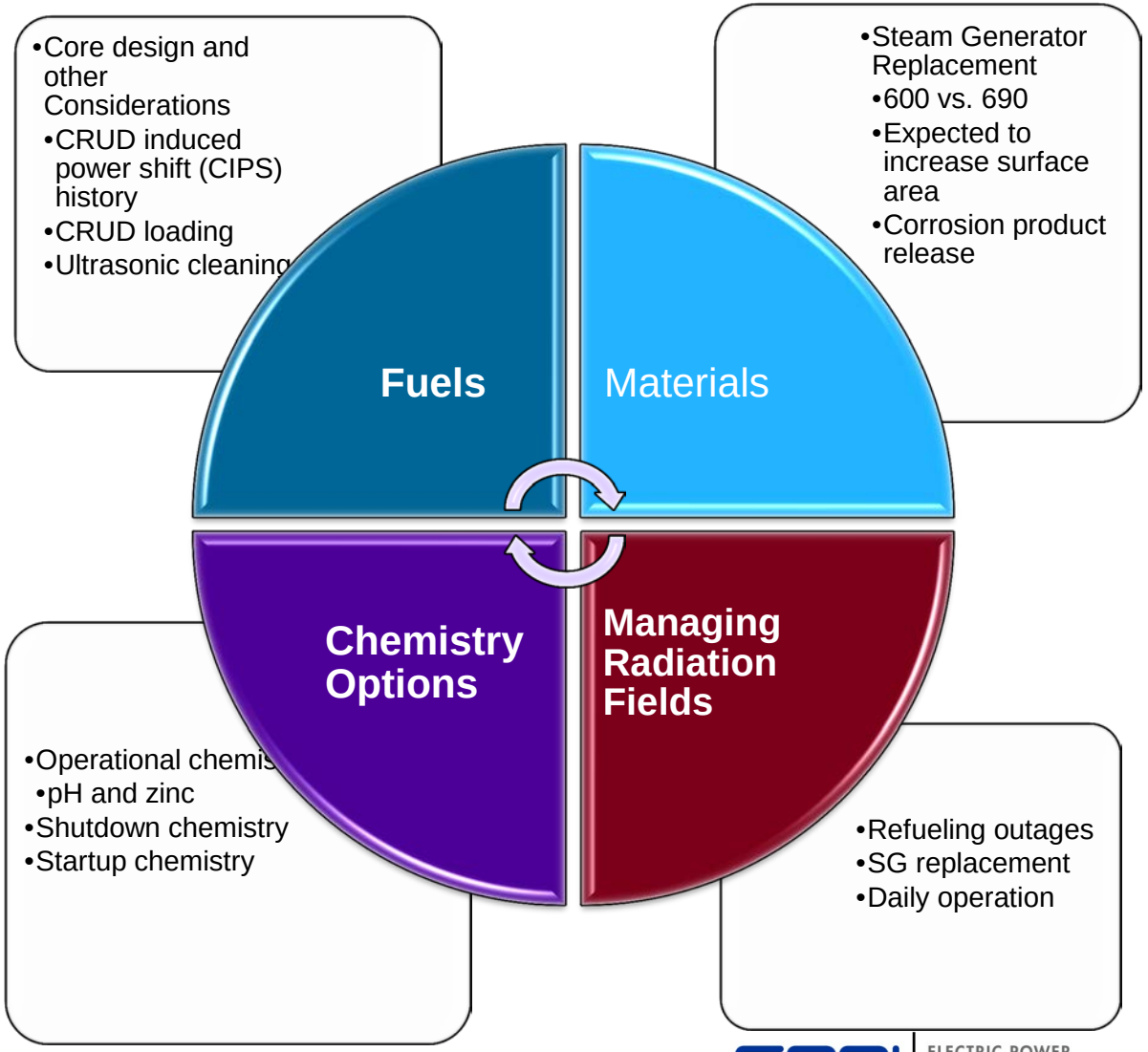
Activity Incorporation

- Large piping surfaces and areas with high flow
  - Activity incorporation appears driven by soluble incorporation
  - Fluid shear is very high in the core and primary circuit piping
- Small bore piping or low flow areas
  - Particulate drop out or deposition will increase local area dose rates
  - Dead-legs, cleanup piping and other low flow areas have relatively low shear forces, increased potential for deposition

PWR Zinc Injection

Why Zinc or Where does Zinc Injection fit?

- **Challenge:** Zinc impacts multiple programs
- **Impacts to Consider:**
  - Fuel performance
    - Short-term to long-term
  - Materials
  - Chemistry program changes
  - Long-term dose rates



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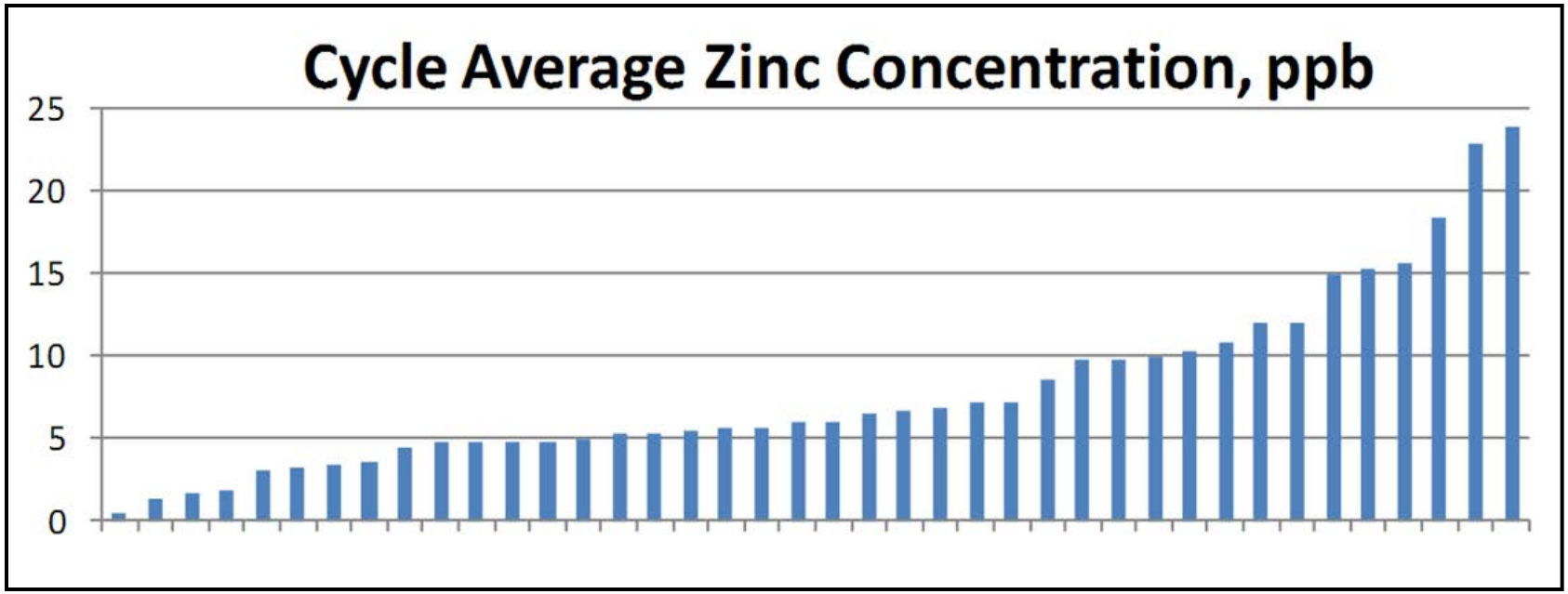
PWR Zinc Injection

Program Strategies

- All plants report using depleted zinc
- Target Concentration
  - Implementation Strategy –low 5 ppb target
    - Mid-cycle zinc injection
    - 5ppb zinc target maintained for remainder of cycle
  - Interim Strategies – increasing target zinc concentration
    - Initial target zinc concentration low (5-10 ppb)
    - Over two or more cycles zinc target concentration is gradually increased
      - Several months at 5-10 ppb, several months at 15 ppb, last few months of cycle at 20 ppb

U.S. PWR Reactor Coolant Chemistry



Target values outside the US similar; typically 5 to 15 ppb

Target values have decreased over time based on field experience and laboratory testing

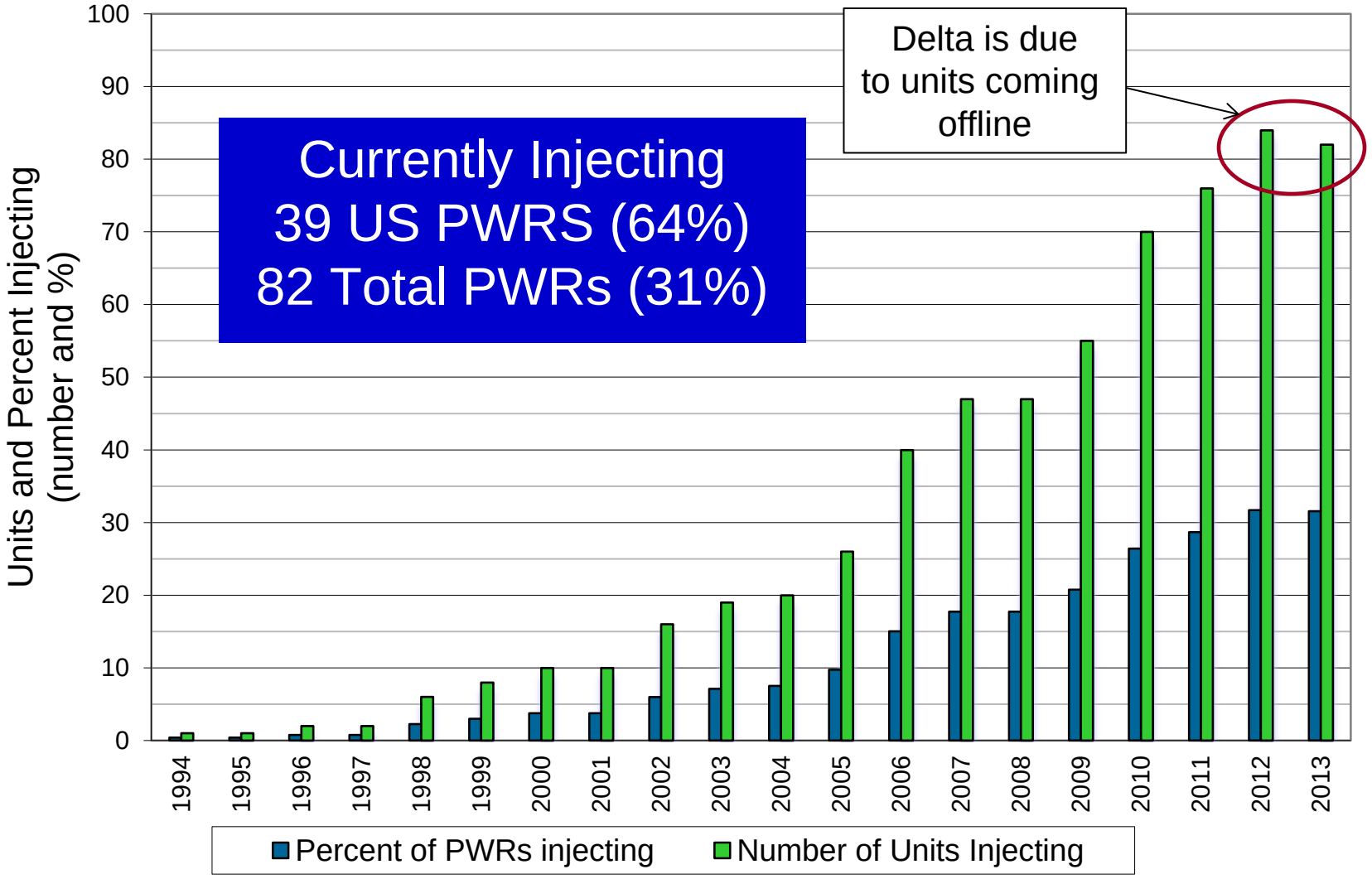
PWR Zinc Injection

Program Strategies

- Intermittent injection strategies
  - Units limited to partial injection cycles
    - Limited by fuel design or chemistry controls
    - Challenging strategy
      - Zinc injected during end-of-cycle operations and impact on startup
        - Lowering zinc concentration and in some cases, zinc concentration reduced to not detectable
      - Impact of strategy related to corrosion and other changes
- Maintenance injection strategies
  - Long-term mature plants

PWR Zinc Injection Status

Zinc Injection Worldwide



Recently Started and Planned Zinc Injection Programs

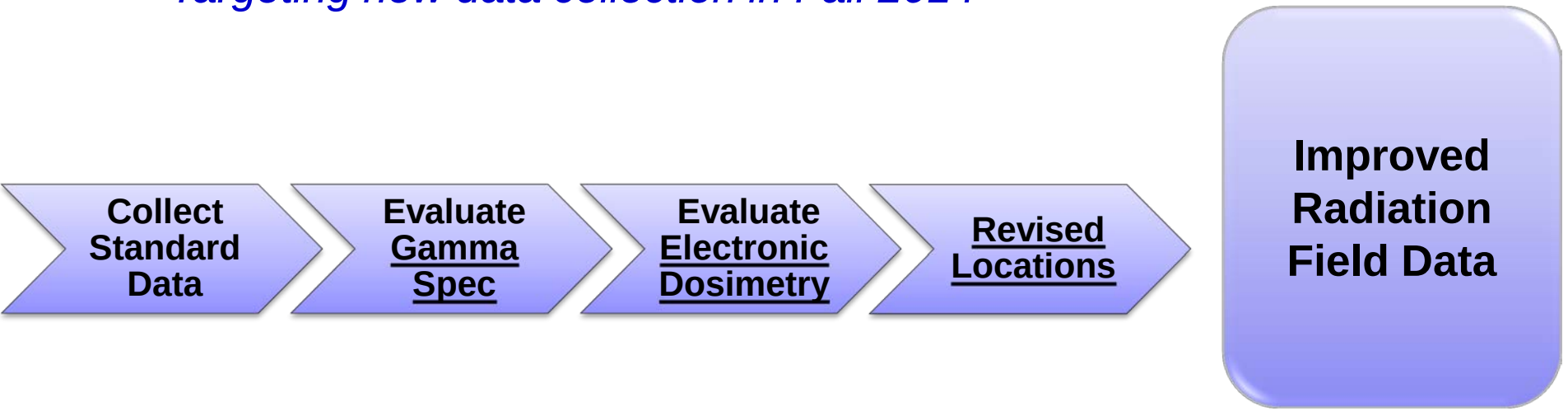
Country	Started 2011-2013	Planned for 2014-2016	Total 2011-2016
Korea	--	15	15
France	13	1	14
US	2	4	6
Japan	0	3	3
South Africa	--	2	2
Total	16	24	40

Field Experience with Zinc Dose Rate Reduction Effectiveness

- Overall, long-term zinc injection expected to reduce out-of-core dose rates by a factor of three or more
  - Dependent on initial conditions
  - Dependent on operational factors
- Expected benefit realized by >90% of plants
- Plants that have not fully realized the expected benefit of the dose rate reduction expectations
  - Behavior likely due to known factors and part of a longer-term evaluation and monitoring of zinc injection
    - Inconsistent injection strategies (restarting injection later in the cycle compared to consistent injection strategies)
    - Mid-cycle outages
    - Short injection with high cobalt-60 film

Radiation Field Characterization

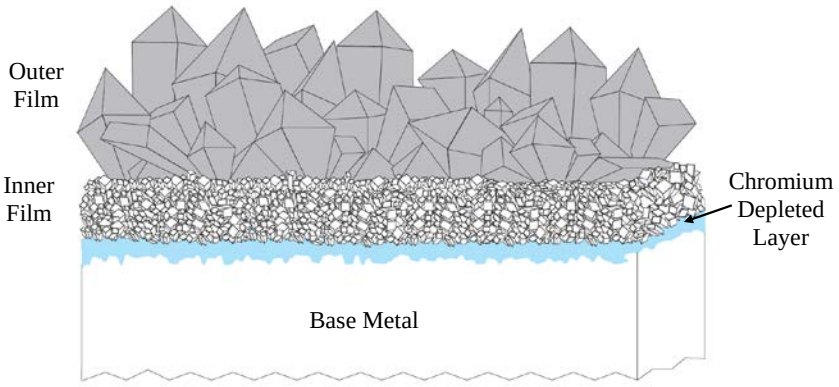
- ***2012-2013 Project***
  - *Revision of SRMP and BRAC*
  - *Publication scheduled for early 2014*
  - *Roll-out communication(s)*
  - *Targeting new data collection in Fall 2014*



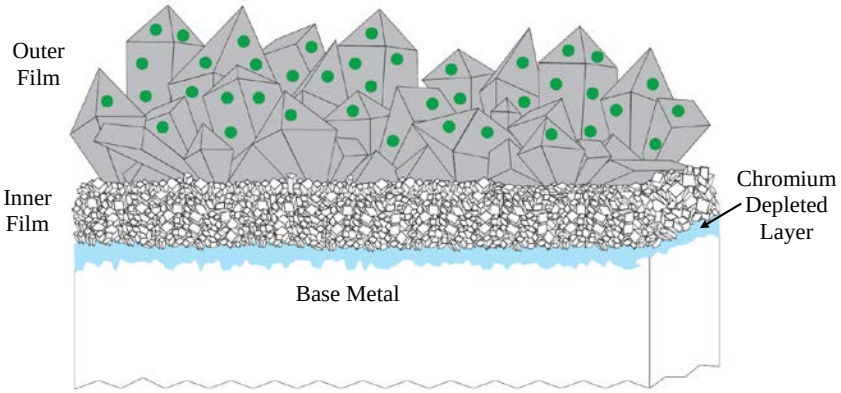
Zinc Effect on Out-of-Core Dose Rates

- Debate continues on exact mechanism
- Most simply, zinc adsorbs and incorporates into the oxide film, blocking new uptake of radiocobalt
  - Negligible substitution for existing radiocobalt
  - Effect considered primarily due to orders of magnitude higher zinc concentration relative to radiocobalt
  - Long-term, also reduces release of new corrosion products to the coolant
  - Diffusion into the oxide is very slow (many cycles)

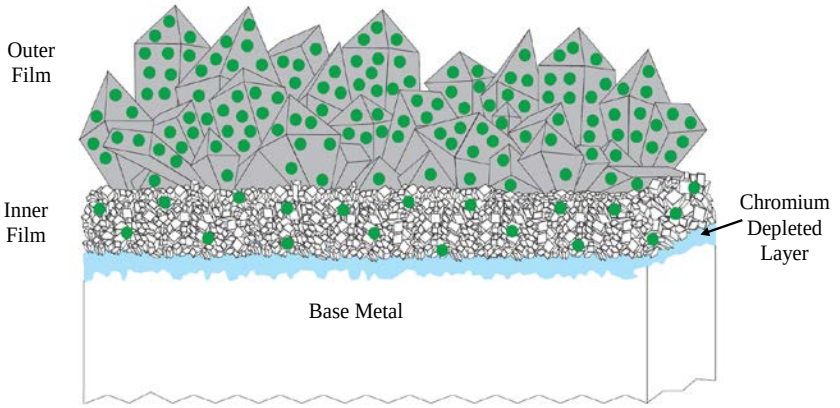
Schematic of the Corrosion Film Formed on Stainless Steel or Nickel Alloys in Primary Water



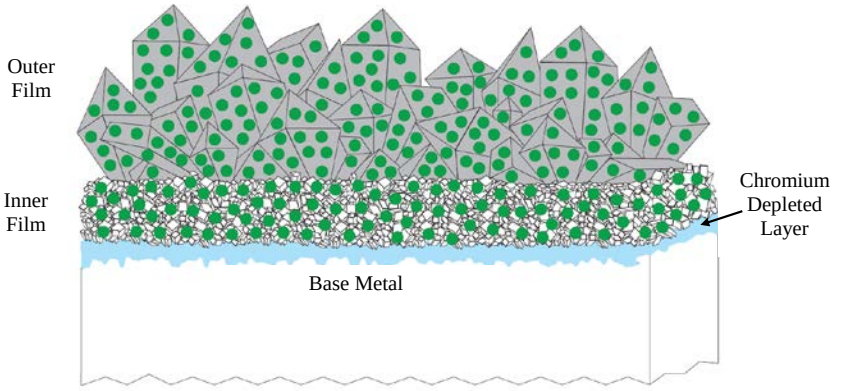
Pre-Zinc



Short-Term Zinc Exposure (<200 ppb-mo)



Medium-Term Zinc Exposure (200-400 ppb-mo)



Long-Term Zinc Exposure (>400 ppb-mo)

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Zinc Sourcebook Revision

Overview

- Expanded and Updated Technical Basis Discussion
  - R&D and Field Experience on fuel effects, dose rate reduction and nickel alloy primary water stress corrosion cracking (PWSCC)
    - PWSCC and other corrosion mechanisms work
    - Fuels impact
    - Dose rate impact
- *Extensive Operating Experience (OE)*
  - *OE now presented in a separate volume*
  - *Data from 46 plants*
- Focus Changed from Program Implementation to Program Maintenance

Zinc Sourcebook Revision

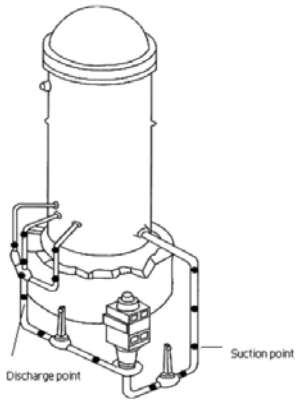
Background (1/2)

- PWR Primary Water Zinc Application Guidelines Rev. 0 published in 2006
- Need for additional guidance identified:
  - Update the current industry experience (dose reduction curves, chemical mitigation assessments, core duty base expansion)
  - Identify best practices and develop a long term zinc injection strategy for all plants, including those with high duty cores
  - Develop guidance for operational decision making related to zinc injection strategies (major component replacement, power uprate, etc.)

Standard Radiation Monitoring Programs
BRAC and SRMP

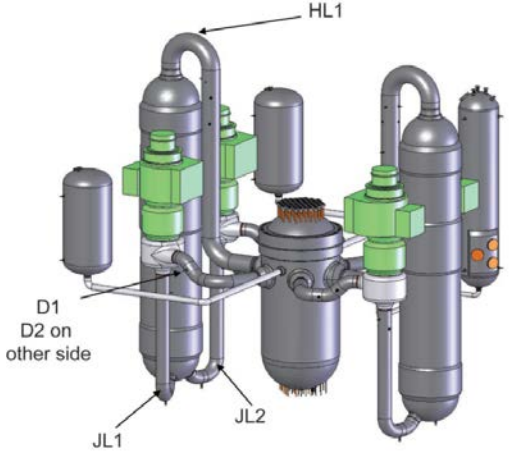
BWR Radiation Level Assessment and Control

- 1977 – current
- 2013 Report (3002000565)



PWR – Standard Radiation Monitoring Program

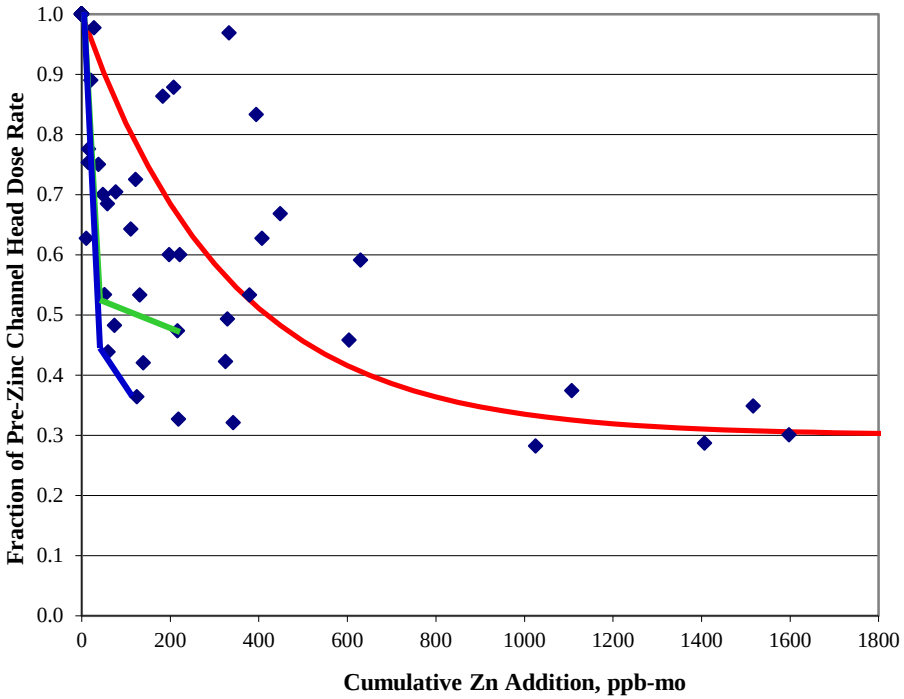
- 1978 to 1996, 2005 – current
- 2013 Report (3002000529)



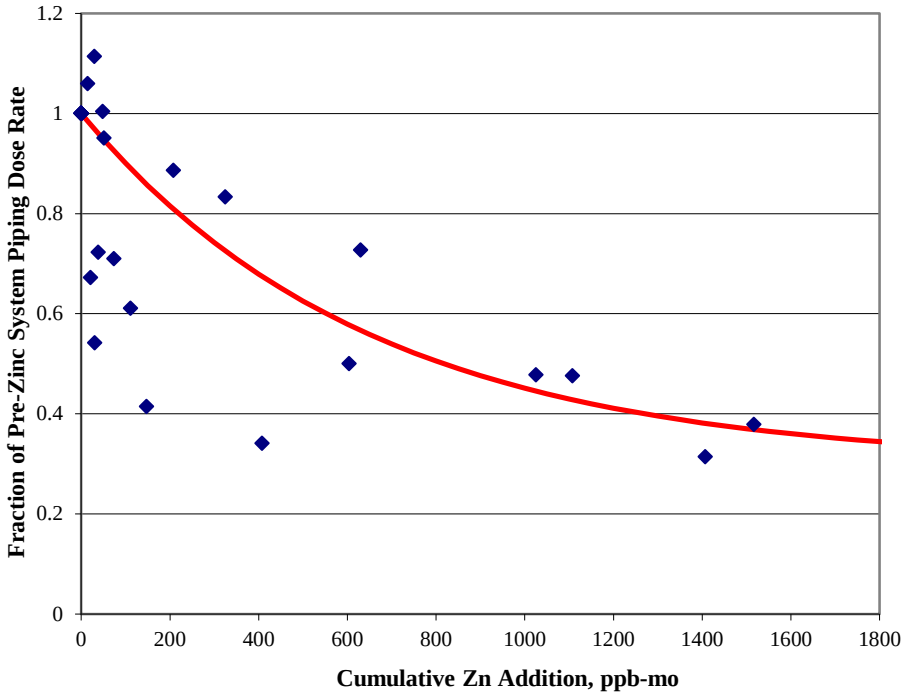
Important Uses:

1. Used to assess effectiveness of source term reduction techniques
2. Supports plant benchmarking efforts

Effect of Zinc on Out-of-Core Dose Rates



Channel Head Dose Rates

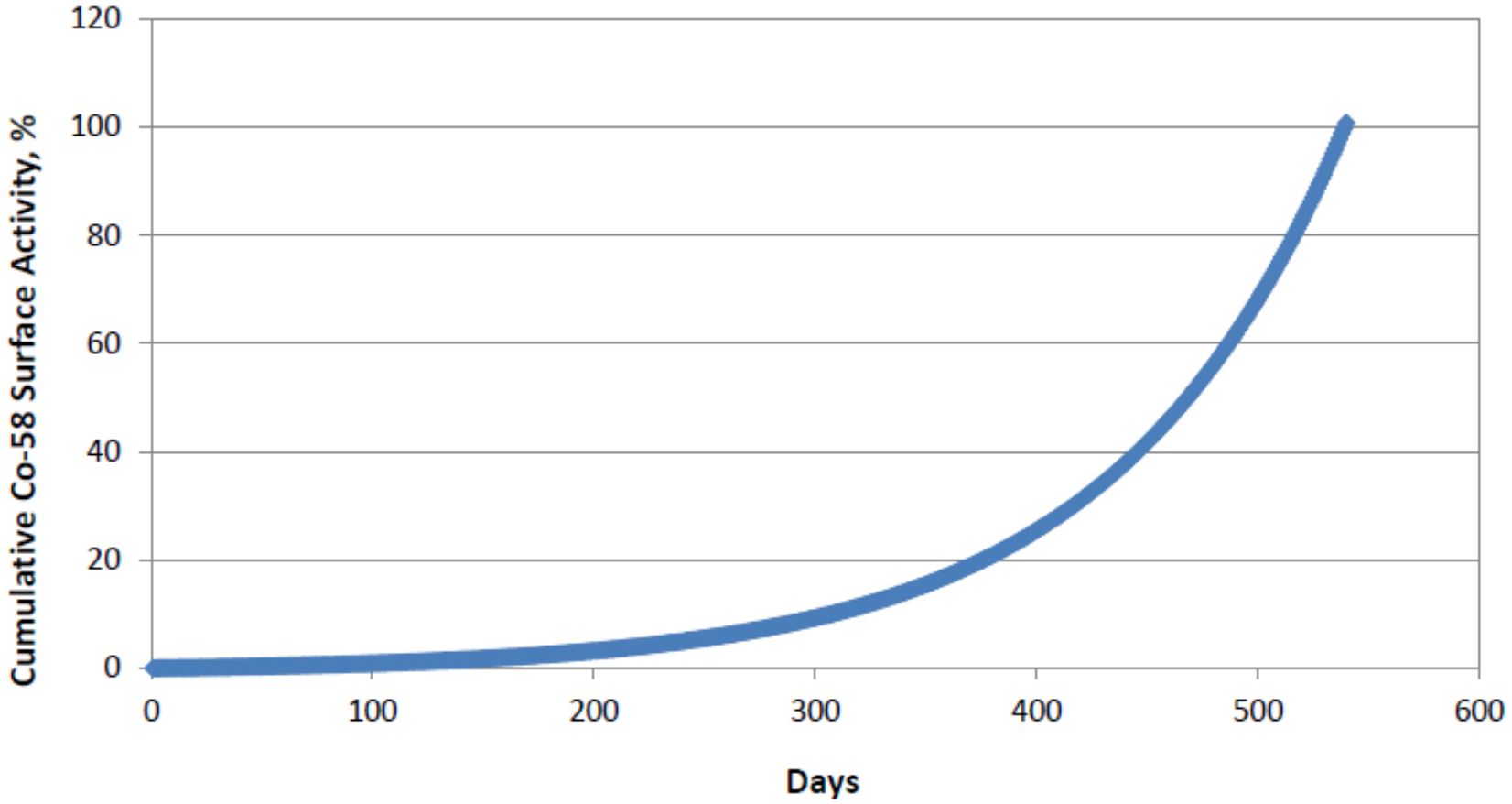


Piping Dose Rates

Long-term, dose rates expected to be reduced by a factor of three or more relative to pre-zinc levels

Co-58 Surface Activity Calculations

End-of-Cycle Impact?



Factors Affecting Zinc Effectiveness (1/2)

- Characteristics of pre-zinc oxide film
  - Age
  - Thickness
  - Morphology
  - Cobalt-60 concentration
- Zinc injection factors
  - Cumulative exposure
    - Target concentration
    - Timing of initiation/termination each cycle
  - Consistency of injection
    - Particularly periods where zinc injection is suspended

Factors Affecting Zinc Effectiveness (2/2)

- Component replacement
- Fuel effects
  - Fuel cleaning
  - Core loading
  - Core duty
  - Fuel failures
- Mid-cycle outages
- Coolant particulate burden

Zinc Related Research and Development Activities (1/2)

- PWR zinc effectiveness assessment: first cycle gamma scanning at Davis Besse
  - Will be performed during spring 2014 outage
- Effect of PWR zinc addition on corrosion product release rates: review of laboratory testing and field experience
  - Work on-going
  - Draft report under review
- Evaluation of atypical dose rate response to zinc addition
  - Scheduled completion first quarter 2014

Status of Zinc-Related Research and Development Activities and Deliverables (2/2)

- Experience summary and guidance on analytical methods for total and dissolved zinc
  - Effort started with information survey
  - Additional input and evaluation needed
- 2013 Technical Update Report
  - *PWR Zinc Addition Effectiveness Assessment: Baseline Surface Activity Concentrations by Gamma Scanning at Davis Besse. EPRI, Palo Alto, CA: 2013.3002001688.*

On Going and Future Work

- Complete evaluation of plants with atypical dose rate response
  - Conclusively identify causative factors to the extent practicable
- Determine needs for additional laboratory testing
- Develop guidance for existing zinc plants to improve effectiveness
  - Including guidance for predicting response to non-chemistry related operational factors
- Improve guidance for non-zinc plants to evaluate expected benefits on a more plant-specific basis

Key Take Aways

- PWR zinc injection has demonstrated benefits over a nearly 20-year period
  - More than 80 PWRs currently injecting
- Additional plants continuing to initiate zinc injection
- Additional research ongoing to understand key factors that influence effectiveness
  - Results will be enhanced guidance for both current and prospective zinc users

Zinc injection is an important tool in radiation reduction efforts

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