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Pressurized Water Primary Water Chemistry Optimization Strategies

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EPRI…

- To conduct research on key issues facing the electricity sector…on behalf of its members, energy stakeholders, and society.
- EPRI members generate more than 90% of the electricity in the United States
- 450+ participants in more than 40 countries
  - Within Nuclear: Argentina, Belgium, Brazil, Canada, Czech Republic, France, Japan Mexico, South Africa, South Korea, Spain, Sweden, Switzerland, United Kingdom and United States

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Overview

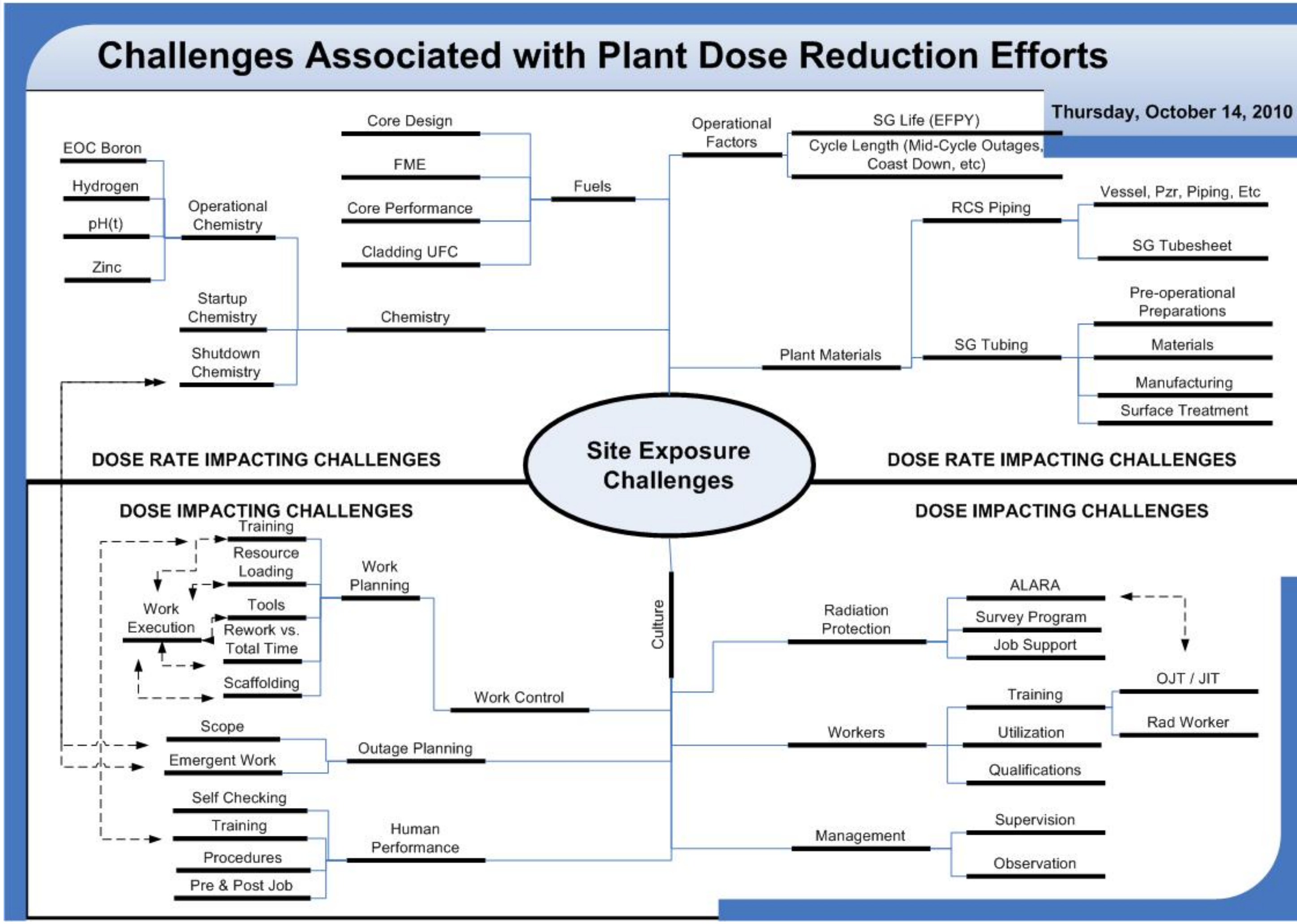
- How do we apply a chemistry control and is there a chemistry control to:
  - Minimize radiation fields in work areas to reduce radiation exposure as safely, economically, and quickly as possible.
- Can we understand and effectively manage the risk for:
  - Problematic activity releases and provide guidance to cleanup as safely and efficiently as possible

- So what are the challenges and why is it so difficult?

Potential Mitigation Strategies for Source Term Mechanisms – Where does Chemistry Impact???

Corrosion and release	• Core design modifications • Zinc injection • Fuel cleaning • Surface preconditioning of corroding surfaces
Corrosion product transport	• Chemistry environment • Temperature • Corrosion product composition
Deposition and activation on the fuel	• Distribute boiling on the fuel • Zinc injection (prevent incorporation, crud stability) • Fuel cleaning
Activated product transport	• Chemistry environment • Temperature • Crud morphology
Deposition and incorporation into surfaces	• Zinc injection • Decontamination/Flushing • Electropolishing/Stabilized Chrome • Chemistry Environment/Shutdown Ops/Fuel Cleaning

Source Term - Radiation Monitoring and Chemistry Partnership



Source Term Issues

Work Culture Issues

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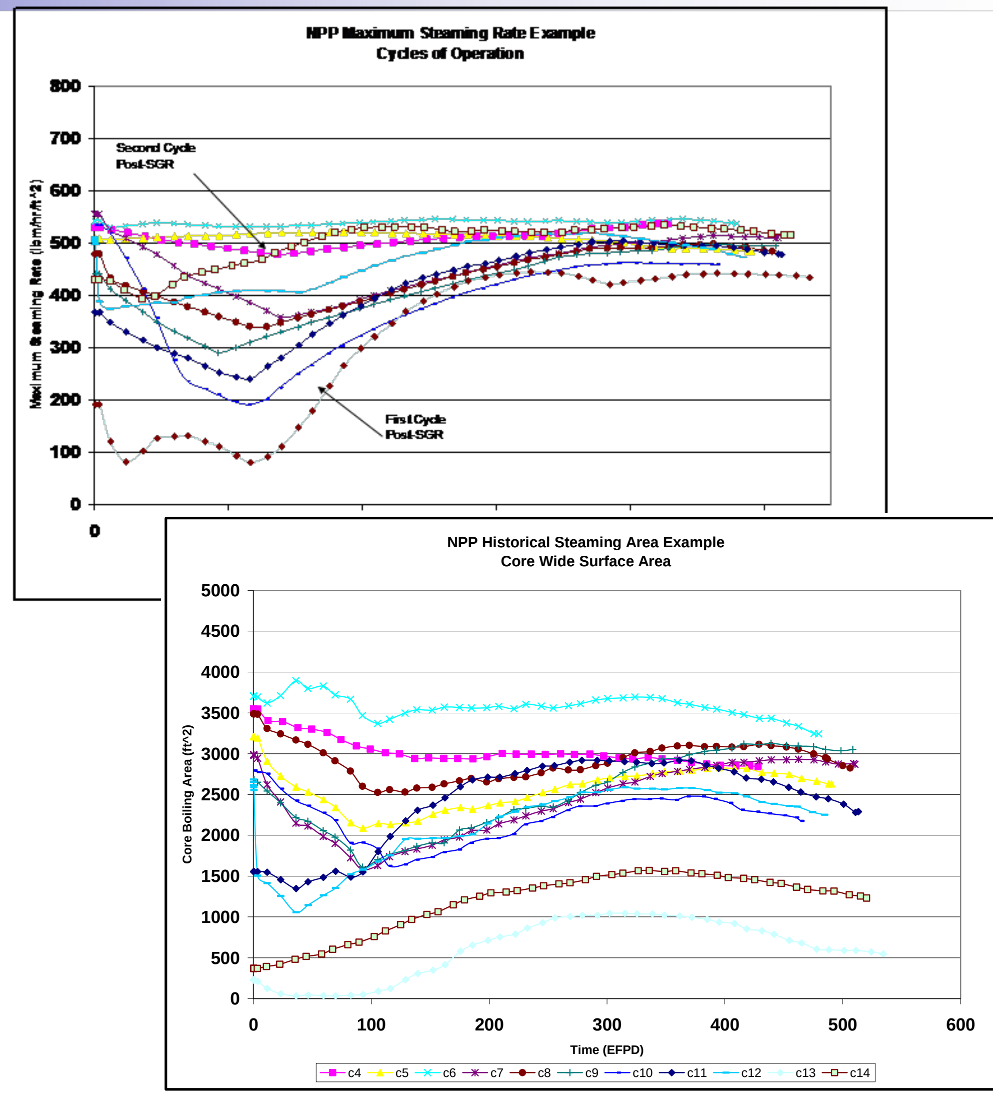
Fuel Design Impact

- Key Factors
  - How to maximize core design and balance chemistry controls.
- Impact
  - Increased fuel cladding surface mass evaporation rates and temperature results in a significant increase in soluble and insoluble deposition on fuel cladding surfaces.



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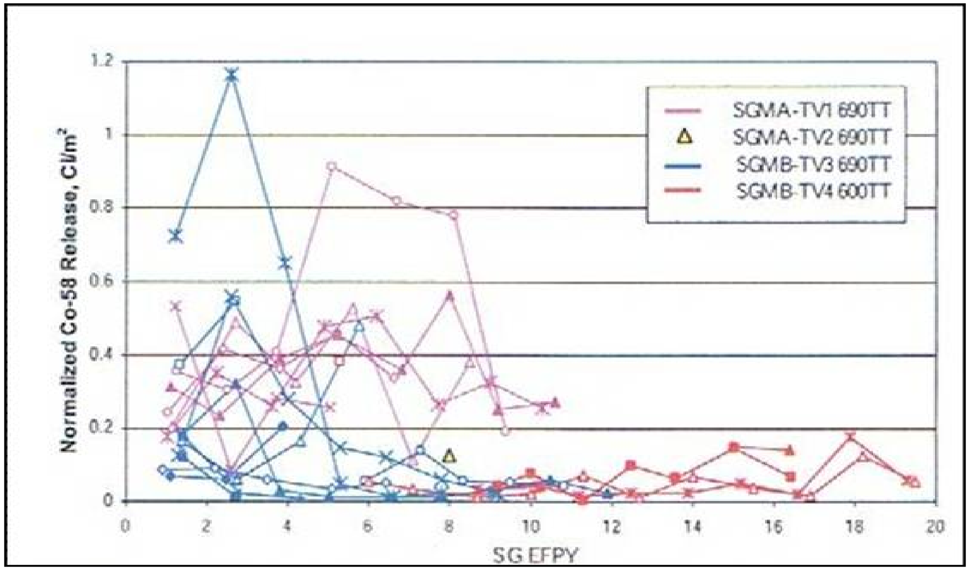
Plant Materials

- Steam generator surface Areas can exceed 50% of the overall wetted surfaces
  - With many replacements significantly increasing surface area (225,000 ft^2 to over 300,000 ft^2)
- Impact on Corrosion Products:
  - 9 – 55 kilograms of nickel and iron released.
  - With letdown purification only removing between 1 – 2 kilograms during the cycle
  - Shutdown chemistry removing 2 – 8 kilograms
  - The balance is…



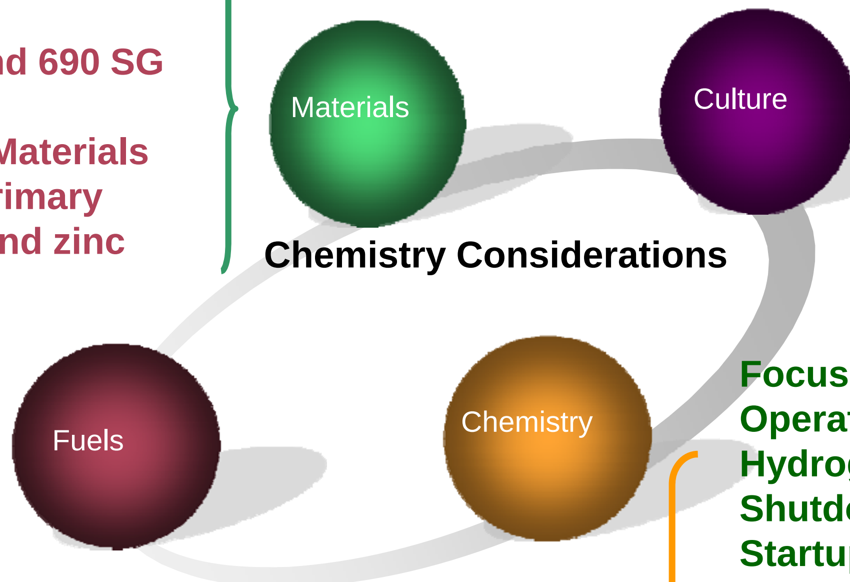
The application of a rigid Cobalt Reduction Program to minimize the cobalt entry into the plant and review of SG tubing or other replacement materials is essential in the long term aspects of operation and impact on source term

Plant Operations – Purification Flow

RCS Area	Mechanism Step	Impact of Tubing Letdown System Flowrate and Efficiency
System Materials	Corrosion Rate	No effect expected. Letdown purification system cleanup half life is too long
	Corrosion Product Release Rate	No effect expected. Letdown purification system cleanup half life is too long
	Soluble Activity Incorporation Rate	No effect expected. Letdown purification system cleanup half life is too long
	Particulate Deposition Rate	Minimal effect expected. Particulates often deposit before the purification system, half-life is too long. Downstream filter changeout reduction reported anecdotally.
Fuel Surfaces	Deposition Rate	No effect expected. Letdown purification system cleanup half life is too long
	Release Rate	No effect expected. Letdown purification system cleanup half life is too long

Chemistry Controls

Challenges
Alloy 600 and 690 SG Tubing
Other RCS Materials
Impact of Primary Circuit pH and zinc injection



Challenges
Training
Procedures
WCC and Outage Management

Focus:
Operational pH and Hydrogen
Shutdown and Startup Chemistry Controls

Challenges
Limited impact
Optimizing Shutdown Chemistry

Focus:
Optimized Core Design
Longer Cycle

Challenges
Deposition
Cladding Integrity
Failure Mechanisms

Chemistry Controls – pH_T Impact

RCS Area	Mechanism Step	Impact of pH_T
System Materials	Corrosion Rate	Lab data indicate decrease of Alloy 600/690 with increasing pH. Limited decreases noted over normal operating band.
	Corrosion Product Release Rate	Lab data indicate decrease of Alloy 600/690 with increasing pH. Limited decreases noted over normal operating band.
	Soluble Activity Incorporation Rate	Beneficial effects of a pH_T increase were noted in early generation plants. Modest benefits noted in some plants, but not all.
	Particulate Deposition Rate	Data are not available. Effects could be significant since deposition will depend on the particle zeta potential.
Fuel Surfaces	Deposition Rate	Effects could be significant since deposition will depend on the particle zeta potential.
	Release Rate	Data are not available.

Chemistry Control – Zinc Injection (PWR)

RCS Area	Mechanism Step	Impact of Zinc
System Materials	Corrosion Rate	Laboratory data indicate that zinc injection significantly reduces corrosion rates of major system materials.
	Corrosion Product Release Rate	Laboratory data indicate that zinc injection significantly reduces corrosion product release rates of system materials.
	Soluble Activity Incorporation Rate	Laboratory and plant data indicate a significant decrease in incorporation of soluble activity into stainless steel and Alloy 600 surface films.
	Particulate Deposition Rate	The effect of zinc on particulate deposition has not been studied.
Fuel Surfaces	Deposition Rate	The effect of zinc on soluble and particulate deposition in the core has not been studied.
	Release Rate	The effect of zinc on activity release rates from PWR core deposits has not been studied.

Zinc Program

Farley Zinc Injection	Zinc Solubility Studies	Industry Zinc Workshop	Zinc Injection Guidelines		Zinc Transient Model	Zinc Users Group Workshop	Component of Chemcial Mitigation	
1994	2001	2004	2005	2006	2007	2008	2009	2010

Objective:

- Provide utilities with a comprehensive zinc program focused on chemistry, materials, nuclear fuel and radiation management with an open forum focusing on industry activities.

Description:

- The EPRI Zinc program combines the technical and leadership resources required to successfully apply zinc in pressurized water reactors.

Results to Date:

- 73 plants are currently injecting zinc with an additional 15 planning injection for the future using the EPRI PWR Zinc Injection Guidelines for guidance

Benefits:

- The coordinated multidisciplinary EPRI Team focused on all aspects of RCS zinc injection (materials, radiation management, chemistry, fuel)

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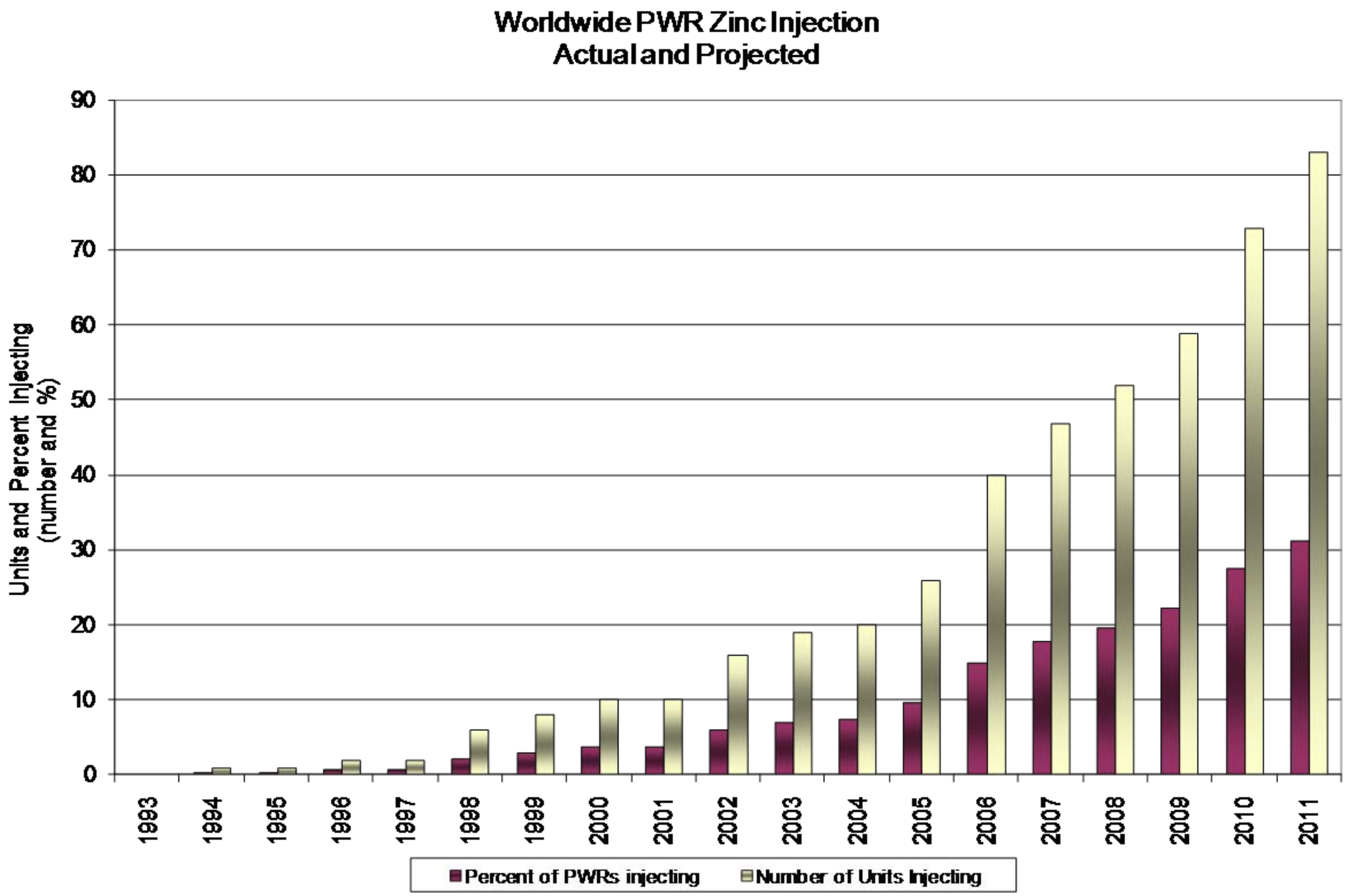
Zinc Addition Worldwide



Zinc Injection – Application of Zinc and Impact on Fuel

EPRI Fuel Reliability Program Objective

To ensure fuel integrity and performance are not challenged from zinc injection.

Approach

– Methodical – theoretical / laboratory / plant demonstration

- Apply zinc at low duty units first and transition to higher duty plants

Plant Demonstrations: Increasing Fuel Duty

Farley » Diablo Canyon » Callaway » Vandellos II » Braidwood/Byron 1

EPRI Sponsored Fuel Surveillances

PWR Zinc Application –
Fuel Performance

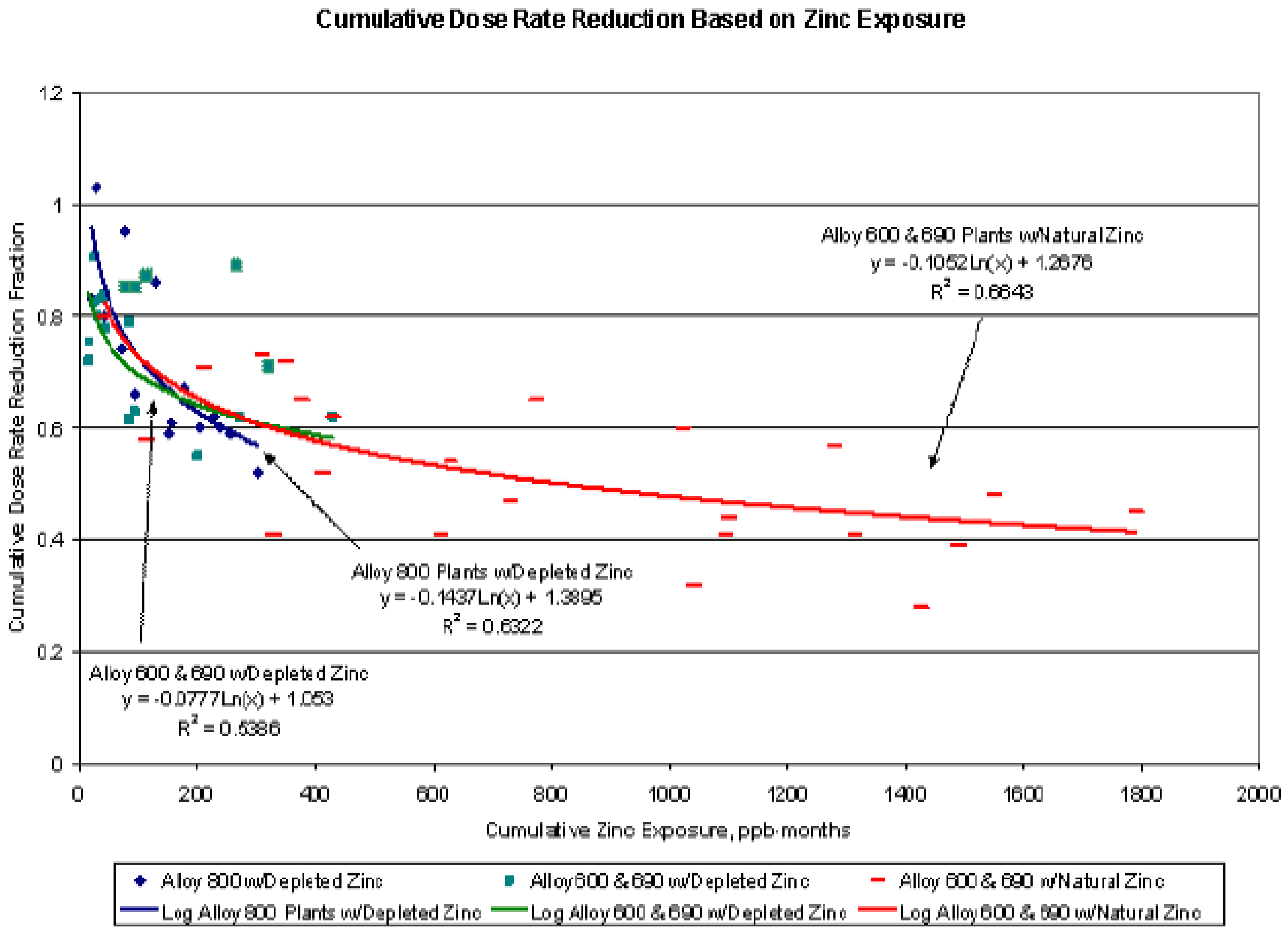
History

- Over 6500 ppb-months exposure in the current database.
- M-5™ Cladding Exposure is increasing.
- Zirlo™ has the most exposure in the industry database with over 5700 ppb-months exposure.
- Zinc addition modeling tool developed for fuel assessments

Some Conclusions to Date

- Zinc has not caused an increase in fuel cladding corrosion at any of the EPRI sponsored campaigns or others that we are aware of.
- No abnormal buildup of crud has been observed
- No fuel performance issues (i.e. AOA, IRI) have been linked directly to zinc injection

Dose Reduction Curves (EPRI Report 1013420)



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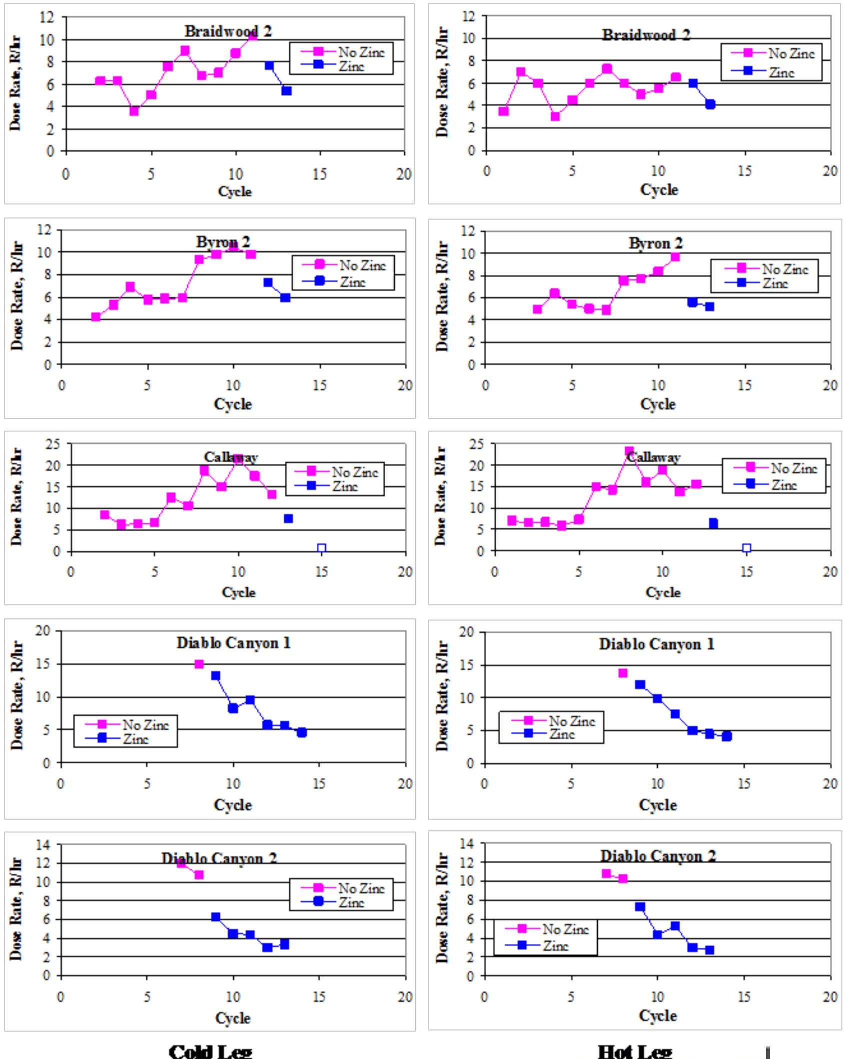
Dose Rates: Effects of Zinc

- Most plants show impact of zinc injection on channel head dose rates



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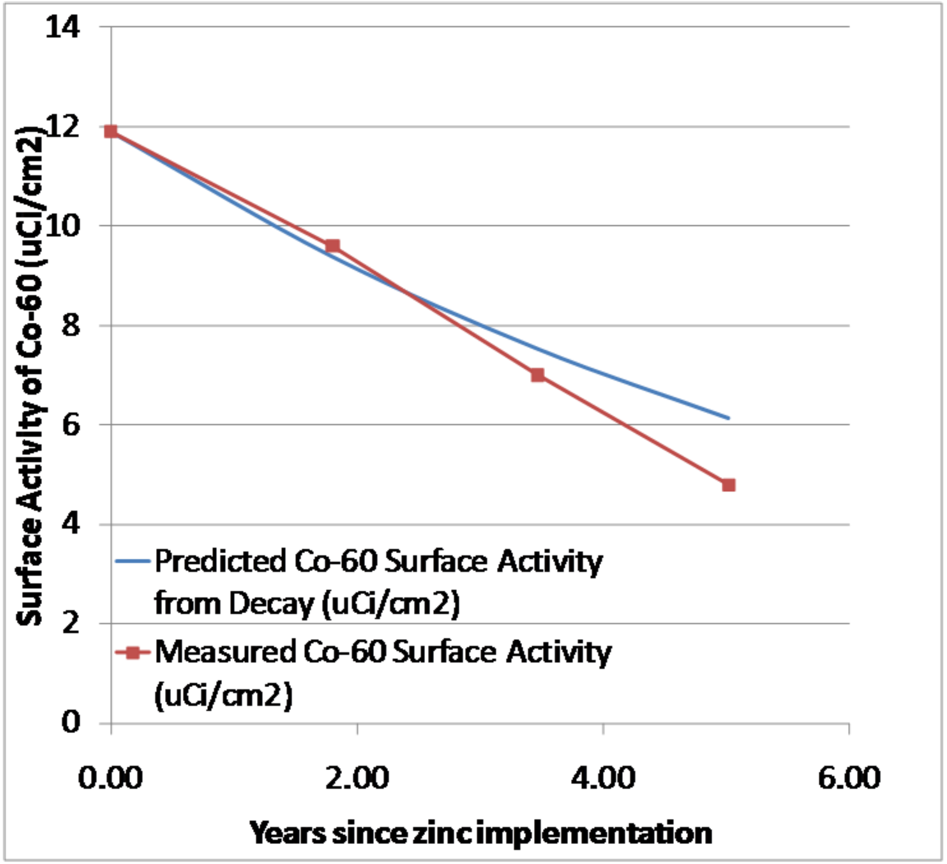
Zinc Injection Impact on Radiation Fields

- Several examples of positive impact of zinc
- Diablo Canyon 1 is most striking
  - Cobalt-60 decay curve is followed
  - Implies no additional activity deposition



For Diablo Canyon 1, since zinc injection, Cobalt-60 surface loading follows Co-60 decay curve at Diablo Canyon 1

Shutdown Chemistry

- What is Shutdown Chemistry?
  - It is not a chemical decontamination methodology!
  - It is not intended to reduce dose rates
    - At best a 2 – 3% reduction may be observed with a well managed shutdown chemistry program
  - Shutdown Chemistry is:
    - *"Prepare the plant for a refueling or mid-cycle outage in as short a time as possible without negatively impacting on shutdown dose rates or particulate contamination levels and associated contamination events."*

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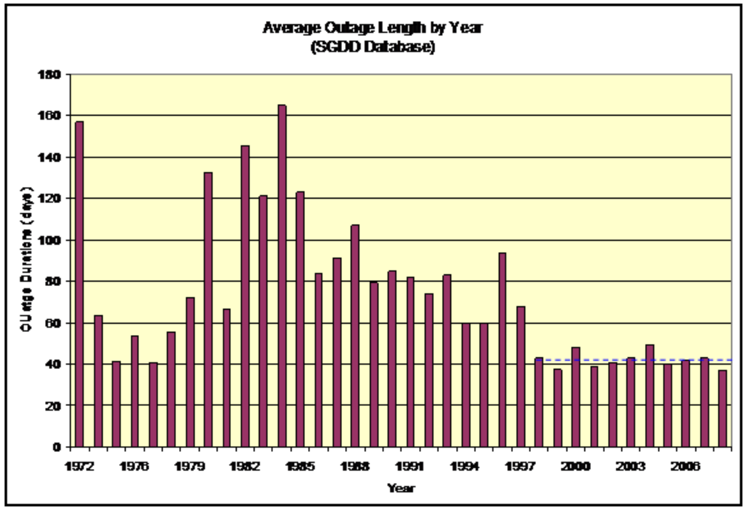
EPRI Studies – Effect of Plant Design and Chemistry on Shutdown Releases and Dose Rates

- Understood or Key Factors To Consider on Shutdown Releases and Dose Rates:
  - EFPY, Steam Generator (Area, Materials and Surface Finish), Core Duty, Chemistry (pH_T and Zinc Addition)

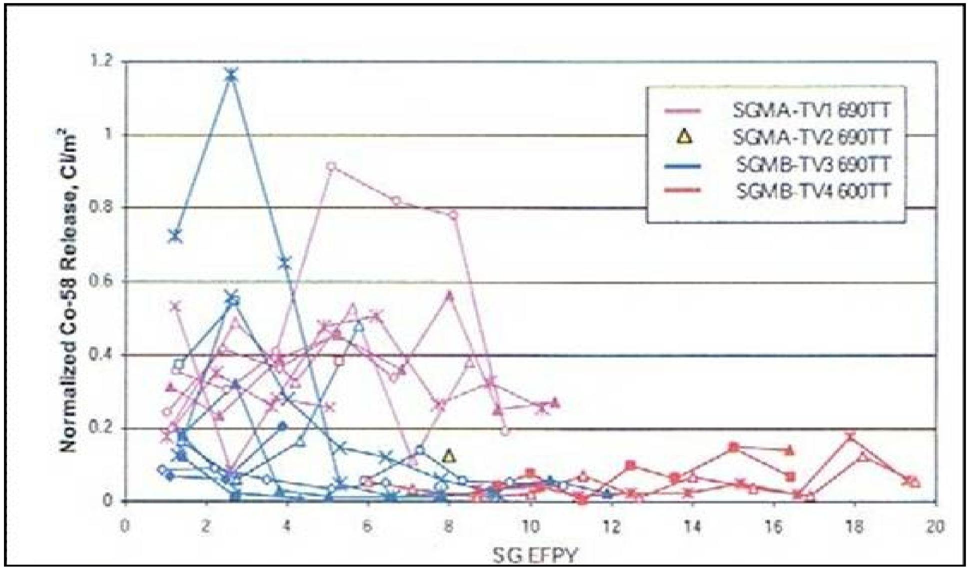
- Other Factors to Consider Related to Shutdown Release
  - Steam Generator Manufacturing Process
  - Plant Operations – Cycle Length, Mid-Cycle Outages, Trips, etc
  - Fuels – Ultrasonic Fuel Cleaning
  - Shutdown Chemistry Evolution

- Chemistry Controls
  - EOC Boron
  - pH Program
  - Letdown and Cleanup
  - Zinc Injection



Shutdown Chemistry

- A review of shutdown chemistry results attempting to compare different manufacturing, operation, fuel design, etc.
  - Results were normalized to surface area and volume
  - Material factor alone does not contribute to the different behaviors



Shutdown chemistry not performed consistently and with proper controls can and as resulted in significant particulate releases. These releases will create significant issues related to outage dose

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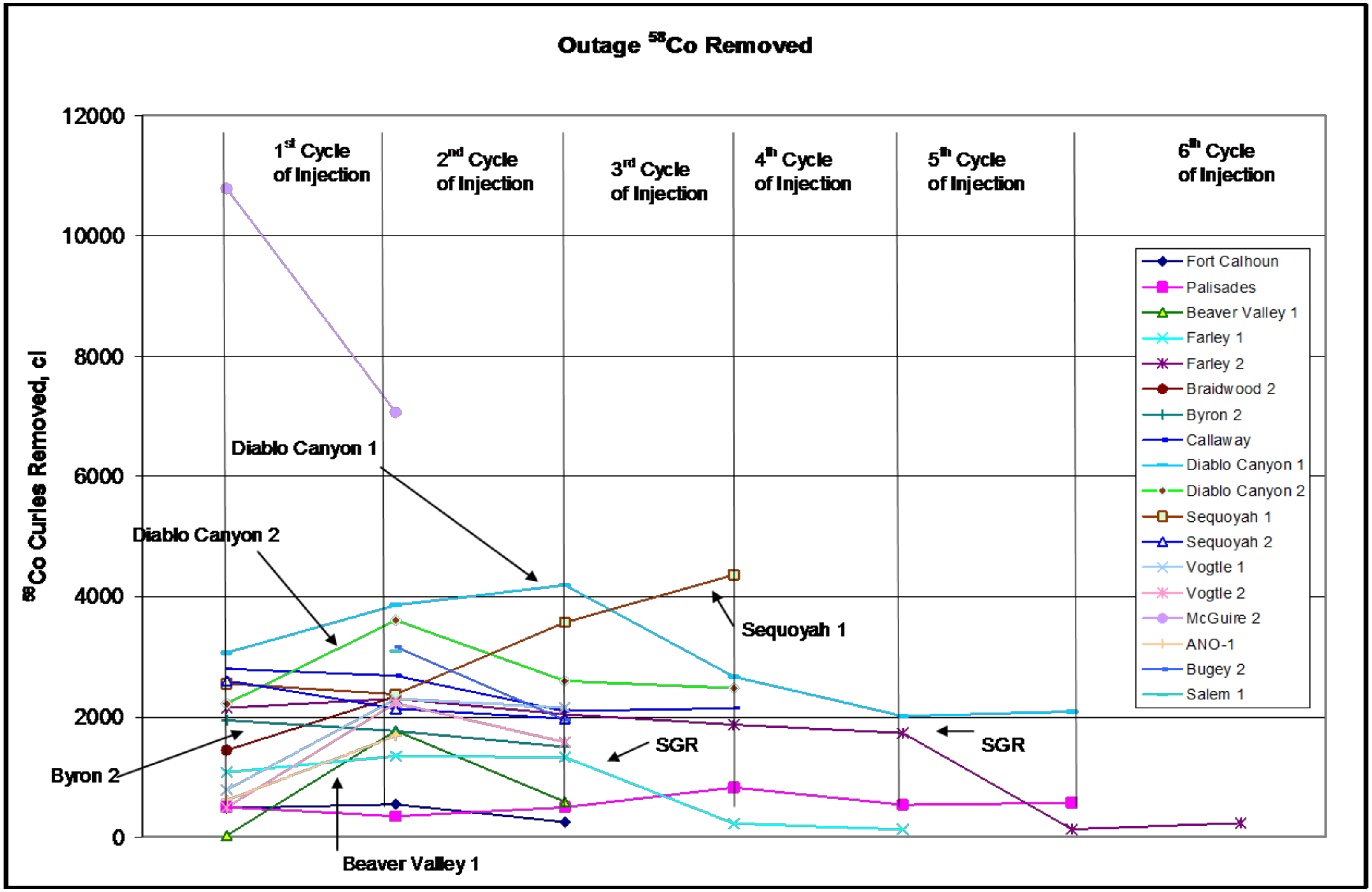
Zinc Impact on Shutdown Releases



Chemistry Controls - Conclusions

- Source Term as shown is a complex process.
  - A coordinated approach is required to develop a strategy
    - Teaming with Fuels, Materials (Engineering), Chemistry, and Radiation Protection is Essential
  - Benchmarking Considerations are Very Difficult
    - Plant-to-Plant Differences
      - Operating cycle history
    - Core Design Differences
    - Chemistry Controls
      - Operating and Shutdown Processes