ELECTRIC POWER RESEARCH INSTITUTE

Industry Zinc Injection Update

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

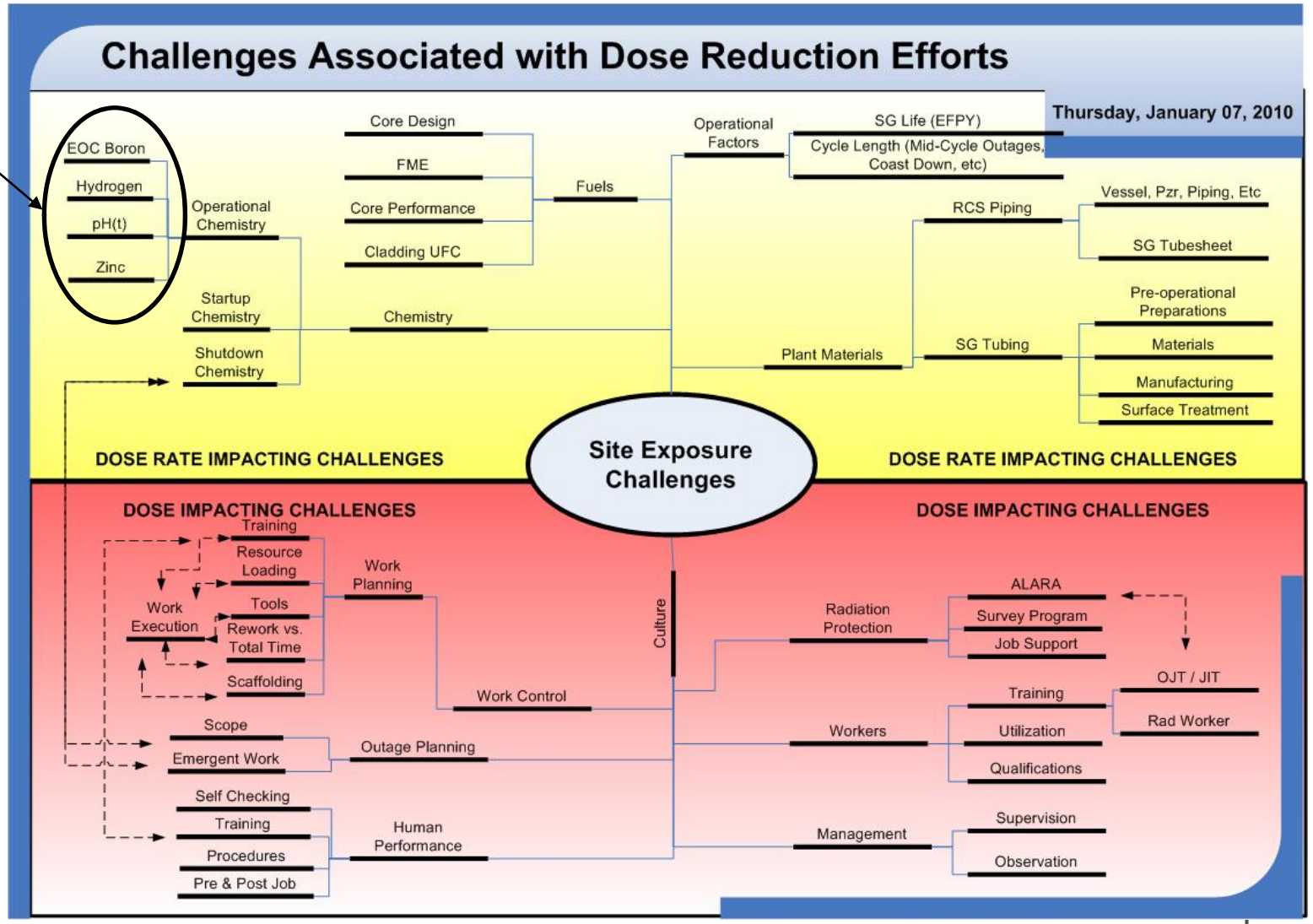
- Understood or Key Factors To Consider on Shutdown Releases and Dose Rates:
  - EFPY
  - Steam Generator Area, Materials and Surface Finish
  - Core Duty
  - Chemistry - pH_T and Zinc Addition

- Other Factors to Consider Related to Shutdown Release
  - Steam Generator Manufacturing Process
  - Plant Operations – Cycle Length, Mid-Cycle Outages, Trips, etc
  - Fuels (other Factors)
    - Ultrasonic Fuel Cleaning
    - Surface Area, etc
  - Shutdown Chemistry Evolution
    - Example: Reactor Coolant Pump Operation

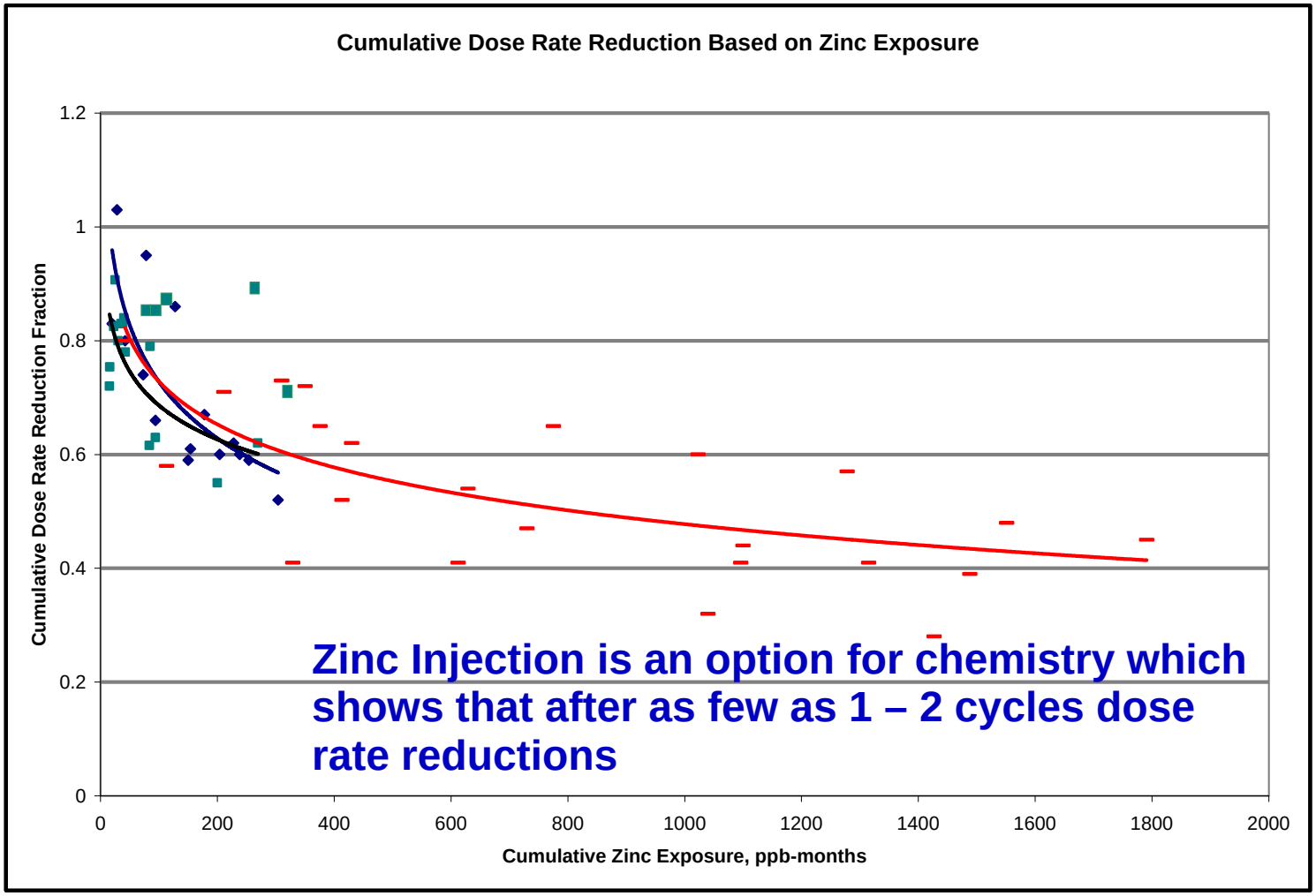
- Chemistry Controls
  - EOC Boron
  - pH Program
  - Letdown and Cleanup
  - Zinc Injection
    - Zinc Injection continues to show a positive impact on dose rates.
    - Reductions in steam generator and piping dose rates were routinely observed following zinc addition with over 80 cycles of data collection efforts.

What Can The Chemist Impact With So Many Variables?

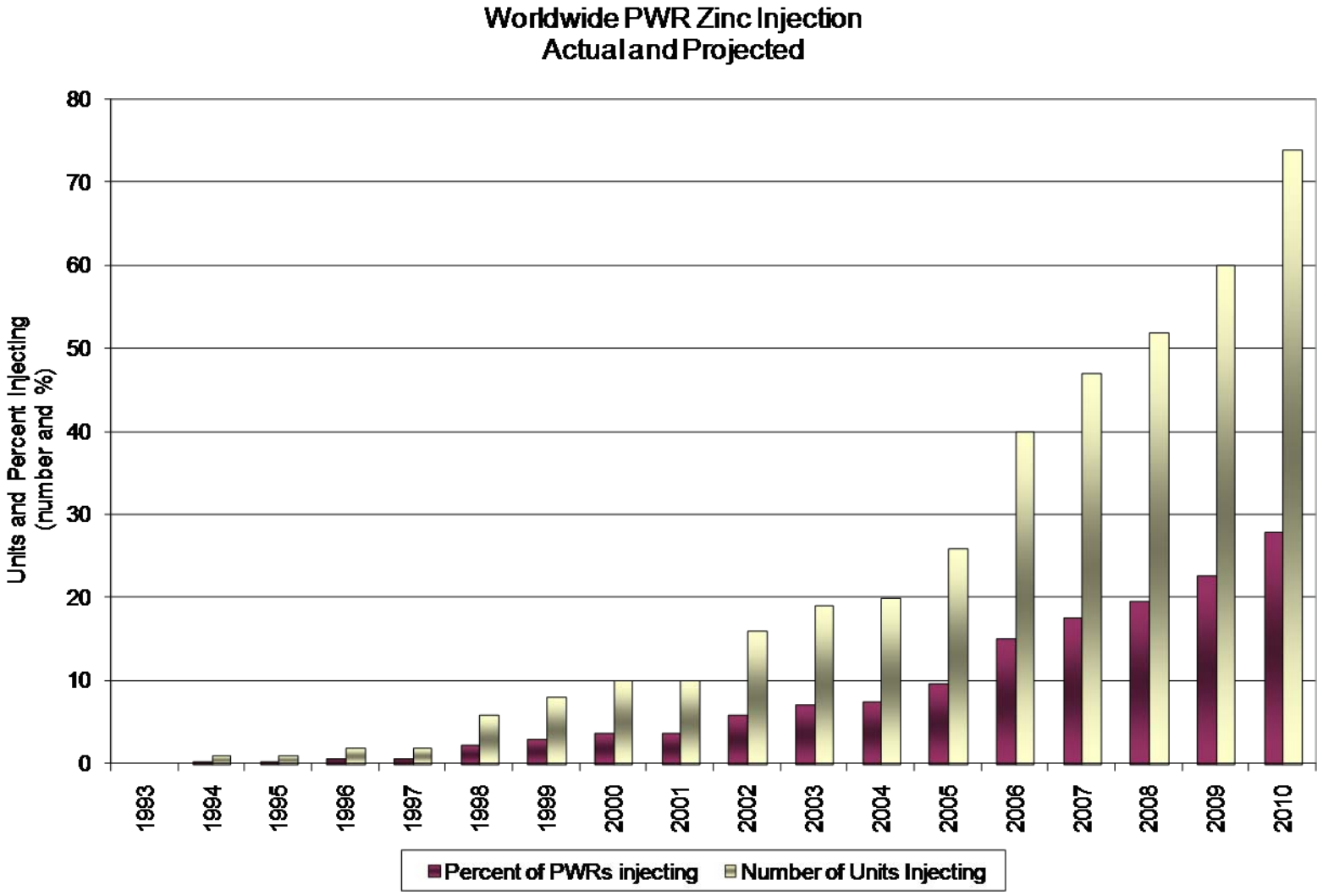
Chemistry Controls



Current Status on Zinc Injection



Pressurized Water Reactor (PWR) Zinc Injection Experience Growing Worldwide



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An Overview of the EPRI Zinc Program

A comprehensive zinc program focused on chemistry, materials, fuels and radiation management with an open forum focusing on industry activities :

- Radiation Field Management - Radiation Protection Program
  - Standardized monitoring approach (SRMP)
  - Collecting, maintaining and evaluating industry data for zinc and non-zinc plants
- Primary Water Stress Corrosion Cracking (PWSCC) Benefits - Materials Reliability Program
  - Potential chemical mitigation option for PWSCC
    - Initiation and/or mitigation
    - Inspection
  - Combined benefit with elevated RCS Hydrogen
- Fuel Performance – Fuel Reliability Program
  - Corrosion Product Management
  - High duty cores
  - CRUD changes

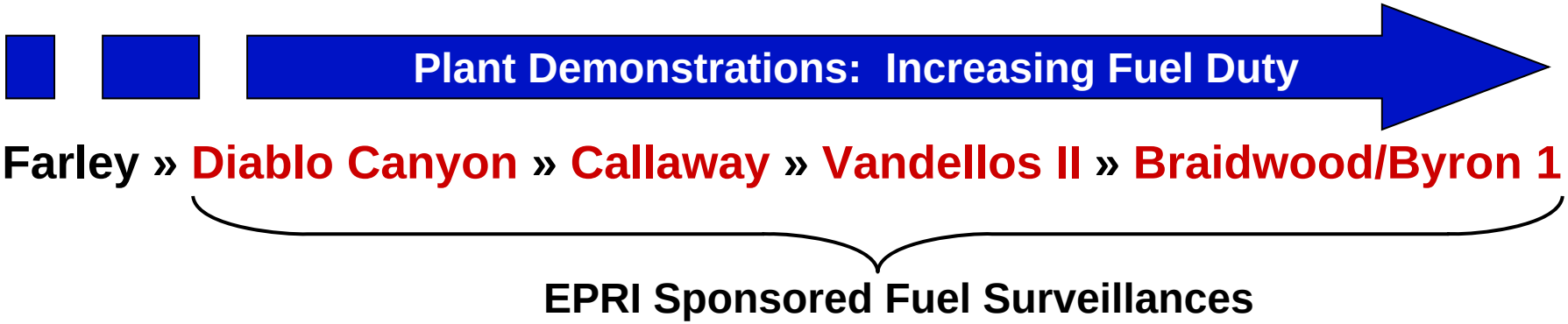
Zinc Injection – Fuel Performance

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



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

Strategy for Applying Zinc in PWRs

What have we learned?

Historical Concerns with Zinc Injection

1. Zinc injection has been observed to cause step increases in coolant **radiocobalts** – suggesting that transition metals would also increase
2. Biblis B and Unterweser reported elevated **Fe** concentrations upon injecting zinc
3. Zinc crud in BWRs is known to be more **tenacious** than non-Zn deposits and contains up to **35 wt% zinc**
4. **Zinc silicate** was measured in deposits in the SNB region of the fuel stack at a U.S. BWR

EPRI Fuel Reliability Program Zinc Program Observations

1. Increases in **radiocobalts** have been observed at many plants while little or no increases have been observed at some.
2. No increase in **Fe** or **Ni** was observed at Vandellos II in either Cycle 15 or 16
   - Alloy 600TT SG tubes
3. No **tenacity** information, but thus far the highest measured zinc fraction contained in PWR crud is **~7.5 wt%**
4. No **zinc silicate** (or Zn ferrite) has been measured in any of the FRP-sponsored plant demonstrations, nor have any such deposits been reported from other PWR campaigns

Zinc Injection – Materials and PWSCC

- Zinc has shown to date to be compatible with all RCS materials
- Zinc continues to show benefits for reduction of PWSCC initiation
- Little or no improvement in mitigation of crack growth rate for thick walled components
  - Looking at combined effect with elevated RCS hydrogen for chemical mitigation
  - Some benefit seen for steam generator tubes

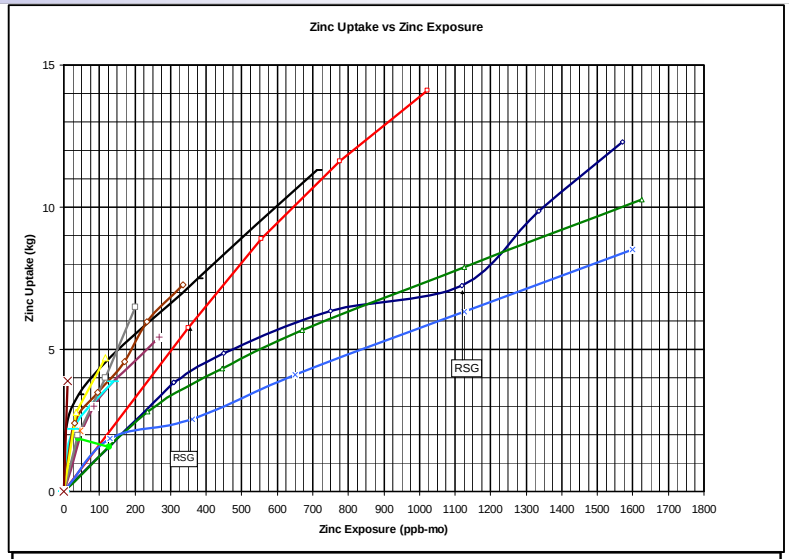
Zinc Injection – Chemistry

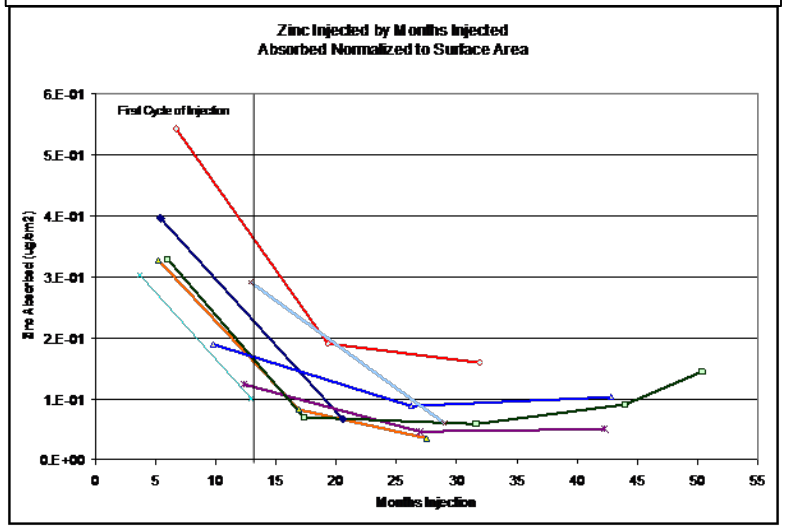
Chemistry Impact

- Apparent reduced zinc demand as zinc exposure increases
- Plants routinely show a reduced zinc demand after 2 – 3 cycles of injections

Continued Evaluations…

- Is there an equilibrium or amount of zinc that utilities can adjust their program and maintain effect?
  - Maintenance Program vs. Injection Program
- Quantify impacts of cycle to cycle changes
  - Core design changes
  - New RCS materials





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Zinc Injection – Chemistry

Chemistry Impact

- Observation:
  - Variable chemistry response to zinc addition
    - Nickel and iron trends vary by plant and materials

Continued Evaluations ..

- Impact of
  - steam generator replacement
  - corrosion products with high duty cores
    - Alloy 600 vs. 690 vs. 800
  - Combined with Elevated pH Program or Elevated Hydrogen Program
  - Cycle Changes

Material	*Corrosion*		*Corrosion Release*	
	with Zn	*w/o Zn*	*with Zn*	*w/o Zn*
600 MA	1.5	2.6	0.3	0.8
600 TT	0.5	2.1	0.2	0.9
690 TT	0.2	1.3	0.1	0.6

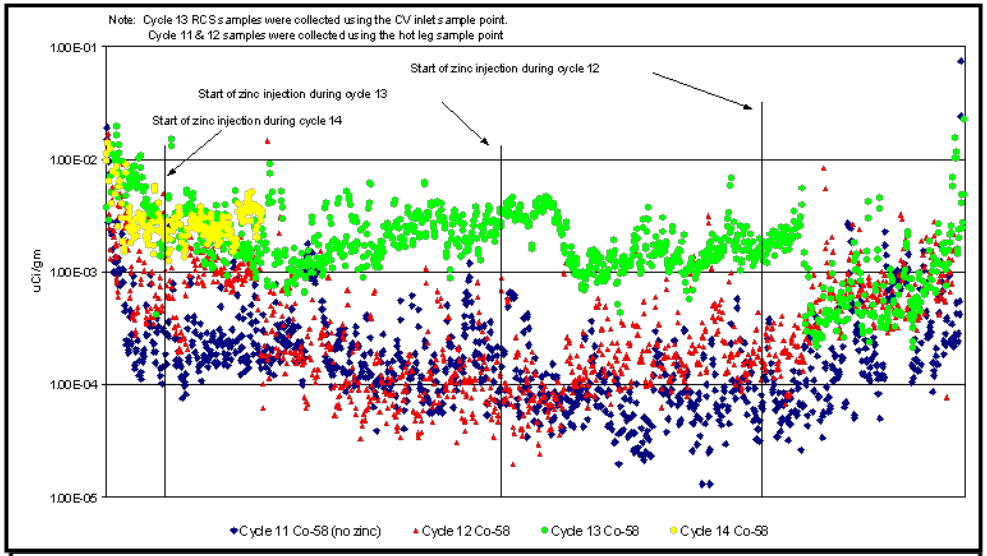
Zinc Injection – Radio-Cobalt Trends

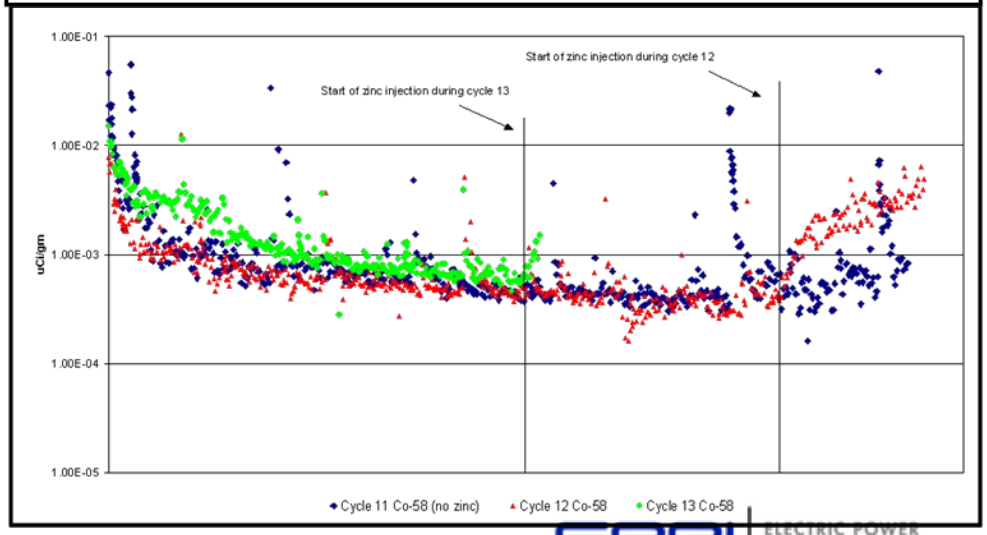
Chemistry Impact

- In general plants may observe a factor of 8 to 10 times increase in cobalt levels compared to pre-zinc levels
  - In several cases plants have not observed any increase
  - In at least one case a factor of 1000 increase was observed

Continued Evaluations…

- Why the difference and is it related to materials (i.e. SG tubing, etc.)…
- Is it related to core design …

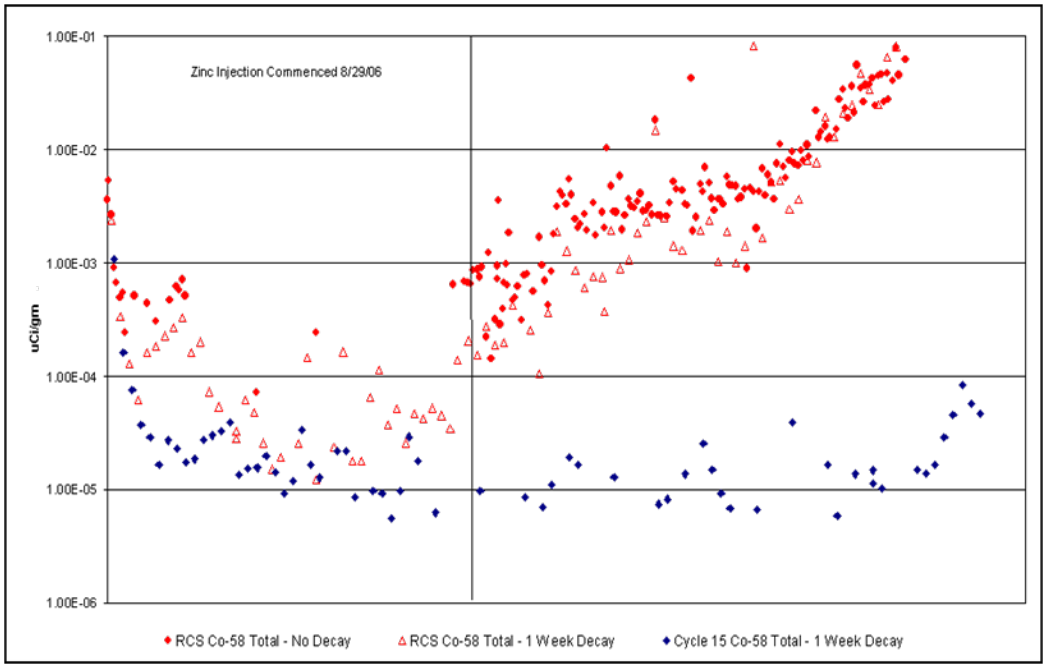




Zinc Injection – Radio-Cobalt Trends

Chemistry Impact

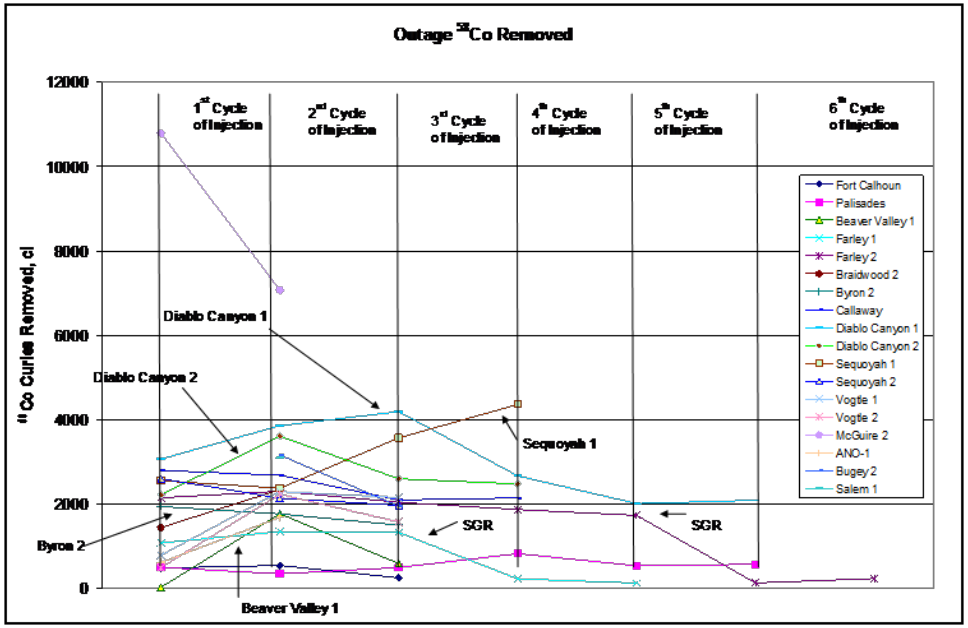
- There have been 2 units that showed a different trend.
  - Co-58 increased to greater than 0.1 µCi/ml and stayed elevated for duration of cycle.



Zinc Injection – Shutdown Releases

Impact on Shutdown Release

- No clear correlation of zinc exposure on peak post peroxide ^{58}Co concentration for Alloy 690 or Alloy 600 plants
- Alloy 690TT plants peak ^{58}Co concentrations appear slightly higher than for Alloy 600 plants.

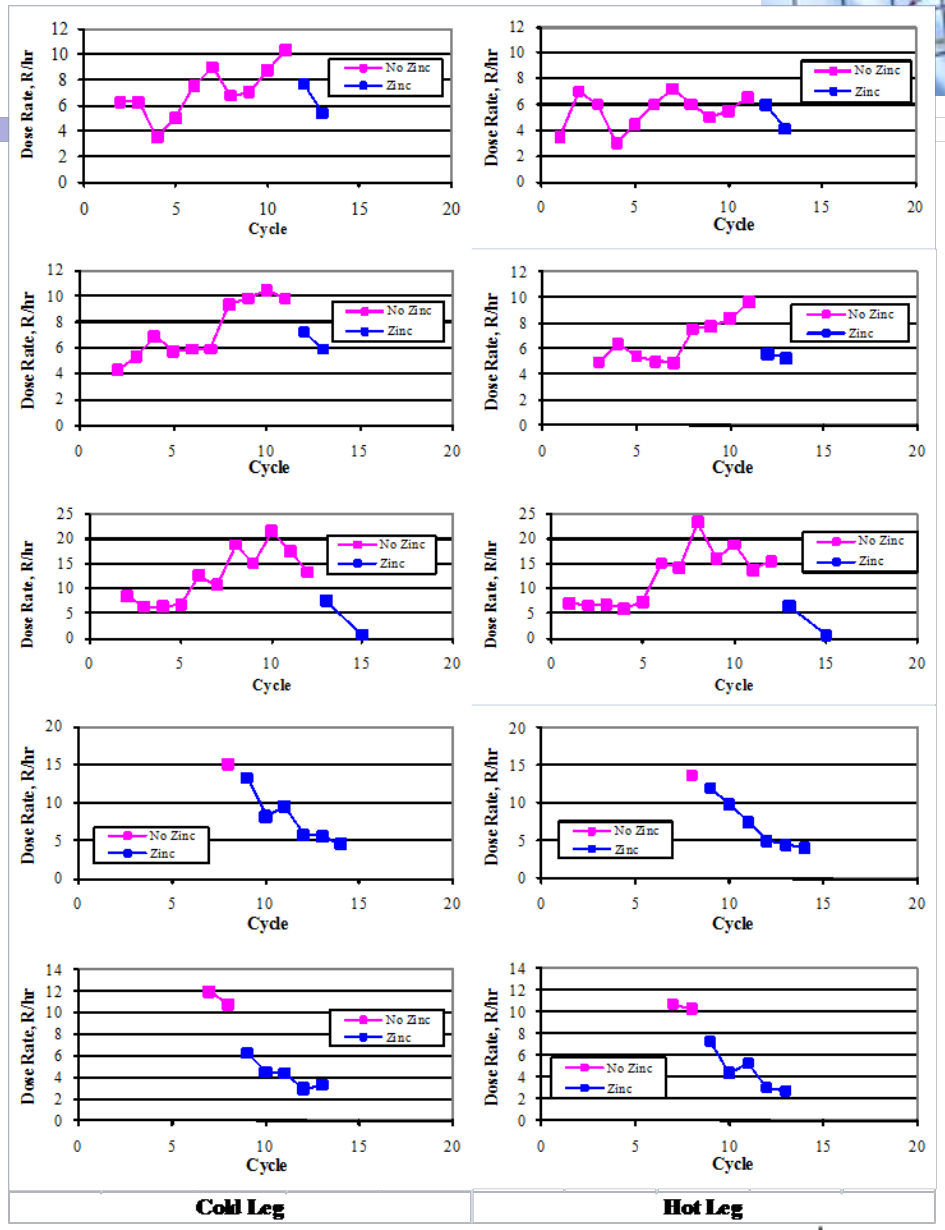


Continued Evaluations …

- Assess differences in shutdown releases for zinc and non-zinc plants to be able to estimate impact of long term zinc injection

Dose Rates: Effect of Zinc On Channel Head Dose Rates

- Most plants start to see a reduction in dose rates following the first cycle of injection
- The dose reductions observed are consistent with expectations and the industry database



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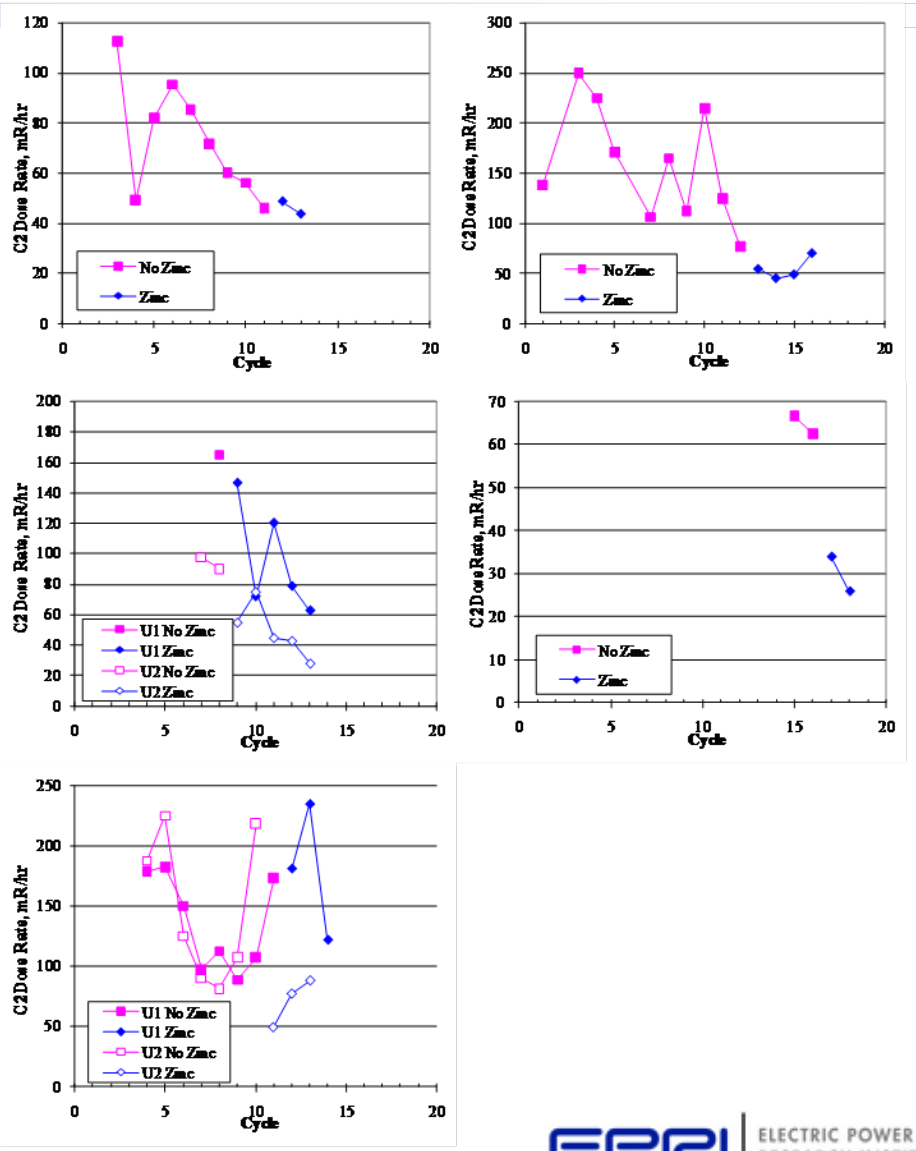
Dose Rates: Effect of Zinc On Loop Dose Rates

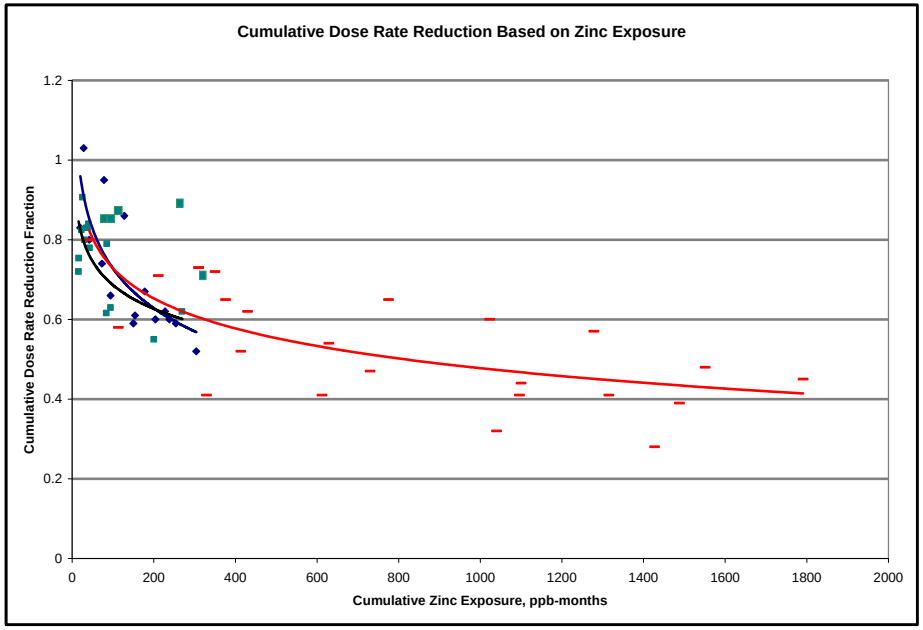
- Loop dose rates follow a similar trend and reductions can be observed in most cases following the first two cycles of injection.



Zinc Injection Guideline – Dose Rates

Dose Rate Trends

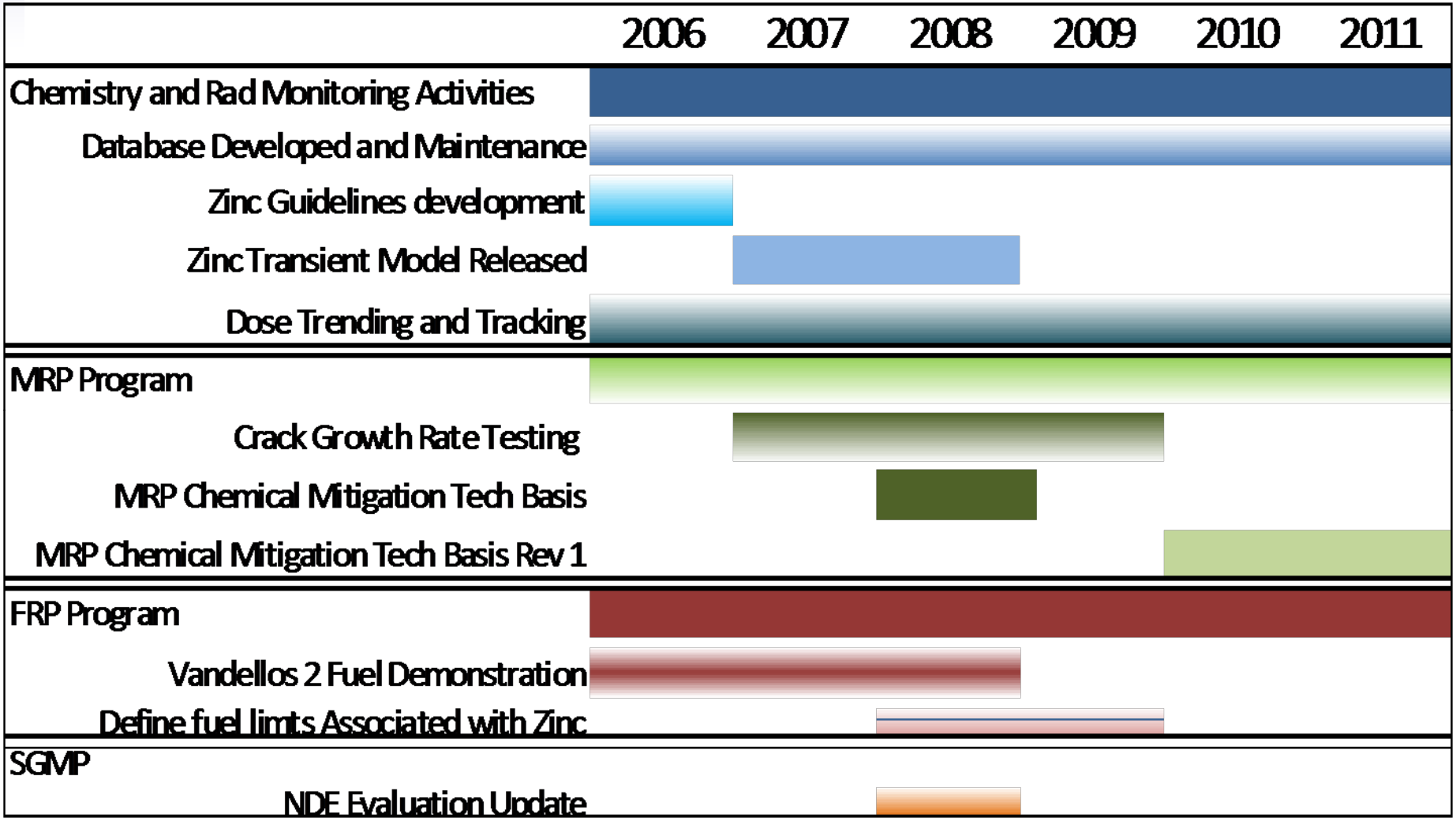
- Long term injection continues to show a dose reduction benefit.



Continued Evaluations …

- Zinc injection using depleted zinc and affect of transition to depleted from “natural” zinc
- Root cause assessments of unexpected results
  - Initial Bugey and Biblis cycle results
  - Impact of power transients during the cycle on dose rates (Palisades)?
- Load-follow plant operation results with zinc injection

EPRI Zinc Addition Program Schedule



Zinc Injection

Current Status

- Over 25% of the fleet pressurized water reactors will be injecting zinc within the next 2 years.
- Zinc injection is not a “Fad” or “Flavor of the Month” but a viable option for plant chemist as part of an overall integrated strategy.
- Zinc injection has shown to reduce dose rates after the first 1 – 2 cycles of injection
- Low, medium and high duty are Injecting and to date there has not been fuel performance related issues
- Zinc Injection shows a favorable impact on PWSCC crack initiation