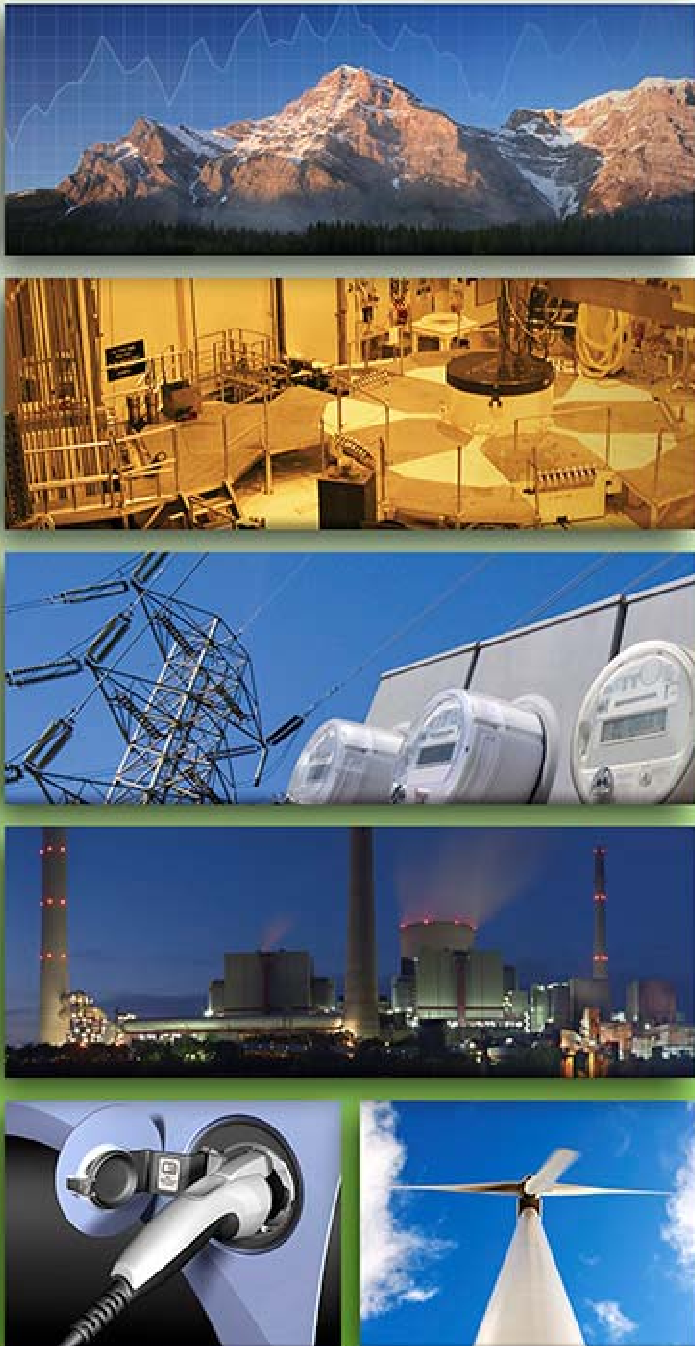

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EPRI Chemistry Guideline Recommendations for Minimizing Dose Rates During Shutdowns

ISOE/EPRI Radiation Protection Conference

January 10 – 13, 2011

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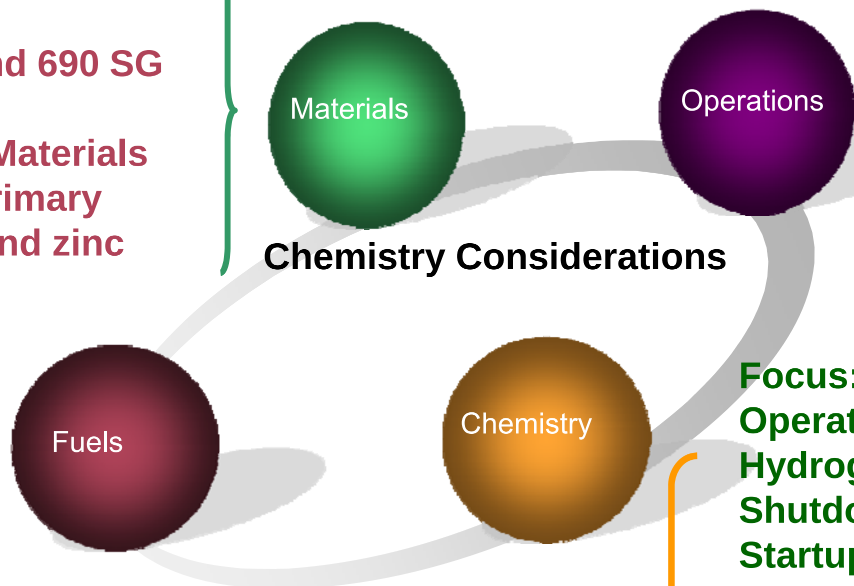
Presentation Goals

- Chemistry
  - Awareness of on-going EPRI efforts to understand and control dose rates
- Radiation Protection
  - Awareness of what Chemistry **can** and **can not** do to reduce dose rates

Chemistry Balance

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



Challenges:
Shortened Outages
Purification Flowrate
Major Component Replacements

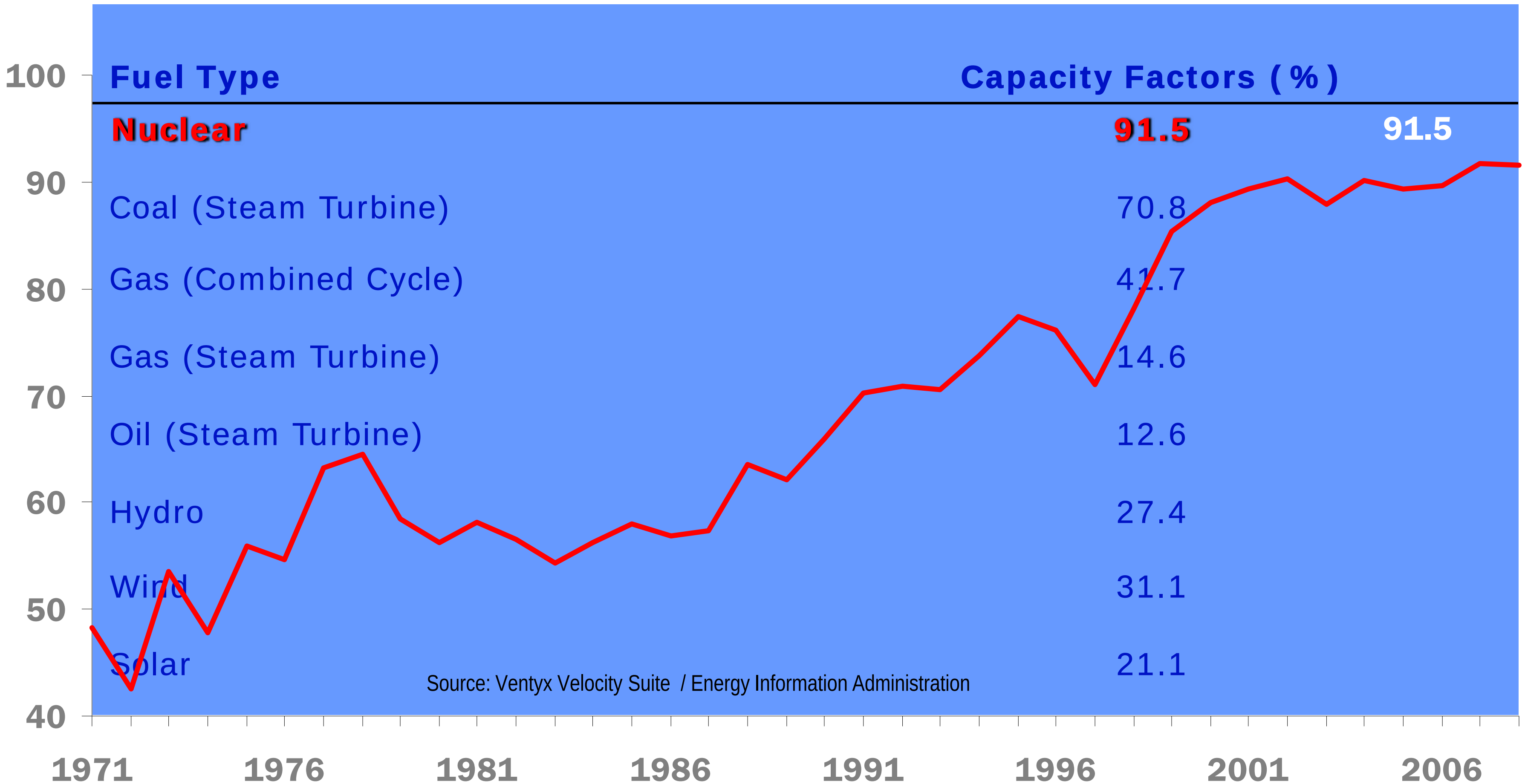
Focus:
Operational pH and Hydrogen
Shutdown and Startup Chemistry Controls

Challenges:
Limited impact
Optimizing Shutdown Chemistry

Focus:
Optimized Core Design
Longer Cycle

Challenges:
Deposition
Cladding Integrity
Failure Mechanisms

U.S. Capacity Factors – Why or Does Shutdown Chemistry Impact?



Fuel Type	Capacity Factors (%)
Nuclear	**91.5**
Coal (Steam Turbine)	70.8
Gas (Combined Cycle)	41.7
Gas (Steam Turbine)	14.6
Oil (Steam Turbine)	12.6
Hydro	27.4
Wind	31.1
Solar	21.1

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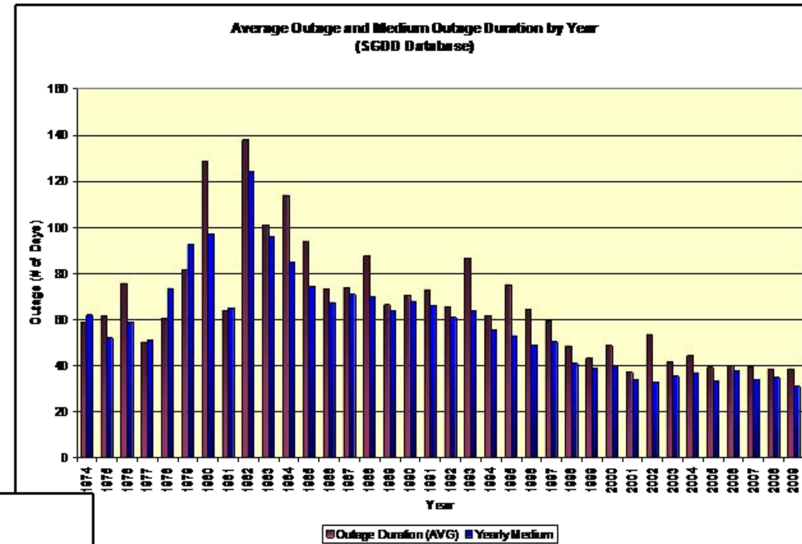
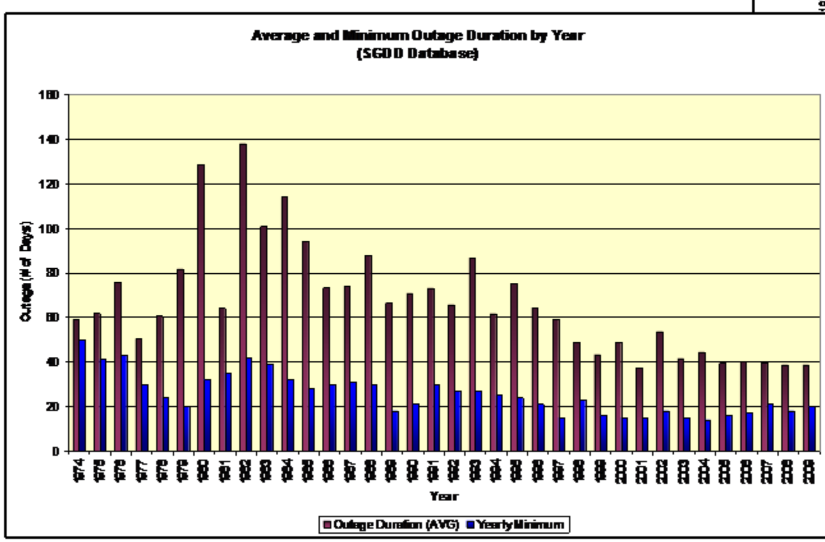
Outage Durations and Trends

- Since 2000:
  - Average Duration – 42 days
  - Min. Duration – 14 days with most recent data suggesting 19 – 20 days





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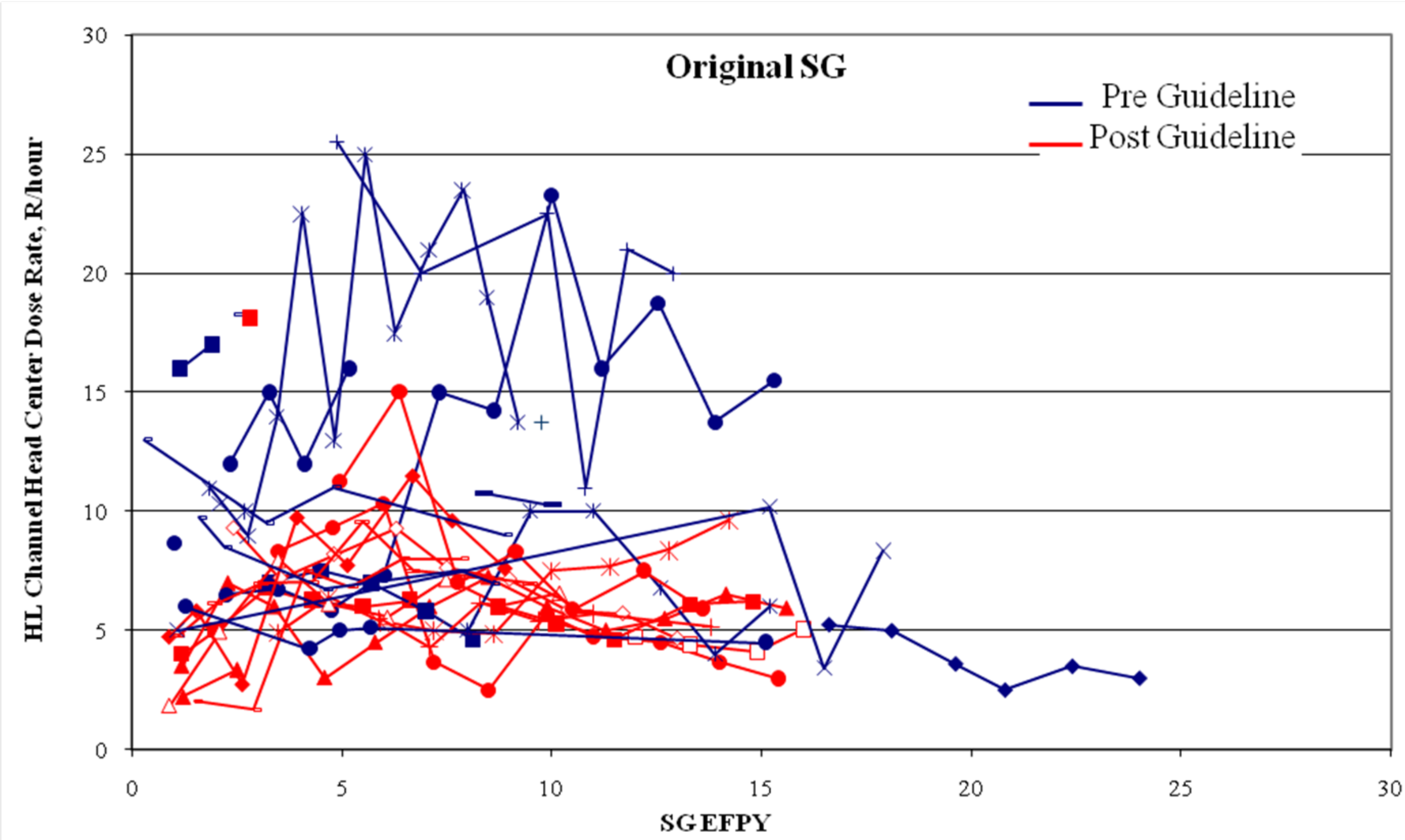
What's in the PWR Guideline tool box?

- Operating pH control
- Operating hydrogen control
- Zinc Injection
- Shutdown Chemistry
- ChemWorks Shutdown Calculator

Impacts of PWR Primary Chemistry Guidelines on Dose Rates



PWR Primary Chemistry (power operation)

- pH
  - Maintain $pH_T \geq 6.9$ from the time reactor is critical
  - Operate at as high a pH_T as practical
    - Likely constrained by Li
  - Adhere to the six Generic Principles for Optimization of Primary System pH

- Hydrogen
  - Maintain hydrogen 25-50 cc/Kg to maintain reducing conditions

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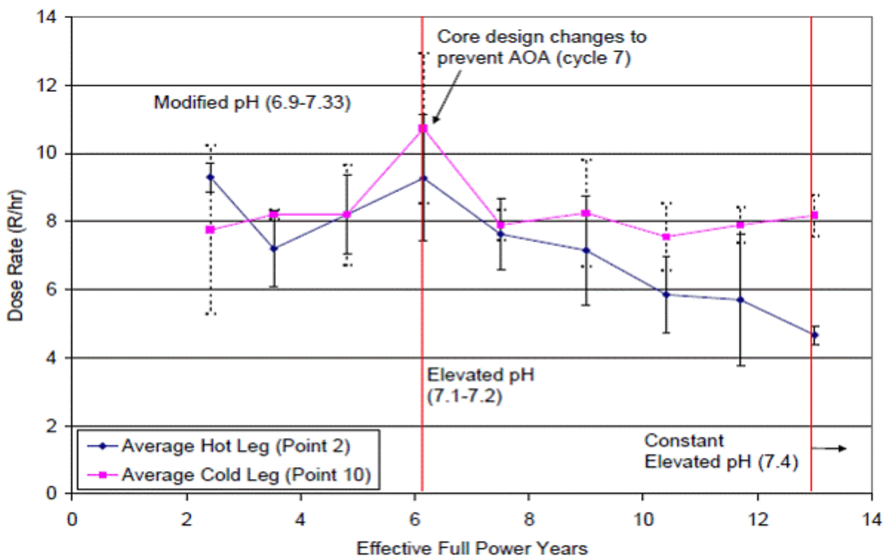
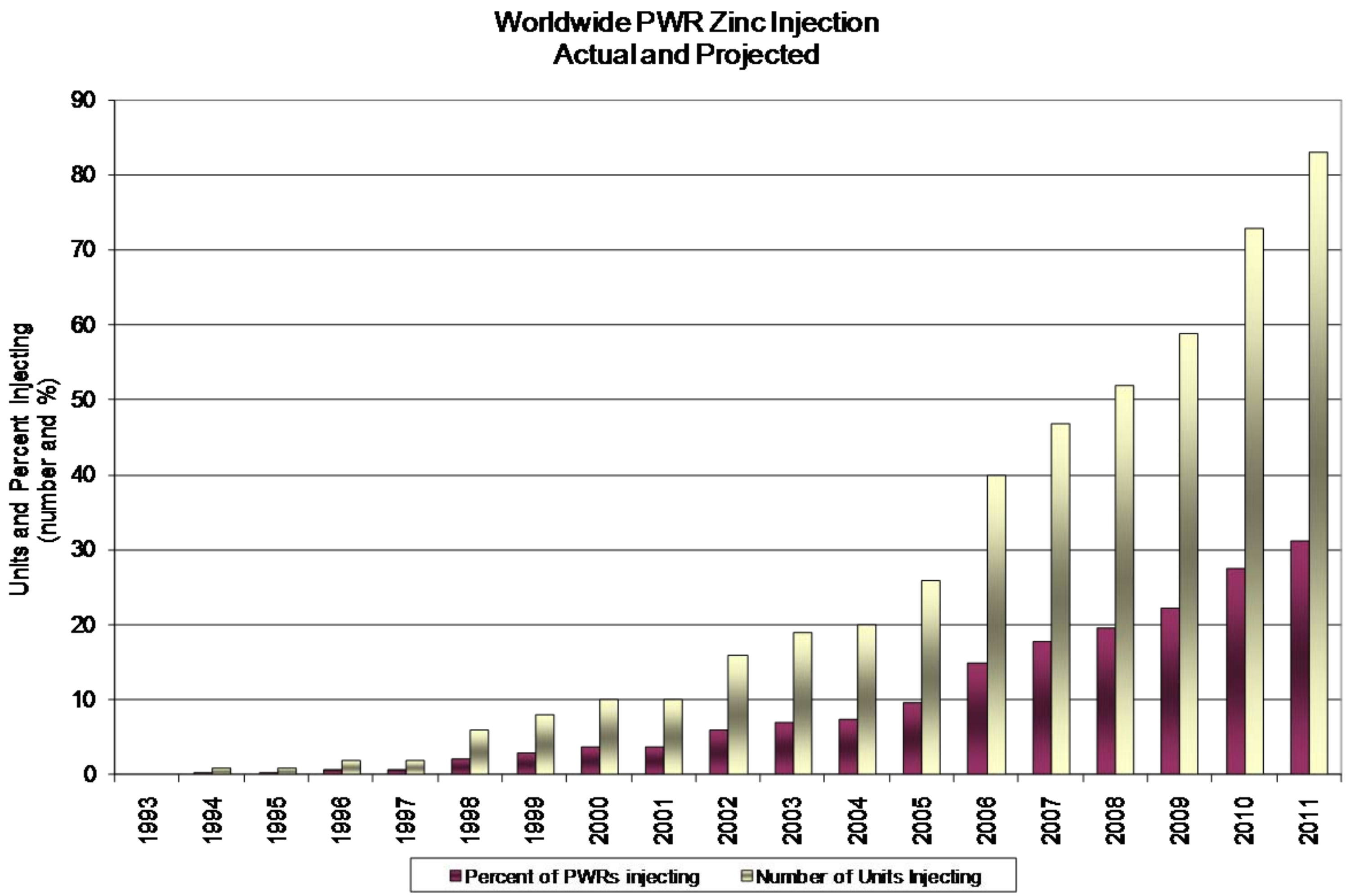
Impacts of Elevated pH on Dose Rates

- Elevated pH program
  - Hot leg showed decrease in Unit 1
  - Other areas showed little improvement



Zinc Injection



Shutdown Chemistry

- What is Shutdown Chemistry?
  - It is not a chemical decontamination methodology!
  - It is not intended to reduce dose rates
  - 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."*

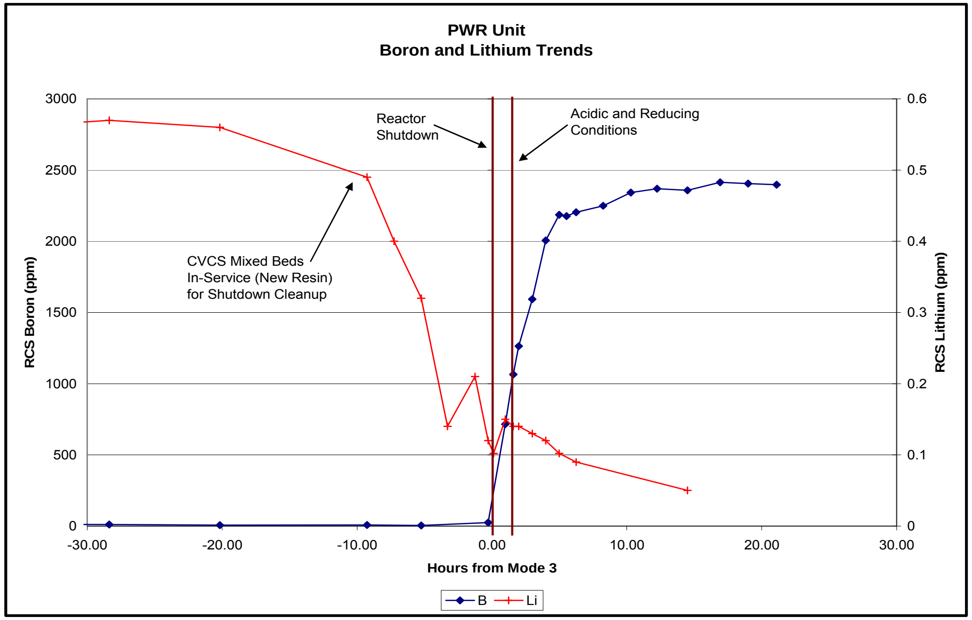
Shutdown Chemistry Controls

The EPRI Pressurized Water Reactor Primary Water Chemistry Guidelines identify 7 specific areas:

1. Control Reactor Coolant pH
2. Establish Acid Reducing Conditions
3. Optimize Reactor Coolant Pump Operations
4. Maximize Cleanup Capability
5. Control Decay Heat Removal System Chemistry
6. Reduce Dissolved Hydrogen Prior to Opening RCS
7. Create Oxidizing Condition by Peroxide Addition

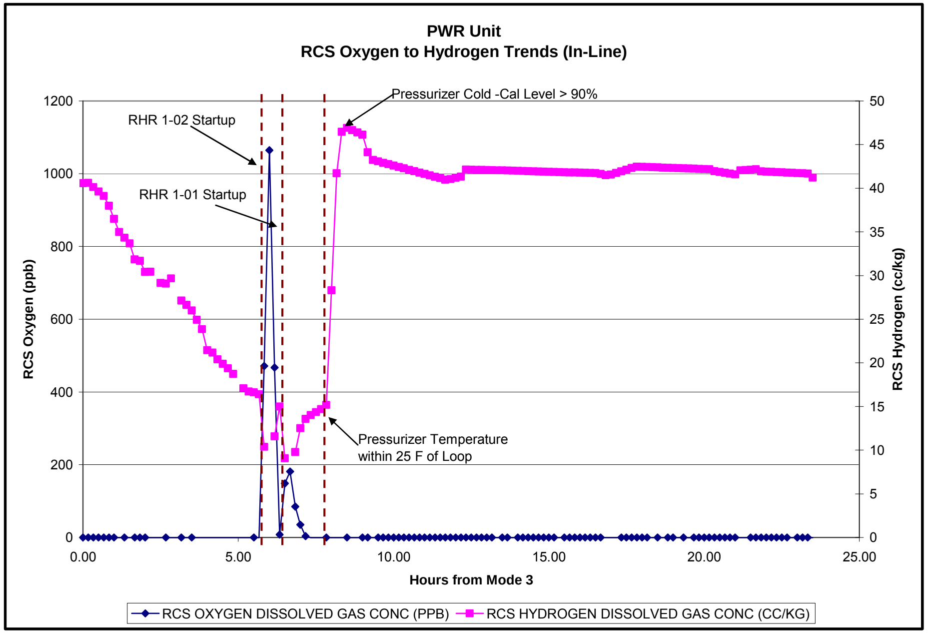
Control Reactor Coolant pH

- Increase time in Acidic Conditions:
  - Can lead to increase solubilization of core deposits
- pH transition
  - U.S. is aggressive in removing lithium compared to Global Community
  - Guideline Issue:
    - Chemistry Adjustments with Failed fuel



Establish Acid-Reducing Conditions

- Acid-Reducing Conditions:
  - RCS Hydrogen Controls:
    - Plants maintain a variety of hydrogen levels on shutdown
- Operating Experience
  - Plants maintain anywhere from > 5 to ~40 cc/kg
    - Mechanical vs.. Chemical Degassing
    - System Design
- Challenges
  - Impact of oxygen entering the system (RHR Startup or other transient conditions)



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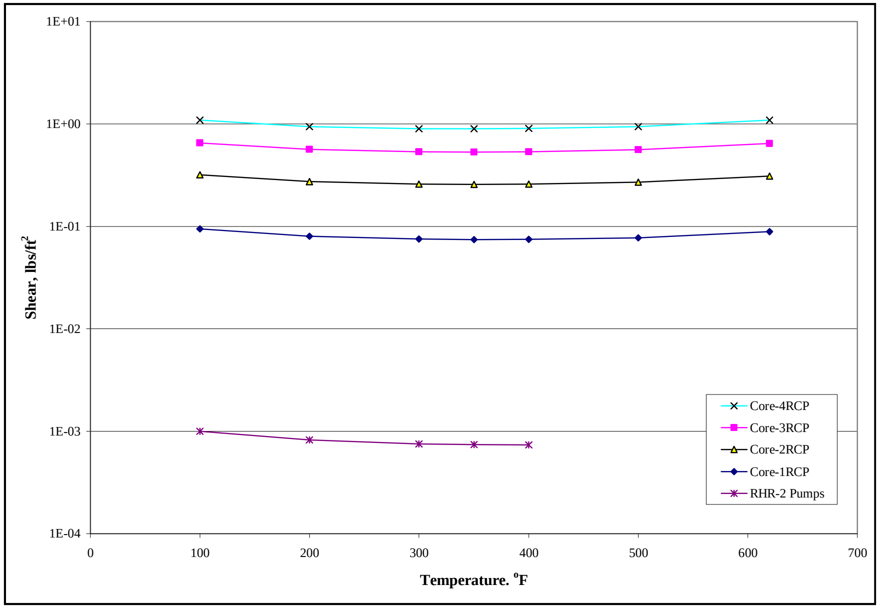
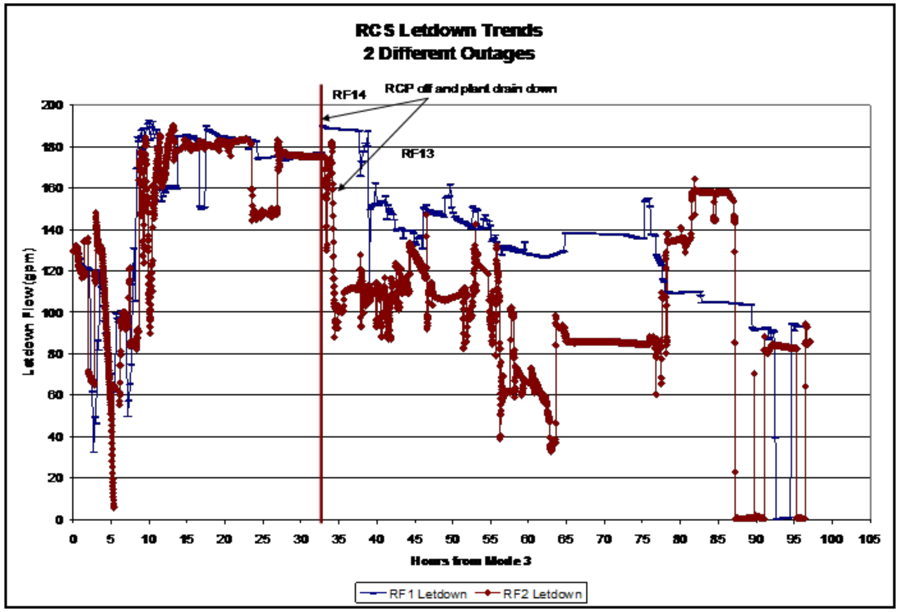
Optimize Reactor Coolant Pump Operation

- Issue:
  - Balancing mixing with core shear
- Impact:
  - Thermal Changes early in shutdown.
  - Particulate releases from the core
- Fleet Observations
  - Industry:
    - One Utility secures RCP's, depressurizes and drains to mid-loop before peroxide addition
    - One utility runs all 4 RCP's for minimum 12 hours post-peroxide



Maximize Clean Flow

- Letdown Flow Optimization:
  - RHR:
    - Operating a second RHR Pump supplying Letdown Flow
    - Design Modifications:
      - Booster Pumps
      - New piping
- Operating Experience
  - Varies across the board
- Challenges
  - Operations
    - Maintaining letdown flow during depressurized conditions



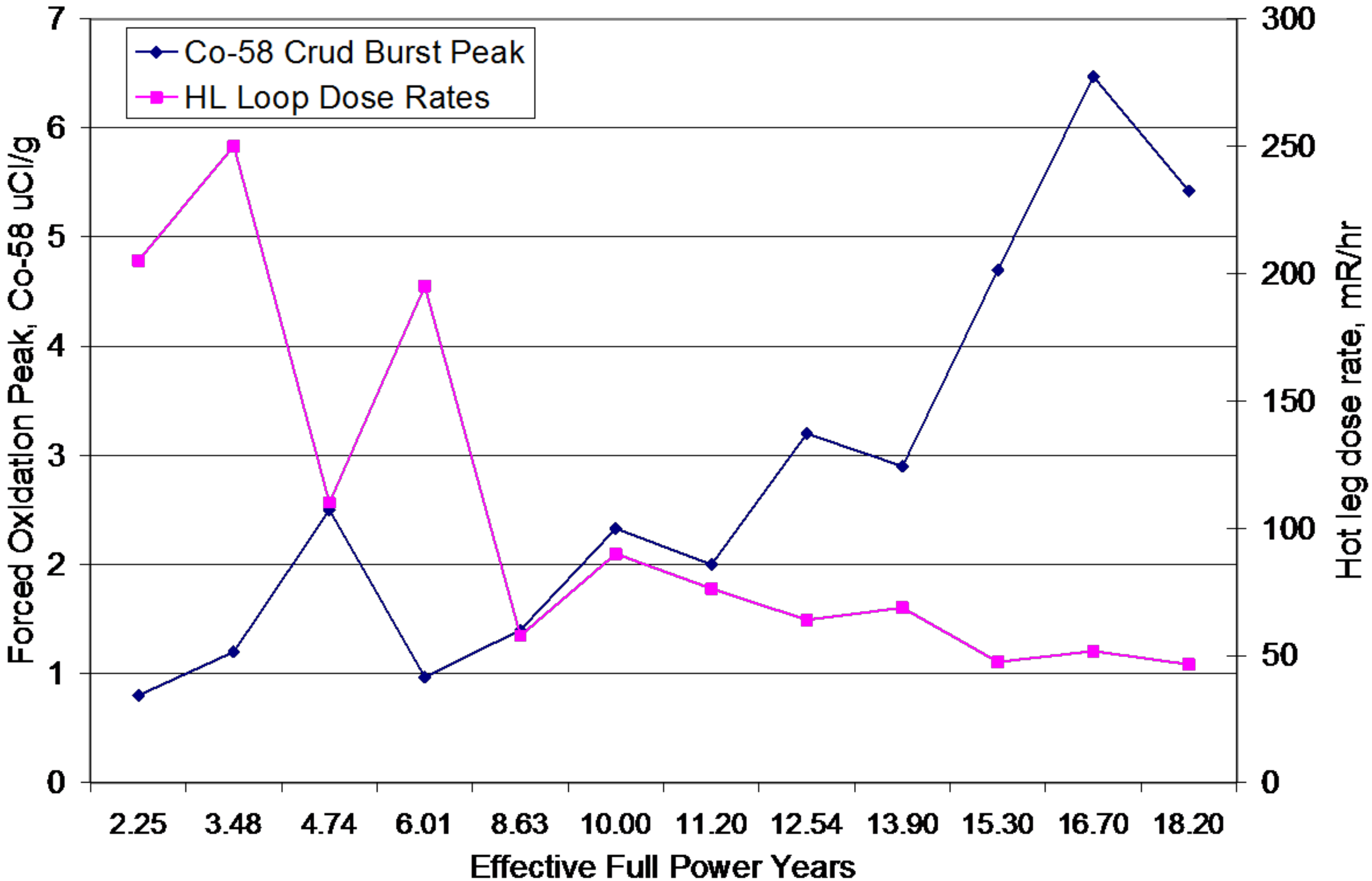
Control Decay Heat Removal System Chemistry

- RHR Chemistry:
  - Challenges:
    - No RCS pH increase
- Operating Experience
  - RHR Recirculation
  - RHR Flushing
  - RHR Hydrazine Addition
  - No Action

Reduce Hydrogen and Create an Oxidizing Condition (Forced Oxidation)

- Hydrogen Reduction:
  - Chemical or Mechanical
  - Ensure RCS hydrogen < 5 cc/kg prior to opening RCS
- Control
  - Maintain > 2 ppm Hydrogen Peroxide and / or Oxygen in RCS
    - Data suggests that utilities maintain from 0.5 ppm to 8 ppm DO residual
      - Limitations:
        - Boron Dilution Concerns limits addition capabilities
        - Operational Limitations

Forced Oxidation Peaks Compared to Hot Leg Dose Rate



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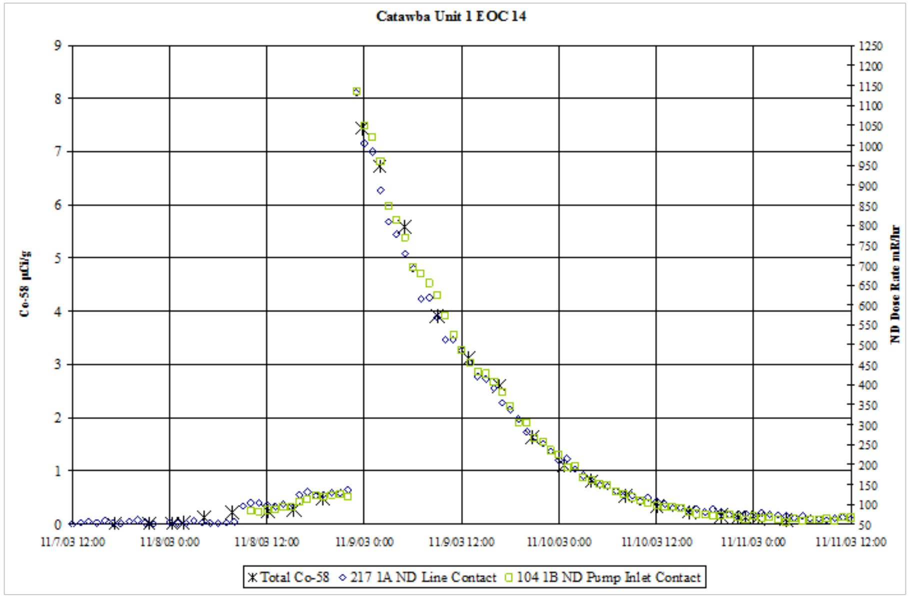
Shutdown Practices to Dose Rates

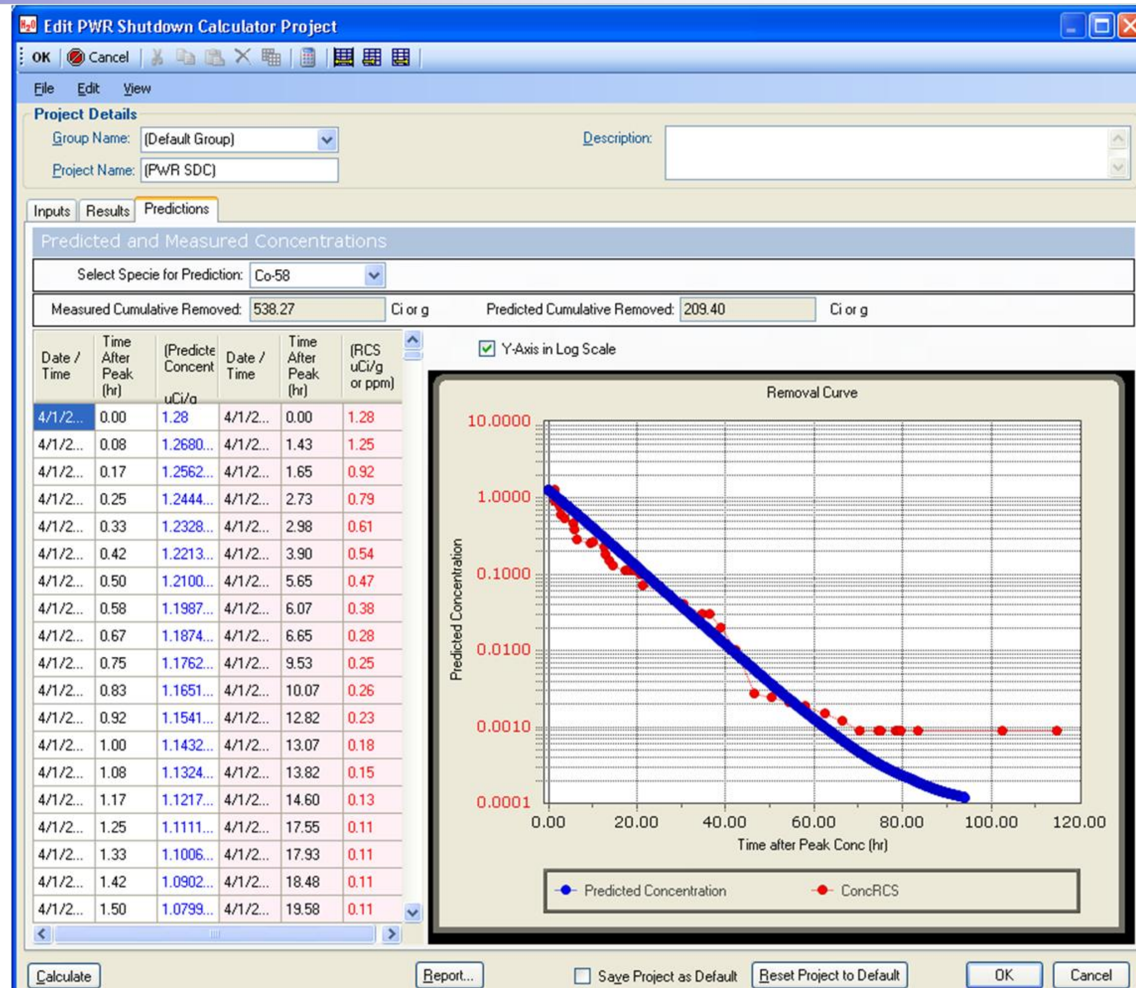
Summary

- Decontamination of system surfaces is not expected.
- Incorporation of soluble activity into out-of-core surface films does not appear to be significant.



Evaluation Tools:
ChemWorks Tools version 3.1

- Download 1020788
- Added modules
  - PWR Shutdown Calculator
    - Includes cleanup predictions based on peak
    - Allows SG isolation



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PWR Guideline issues being considered

- **Shutdown Chemistry with Failed Fuel**
  - Experience Base:
    - Fort Calhoun, KHNP, and Others
  - Current Guidelines
    - Limited Discussion
  - Experience to Consider
    - KHNP (to be discussed in more Detail by the KHNP Presentation)
    - Fort Calhoun and Others
- **Mid-Cycle Outages**
  - Decision Tree for Planning Actions
- **High Levels of Antimony**
  - Secondary Source Failure, etc
  - Action Plan or Changes to Shutdown Chemistry Controls
- **High Levels of Silver-110m**
  - Control Rods (Ag-In-Cd), etc.
  - What changes are required in Shutdown Planning
- **Reactor Coolant Pump Operation**
- **CANDU and VVER designs**

EPRI Activity Release Behavior Research and Development Efforts

Program	Deliverables
Chemistry	• PWR Primary Chemistry Guidelines V1 and V2, 1014986, 2007 • High Activity Crud Burst Impacts and Responses, 1016766, 2008 • ChemWorks Tools, v 3.1, 1020788, 2010
Radiation Management	• EPRI Cobalt Reduction Sourcebook, 1021103, 2010 • Plant Specific Recommendations for PWR Radiation Source Term Reduction, 1019225, 2009 • Technology Evaluations and Operations Strategies for PWR Radiation Source Term Reduction, 1016767, 2008 • Application of the EPRI Standard Radiation Monitoring Program for PWR Radiation Field Reduction, 1015119, 2007 • Source Term Reduction: Impact of Plant Design and Chemistry on PWR Shutdown Releases and Dose Rates, 1013507, 2006 • Dose Rate Impacts of Activity Transport in Primary Coolant Systems, 1011736, 2005
Fuel Reliability Program	• Fuel Reliability Guidelines: PWR Fuel Cladding Corrosion and Crud, 1015449, 2008

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BWR Chemistry Guidelines

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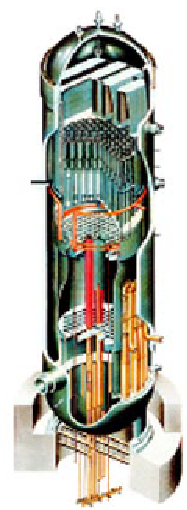
BWRVIP-190: BWR Vessel and Internals Project

BWR Water Chemistry Guidelines—2008 Revision

LICENSED MATERIAL



PROPRIETARY INFORMATION

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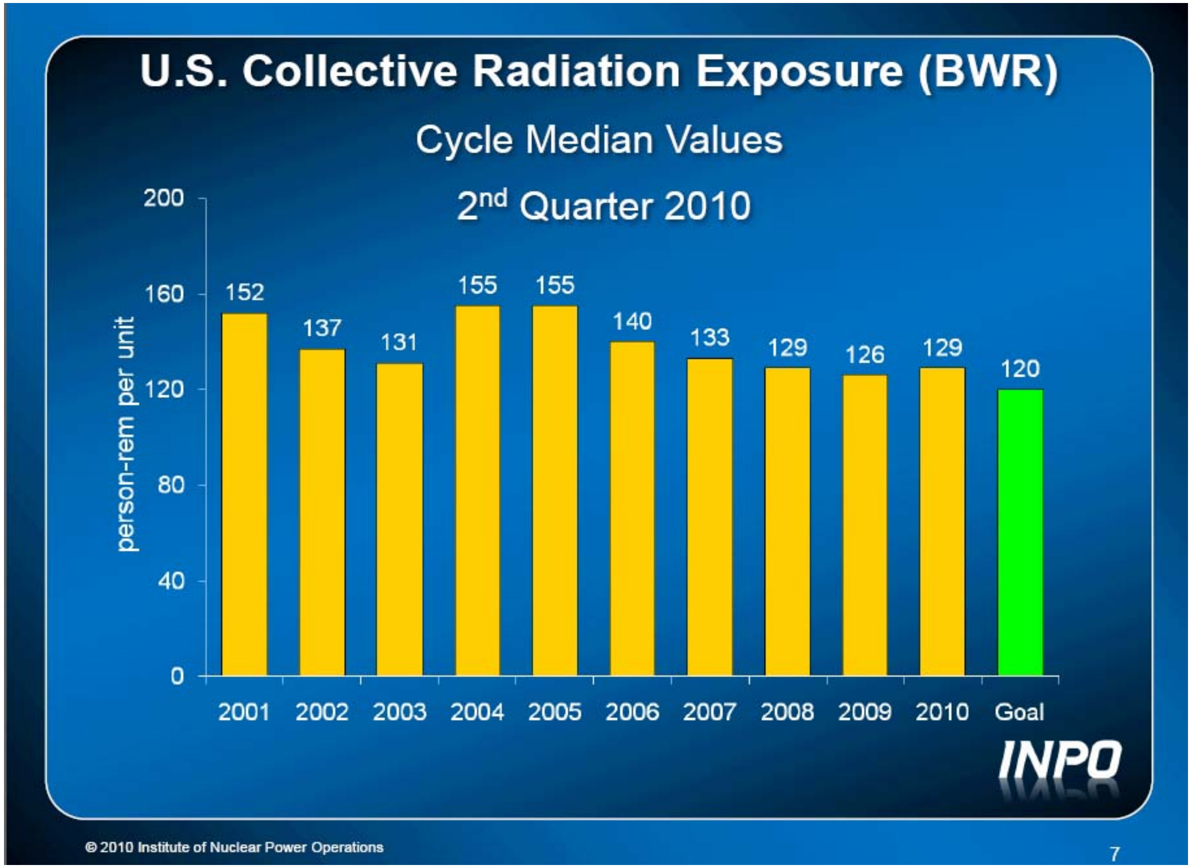
Significance of Shutdown & Startup Chemistry Control

- Exposure
- Operations
- Fuel Performance
- IGSCC Mitigation



All important factors

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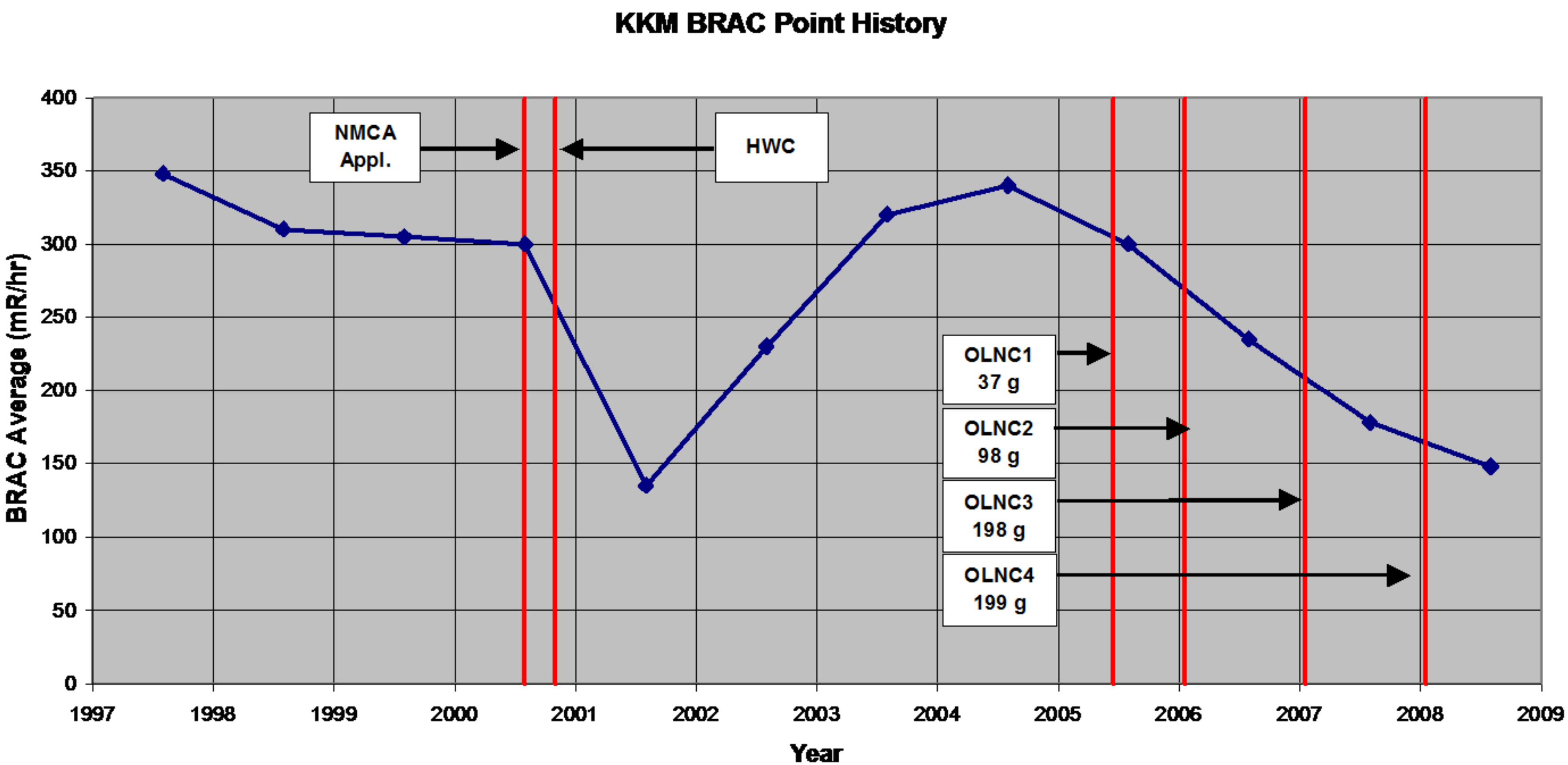
BWR Chemistry Toolbox

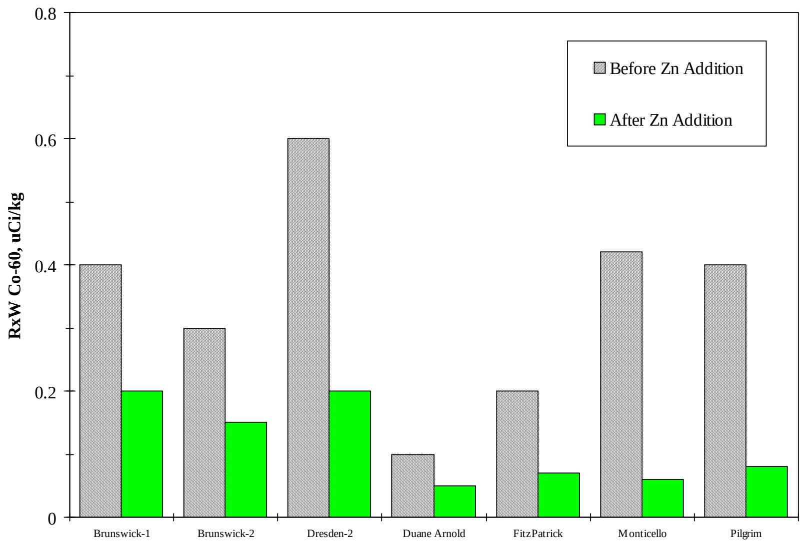
- Online NobleChem (OLNC)
- Zinc Injection
- Shutdown and Startup Chemistry

Online Noble Metal Impact on Piping Dose Rates



Dose rates have decreased >50% since OLNC applications

Zinc Injection Experience



- **RxW Co-60 levels significantly reduced with Zinc Injection**
- Co-60 is the major dose contributor to BWR shutdown dose rates
- Decontamination of piping was very common in U.S. prior to Zinc addition
- U.S. exposures on decreasing trend since 2005
- Implementation of Zinc Injection in U.S. is a key contributor

BWR Shutdown and Startup Chemistry Experience and Application Sourcebook (BWRVIP-225, TR-1019072)

- Previous report: *BWR Shutdown Chemistry Experience Report and Application Guidelines* TR-1014999 (BWRVIP-176) issued Nov. 2007
- Focused on shutdown evolutions and radiation control during outages
- Document published Dec. 2009
  - Includes significantly more plant operating experience (32 outages)
  - Includes startup recommendations
  - Includes Online NobleChem appendix
  - Contains 23 plant data appendices
  - Recommendations in document are "Good Practices", consistent with NEI 03-08 and BWRVIP-190 classifications

BWR-176	New Document
Clinton RFO10	Hatch 2, RFO17, RFO18, RFO20
Copper RFO 23	LaSalle 1 RFO12
FitzPatrick RFO17	Limerick 1 RFO12
Hatch 2 RFO19	Oyster Creek RFO22
LaSalle 1 RFO11	Columbia RFO18
Limerick 1 RFO11	Dresden 2 RFO20
Nine Mile Point 1 RFO19	Browns Ferry 2 RFO14
Oyster Creek RFO21	Browns Ferry 3 RFO13
Peach Bottom 2 RFO16	Susquehanna 2 RFO13
	Duane Arnold RFO21
	LaSalle 2 RFO12
	Dresden 3 RFO19
	Peach Bottom 3 RFO16
	Quad Cities 2 RFO19
	Hatch 1 RFO 20, RFO21, RFO22, RFO23
	Limerick 2 RFO10
	Perry RFO11

Plant experience continues to be collected

Document revision planned for 2012

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Sourcebook Outline

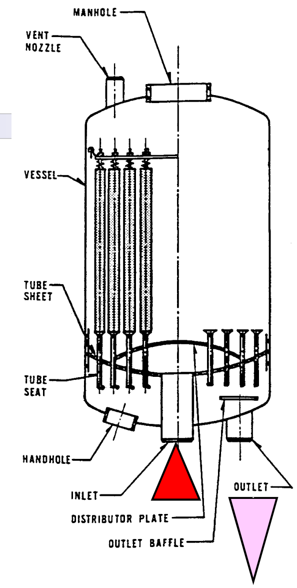
- Chapter 1 - Introduction
- Chapter 2 - Power Operation to Cold Shutdown Evolutions
- Chapter 3 - Refueling Outage Activities and Evolutions
- Chapter 4 - Shutdown Water Chemistry
- Chapter 5 - Shutdown Chemistry Control Operating Strategies
- Chapter 6 - Shutdown Chemistry: Industry Experience
- Chapter 7 - Startup Chemistry Control
- Chapter 8 - Recommendations
- Appendices
  - Appendix A - Shutdown Data Template
  - Appendix B - Classic Noble Metal Chemical Application (NMCA)
  - Appendix C - Chemical Decontamination and Low Temp NobleChem
  - Appendix D - Online NobleChem
  - Appendix E - Startup Data Template
  - Plant Data

Shutdown Chemistry Control Strategies

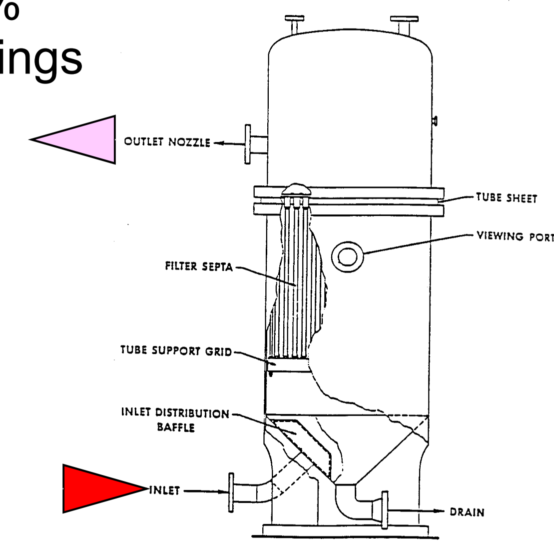
- Key Strategies
  - Maximize cleanup system availability
  - If cleanup systems must be removed from service for system maintenance, schedule after fuel moves have commenced
  - Temporary cleanup systems should be available and ready to use
  - Establish performance criteria for cleanup systems
- Shutdown Chemistry Experience in Sourcebook
  - Extensive collection and review of plant data
  - Correlations between Co-60 and key dose rates evaluated
  - RWCU and FPC treatment system performance data evaluated
  - Updated industry good practices and conditions to avoid

RWCU F/D Performance

- Sufficient RWCU F/D available to perform separate evaluations based on F/D type:
  - Bottom tubesheet designs need higher cation resin loadings (approaching 0.5 equivalents/ft^2) to achieve Co-60 removal efficiencies above 99%.
  - Top tubesheet designs can achieve 99% removal efficiencies at cation resin loadings as low as 0.33 equivalents/ft^2.



Bottom Tubesheet



Top Tubesheet

New Operating Experience in Sourcebook

- Beneficial Practices
  - Submersible deep bed cleanup systems
  - Improved cavity decontamination methods
  - Lower fill rate for vessel floodup
  - Main steam lines filled with RWCU F/D effluent
- Conditions to Avoid
  - Loss of water clarity following chemical decon
  - Unexpected high steam side dose rates
    - Increased Moisture Carryover (MCO) with elevated activated corrosion products is likely to result in high dose rates and contamination levels in steam side equipment.
    - EPRI completed a MCO Scoping Study in 2010 that evaluates this emergent industry issue (TR-1021185).

Questions?

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