Source Term
The Coolant and Plant Radiation Fields
Version 2

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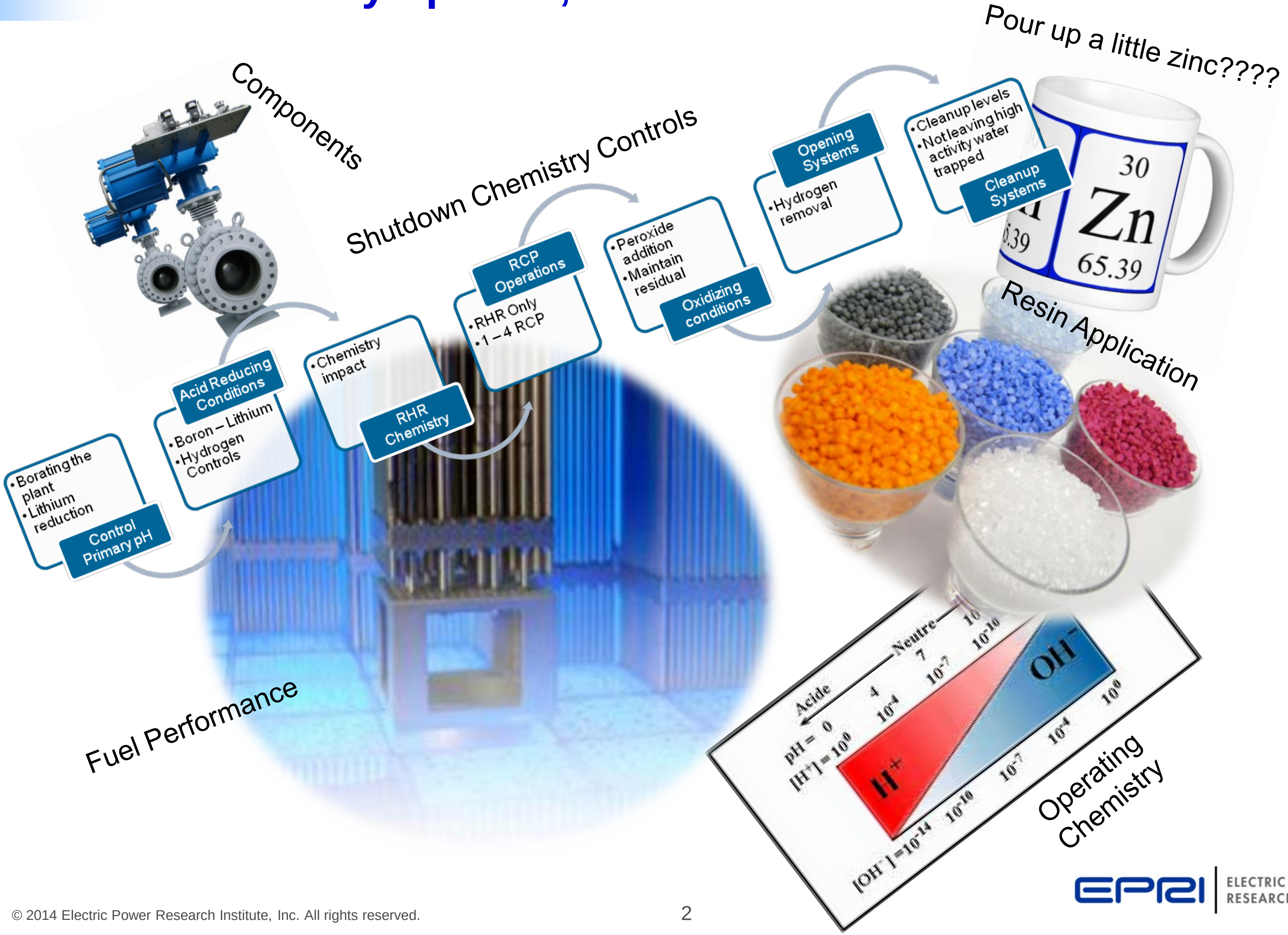
Source Term
With some many options, what is in the decision…



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Source Term
Are we all talking the same...

- How can source term be defined:
  - Simply Defined as: Activated nuclide(s) that may be transported throughout the system and available for deposition on ex-core surfaces generating radiation fields.
- But does everyone have the same in the industry…
  - Chemistry – any metal released during corrosion
  - Nuclear Engineering - amount of material deposited on fuel
  - Radiation Management – Three generic categories
    - Refuel pool activity and dose rate to refueling operators
    - Peak dose rates associated with release post-peroxide addition
    - Any dose received by workers from piping

Overview of Factors Impacting Worker Dose

Indirect Driver for Radiation Field Reductions

Regulated Parameter

Related to crud

Local Dose Rate $\left[\frac{mSv}{hr}\right]$ X Time in rad. field $[hr]$ = Individual Worker Dose $[mSv]$

Factors that impact:

- Amount of activated corrosion products in the water and incorporated/ deposited into/on piping surfaces
- Distance from source
- Shielding

Factors that impact:

- Work Control/ Outage Planning
- ALARA Planning
- Human Performance (e.g. training, prior experience, work quality)

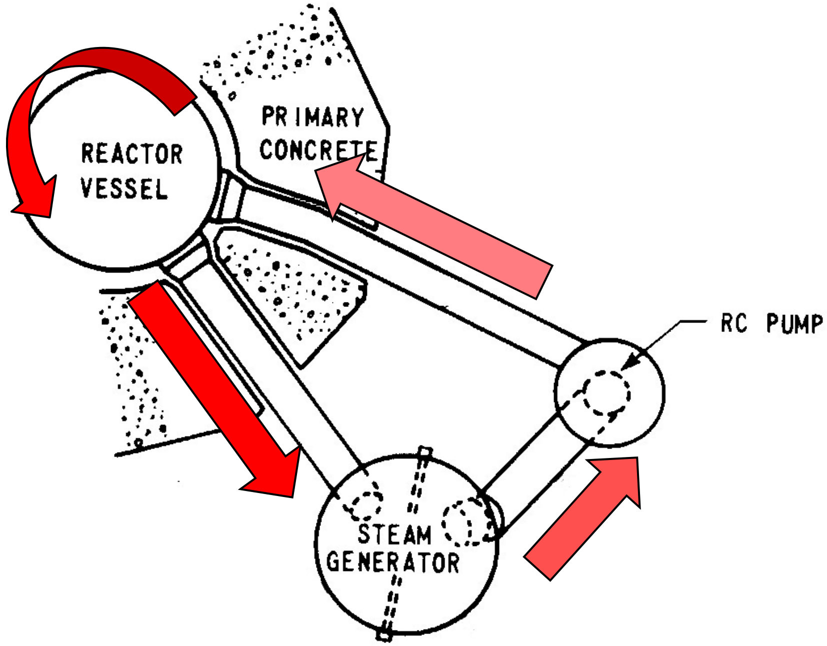
Sum all individual dose for Cumulative Radiation Exposure (CRE)

Industry Goal

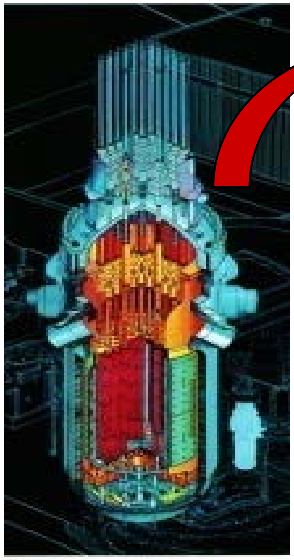
Radiation Field Generation

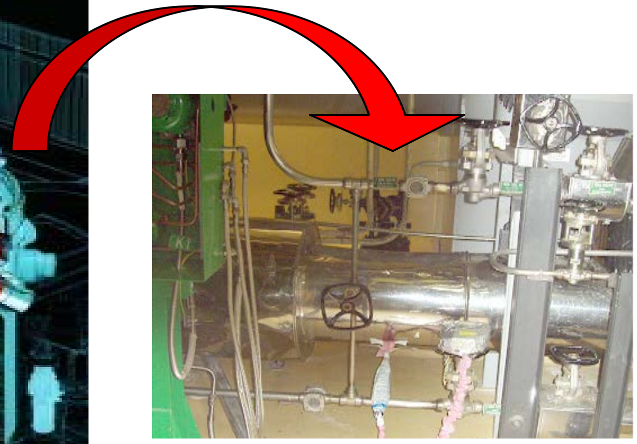
Two Phases: Coolant Activity and Deposition

1. During operation activity incorporation into surface oxides appears governed by soluble species
2. Particulate dropout in dead legs or low fluid shear regions will increase local dose rates



During Operation – Soluble

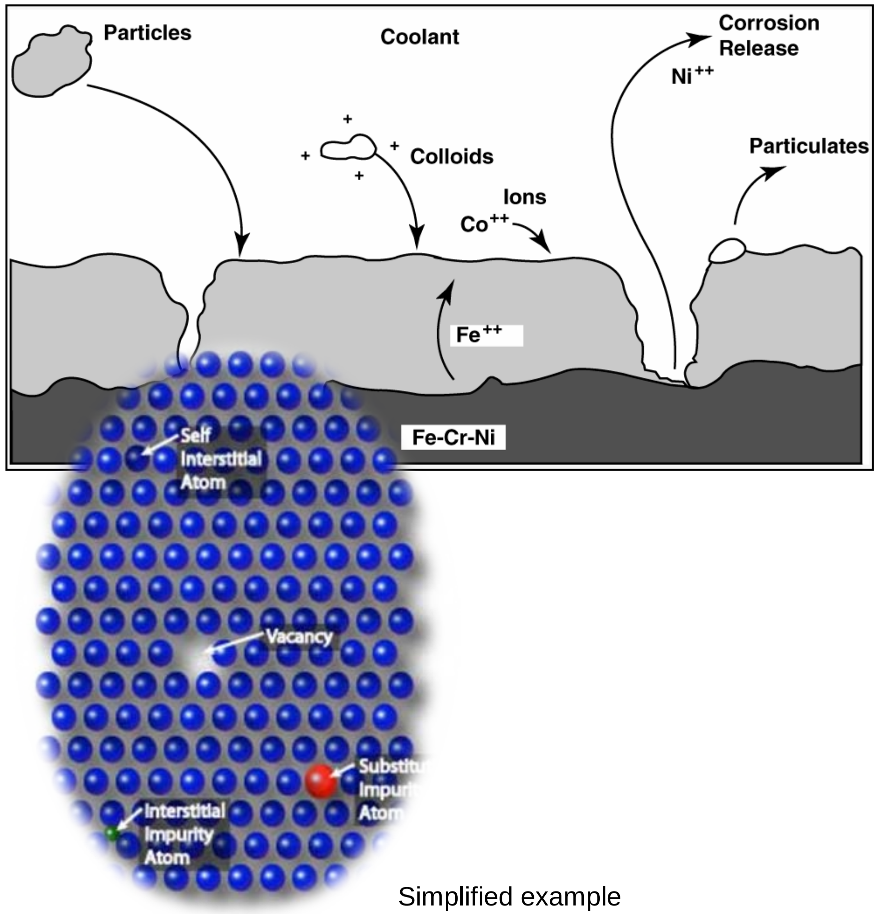




During Shutdown – Particulate

Corrosion, Release and Uptake
Metals and Activated Corrosion Products

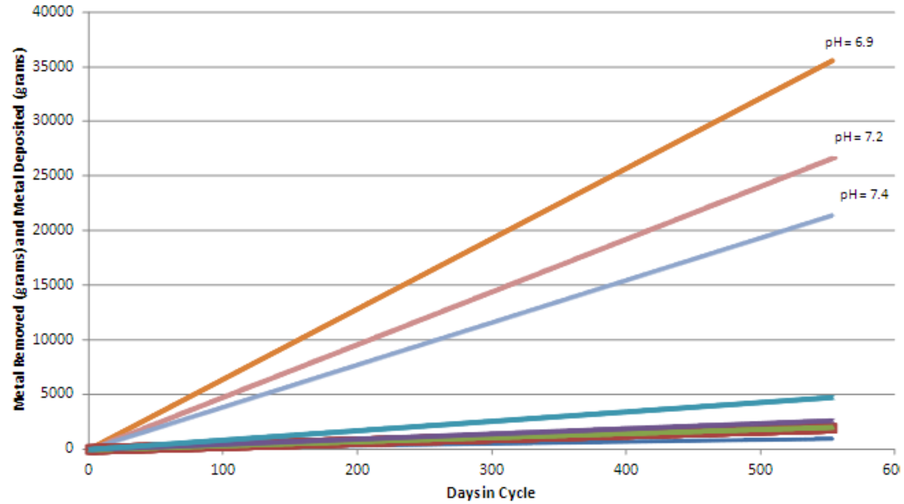
- Metallic non-radioactive corrosion and wear products:
  - Soluble, colloidal or particulate species
- Deposition on the fuel rod surfaces by precipitation, adsorption, or particle deposition
- Activated by absorbing fast or thermal neutrons in the reactor core
- Release:
  - Erosion, thermal, hydraulic, chemical, redox potential or solubility changes
- Uptake into oxide – radiation field build-up



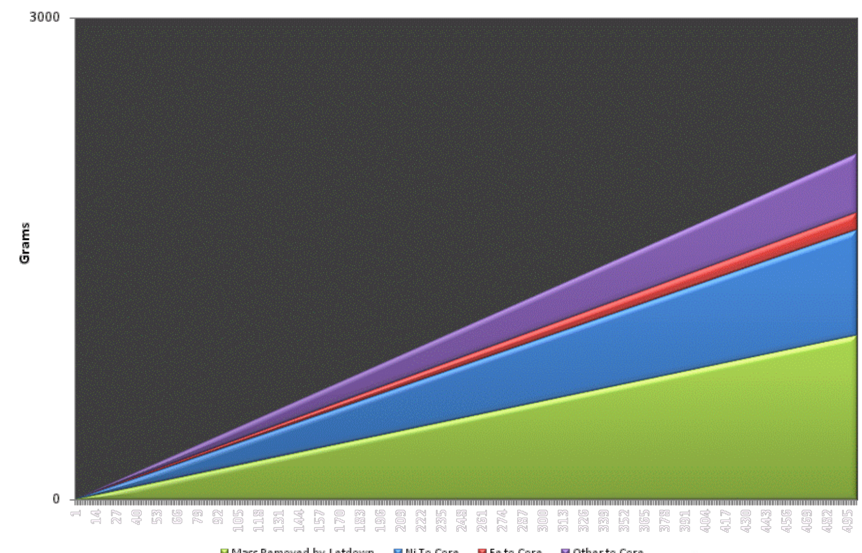
Simplified example

Corrosion Product Transport
The challenge for cleanup systems

- Generic example
  - Alloy 600TT tubing, medium to high duty core with a standard letdown system
    - ~20 to 35 kilograms of metals transported to the fuel
    - Letdown removal (normal range assuming 100% removal)
      - 500 to 2000 grams removed
  - What is the 690 effect
- Corrosion product challenges:
  - Activation, fuel performance (thermal and CIPS), end-of-cycle releases, etc
  - Colloid, Soluble or insoluble…
    - What are these?



Example Mass Transported
Amount Removed by Letdown and Mass Transported to Fuel



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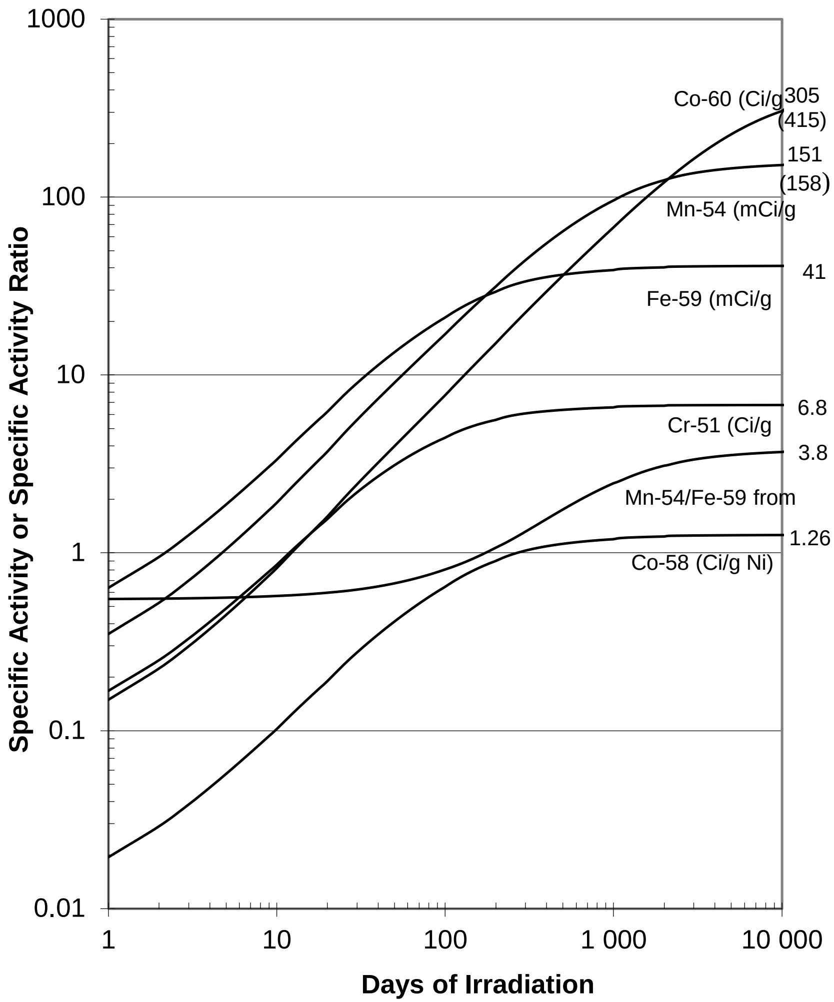
In-Core Deposition and Activation

- Fuel deposit formation in tied directly to sub-cooled nucleate boiling
  - Impact of core materials of construction
  - Residence times can be evaluated using specific activity
  - Shifts in radial and axial distribution of boiling can cause deposit redistribution

What are the optimum properties of fuel deposits for reducing radiation fields and can they be targeted?



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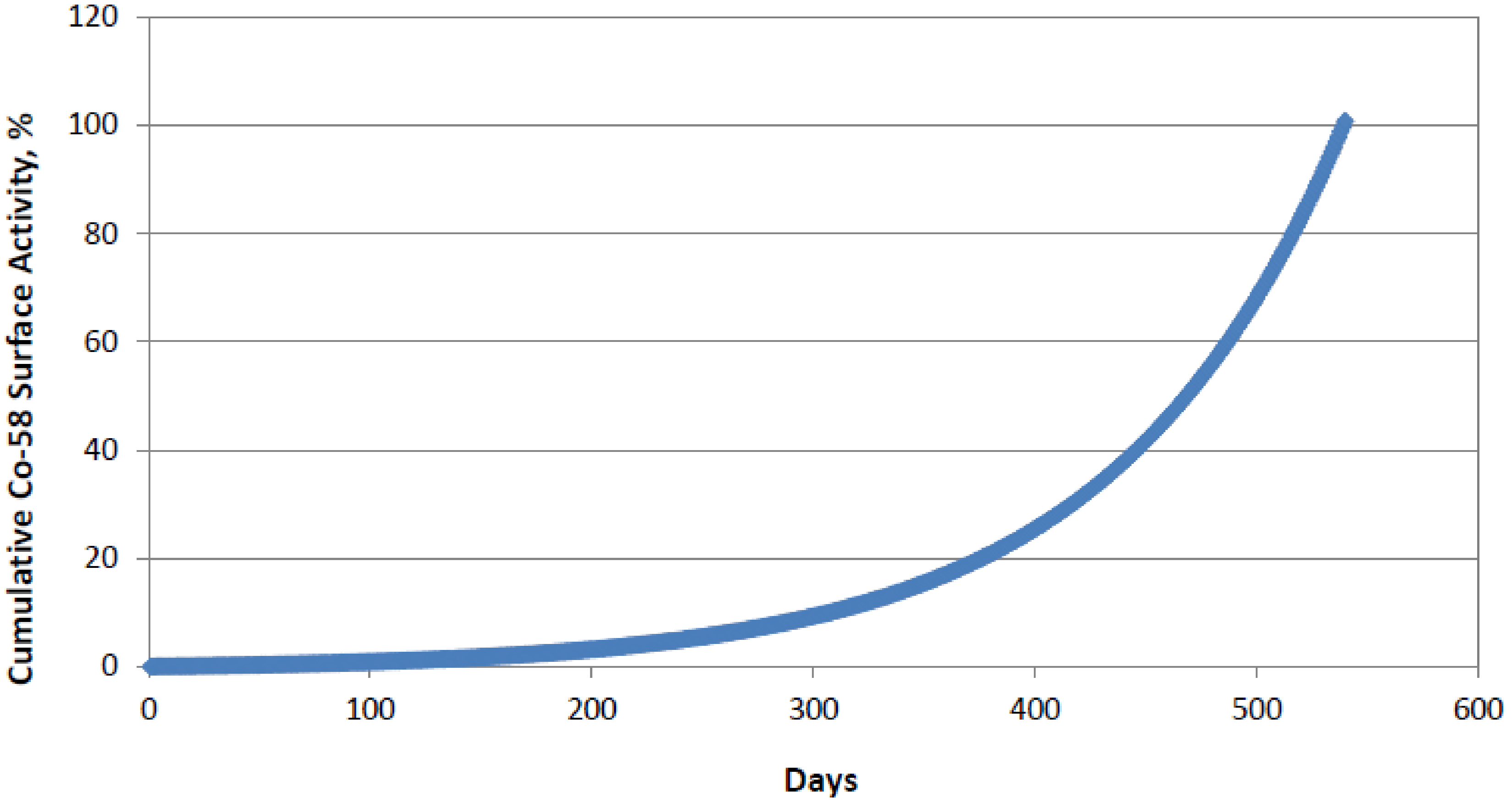
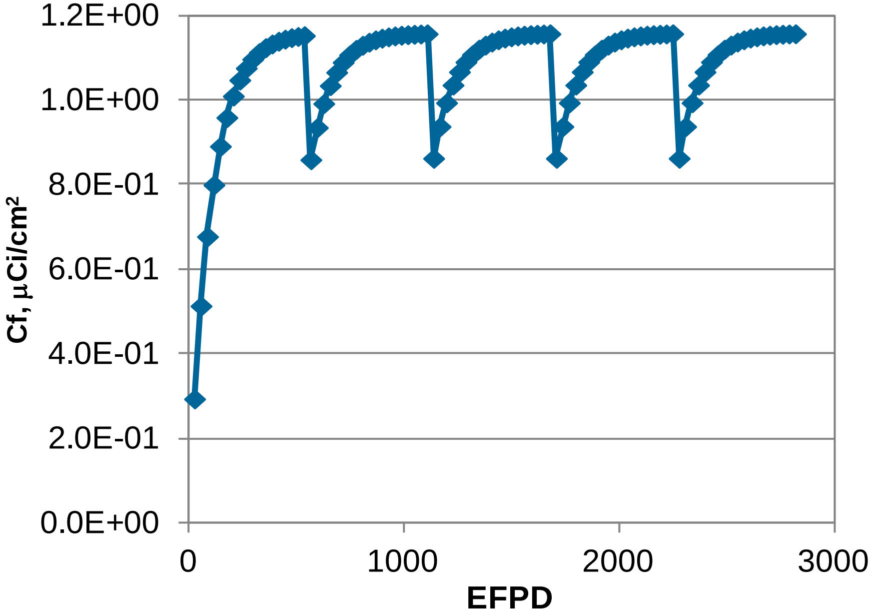
Co-58 Surface Activity Calculations

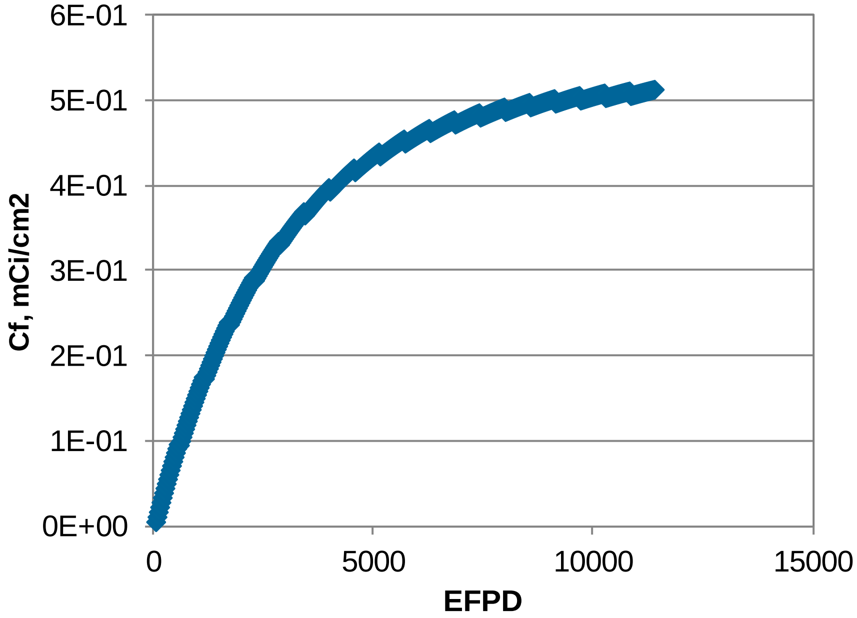


Time to Surface Activity Equilibrium (1025307)

Change in Co-58 Surface Activity with Time
(18-mo cycles, $C_{Co\text{-}58}$ constant 1E-3 µCi/ml)



Change in Co-60 Surface Activity with Time
(18-mo cycles, $C_{Co\text{-}60}$ constant 2E-5 µCi/ml)



- Co-58 rapidly reaches equilibrium while Co-60 takes many cycles to reach equilibrium
- Both Co-58 and Co-60 coolant concentrations must be considered when attempting to correlate surface activities/shutdown dose rates to operating chemistry.

Impact of PWR Coolant Radiocobalt Concentrations on Shutdown Dose Rates: Interim Report. EPRI, Palo Alto, CA: 2012. 1025307.

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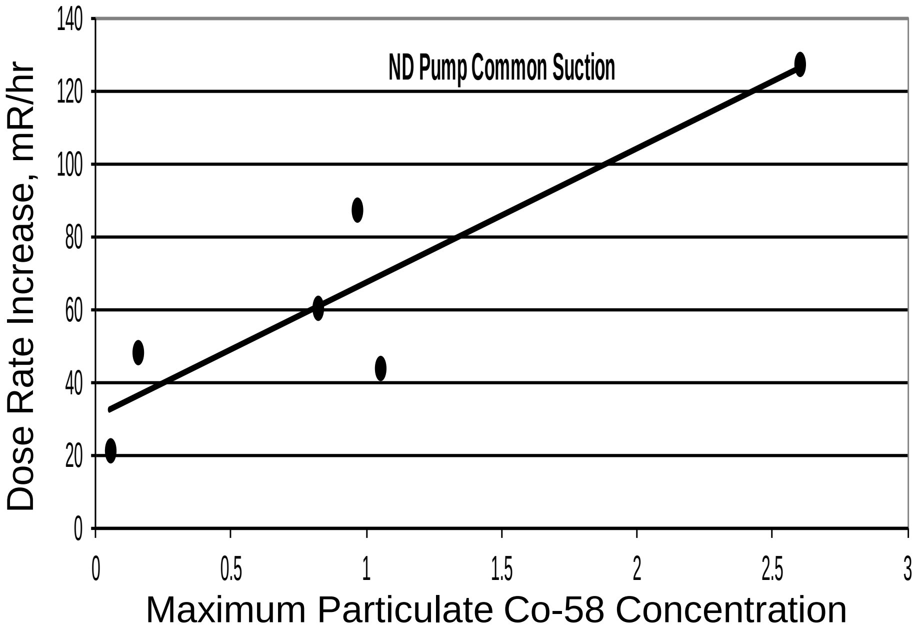
Activity Buildup During Shutdown

Low Flow Areas

- Insoluble deposition in dead legs and regions of low fluid shear <u>during shutdown</u> transients lead to increased dose rates
- At one plant dose rates in decay heat (RHR/ND) correlate reasonably with maximum particulate concentrations, but more data will be necessary to extend correlation to other plants*



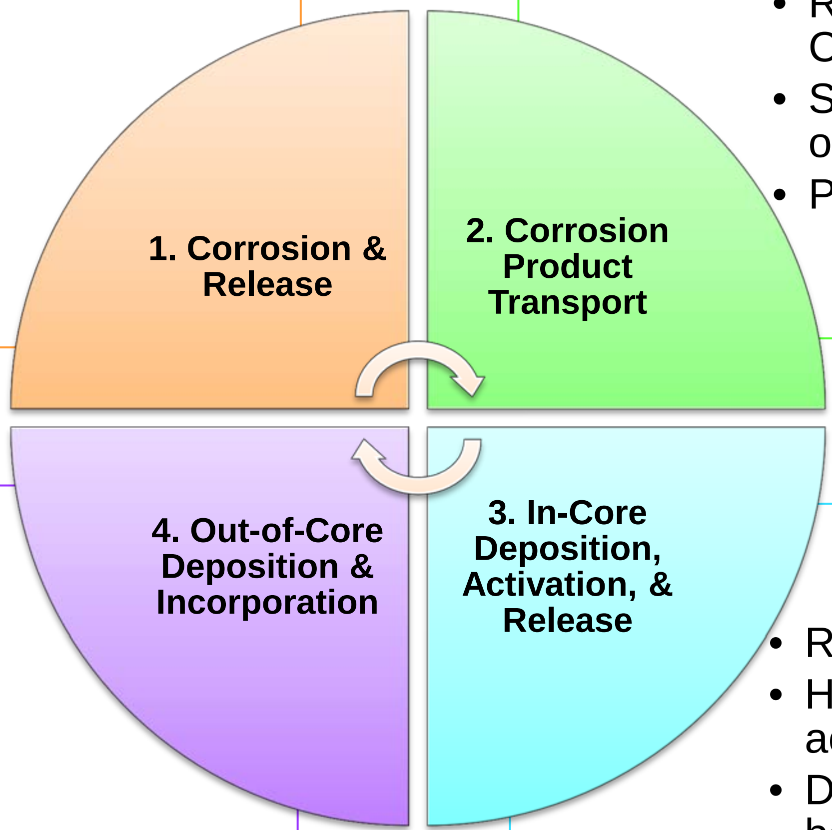
*Impact of PWR Operational Events on Particulate Transport and Radiation Fields. EPRI, Palo Alto, CA: 2012. 1025305.

Key Gaps Related to Primary Side Deposits Radiation Field Source

- Impact of chemistry (pH, hydrogen, zinc)
- SG startup operation
- Tubing processing
- SD Ni release
- Impact of time

Relationship?

- Impact of chemistry (pH, hydrogen, zinc)
  - Soluble/Particulate deposition
- Impact of time



- Reactor Coolant Cleanup Optimization
- Startup and Shutdown operation
- Particulate transport

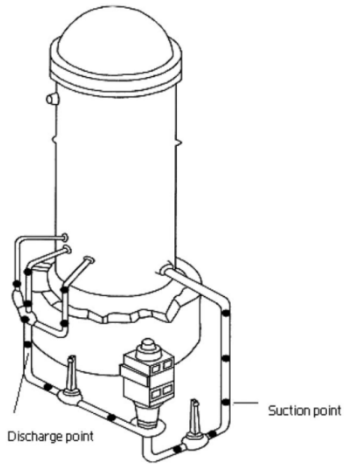
- Residence times
- High temperature boric acid speciation
- Deposit properties and boiling

Standard Radiation Monitoring Programs
BRAC and SRMP – How to track

Dose rates representative of activity incorporation into piping oxide films during operating cycle.

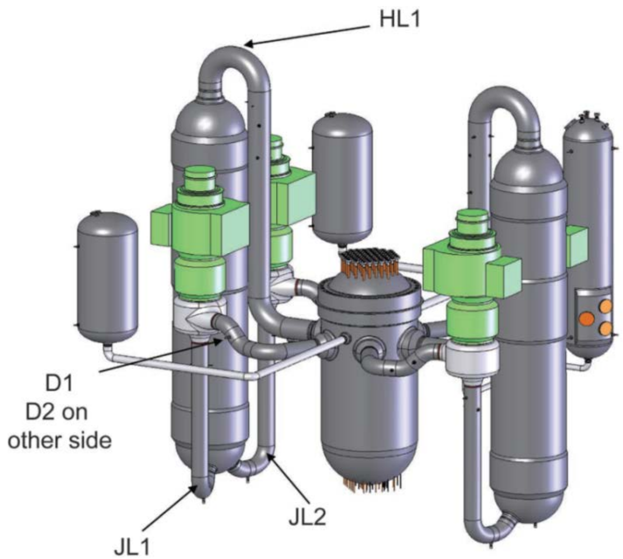
BWR Radiation Level Assessment and Control

- 1977 – current
- Long running data collection program
- 2013 Report (3002000565)



PWR – Standard Radiation Monitoring Program

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

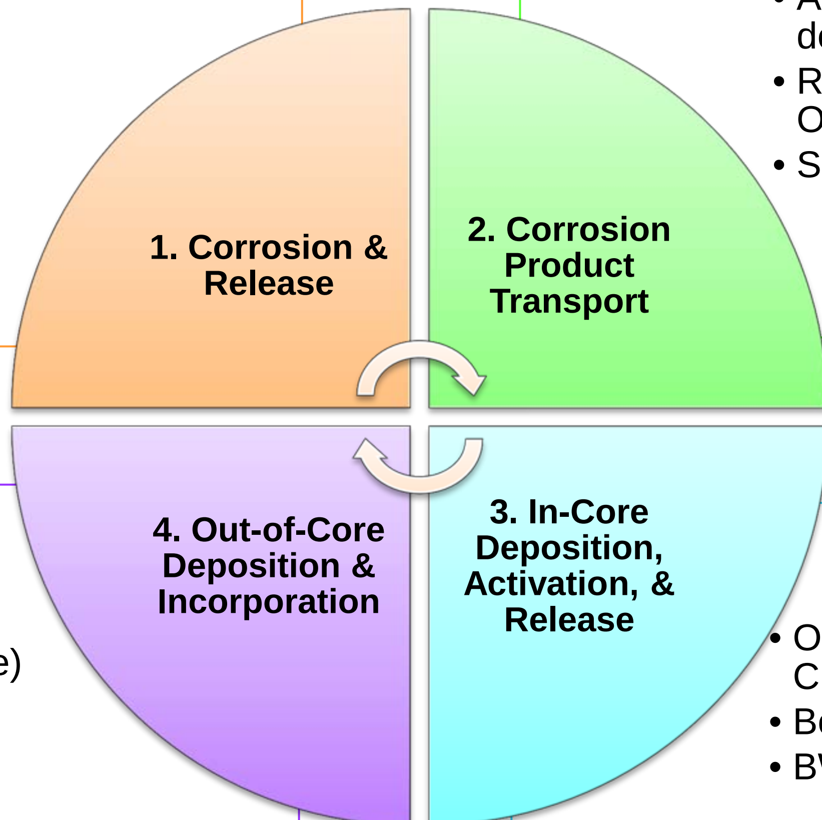


Source Term – A Process
Ongoing EPRI Work and moving forward…

- **Zinc injection**
- Surface Modification
- SG Nickel Releases

- Advanced resin/media development
- Reactor Coolant Cleanup Optimization
- Startup and **Shutdown**

Dual Purpose Technologies



- Impact of Chemistry on Dose Rates(Complete)
- Radiation Field Modeling
- Alternative Shutdown Chemistry

- Optimized Fuel Crud Characteristics
- Boric Acid Speciation
- BWR Fuel Cleaning

✓ **2014 Fundamental Activity: SRMP/BRAC Project**

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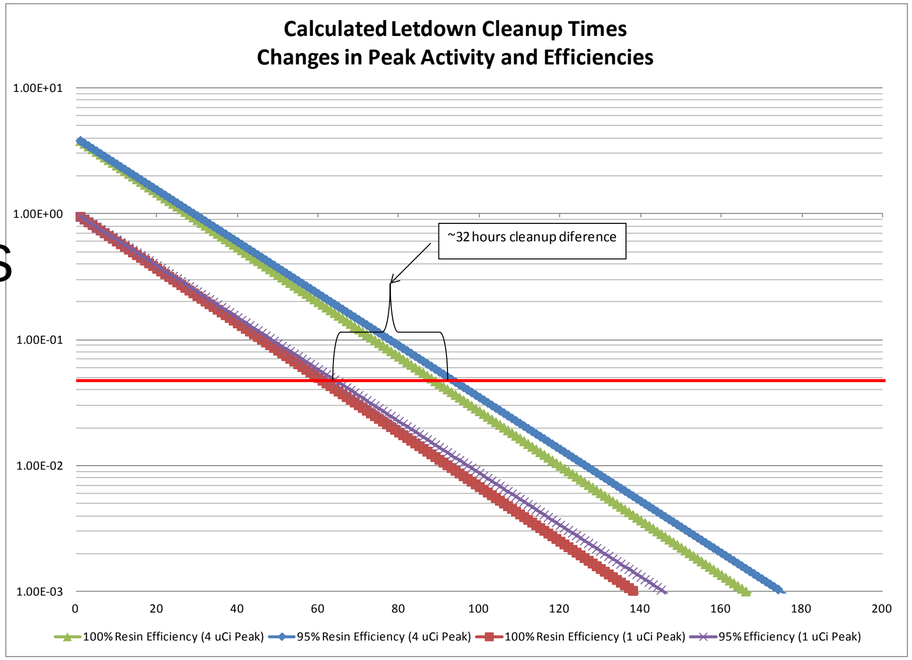
Letdown Optimization

Mass Removed and Resin Efficiencies – Refueling Operations

- Refueling operations:
  - Letdown Systems
    - Flow: 45 to 250 gpm
    - Resin: Usage of CVCS, BTRS and other
      - Efficiency improvements
- Impacts on performance:
  - Activity release
    - Soluble, insoluble or colloid impact
  - Cleanup flow and volume
  - Resin efficiency

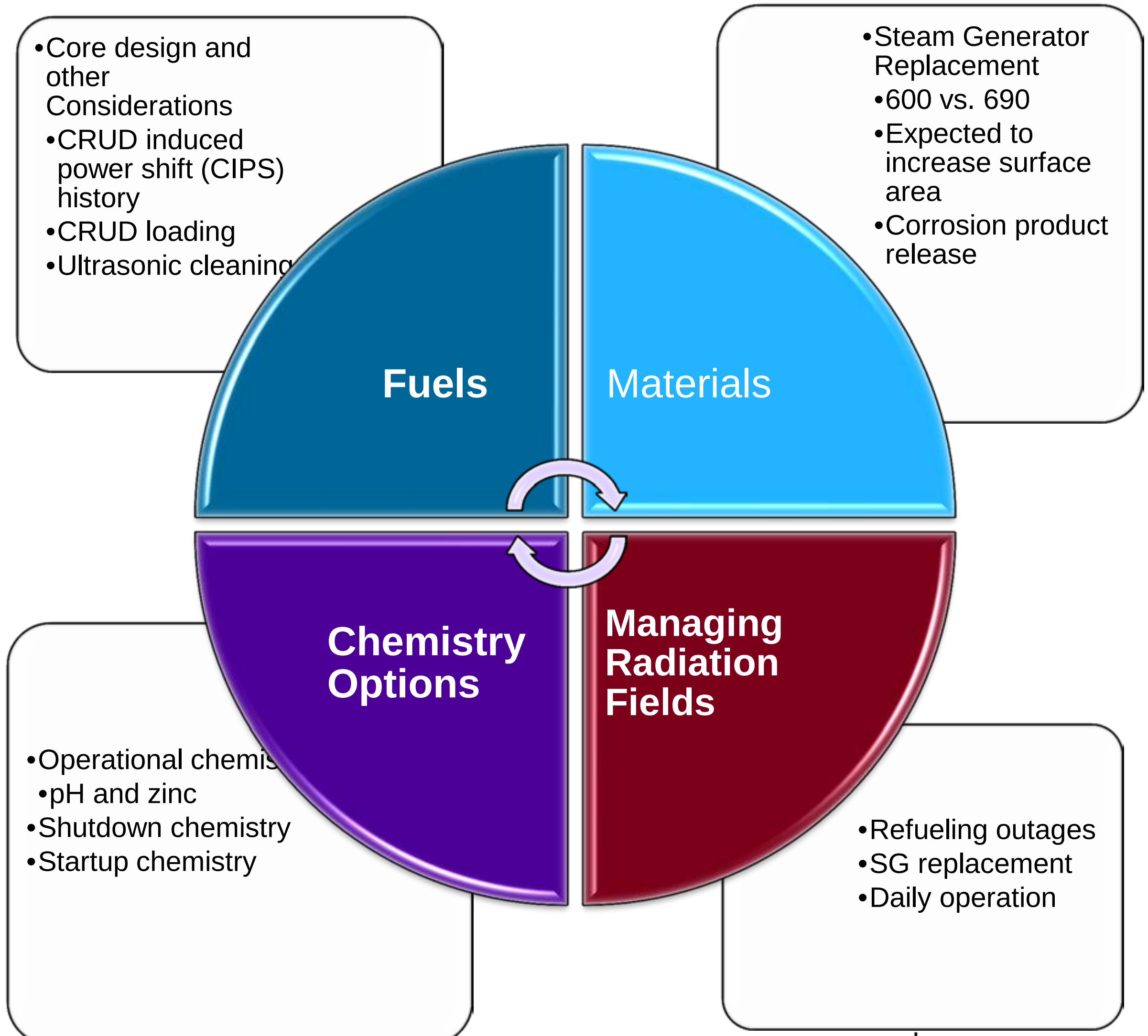


***Optimized shutdown processes with optimized letdown performance** = minimal impact on outage.*

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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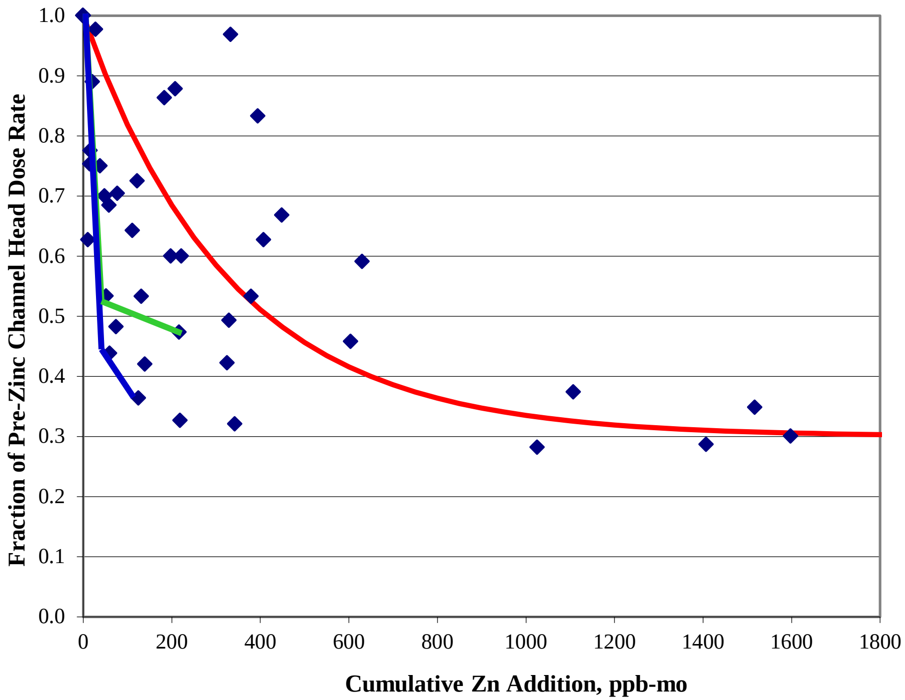
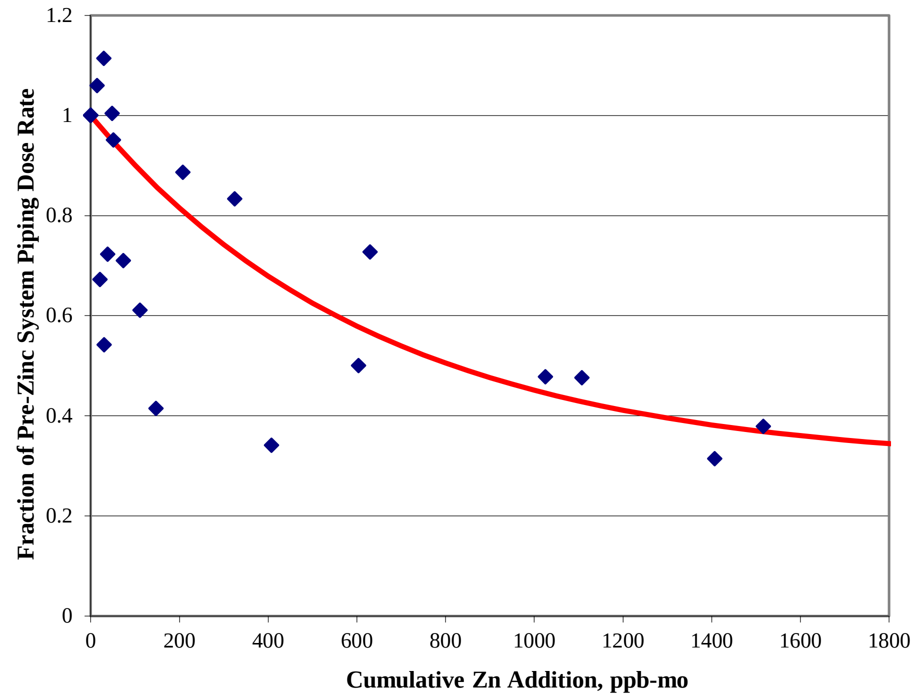
Effect of Zinc on Out-of-Core Dose Rates



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

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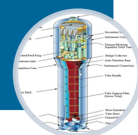
Shutdown Releases

- Impacts dose rate and activity release
- Corrosion film maturity
- Activity Incorporation

Operating Time (SG EFPY)

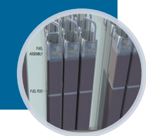
- Several factors to consider
- Increased surface area
- Surface Characteristics

SG Tubing



- Mass evaporation
- Thermal flux

Core Design

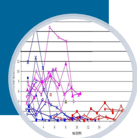


- Nuclide activation
- Mid-cycle outages
- Coast down and crud movement

Power Generation

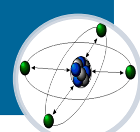
- Mass transfer
- Shear Force
- Impact on particulates
- Outage schedule impact

Reactor Coolant Pump Operation



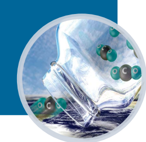
- Activation source (Ni, Fe, Cr, etc)
- Activation incorporation (soluble vs. insoluble)
- Impact of zinc

Primary System Surfaces



- Primary circuit pH
- Zinc injection
- Hydrogen control
- EOC boron (letdown pH)

Chemistry Control



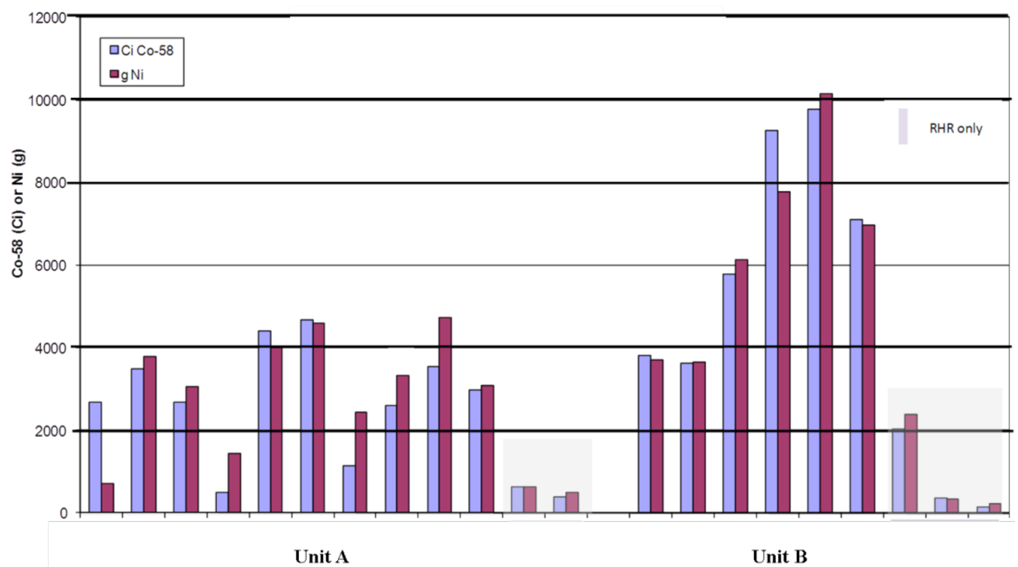
- Fuel deposits removed

Ultrasonic Fuel Cleaning

Failure to cleanup activity post-peroxide prior to cavity fill resulted in high dose rates on refueling bridge

Alternate Shutdown Strategies

- Alternate shutdown:
  - Soft shutdown, controlled cool down and reactor coolant pump operating strategies.
  - Allowed by the Primary Water Guideline
  - Must be coordinated between Operations, Chemistry, Fuels, Radiation Management, and Outage

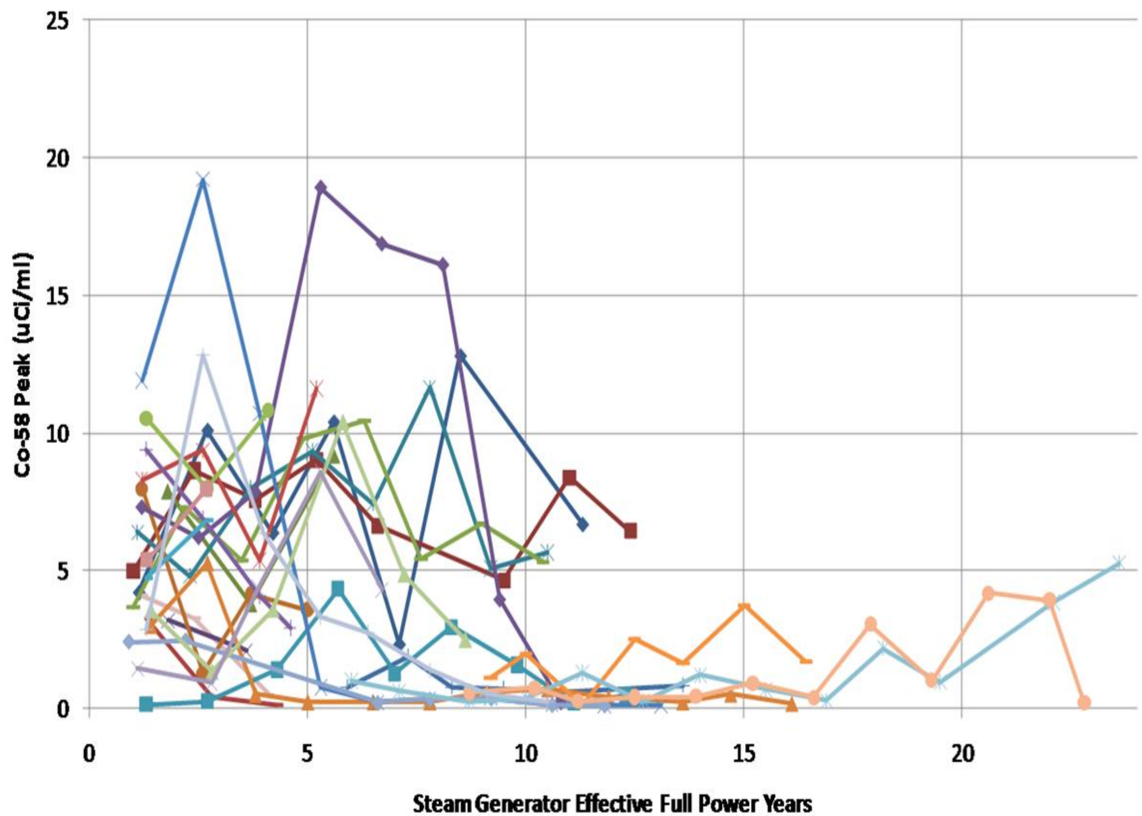


Operating Experience

- *Increasing trend related to the number of plants securing reactor coolant pumps*
  - *Lower peaks observed*
- *4 plants have increased the RCP run time post-peroxide*
  - *2 units have experienced Increased peaks observed*

Post-SGR Co-58 Shutdown Peaks:
RM TSG Technical Update

- ✓Observations
  - ✓The expected post-replacement trends were evident considering materials corrosion
  - ✓In general terms, peak activities lower after the first 8 SG EFPYs
- ✓How does this impact dose rates, fuels, and chemistry?
- ✓Does this capture the whole story?
  - ✓RCP operating strategies, etc



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Conclusions

- Address the gaps…
  - Surface chemistry interactions and radiation field buildup considerations
  - Impact of optimized fuel, materials, chemistry and how to factor these impacts into future planning
- Benchmarking:
  - One size shoe does not fit all
  - Get the rest of the story…
- Can we model?
  - Example - PWR that is a mature plant with steam generator replacement
    - Zinc injection, aggressive or alternate shutdown chemistry regimen, pH control, does the plant apply ultrasonic fuel cleaning
    - Decontamination of the outer oxide
      - Industry data from Decommissioning Program – 95% reduction in Dose Rates
- Source Term: Site effort and **<u>not a RP and Chemistry ONLY EFFORT!</u>**

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