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Shutdown Chemistry

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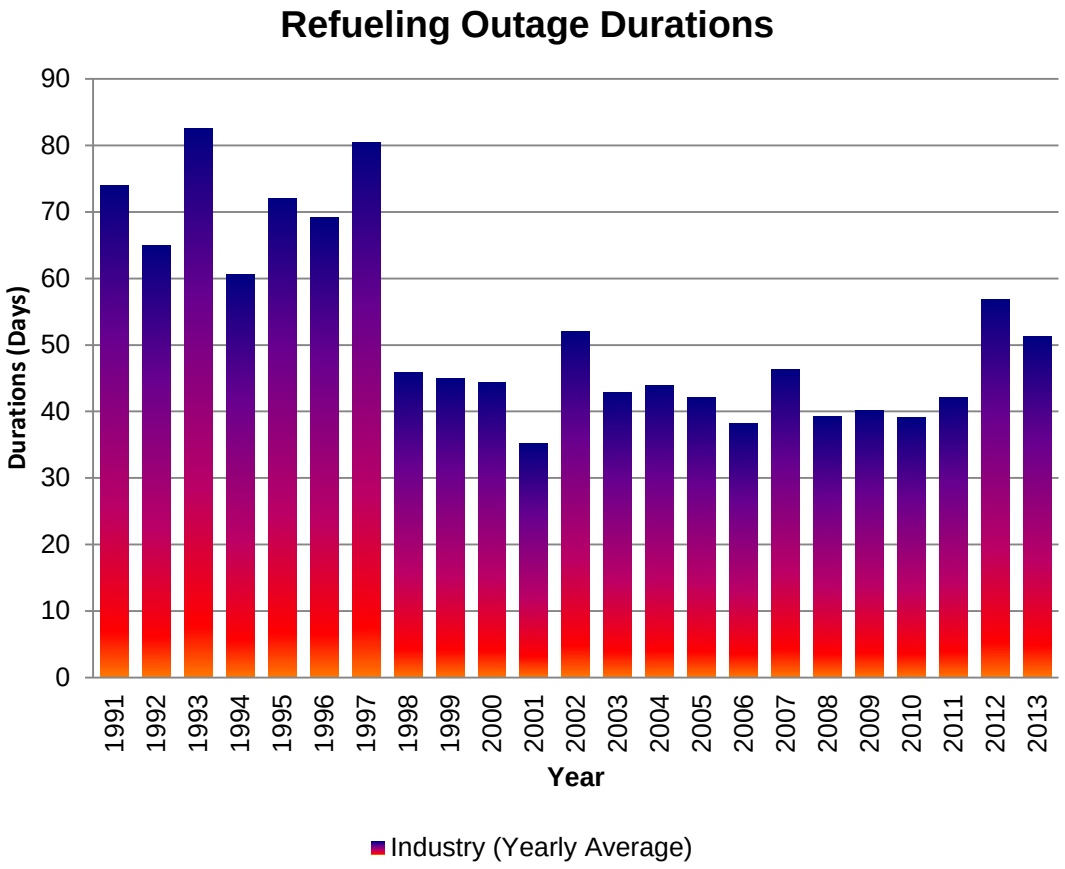
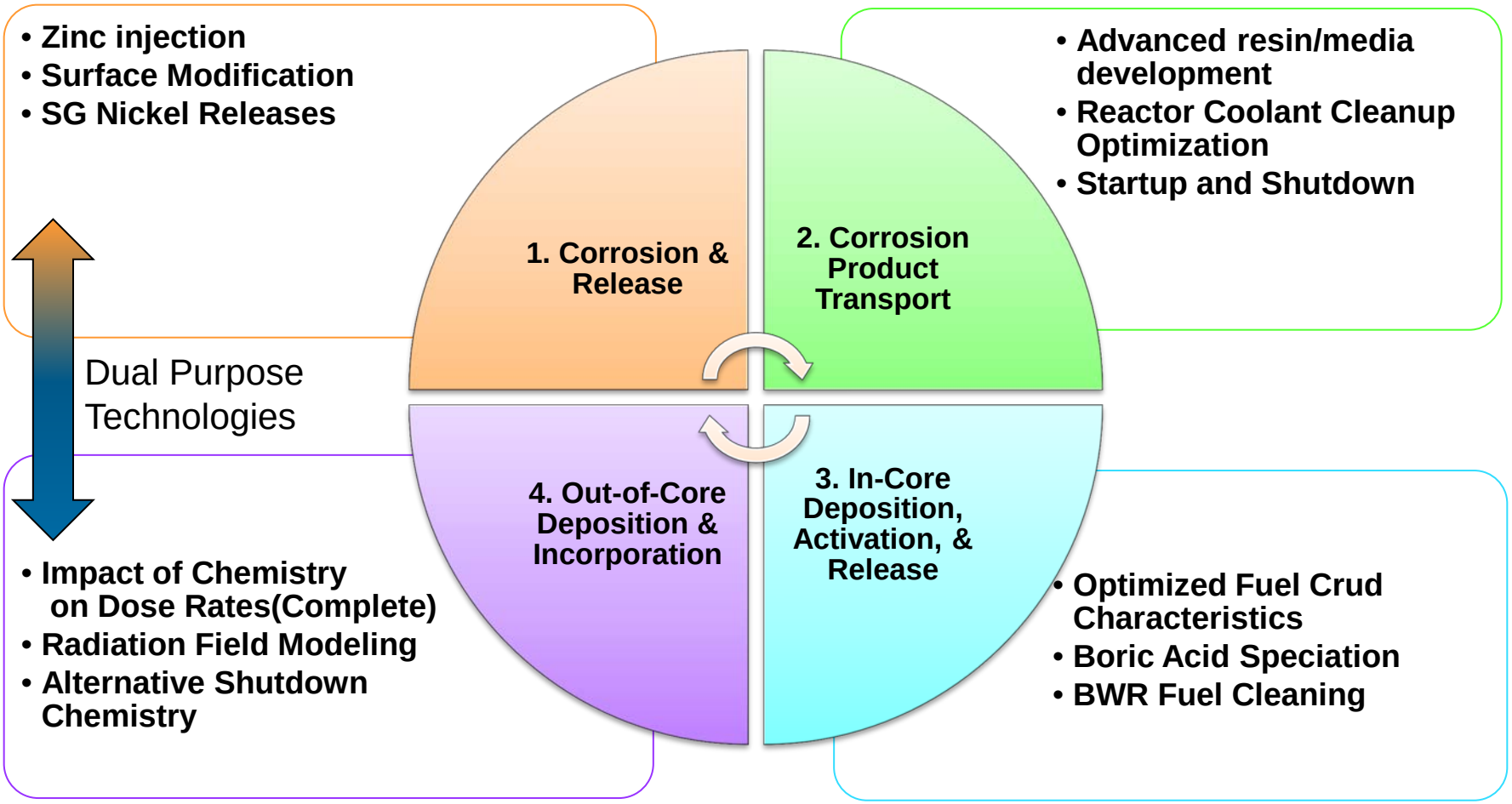
Outage Durations



- ✓Outage Duration
  - ✓How to transition the plant…
- ✓Data
  - ✓SGDD - > 1000 RFO
- ✓Some Numbers
  - ✓Since 2000:
    - ✓202 < 30 days
    - ✓62 < 25 days
    - ✓33 < 20 days

Outage planning is based on the *Long Range Asset Management Plan* focused on the nuclear plat life cycle economics. These may include; regulatory mandates, equipment reliability, process or elective scope

Source Term – A Process



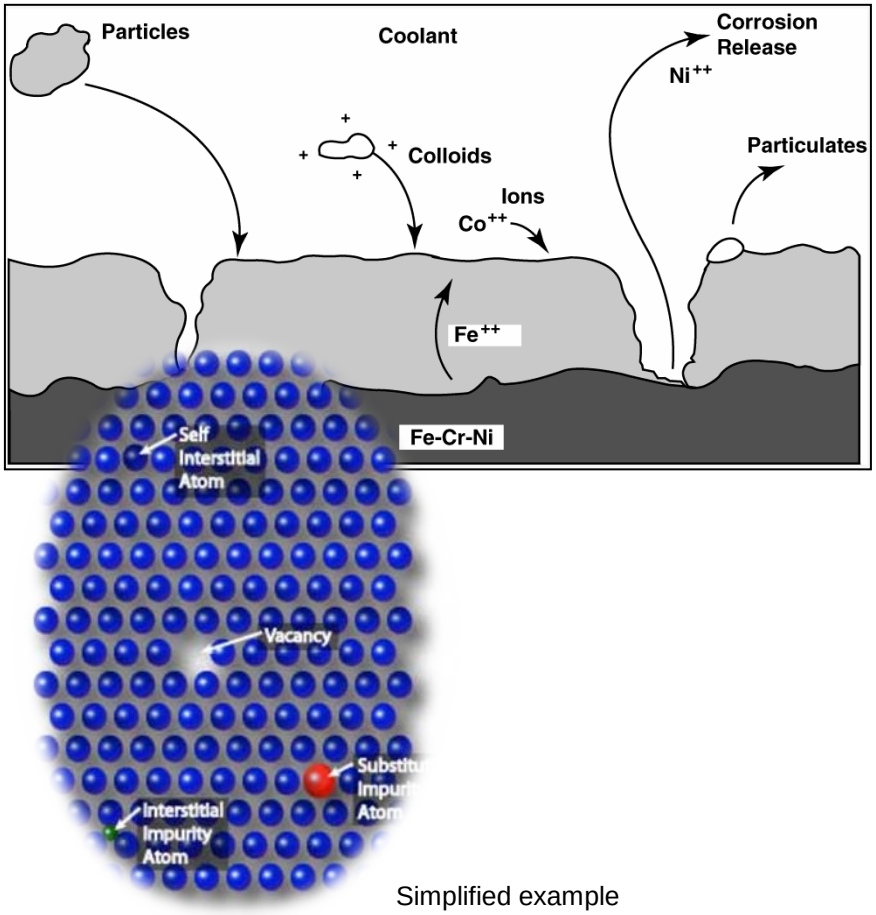
✓ 2014 Fundamental Activity: SRMP/BRAC Maintenance (Continuing)

Composition of Major Structural Components

	Steam Generator Tubing			Structural	
Element	**Alloy 600**	**Alloy 690**	**Alloy 800**	**304 SS**	**316 SS**
C	0.01–0.05	0.015–0.025	<0.03	≤0.08	≤0.08
Co	0.015–0.10	0.015–0.10 (≤0.015 for tubing)	<0.10		
Cr	14.0–17.0	28.0–31.0	20-23	18-20	16-18
Cu	<0.50	<0.50	<0.75		
Fe	6.0–10.0	7.0–11.0	balance	balance	balance
Mn	<1.0	<0.50	0.4–1.0	≤2.00	≤2.00
Mo					2.0-3.0
Ni	>72.0	>58.0	32.0–35.0	8-11	11-14
P				≤0.04	≤0.03
S				≤0.03	≤0.03
Si				≤0.75	≤0.75

Corrosion, Release and Uptake
Metals and Activated Corrosion Products

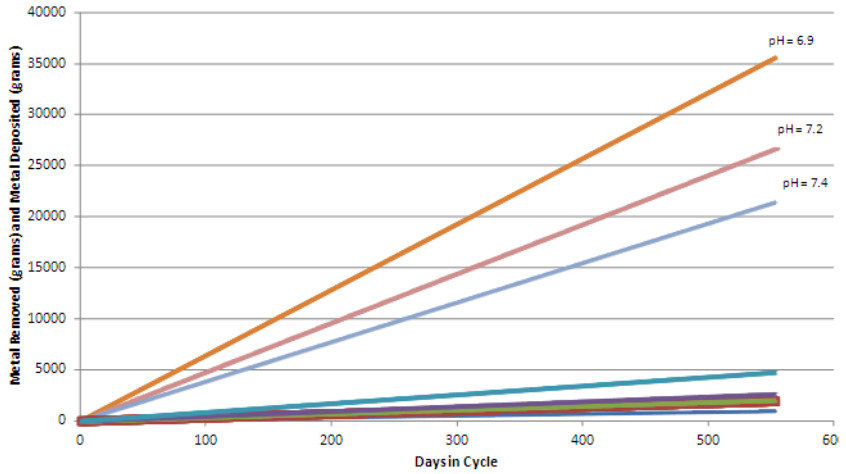
- Metallic non-radioactive corrosion and wear products:
  - Soluble, colloidal or particulate species
- Deposition on the fuel rod surfaces by precipitation, adsorption, or particle deposition
- Activated by absorbing fast or thermal neutrons in the reactor core
- Release:
  - Erosion, thermal, hydraulic,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



Simplified example

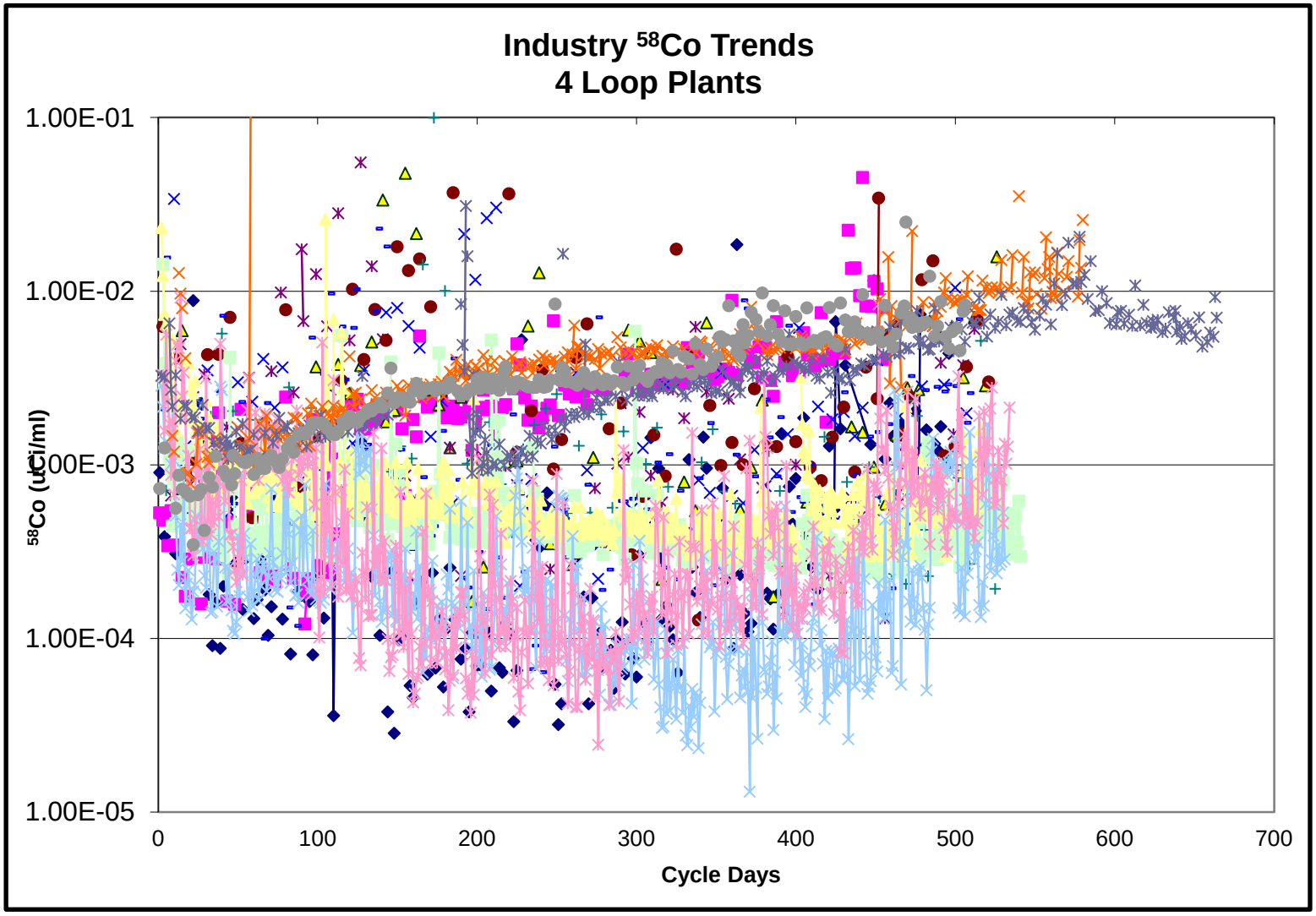
Corrosion Product Release Transport to Fuel Surfaces

- As an 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
- Corrosion product challenges:
  - Activation, fuel performance (thermal and CIPS), end-of-cycle releases, etc



Challenge: Reduction of generation and transport of metals to core fuel surfaces?

Cycle Trends
4 Loop Westinghouse Plants



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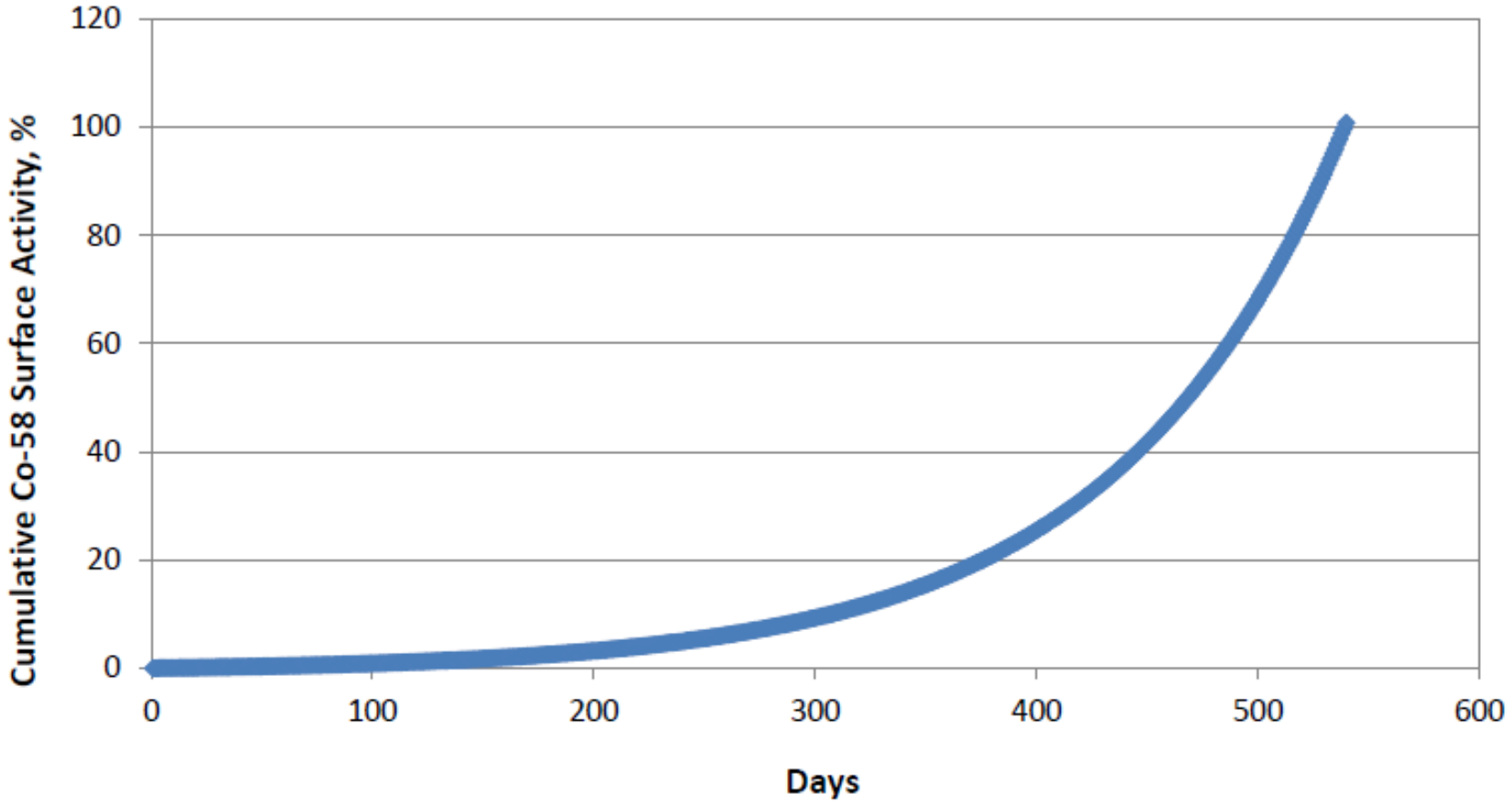
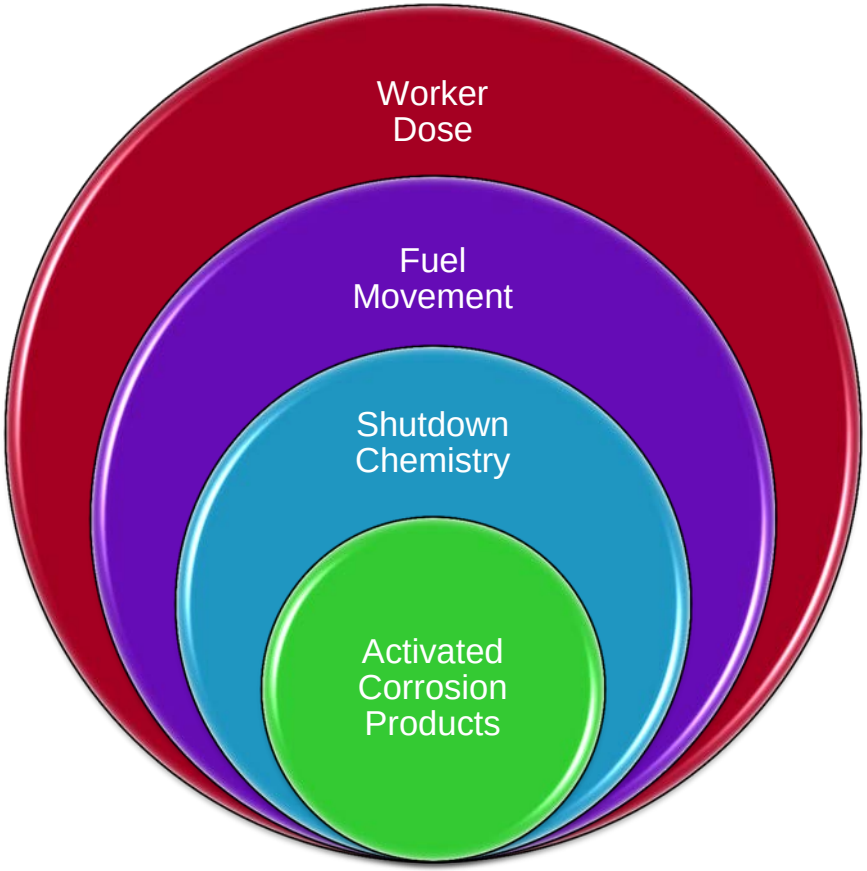
Co-58 Surface Activity Calculations



Shutdown Chemistry Controls and Challenges



- ✓Shutdown Chemistry
  - ✓Prepare the plant for refueling
- ✓How…
  - ✓Perform a CONTROLLED release of activated corrosion products
- ✓Standard of Success
  - ✓Refueling Bridge Dose Rates
  - ✓Cavity Clarity for Fuel Movement
  - ✓Minimal Impact on Overall Dose Rates due to Deposition

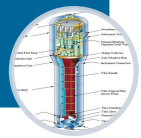
Factors Impacting Shutdown Releases

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

Operating Time (SG EFPY)

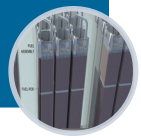
- Several factors to consider
- Increased surface area
- Surface Characteristics

SG Tubing



- Mass evaporation
- Thermal flux

Core Design

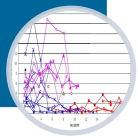


- Nuclide activation
- Mid-cycle outages
- Coast down and crud movement

Power Generation

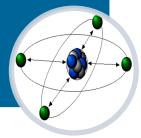
- Mass transfer
- Shear Force
- Impact on particulates
- Outage schedule impact

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)

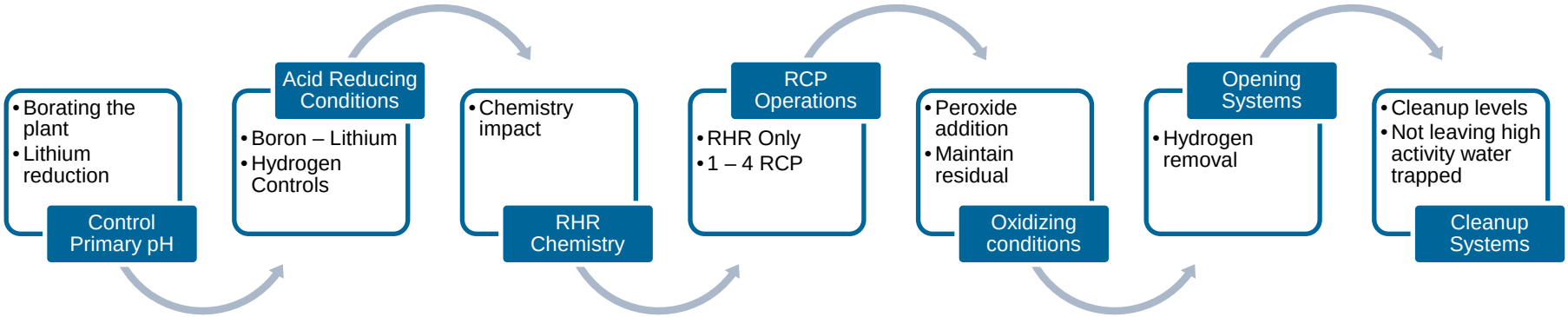
Chemistry Control

- Fuel deposits removed

Ultrasonic Fuel Cleaning

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

Shutdown Process and Benchmarking



Common Challenges

- ✓ Boration rates
- ✓ Lithium reduction or pH(T) goals

✓ In general:

- ✓ US Fleet more aggressive

RCP Pump Operations

- ✓ Promote dissolution
- ✓ Minimize transients

✓ Thoughts

- ✓ Various combinations across globe

Cleanup systems

- ✓ Resin loading
- ✓ Cleanup flow modifications

✓ Common Questions

- ✓ What is the right resin combination, specialty resins, letdown modifications

Failure to maintain residual oxygen / peroxide resulted in significant release on cavity fill

Shutdown Chemistry Evolution

Power Reduction –

- ✓Plant Conditions:
  - ✓Power – 0 – 100%
  - ✓Temperature: 525 – 590°F (274 - 310°C)
  - ✓Chemistry: Hydrogen > 15 cc/kg, Li < 1 ppm, and B ≥ 0 ppm
- ✓Fleet:
  - ✓Normal Reduction in power until ~20%
  - ✓Hard vs. soft shutdowns – Trip the reactor or drive rods
- ✓Duration (in general):
  - ✓U.S. 2 – 12 hours (1 Unit reported 50 hours)
  - ✓Globally – 2 – 50 hours
- ✓Challenges – Document and clarify differences between the different shutdown methodologies

High dose rates from refueling water storage tank resulted in sections of the site yard being isolated until the RWST water activity could be removed

Shutdown Chemistry Evolution

Boration and Cool Down –

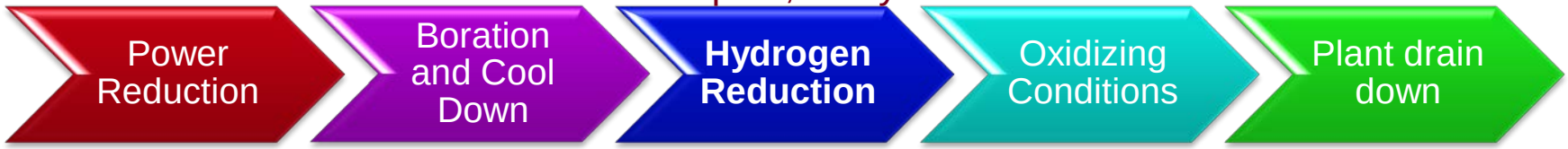
- ✓Plant Conditions:
  - ✓Temperature: 200 – 525°F (93 - 274°C)
  - ✓Chemistry: Hydrogen > 5 cc/kg, Li < 1 ppm, and B ≥ 500 - 3000 ppm
- ✓Fleet:
  - ✓Time to borate and lithium reduction varies across the fleet
- ✓Duration:
  - ✓U.S.: Time to borate 7 –24 hours with some noted exceptions
  - ✓Globally – Time to borate 4 – 60 hours and time to cool down 12 – 74 hours
- ✓Challenges – Review guidance and consider expanding the discussion on cool down impact, if any.
- ✓Challenges – Dose rates begin to increase in small bore piping and RHR systems

High dose rates from refueling water storage tank resulted in sections of the site yard being isolated until the RWST water activity could be removed

Shutdown Chemistry Evolution

Hydrogen Reduction –

- ✓Plant Conditions:
  - ✓Temperature: 150 – 325°F (66 - 163°C) and may start at higher temperatures
  - ✓Chemistry: Hydrogen < 5 - 30 cc/kg, Li < 1 ppm, and B ≥ 1000 - 3000 ppm
- ✓Fleet:
  - ✓Varies from aggressive to none for chemical degassing plants
    - ✓Mechanical vs. chemical degassing
- ✓Duration and Hydrogen Residuals:
  - ✓U.S.: Typically hydrogen reduction is complete in < 15 hours with ranges from 5 cc/kg and up
  - ✓Globally – Typically hydrogen reduction is complete in <24 hours with ranges from 5 cc/kg and up
- ✓Challenges – Previous documents have provided guidance but consider expanding the discussion on cool down impact, if any..



Secured RCP's with > 1.5 uCi/ml (~5E+07 Bq/kg) resulted in high loop dose rates impacting outage dose

Shutdown Chemistry Evolution

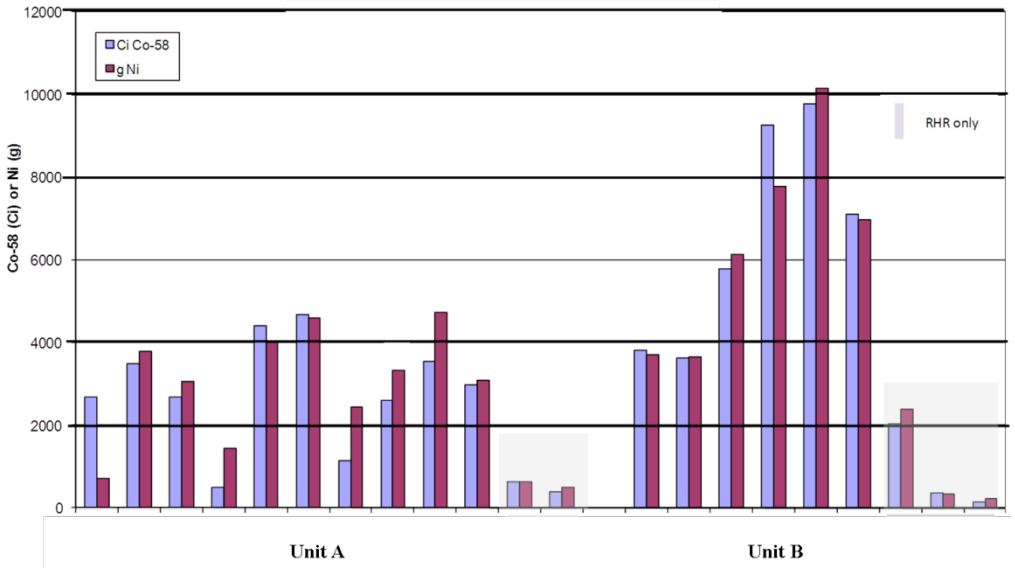
Oxidizing Conditions –

- ✓Plant Conditions:
  - ✓Temperature: 110 – 190°F (43 - 88°C)
  - ✓Chemistry: Hydrogen < 5 - 48 cc/kg, Li < 1 ppm, and B ≥ 2000 ppm
- ✓Fleet Oxidation Practices:
  - ✓Peroxide additions – mid-loop to running maximum number of RCPS
  - ✓Demineralizers – Bypassed to maintain in-service
- ✓Duration (Time to peroxide addition):
  - ✓In general: 18 – 84 hours and varies depending more on individual plants
- ✓Challenges – Recent data reviews show an impact of RCP operation and potential particulate challenges.

Higher than expected or unexpected higher released have resulted in higher outage dose rates and dose.

Alternate Shutdowns

- 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

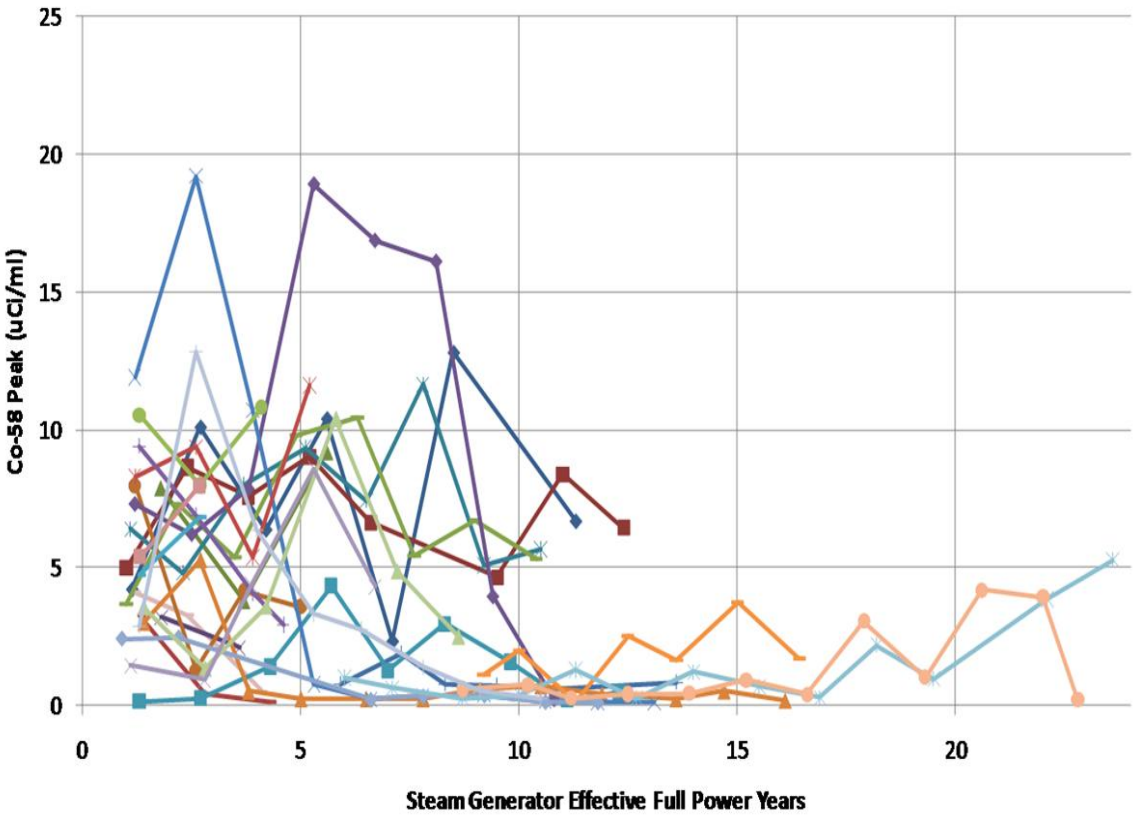


Operating Experience

- *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?



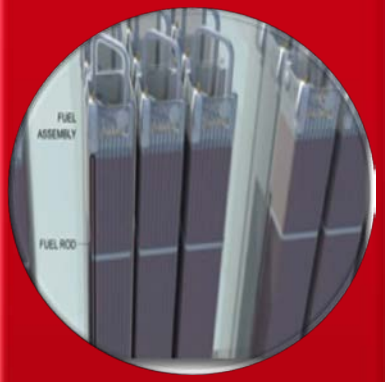
Shutdown Chemistry Evolution

Plant Drain Down –

- ✓Plant Conditions:
  - ✓Temperature: 110 – 150°F (43 - 66°C)
  - ✓Chemistry: Oxygen 0.5 – 5 ppm, Peroxide 2 – 5 ppm, and B ≥ 2000 ppm
- ✓Plant:
  - ✓Drain down activities to support head disassembly
  - ✓Demineralizers – Flow should be maximized to support cleanup goals
- ✓Duration (Cleanup window to ≤0.05 µCi/ml (~1.9E+06 Bq/kg)):
  - ✓U.S.: 24 – 50 hours
  - ✓Globally – 24 – 72 hours
- ✓Challenges – Extended releases, maximizing or maintaining cleanup flow, and contingency planning

Letdown not restored following site event resulted in cavity fill with ~2 – 2.5 µCi/ml (~8.5E+05 Bq/kg) in primary circuit led to > 100 mR/hr on refueling bridge.

EPRI Recent Work: Leveraged or Organizational



Fuels

- Nickel Release during SD
- TMI-1, Crystal River 3 and Davis-Besse Crud Observation Assessment and Root Cause
- Crud Scrape and Analysis Results from Davis-Besse Cycle 16
- Impacts of zinc, pH, and Time on the Release Rates of Steam Generator Tubing
- Assessment of Comanche Peak, Ringhals, and Diablo Canyon Elevated pH Programs

Radiation Management

- PWR Activity Releases (RM TSG)
- Impacts of PWR Operational Events on Particulate Transport and Radiation Fields: McGuire 1 Case Study
- Impact of PWR Coolant Radiocobalt Concentrations on Shutdown Dose Rates: Interim Report
- Refueling Dose Reduction Options
- PWR Standard Radiation Monitoring Summary (Numerous)
- Dose Rate Impacts of Activity Transport
- Cobalt Reduction Source Book

Chemistry

- Benchmarking PWR SD Practices
- Extended Release Report
- PWR Activity Transport and Source Term Assessment: Surface Activity Concentrations by Gamma Scanning
- PWR Primary Guidelines
- PWR Zinc Update Report

- ✓Cross-cutting – How to…
  - ✓Prepare the plant for refueling
  - ✓Minimize worker dose
  - ✓Optimize fuel design
- ✓Answer…
  - ✓Leveraged approach within EPRI
  - ✓Coordinated approach within industry groups
  - ✓Partnering between onsite groups

Together…Shaping the Future of Electricity