Exelon's Careful and Critical Comparison of Two Source Term Reduction Methods at Byron-1 and Braidwood-1

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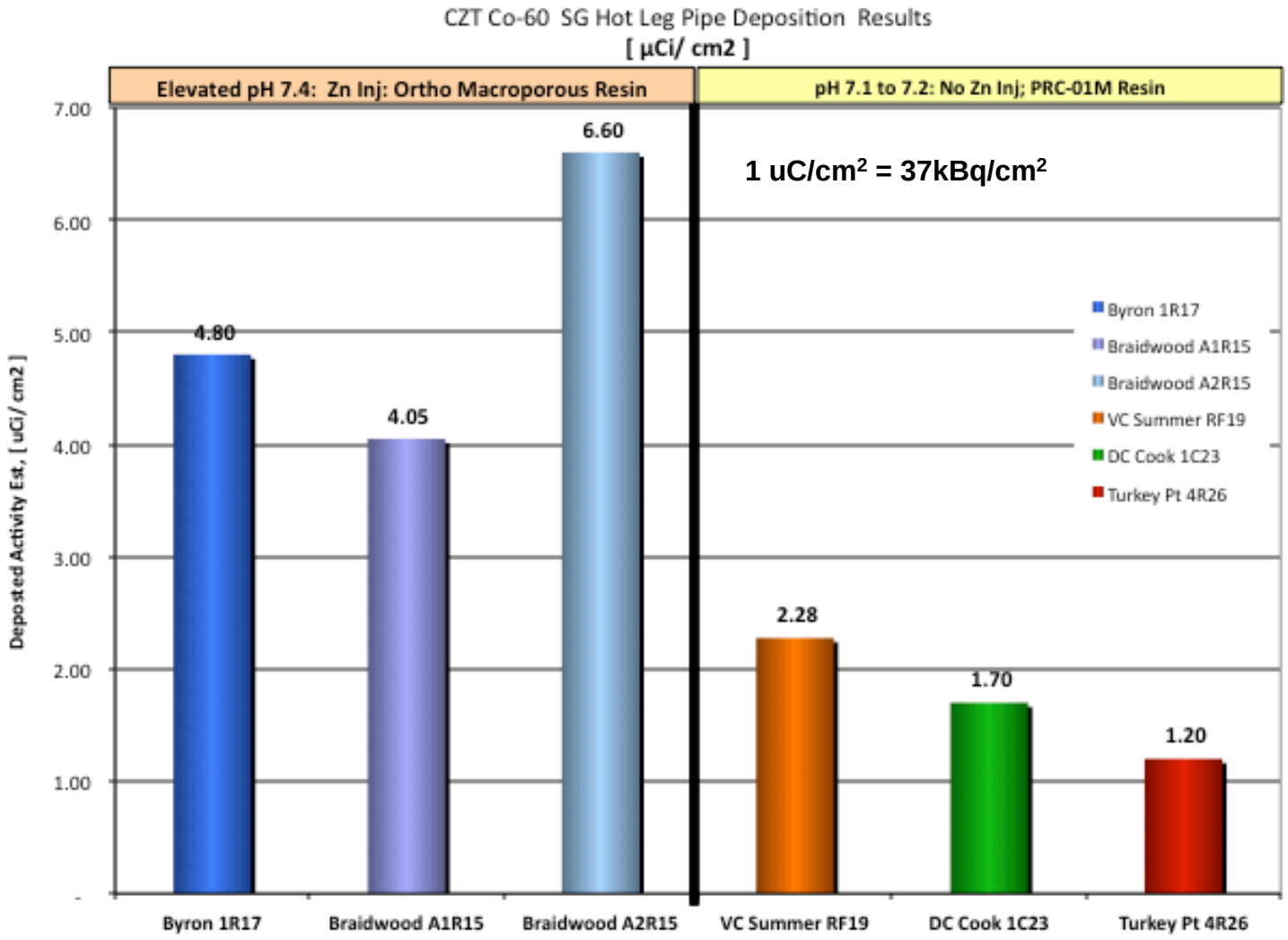
Braidwood-1,2 and Byron-1,2 Essentially Identical

- Westinghouse 4-Loop PWR
  - Unit 1 : 1194 MWe
  - Unit 2: 1166 Mwe
- Reactors on Two Sites
  - Byron-1 = Braidwood-1
  - Byron-2 = Braidwood-2
  - 4 Identical Designed Units
  - Unit 2's have 600 TT SG

In 2003, Exelon Radiation Protection Identified Emerging Technology for Source Term Reduction

- Byron and Braidwood RP had identified new technology for better and faster source term reduction
  - Unable to gain support from Chemistry with early data
  - Chemistry Only Supported Implementation of Ortho-Macroporous Resin
  - Braidwood-1,2 and Byron-1,2 Implemented Macroporous resin for past 8 years
- 2003 to 2010, RP continued to follow industry data and continued to build the case for implementation of PRC-01M Technology
  - Lead Plants Provided Benchmark Data
  - Documented Significant and Sustained Reduction - Dose Rate Decline
  - Documented Significant and Sustained Reduction – Core Curie Release
  - And Used Canberra CZT Gamma Spectroscopy Measurement Data to Compare Byron and Braidwood to Lead PRC-01M Technology Plants

Benchmark Data Showed Better Performance than Byron-1 and Braidwood-1



Evolution of Exelon's Process to Determine Best Solution for Source Term Reduction (STR)

- In 2010, Exelon CNO and Board Member, Became Aware of Success with PRC-01M Source Term Solution
  - Through Exelon CNO Participation on DC Cook Nuclear Safety Review Board participation;
  - Through Exelon Board Member Participation with North American Technical Center and RP Conference Attendance
- Executives Heard Reports on What RP had Been Saying
  - New **Proprietary** Resin Technology, PRC-01M
  - Results Reported by Many Nuclear Power Plants in US:
    - Consistent and Sustained Reduction in Dose Rates and Core Curie release
    - Resulting in Reduced Critical Path Time, Reduced Radiation Exposure, Reduced Dose Rates and Reduced Outage Resources
- **Overall Outage Performance Improvement:**
  - **Reduction in Operating and Maintenance Cost and Collective Radiation Exposure**

Executive and Board Challenge
Was Exelon Leading or Lagging STR Performance?

- Chemists and RP Still Disagreed -Different Positions, Different Reasons
  - Chemists Controversy: Opposing Based on Theory and Assumptions
    - Demineralizer Vessel have high DFs (efficiencies Co-58 & Co-60) and therefore cannot do any better.
    - Or… Must be something other reason, that they cannot define.
  - RP Controversy: Supported Implementation based on **Data and Results** of Dose Rate Reduction in all major systems: Primary, CVCS and RHR systems
  - Discrepancy:
    - Large Dose Rates Reductions were/are occurring at other Stations, who also had CVCS resins with high DFs **prior to** PRC-01M Technology Installation.
- Controversy Likely Emerged
  - Because of Intellectual Property Protection and Disclosure Restrictions;
  - and Results/Data Generated by Lead Plants Were Disregarded by Chemistry
- Fact Remained:
  - Many other PWRs were Reporting Performance Data Better than Exelon PWRs, in the Rate of Decline in Radiation Source Term Using New Method
- **Conclusion: Exelon PWR's Performance was Not Leading The Industry But Lagging in Source Term Reduction Performance**

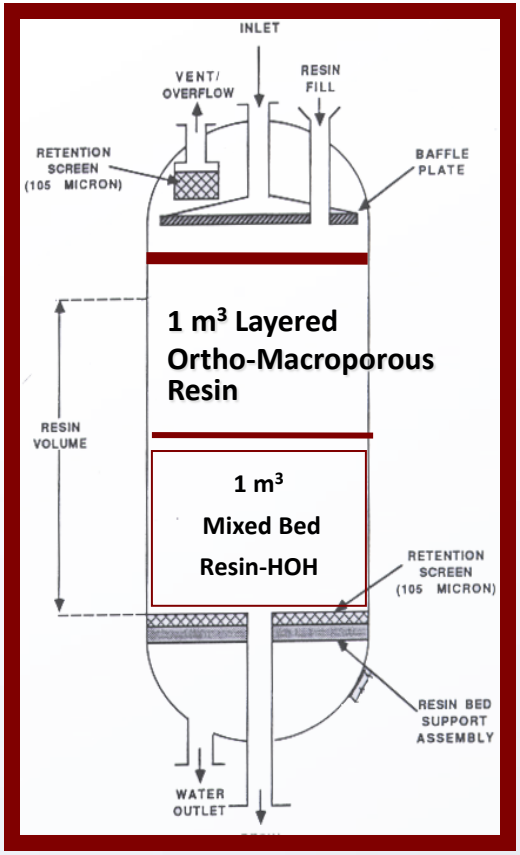
Exelon Senior Executive Management Approach: "Vett or Compare" the Different Methods and Technology

- Process Objective: Validate or Invalidate
- Goal:
  - Eliminate Controversy -- Determine "Best" process
  - "Raise our Own Bar" -- Implement "Best" process at Exelon Fleet Wide
- "Vetting or Comparison" Process Established by Exelon Chief Operating Officer
  1. Braidwood-1,2: Implementation of the NPE Method and LANL Technology in PRC Resin Media
  2. Byron-1,2: Exelon Standard Method and Ortho Macroporous Resin Technology
  3. Established a Careful and Critical Measurement Process
  4. Added New Measurement Methods and Expanded Measurement Locations (e.g. CZT Gamma Spectroscopy)
  5. Conduct the Vetting Process, Sufficient in Length, to Yield **Certainty** of Solution
- Exelon Chief Operating Officer, Maintained Active Oversight
  - Semi-Annual Briefing from Site
  - COO Briefings to Board of Directors

One to One In Plant CVCS System Comparison

Existing Plant Systems PWRs: CVCS, SFP BWRs: RWCU, CPS, FPC

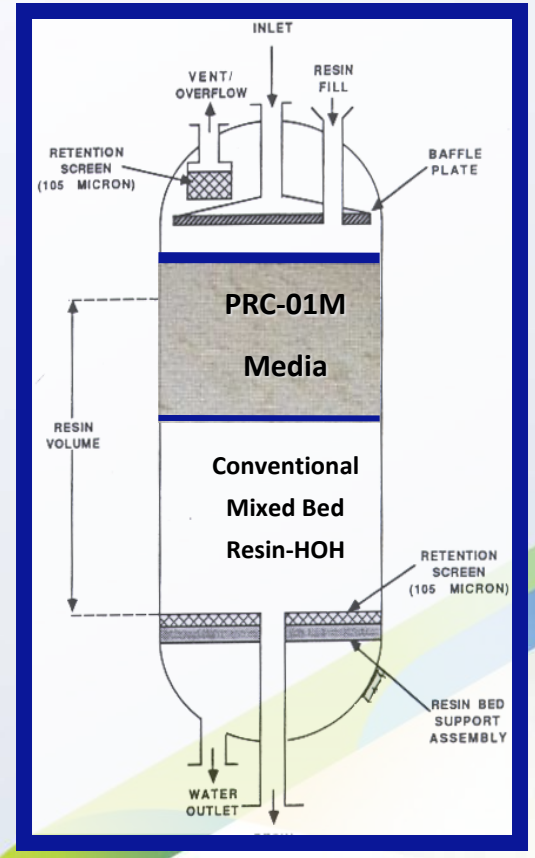
- PWR: PRC-01M (bead) or BWR: PRC-2 (powdered)
- Technology Exclusively Licensed from Los Alamos National Laboratory
- Existing Plant Equipment, CVCS Demineralizer Vessel



Old Resin: 2006 to 2014
Byron-1,2

Byron-1 Macroporous Resin CVCS & SFP

Braidwood-1,2 PRC-01M Resin in CVCS & SFP



New Resin: 2010 to 2014 Braidwood- 1,2

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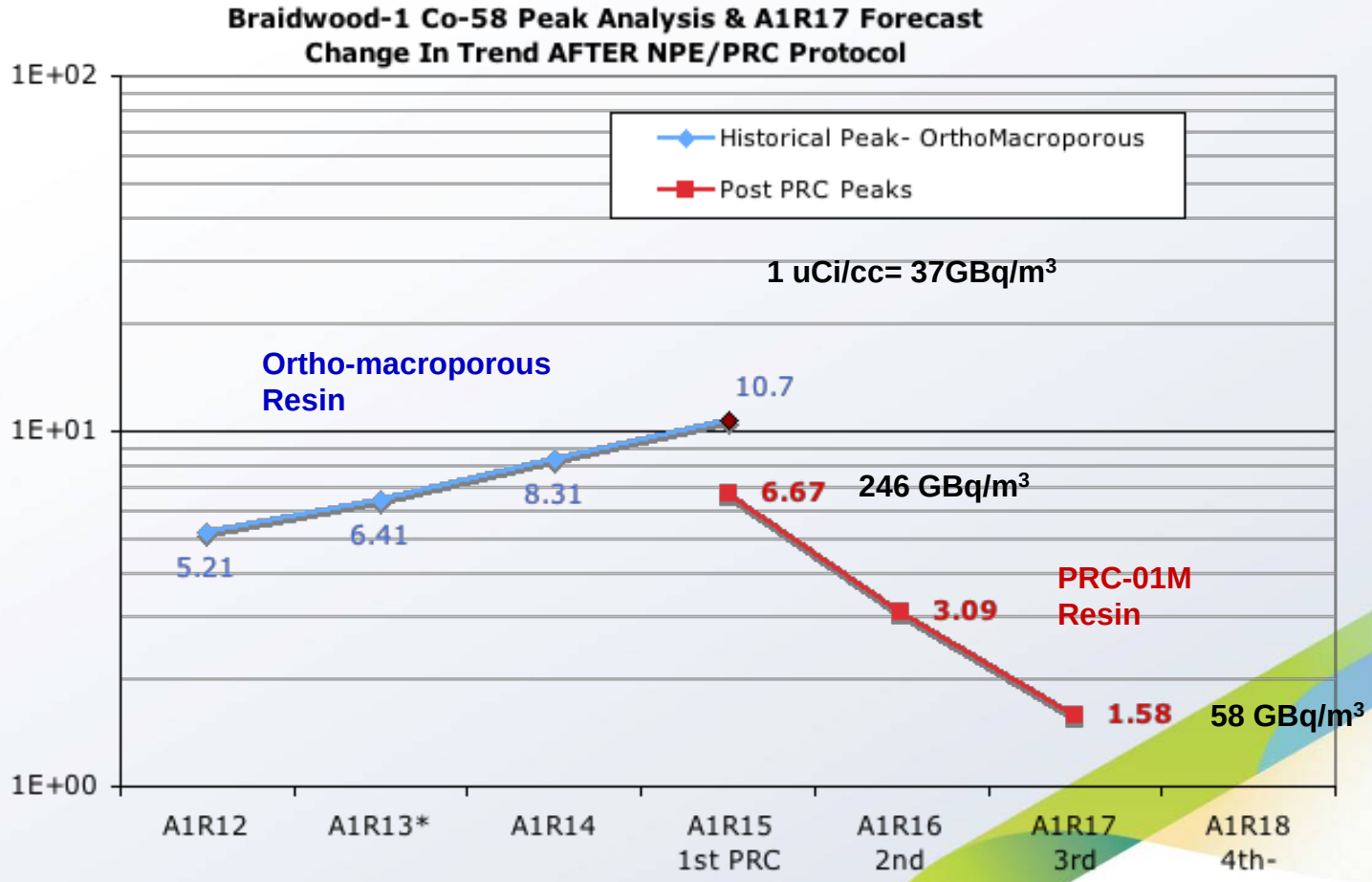
Determination of Best Technology
Robust RP and Chemistry Data Collected

- COO Challenged RP Organization for **Robust** Measurements
  - **OBJECTIVE: To ensure that data would yield clear performance difference and permit clear conclusions**
- RP Metrics: Crud Traps, Components, Pipe Runs
  - Base Point Data: 45 Measurement Locations
    - Instruments: Ion Chamber, GM to Compensated Ion Chamber
  - Electronic Dosimeters: Specific Locations
  - Containment Penetration Monitors
  - CZT Gamma Spectroscopy - Expanded Locations (EdF Locations)
  - SRMP - Expanded Locations
- All Data to Support Measuring the Rate of Change in Source Term from Refueling Outage to Next Refueling Outage

Results: Braidwood-1
Reversal of Trend for Peak Co-58

- Degrading Trend of Core Curie Release
- Reversed Trend of Core Curie Release- Declined by 3 X from A1R15 to A1R17



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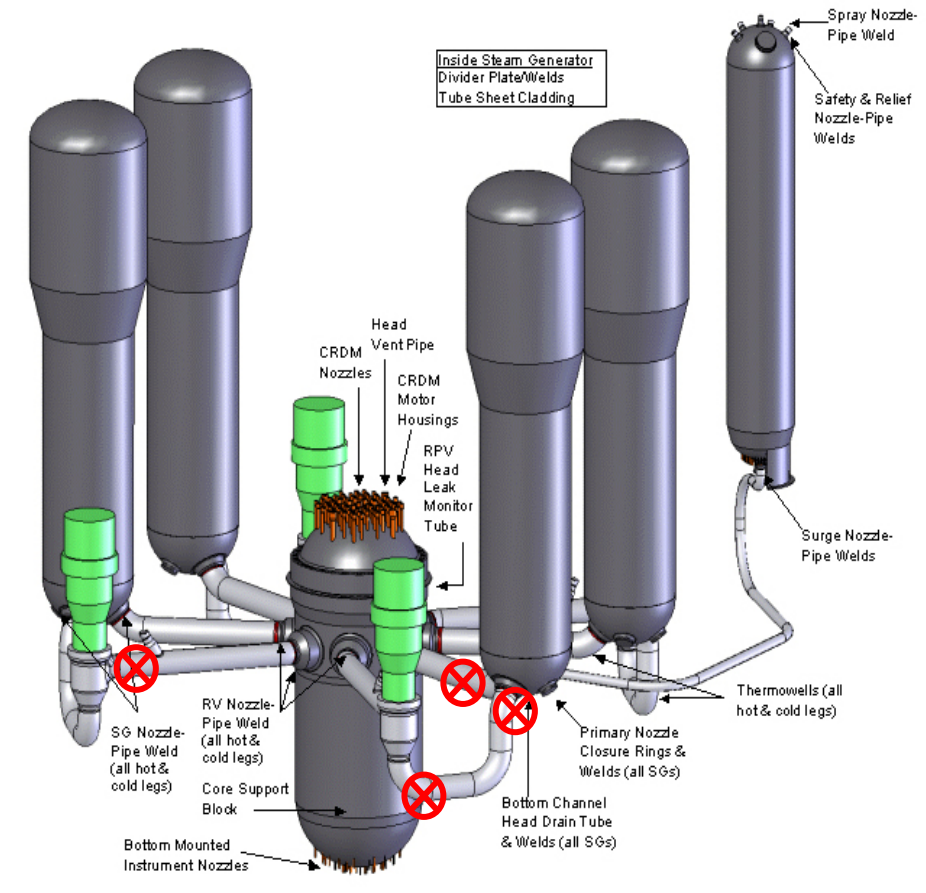
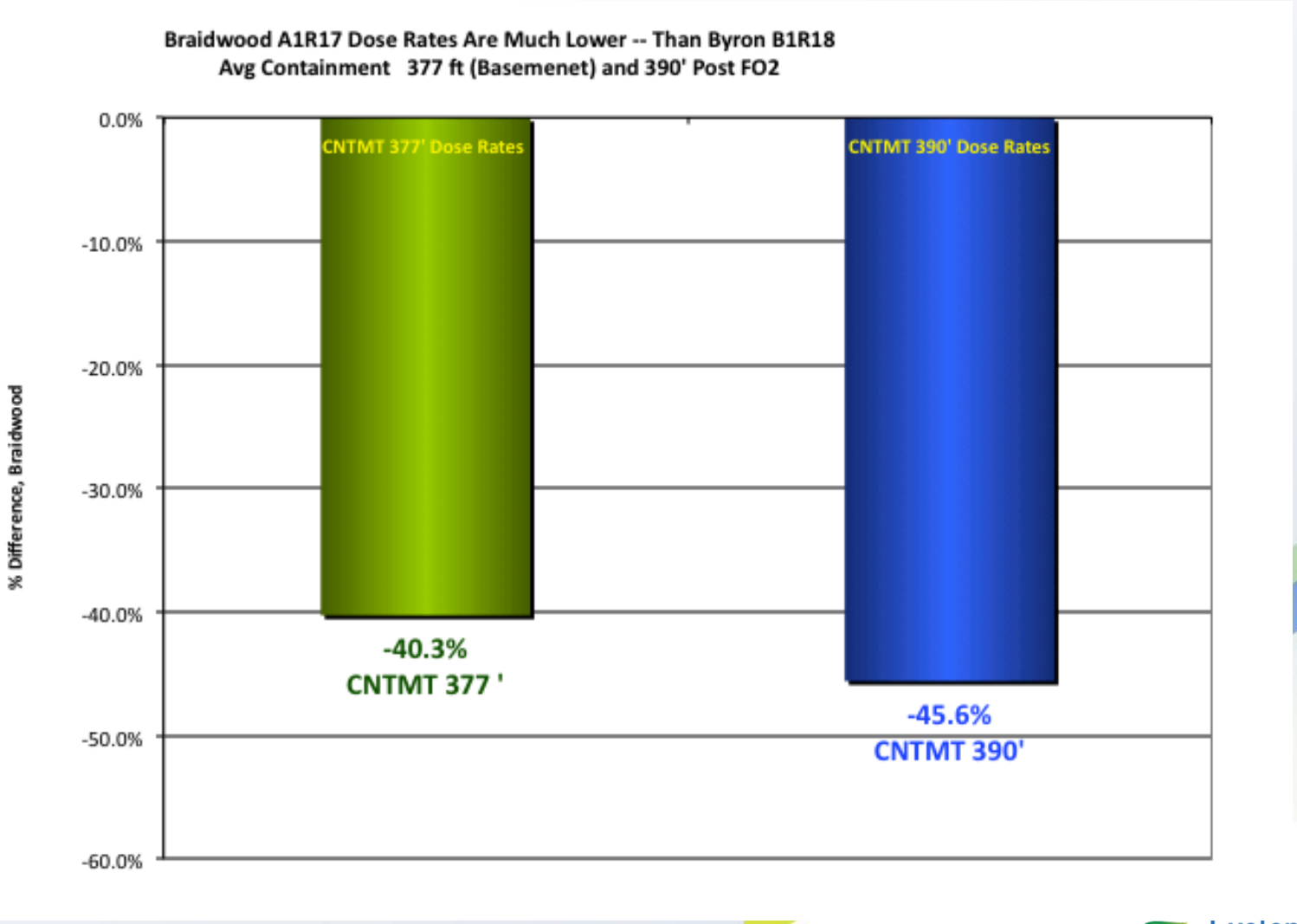
Braidwood-A1R17 Vs. Byron-B1R18



- Braidwood-1 A1R17
  (PRC-01M Integrated)
  - RFO: 21 days 18 hours
  - Planned: 49 REM
  - Challenge Goal: 42 REM
  - **Actual: 25.352 REM (0,253 Sv)**
  - PCE's: 5
- Byron-1 B1R18
  (Layered Ortho-Macroporous)
  - RFO: 27 days, 23 hrs
  - Planned: 66 REM
  - Challenge Goal: 49.9 REM
  - **Actual: 50.735 REM (0,507 Sv)**
  - PCE's: 10

Byron-1 B1R18 vs Braidwood-1 A1R17
Dose Rates -44 to -45% Lower Than B1R18

Two lower levels of containment



Exelon Sr. Executives: Expanded Fleet Deployment Based on Comparison Results Byron-1 R19 March 2014

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Byron-1 B1R19 Refueling Outage, March 2014

- 1st PRC-01M Integration
- 18 days Refueling Outage
- Scope:
  - Routine refueling outage with normal scope maintenance
    - High Duty Core
    - 48% New Feed Fuel
  - Significant valve scope
    - > 110 Valves
- Outage Collective Radiation Exposure
  - 54.4 REM (0,544 Sv) Planned CRE Based on B1R18 Dose Rates
  - 49 REM (0,490 Sv) Stretch Goal

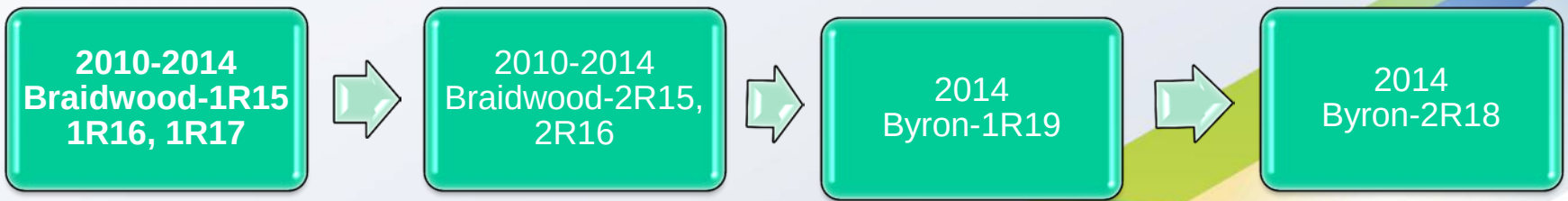
Byron-1 Refueling B1R19
Shutdown Core Release and RCS Purification

- Shutdown RCS Results

Byron B1R19 Shutdown	RCS Activity [uCi/cc]	RCS Activity [GBq/m³]
Actual: Peak Co-58	0.66	24.42
Goal: Last RCP Stop	0.5	18.50
Goal: Prior to Flood Up	0.05	1.85
Actual: RCS at Flood Up	1.47E-03	0.05

Byron-1 B1R19 Refueling Outage, March 2014

- Actual Final (Electronic Dosimeter)
  - 28.748 REM (0,287 Sv) **BYRON-1 BEST**
- Improvement
  - **-47.9% Decline over previous RFO, B1R18**
    - Dose Rates Reduced RCS, CVCS and RHR
- Personnel Contaminations:
  - Goal: < 10
  - Actual: 3 **BYRON-1 BEST**



Byron-1 B1R19 (1st PRC-01M RFO)

- Final Cavity Decontamination
  - Reduced Critical Path 4-hours, ~ $200,000 USD Value
- High Radiation Areas Down Posted Due to Lower Dose Rates
  - Residual Heat Removal Pump Rooms
  - Residual Heat Removal Heat Exchanger Rooms
  - Containment Penetrations
  - Auxiliary Building Penetrations
  - Containment Spray (ECCS) Pump Rooms
  - CV System valve aisles
- Released many areas from Contaminated Area
- Reduced Generation of Dry Active Waste
- Reduced Personnel Contamination Clothing Use

Impact and Value for Braidwood-1 and Byron-1 Far Reaching in O&M Costs and Dose Savings

- Dose Rate Decline Enables Outage Performance Improvement
  - Decline in Number of Locked High Radiation Areas(LHRA)
  - Reduced Number of HRAs to Radiation Areas
  - Worker Efficiency Gained
- Critical Path Reduced
  - Worker Efficiency Gain
  - Final Cavity Decon Time, reduced 4 critical path hours, $200K
- “Cleaner” Nuclear Core
  - Lower Peak Activity, Less Time to Clean-Up and Lower Containment Dose Rates during peroxide injection
  - Reduced Crud Related Fuel Risks, Axial Off-Set, Crud Induced Failures
- Fuel Cleaning No Longer Needed
  - Not Required, No CRUD to Clean
  - Cancel Capital Costs: $2.7 M for Fuel Cleaning Equipment
  - No Service: $80K/ RFO
- LLW:
  - Impact of Waste Storage/Disposal
  - Less Curie Surcharge
  - Future Class A Resins, Saving $600K/ shipment

Conclusion

- Exelon Innovative Method of Vetting Technology Between Sister Units
  - Has Determined Best Technology to Drive World Class Performance in CRE
  - Eliminated Long Controversy with Careful Comparison
  - Provided a Simply Solution- New Resin
- Exelon Corporate Executives Expanded Best Technology Use to Fleet
- US PWRs Now the Technology To Lead World Nuclear Industry in Collective Radiation Exposure in Very Near Future
- **Future Expectations for Braidwood-1,2 and Byron-1,2:**
  - **Unit 1: 10 to 15 REM RFOs with SG ECT (0,01 Sv to 0,015 Sv per RFO)**
  - **Unit 2: 15 to 20 REM RFOs with SG ECT (Older SGs)**

**"Good ideas are not adopted automatically.
They must be driven into
practice with courageous patience. "
----- Admiral H. Rickover, US Navy**

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UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
Department of Nuclear, Plasma and Radiological Engineering
University of Illinois at Urbana-Champaign

Dr. John L. Palms Outstanding Innovation Award

"The Innovation Award program is to inspire engagement in applying technology to positively impact the public and/or occupational radiation safety as it relates to industrial sources of radiation by recognizing individuals, organizations, and companies that use innovative technology solutions and processes.

It is the goal of Innovation Awards to showcase their compelling stories through communication to world nuclear power organizations, and reward their brilliant accomplishments in radiation protection."

Department of Nuclear, Plasma and Radiological Engineering
University of Illinois at Urbana-Champaign

Dr. John L. Palms Innovation Award

- **Announcement of Award:**

  Dr. James Stubbins, Head,

  Department of Nuclear, Plasma & Radiological Engineering, College of Engineering, University of Illinois

- **Exelon Braidwood & Byron Stations, 2014 Winner**

"For Extraordinary Achievement in Occupational Dose Reduction by applying new technology in a parallel study of duplicate Westinghouse reactors, with and without, Los Alamos National Laboratory, developed technology embedded in new specialty resin, over three cycles to prove the value of the technology. "

The Braidwood site achieved a 25.303 person rem outage dose in 2013: a remarkable dose reduction achievement!

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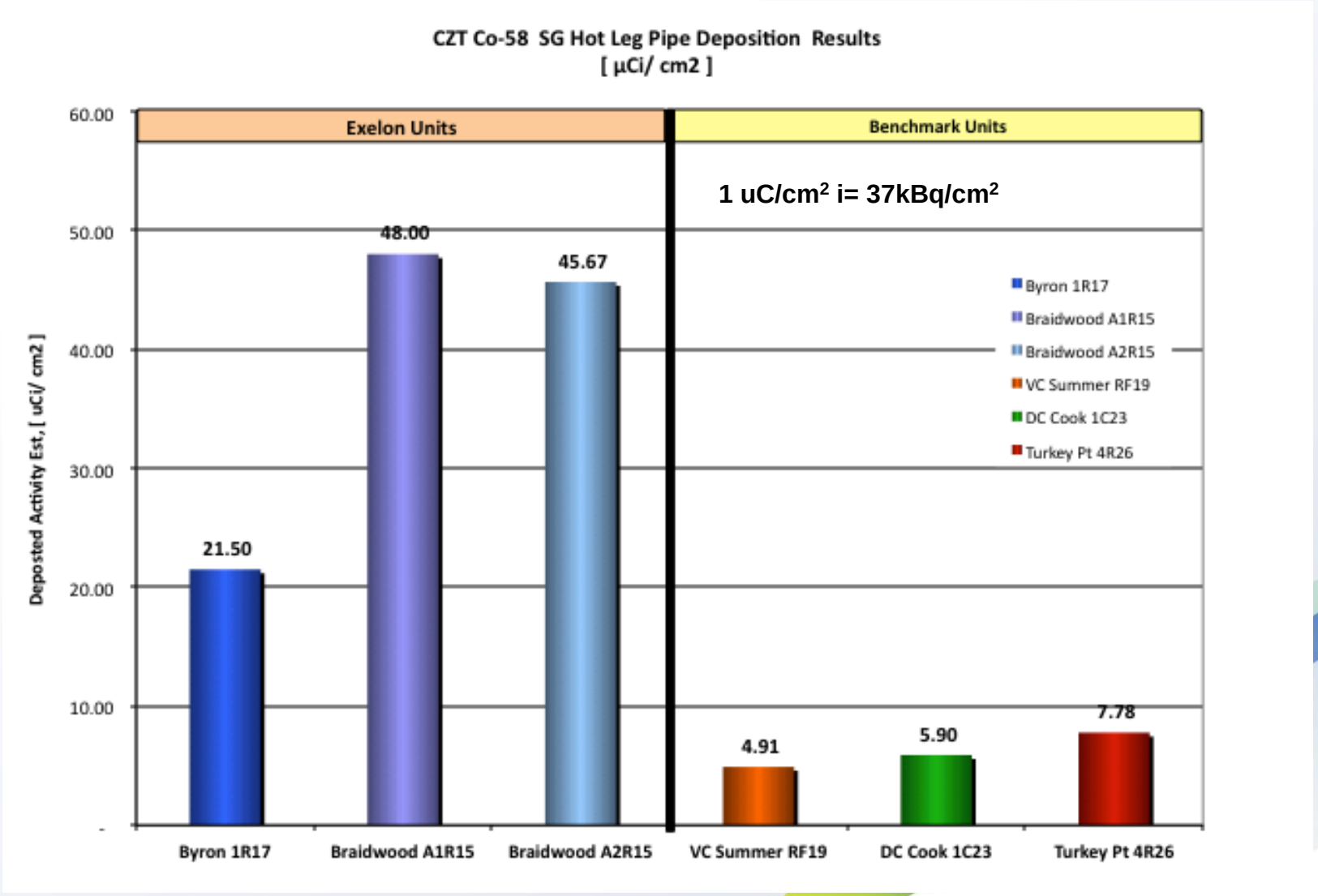
Thank You!

BACK-UP Slides

Benchmark Data Showed Better Performance than Byron-1 and Braidwood-1



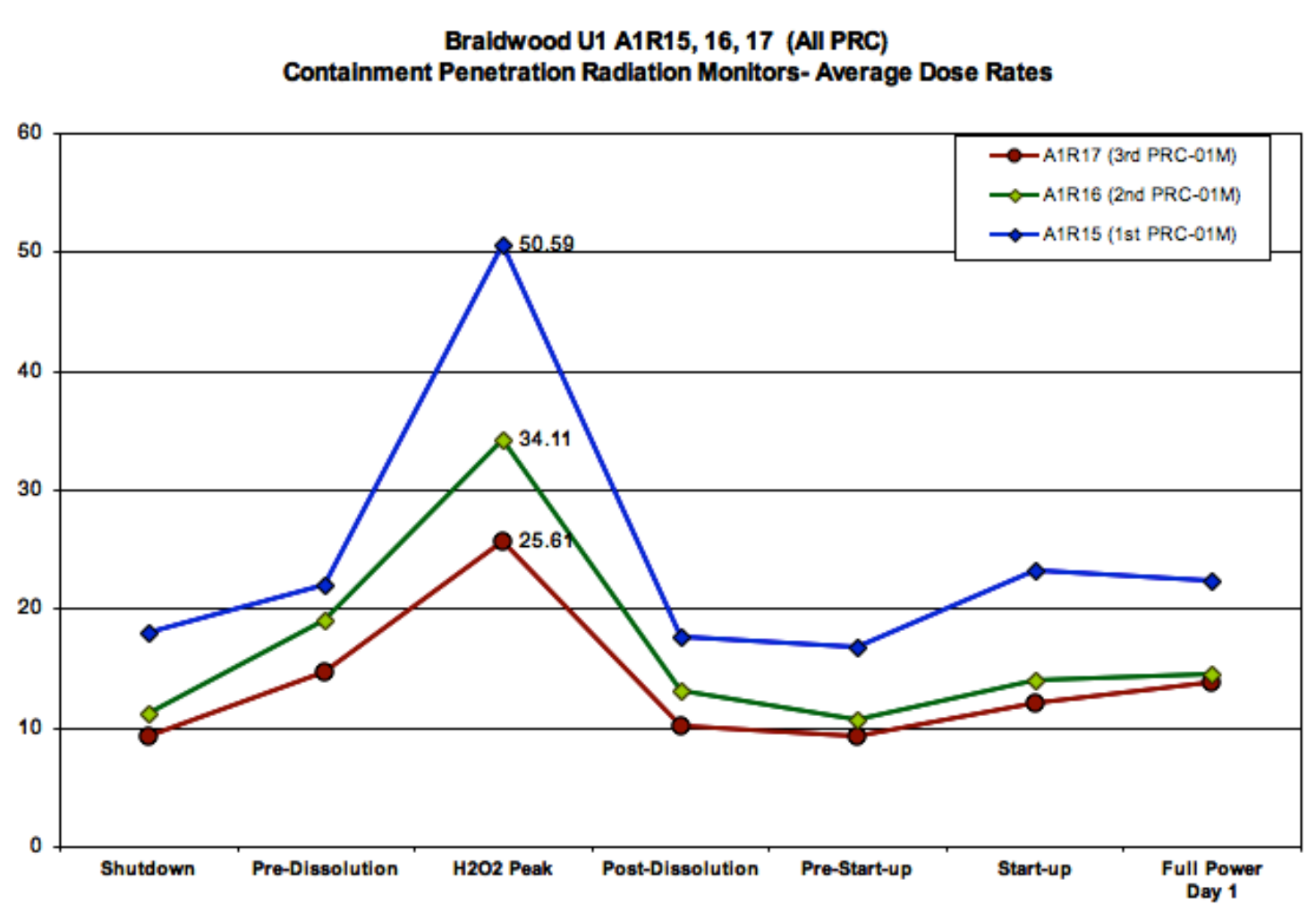
Byron-1 vs Braidwood-1
Side by Side Test of Source Term Reduction Methods

- How Do Byron-1 and Braidwood-1 Compare?
- Essentially The Same
  - Design and Layout
    - All Equipment in Identical Location in Containment
  - Steam Generators
  - pH and Zinc Injection Programs
  - Fuel Duty and Core Design
  - CVCS Primary Resins for 8 years Prior to Change
  - Shutdown Sequence for 8 years Prior to Change
- Byron-1 has 1 operating cycle longer than Braidwood-1
- Excellent Similarities for Comparison

Side by Side Comparison
Byron-1 vs. Braidwood-1

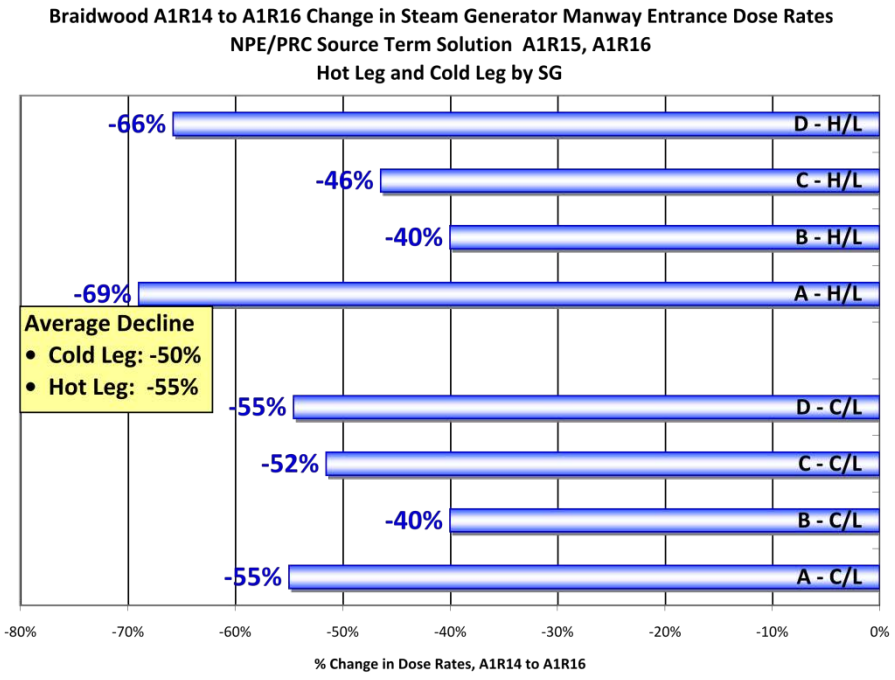
- Braidwood-1 followed 3rd Party Subject Matter Experts Specified Protocols for Rx Shutdown, Start-Up and Technology Utilization
  - Implementation performed by Chemistry, Outage Management and Operation Departments
  - Data collected by Radiation Protection on Dose Rates, Gamma spectrums
- Only 2 Key Changes at Braidwood-1:
  - Different CVCS Clean-Up Resin, PRC-01M
  - Protocol Called for Adherence to EPRI Guidelines and RCP Run time to 0.7 uCI/cc goal prior to Last RCP stop
- Braidwood-1 Specific Changes:
  - CVCS Resin at Power and Shutdown, PRC-01M. Eliminated Layered Ortho-Macroporous
  - RCP Run time Post Forced Oxygenation from 4 hours to Running RCPs to Goal, 0.7 uCi/cc Co-58 in RCS
  - Increased RCS Filter Size from 0.1 um to 0.45 um for shutdown

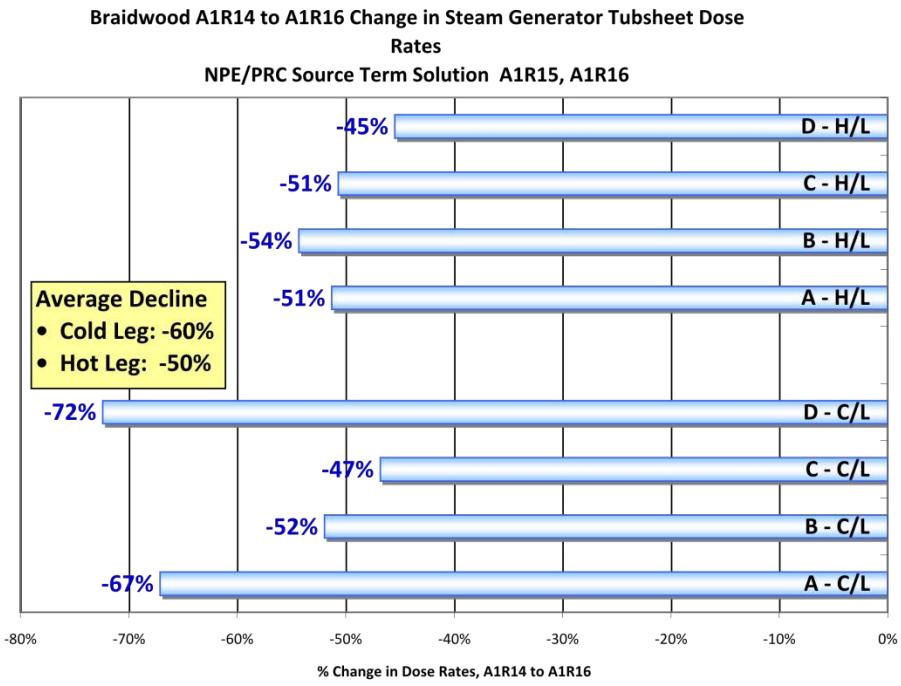
Results: Containment Penetration Area Radiation Monitors Shows Consistent Decline in Dose Rates



A1R16 Source Term Success: SRMP

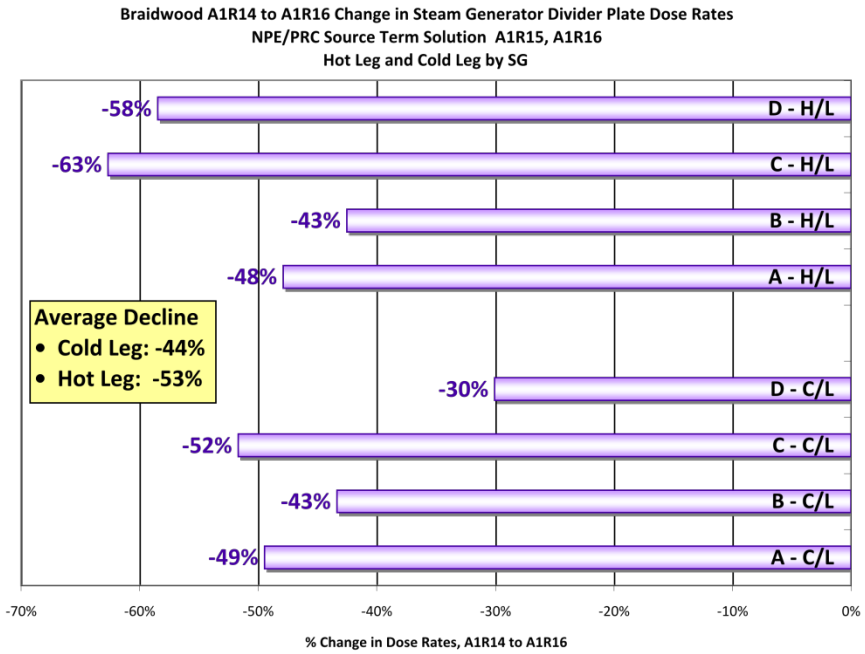
- ✓ A1R14 to A1R16 Significant Decline In Dose Rates in SG Manway Entrance and 3 ft
- ✓ SG Manway Entrance: Cold Leg -44%, Hot Leg -53%
- ✓ Tubesheet MP: Cold Leg -59%, Hot Leg -45%

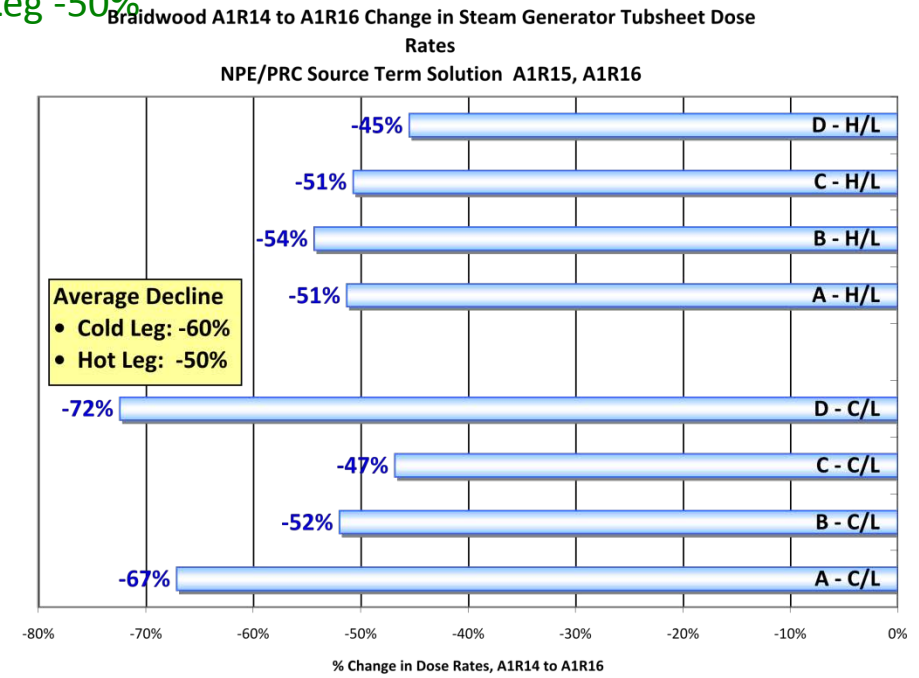




A1R16 Source Term Success: SRMP

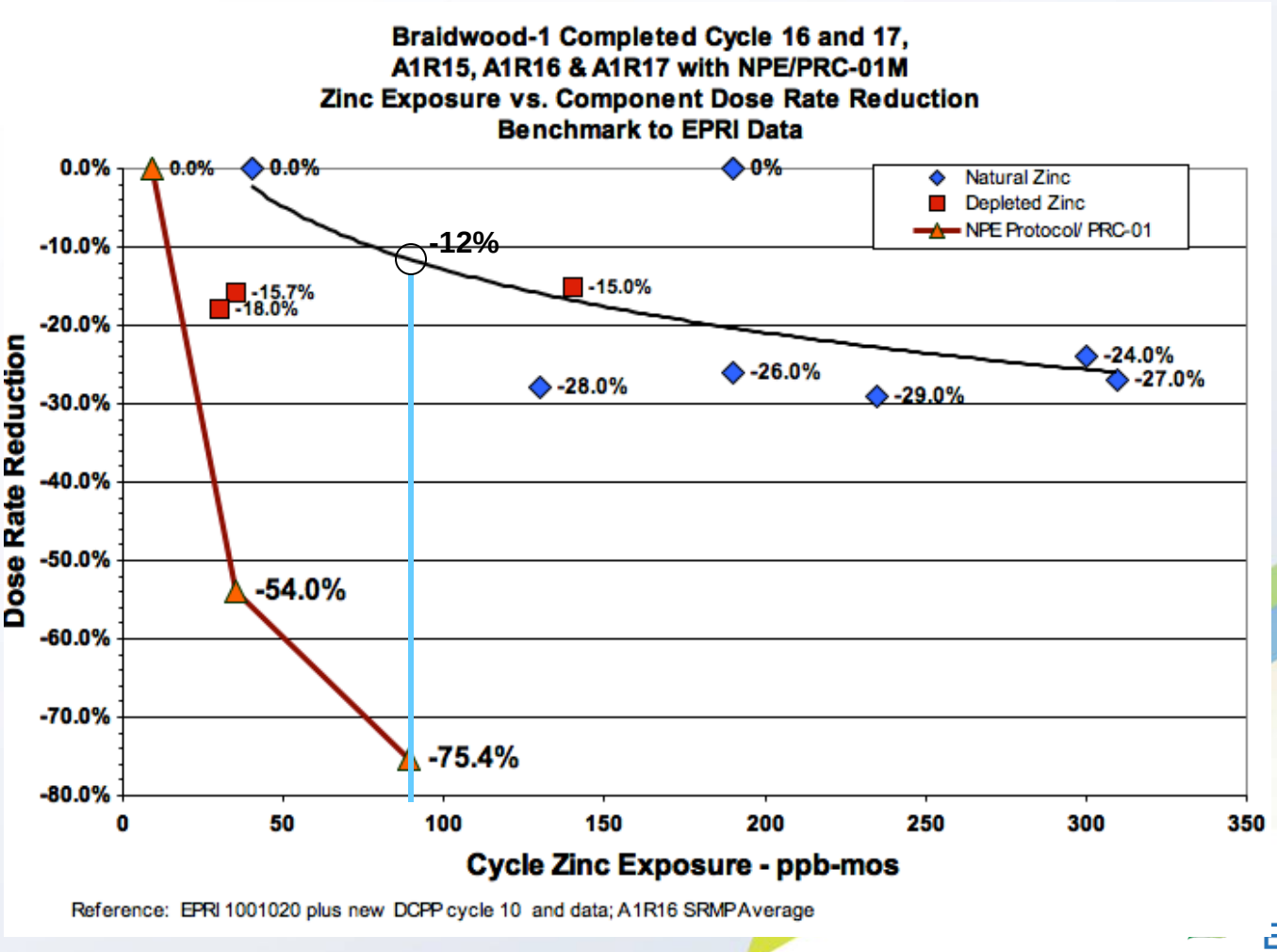
- ✓ A1R14 to A1R16 Significant Decline In Dose Rates in SG Channel Head
- ✓ Divider Plate: Cold Leg -44%, Hot Leg -53%
- ✓ Tubesheet MP: Cold Leg -60%, Hot Leg -50%





Braidwood-1 Performance Exceeds Predicted Benefit from Zinc Injection with PRC-01M

- Predicted based on EPRI Zinc Data: -12% Decline in Dose Rates
- Actual A1R15 to A1R17: -75.8% Decline in Dose Rates
- Conclusion: Results Dominated from PRC-01M , not zinc
- Consistent with Results from NON-ZINC Benchmark Plants



Byron-1 B1R19

- Modified Protocol for Shutdown
  - Ensure Early Acid Reducing Achieved
  - Ensure PRC-01M Technology In-Service and Fully Enables
  - Ensure Outage Schedule can be maintained by Managing H2 Gas Inventory
  - Turned Zinc Off to Mitigate Particle Formation and Transport into Crud Traps
- Shutdown Timeline Accomplished:
  - +5.75 Hours Cooldown to < 200 F
  - +13 hrs Pressurize Solid
  - +19 hrs Forced Oxygenation with Peroxide Injection
  - +48 hrs Reached 0.05 uCi/cc BYRON BEST
  - RCS Activity Prior to Flood Up : 8.87 E-4 uCi/cs BYRON BEST

What Was the Difference in Performance?

- One to One Comparison Byron-1 and Braidwood-1 Completed
- Comparison Process Established and Strictly Followed
  - Results Separated Performance between Byron-1 and Braidwood-1
  - Braidwood-1 out performed Byron-1 in Rate of Change of Source Term
- Successful Results Remain a Mystery to Chemistry
  - Still want to say it is “other factors” but cannot cite “other factors” that were different and relevant in the test.
- Data Clearly Identifies the Braidwood-1 Method of PRC-01M/Protocol Produced a rapid change in Source Term
  - Cannot be Attributed to Zinc, as other stations NOT using Zinc see the SIMILAR rates of decline using PRC-01M.
  - Cannot be Attributed to Differences in Design or Operation
    - Both Units follow EPRI Guidelines
    - Both Units follow Shutdown and Start-up Protocols that are almost identical
      - Except RCP run to 0.7 uCi/cc being different, but not in control of achieving 87% overall decline in dose rates