

# Radiation Field Control through Source Term

Overview of EPRI Research &  
Industry Support Activities

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**PWR RP/ALARA Winter Meeting**

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# EPRI's Principles

## Independent

Objective, scientifically based results address reliability, efficiency, affordability, health, safety and the environment

## Nonprofit

Chartered to serve the public benefit

## Collaborative

Bring together scientists, engineers, academic researchers, industry experts

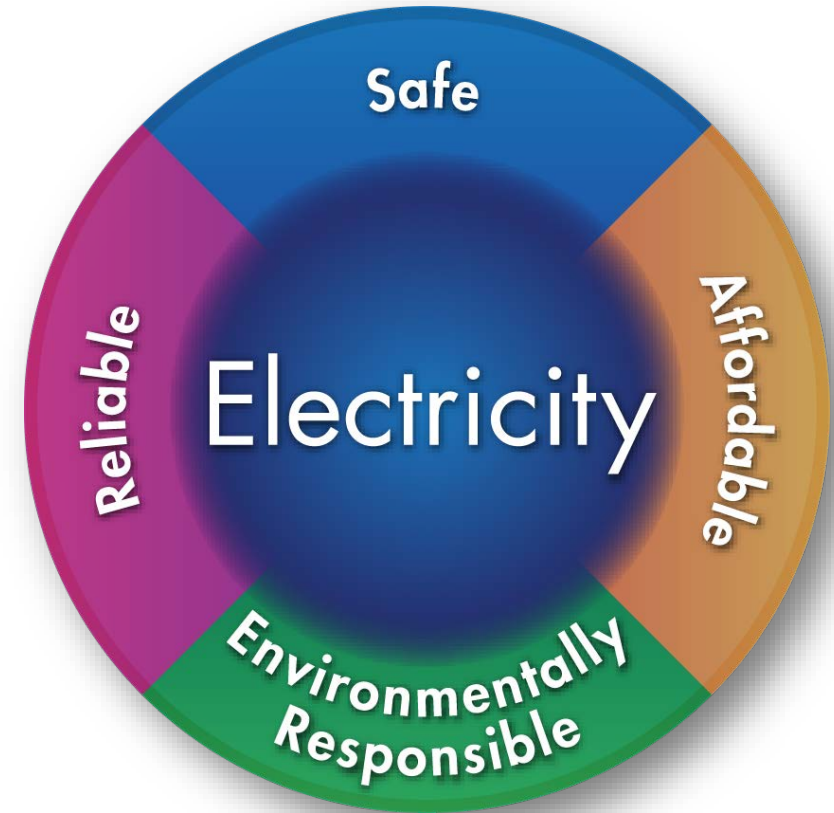


Founded in 1972

Major offices in Palo Alto, CA;  
Charlotte, NC; Knoxville, TN

# EPRI's Mission

Advancing  
***safe, reliable, affordable*** and  
***environmentally responsible***  
electricity for society through  
global collaboration, thought  
leadership and science  
& technology innovation



***Together...Shaping the Future of Electricity***

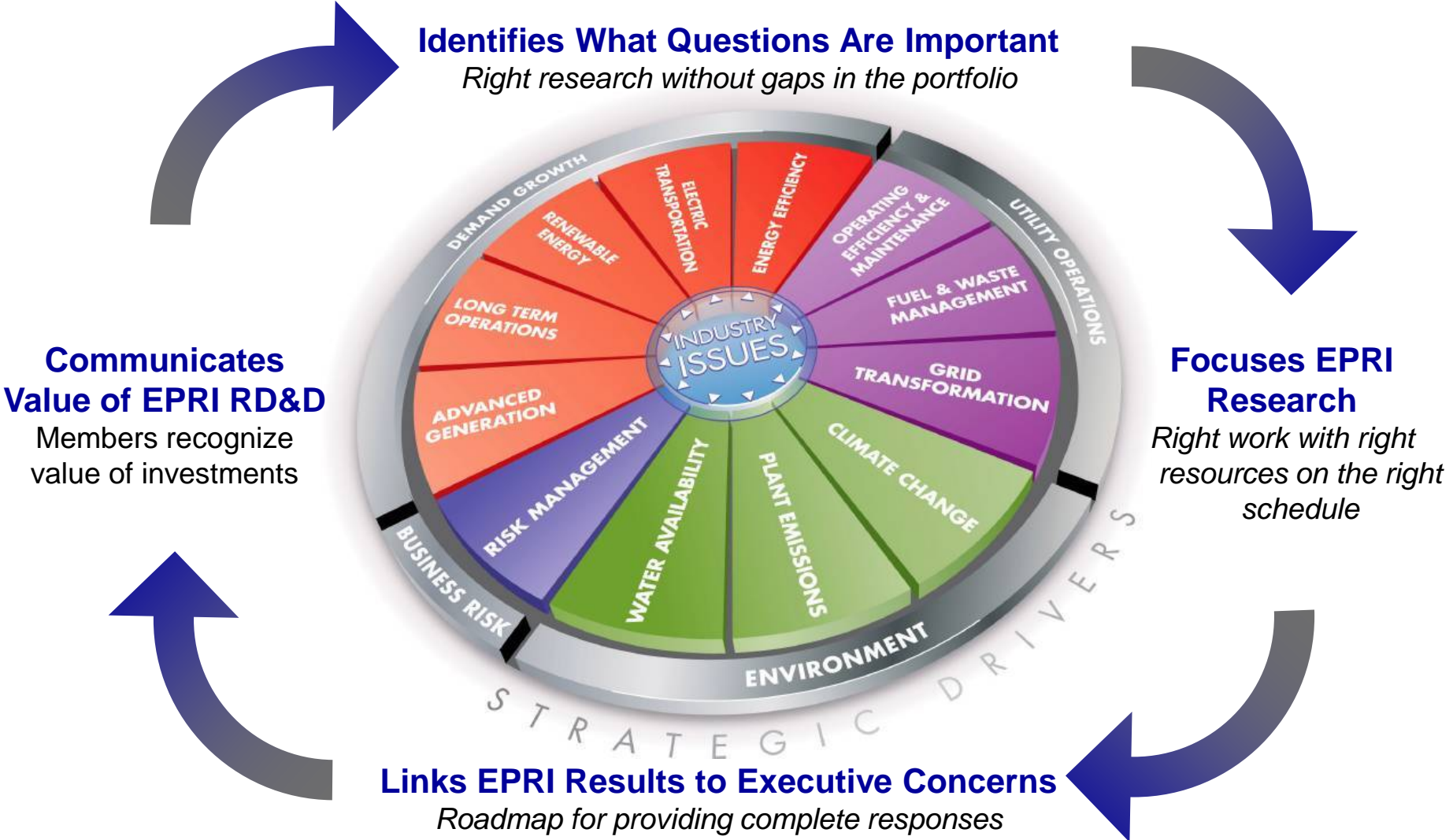
# EPRI's Membership

- 450+ members in 30+ countries
- EPRI members generate ~ 90% of the electricity in the United States
- EPRI's research, development and demonstration funding
  - About 75/25% contribution from national/international members
  - About 40% of funding is contributed by nuclear sector



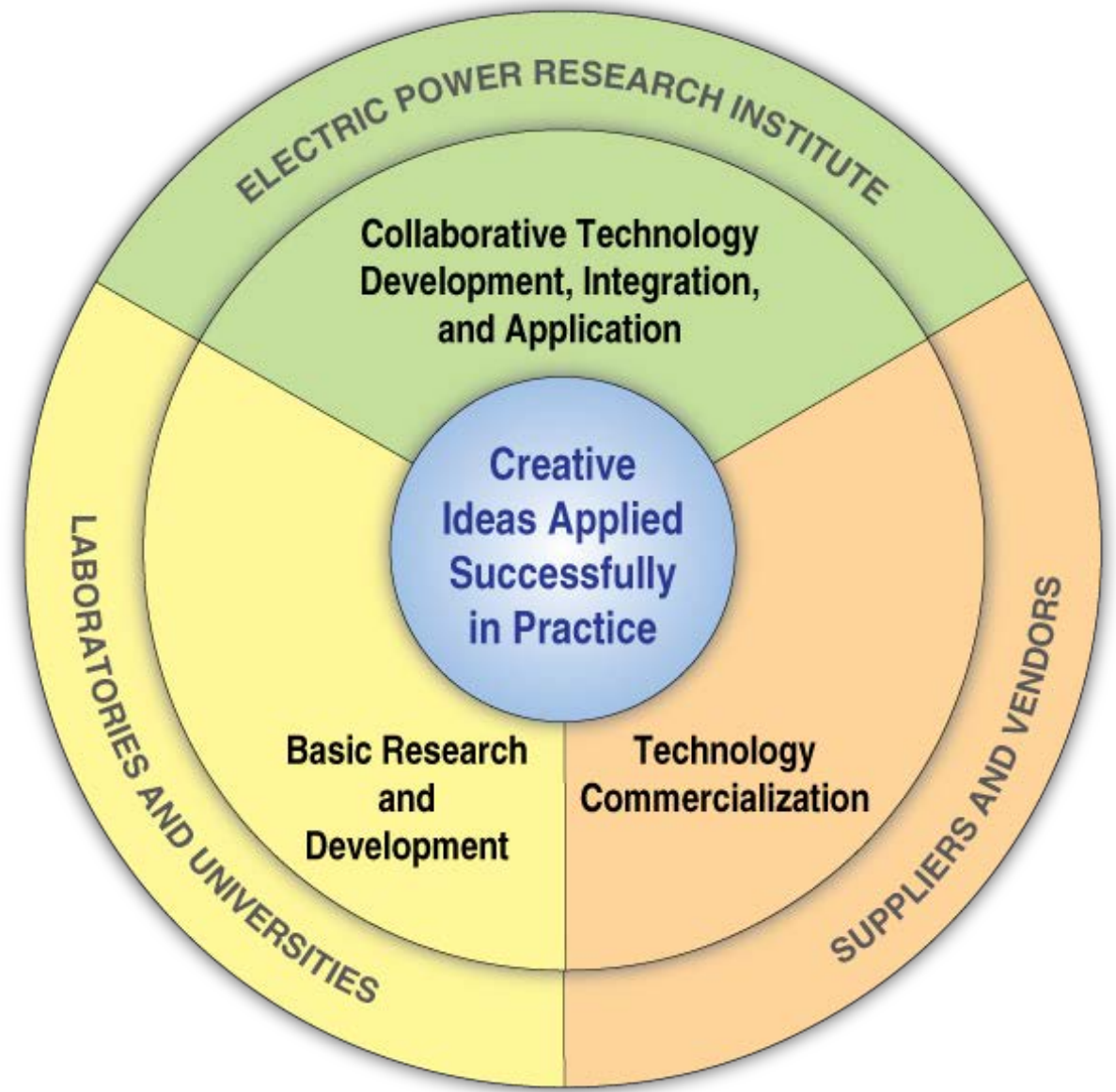


# EPRI Taps the Voices of the Industry

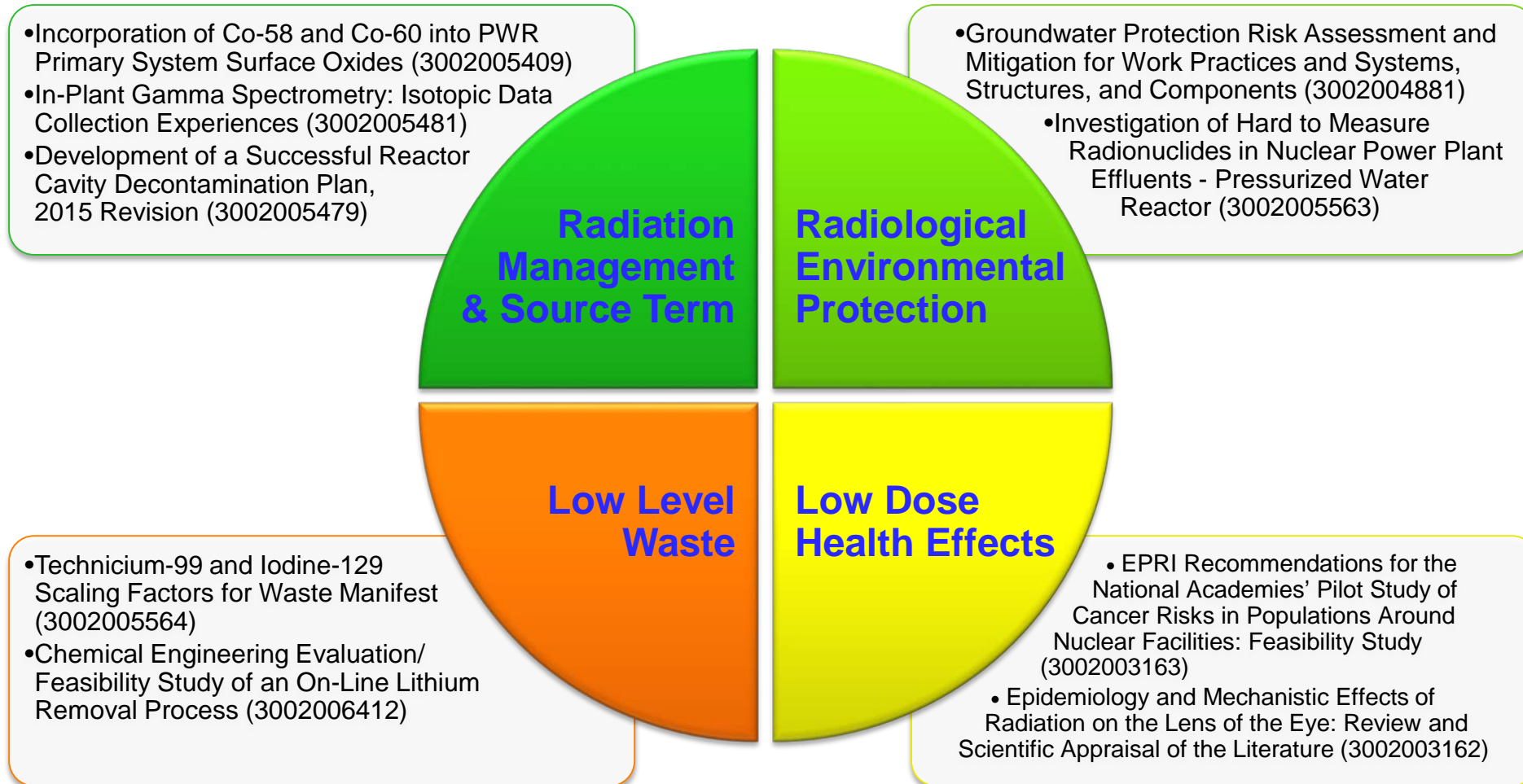


# EPRI's Role

*Stimulate innovation and help accelerate technology to commercial development*



# EPRI Radiation Safety Program



Enhance Radiation Safety for Workers and the Public

# EPRI Radiation Safety – Research Focus Areas



## ALARA Strategies and Technologies

- Combines source term reduction technologies with typical dose reduction tools and work planning improvements to provide a comprehensive strategy for reducing dose to workers.



## Radioactivity Generation and Control (Source Term Reduction)

- Understanding radioactivity and radiation field generation and transport processes and tools/technologies for improved control of radioactivity for reducing radiation fields and effluents



## Radiation Safety Guidance

- Development and maintenance of guidelines, guides and sourcebooks for radiation protection, source term reduction, radiological environmental protection (which includes groundwater), and low level waste.



## Accurate Dose Reporting for Workers and Public

- Provide more accurate dose assessment methodologies for determining worker dose and public dose due to effluents.



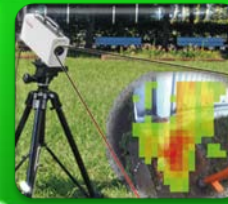
## Benchmarking and Trending (Fundamental)

- Maintenance of databases for the Standard Radiation Monitoring Programs (SRMP/BRAC) and the industry low level waste benchmarking database, RadBench™.

## Optimized Worker Protection

## Integration of Industrial and Radiological Safety

- Includes research related to the development of technologies and strategies that better meet the needs for an integrated approach for addressing worker protection, addressing both radiological and industrial hazards.



## Radiation Detection and Measurements

- Includes the evaluation and use of new measurement technologies for radiation detection and isotopic measurements.



## Environmental Monitoring and Remediation

- Includes all research related to environmental monitoring and remediation of groundwater and soil.

EPRI Membership Suggests and Prioritizes Research, in addition ...



# ERPI Radiation Safety – Technical Strategy Groups



## Radiation Managements and Source Term (RMST TSG)

Carola Gregorich, [cgregorich@epri.com](mailto:cgregorich@epri.com), +1 (650) 855 8917

## Groundwater (GW TSG)

Karen Kim, [kkim@epri.com](mailto:kkim@epri.com), +1 (650) 855 2190

## Low Level Waste (LLW TSG)

Karen Kim, [kkim@epri.com](mailto:kkim@epri.com), +1 (650) 855 2190

### TSG Membership

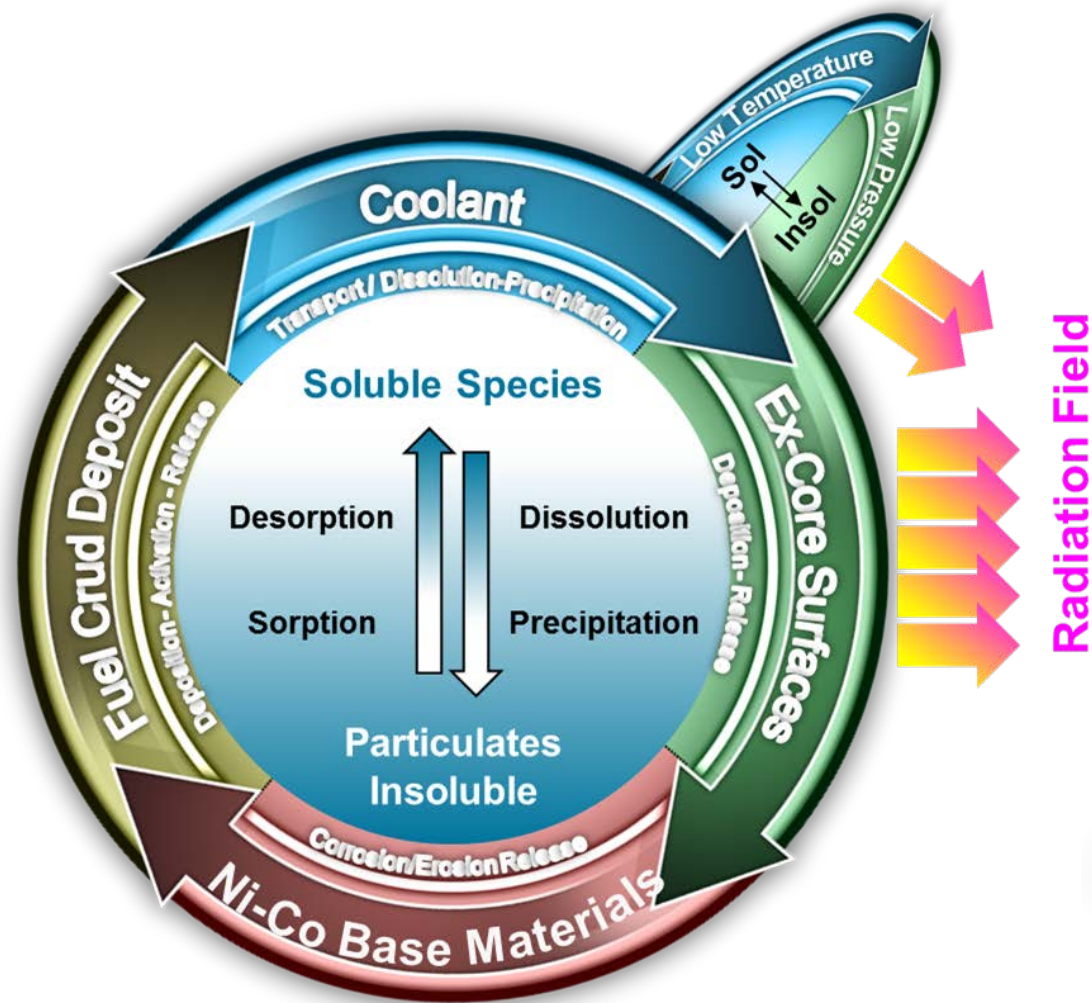
- 3-Yr Commitment Basis (in addition to RS Base)

### Offers

- Knowledge transfer
- Influence on research direction
- Benchmark of emergent issues
- Surveys of practices
- Independent assessment one (1) pre membership period
- Access to
  - Deliverables
  - Collaboration SharePoint
  - Webcasts
  - Workshops

Highly Interactive & Collaborative Peer Groups

# Radiation Field & Source Term Reduction



Radiation Field



is a Team Sport

# EPRI's Radiation Field and Source Term Research - 2016

## ■ Fundamental

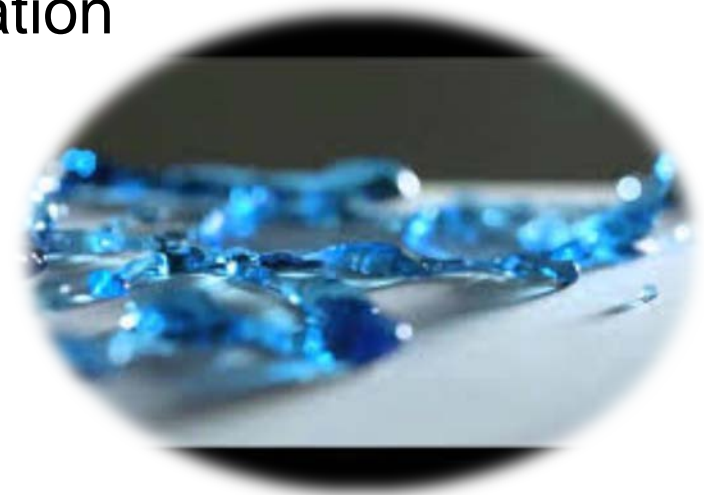
- Standard Monitoring of Utility Radiation Fields Program [BRAC + SRMP = SMURF]
- Chemistry Monitoring and Assessment Program [CMA]

## ■ Base

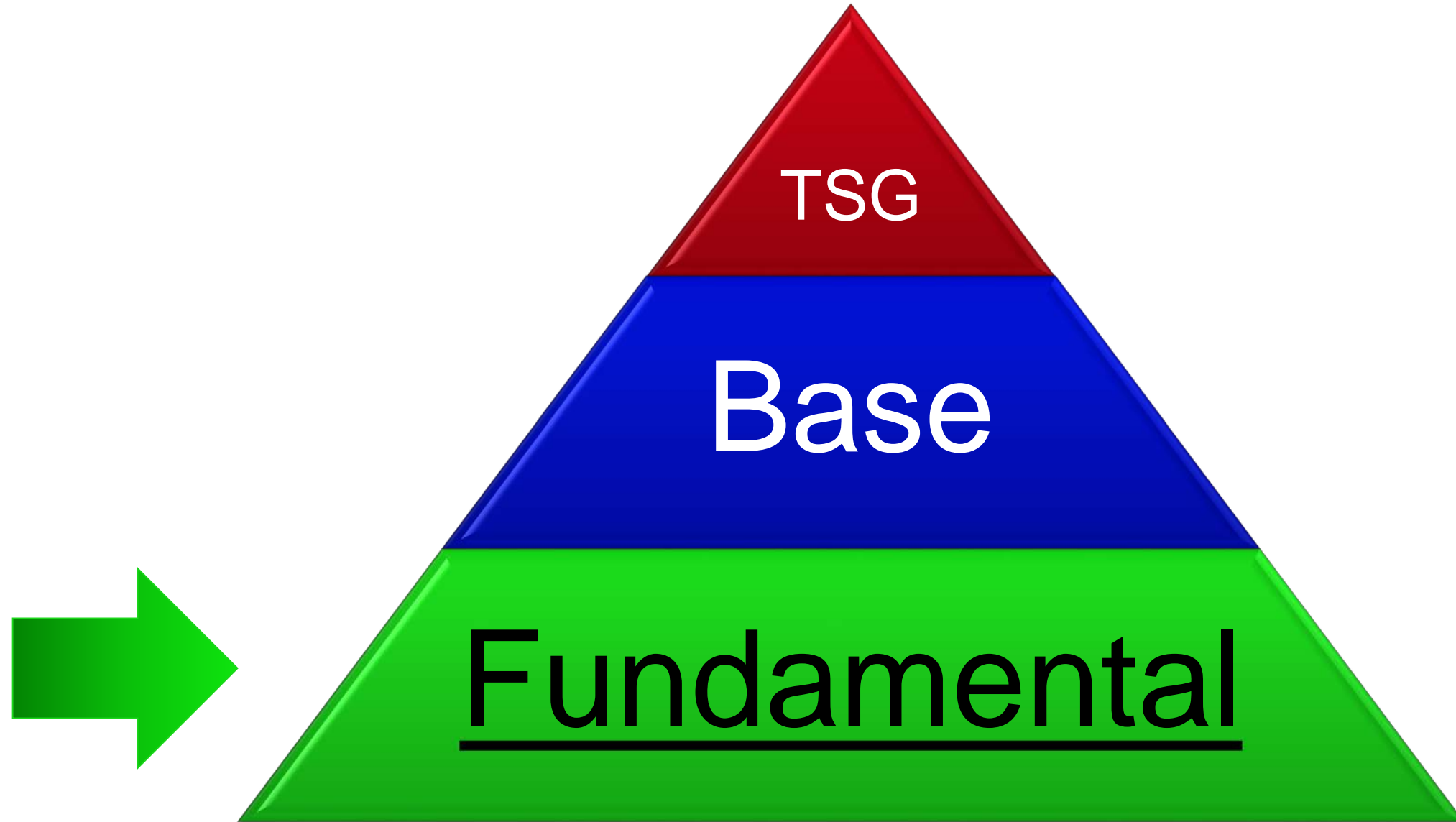
- Surface Passivation to Reduce Radiation Fields
- Micro-Environments Influence on Radiation Field Generation
- Silver and Antimony Impact on Radiation Fields
- Hydrophobic Coatings as Dose and PCE Control Tool
- Top Ten ALARA Tools for New Builds

## ■ RMST TSG

- Review of Activity Transport Modeling State-of-the-Art
- OSCAR Benchmarking
- NitroXX testing



# EPRI's Radiation Field & Source Term Efforts

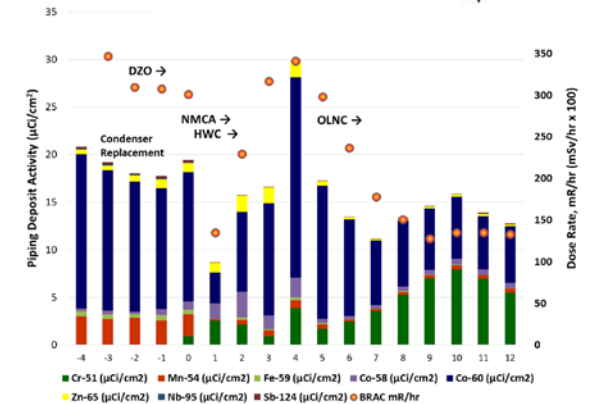
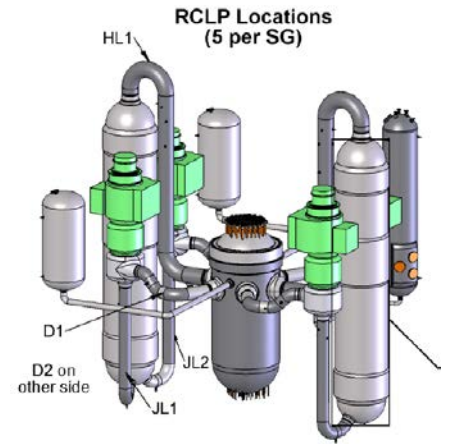




# Fundamental: Standard Monitoring of Utility Radiation Fields (SMURF)

- Objective:
  - Establish standard practices for radiation field monitoring
  - Collect, house, and make accessible radiation field data
- Scope:
  - Curate data to support cause and effect analysis
    - Organize information and manage data
  - Assist plants in implementing the SMURF programs
- Benefit:

Access to reliable and validated plant radiation field data taken following a standardized protocol is crucial for the successful execution of utility benchmarking, plant support, plant assessments, and EPRI research



# 2014 Revisions of Standard Radiation Field Monitoring Programs 'Highly Recommended' to Implement Gamma Isotopic Monitoring

## Purpose:

Obtain reliable data of the isotopic composition of plant radiation fields

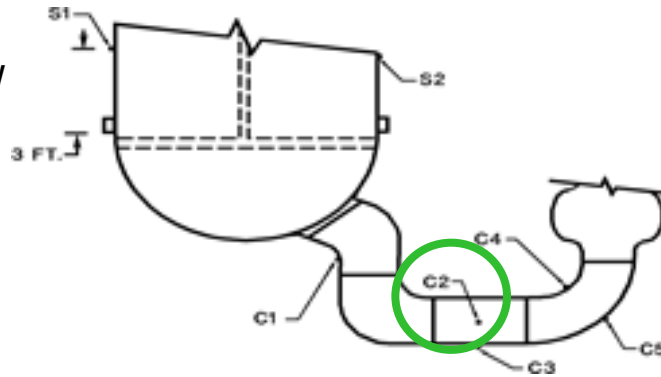
## To:

Improve our understanding of plants' radiation field generation and their responses to plant changes

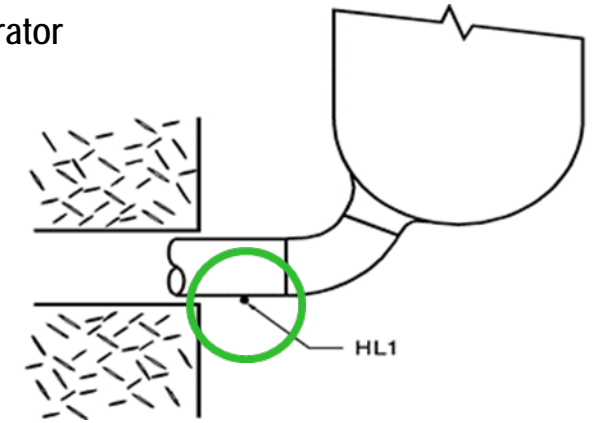
**Go-To Resources: 3002003155 & 3002003157**

# PWR Standardized Location for Highly Recommended Isotopic Characterization on Primary Circuit Loop Piping

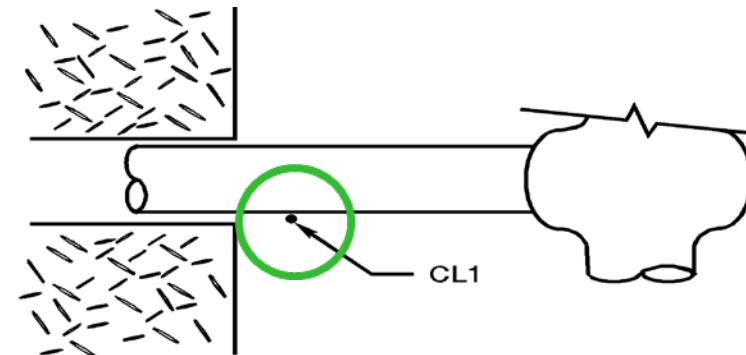
Crossover Piping (C2) - Straight section of crossover (crossunder) piping between Steam Generator outlet and Reactor Coolant Pump, side of pipe (generally away from primary concrete shield)



Hot Leg Piping (HL1) - Bottom of hot leg piping between Steam Generator inlet and Reactor Vessel Shield



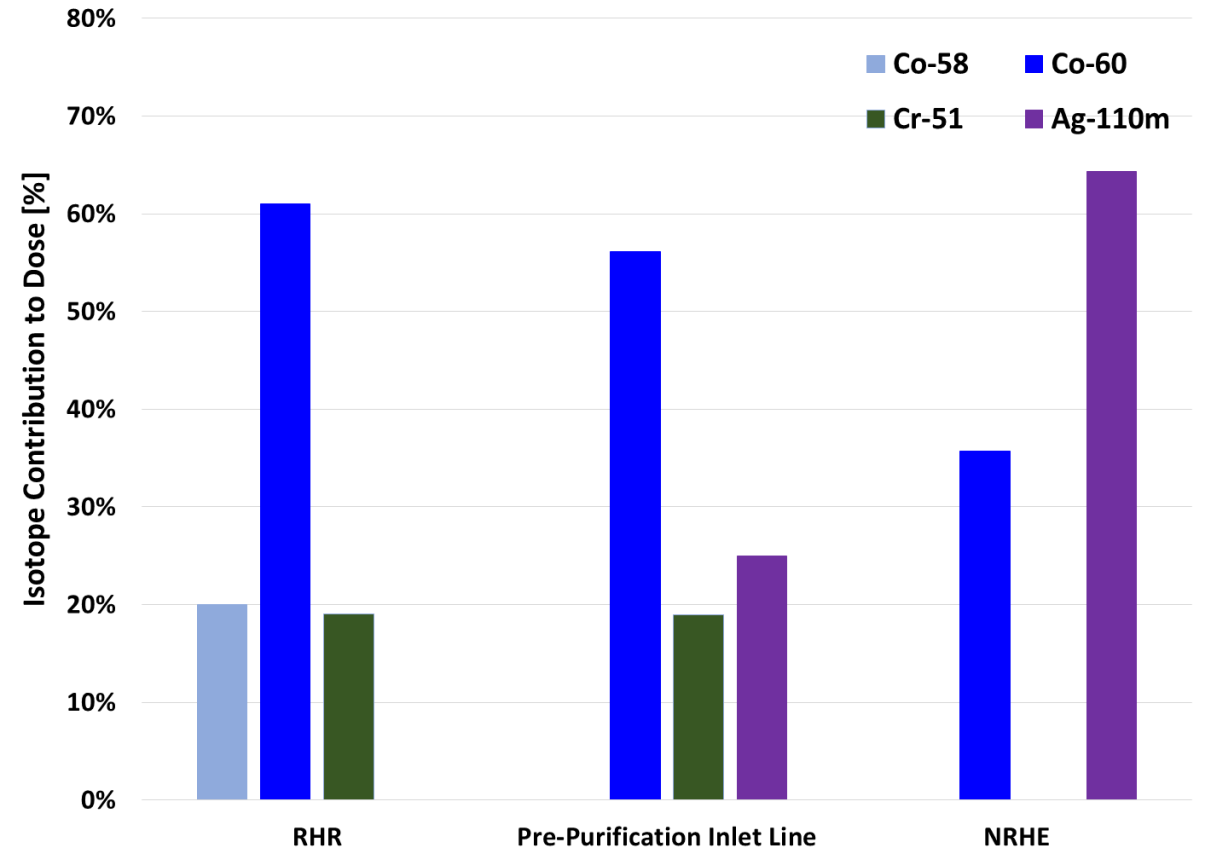
Cold Leg Piping (CL1) - Bottom of cold leg piping between Reactor Coolant Pump and Reactor Vessel Shield



**Dose Rate Measurements Are Essential – Isotopic Data Greatly Enhance Data Value**

# PWR Standardized Location for Highly Recommended Isotopic Characterization on Auxiliary System Locations

- Letdown and Return Line
  - Chemical and Volume Control / Make-up and Purification
  - Residual Heat Removal (RHR) System / Decay Heat / Shutdown Cooling (SDC)

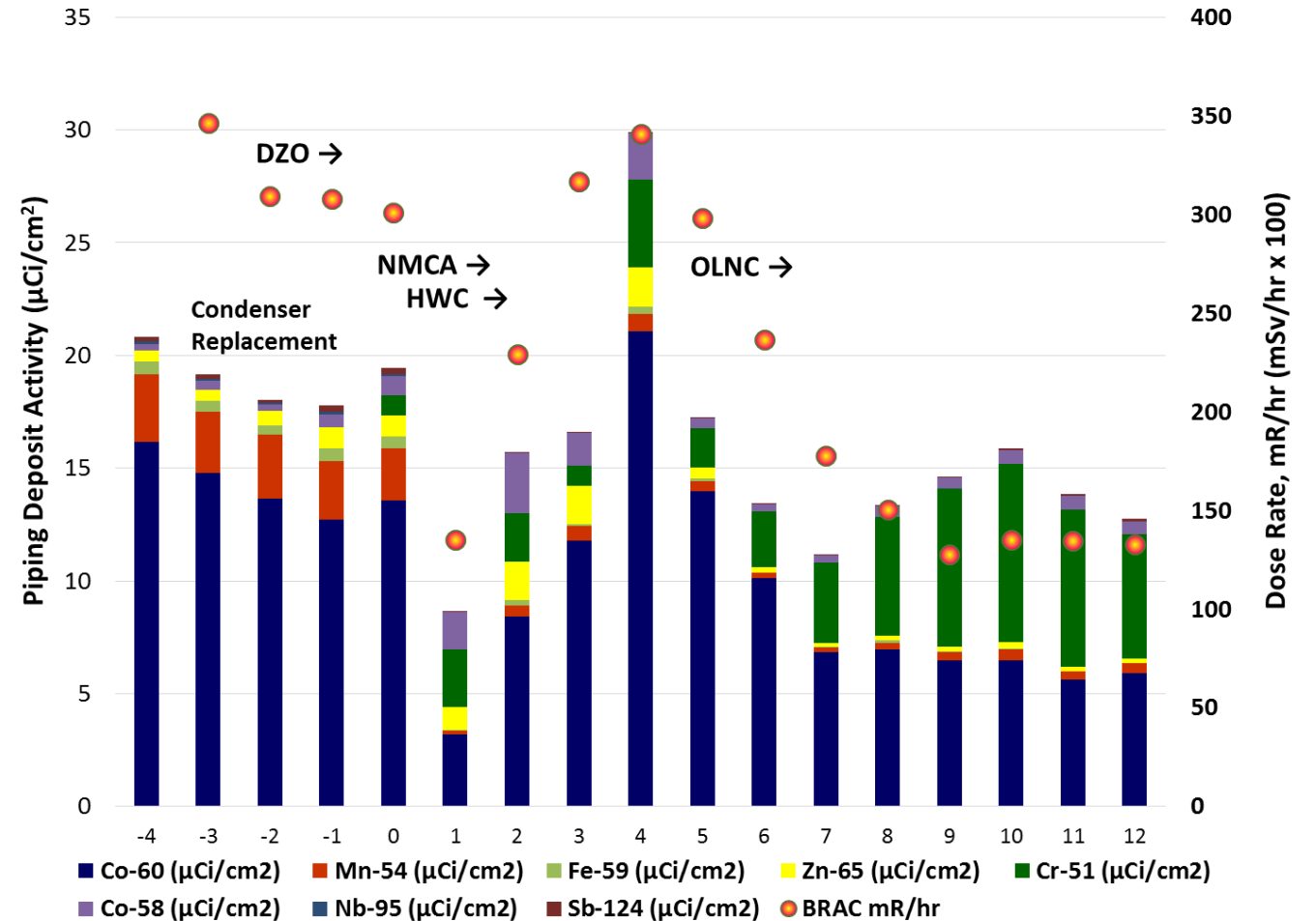


More than Co-58



# BWR Standardized Location for **Highly Recommended** Isotopic Characterization on Primary Circuit Loop Piping

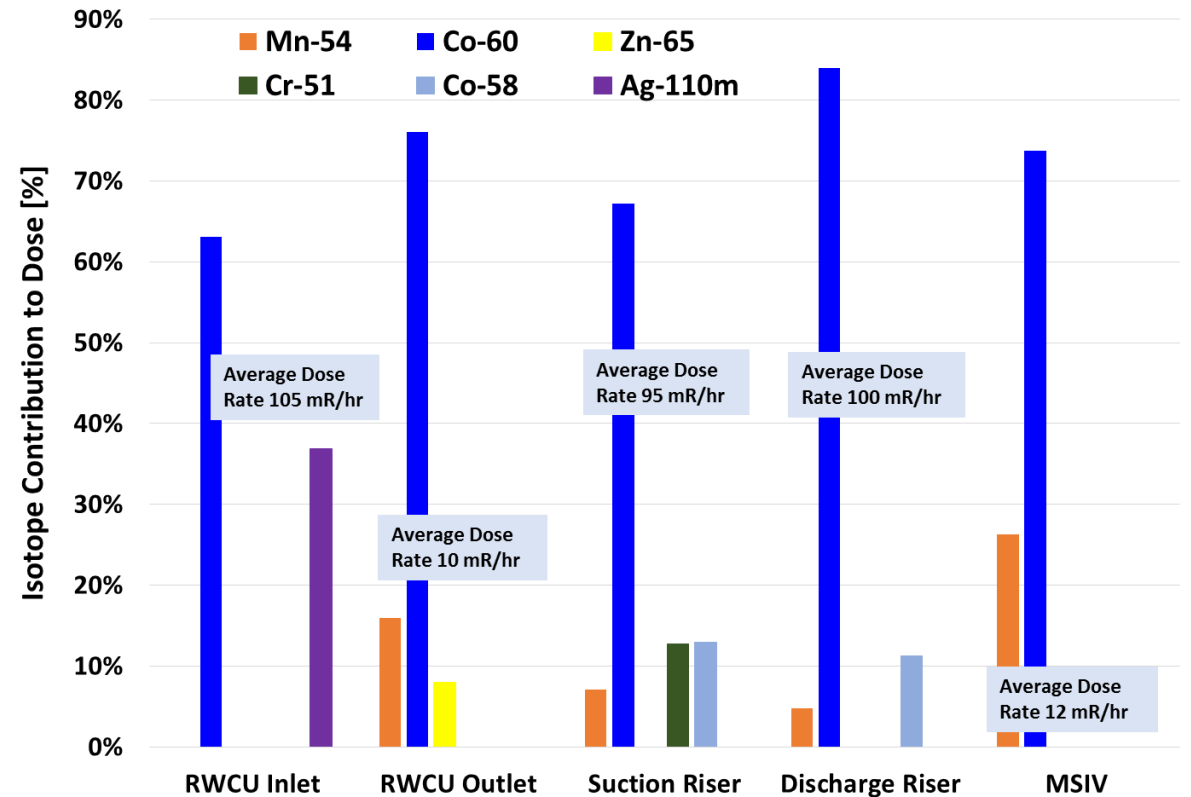
- Reactor Recirculation System Piping



More than Co-60

# BWR Standardized Location for Highly Recommended Isotopic Characterization on Auxiliary System Locations

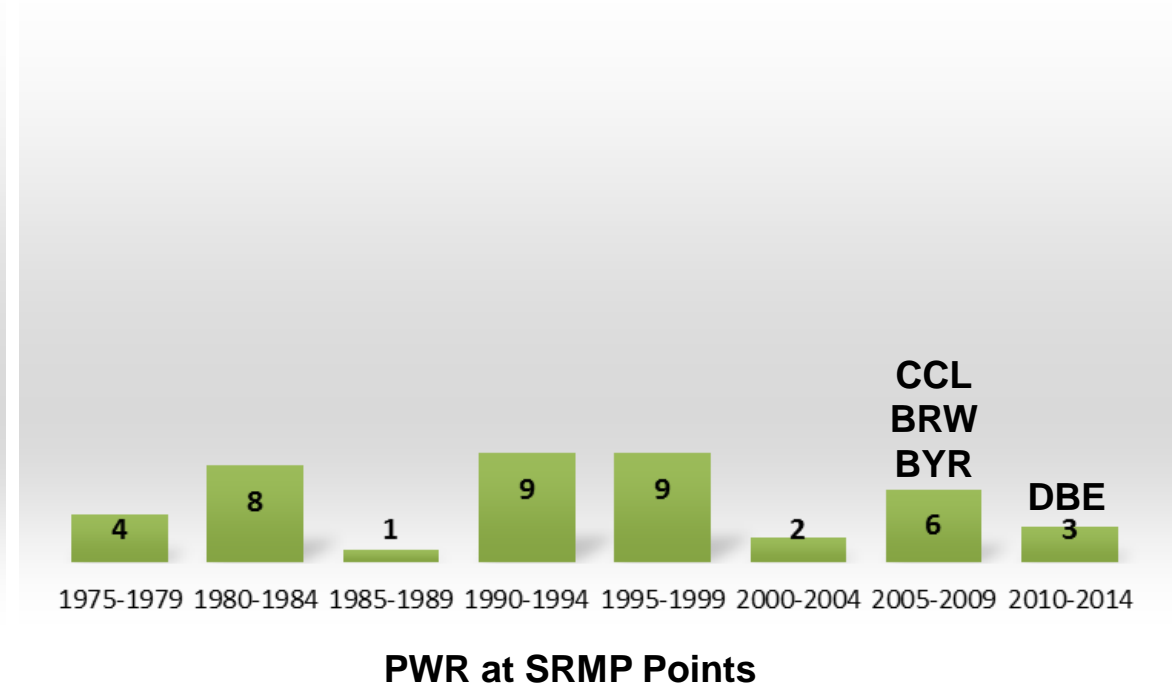
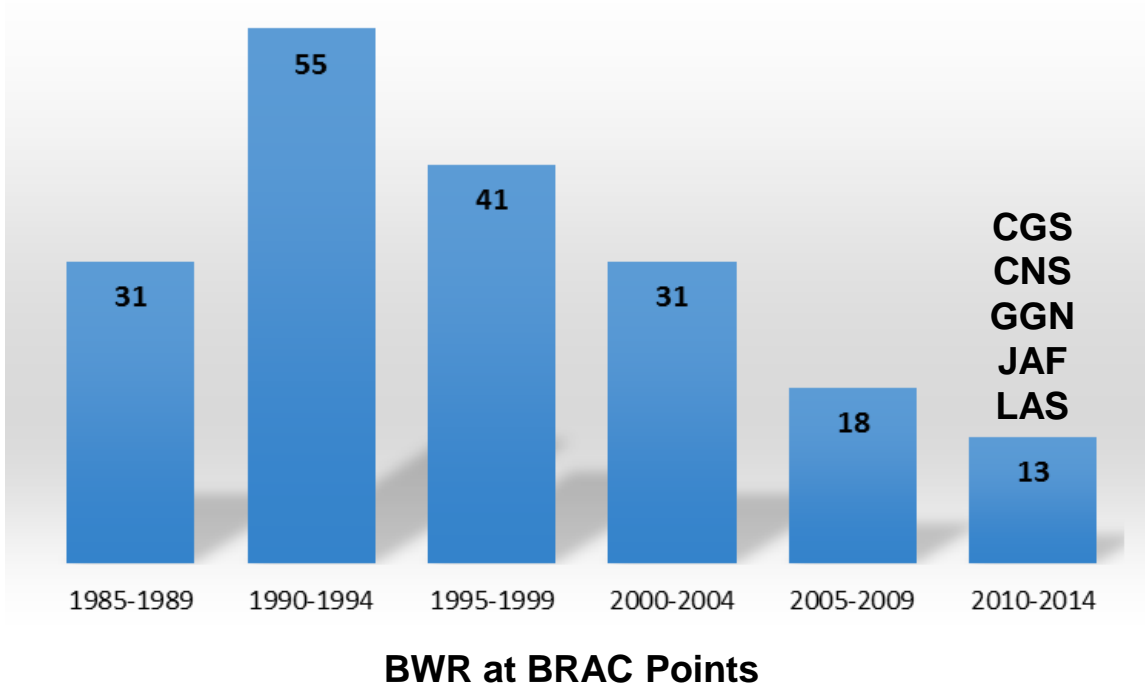
- RWCU Inlet Piping
- RHR Shutdown Cooling (SDC) Header



Isotopic Data Change Our Understanding

# Available In-Plant Gamma Data

- As of May 2015, the BRAC database houses gamma spectrometric data from 37 BWRs taken during 320 respective outages.
- Isotopic characterization data are less prevalent in the U.S. PWR fleet than in the BWR fleet.



**5-Year Frequency Distribution of Gamma Spectrometric Measurements performed in U.S. Fleet**

# Standard Monitoring of Utility Radiation Fields (SMURF) Deliverables

*In-Plant Gamma Spectrometry: Isotopic Data Collection Experiences.*

EPRI, Palo Alto, CA: 2015. 3002005481.

- Collates and reviews available measurement practices and data sets.
- Identifies options for standardizing measurement protocol.
- Illustrate insights and value derived from the analysis of the data collected by in-plant gamma spectrometry.
- Describes lessons learned and identifies gaps.

## **In-Plant Gamma Isotopic Radiation Field Monitoring – Fundamentals 101**

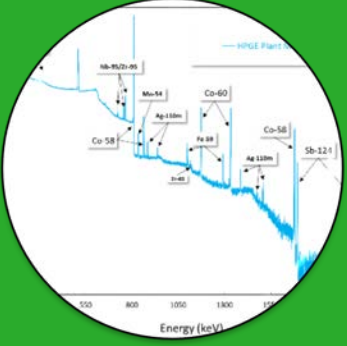
Sep 15, 2016 Charlotte, NC

*(in conjunction with the 2016 Source Term and Radiation Field Reduction Workshop)*

In-Plant Gamma Spectrometry Go-To Resource for the Practitioner



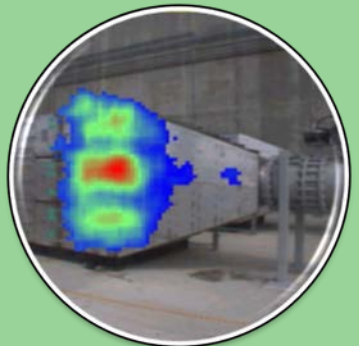
# Current Measurement Equipment Options



HPGe



CZT



Gamma Camera

All Provide Isotopic Characterization of Radiation Fields



Flow Chart Aids in Tool Selection

# Data Collected and Submitted to EPRI

## Now What?

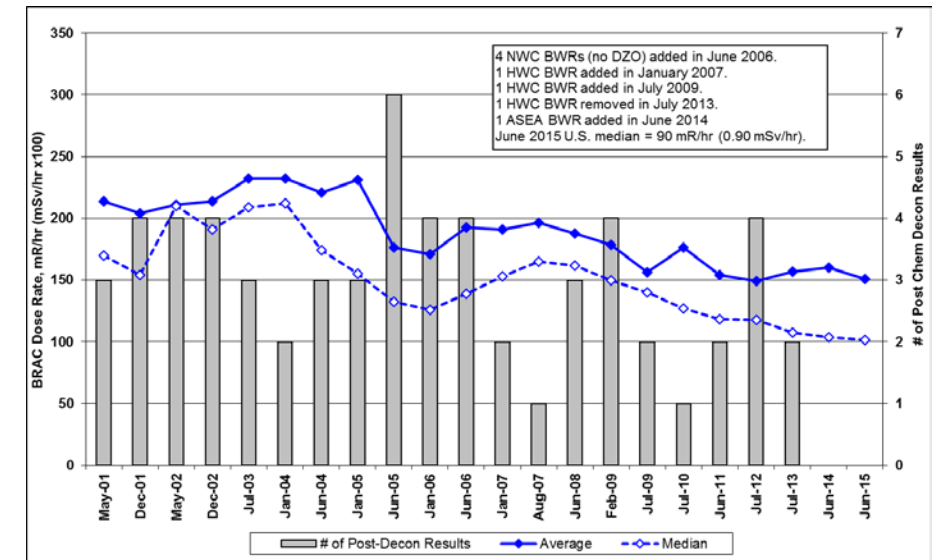
# Data in SMURF & CMA Enable

## ■ Benchmarking

- Boiling Water Reactor Shutdown Chemistry and Dose Summary (3002005162)
- Plant Source Term Assessments (Columbia, Nine Mile Point, and Laguna Verde)
- Plant Requests (Duke, Dominion, Exelon)

## ■ Research Projects

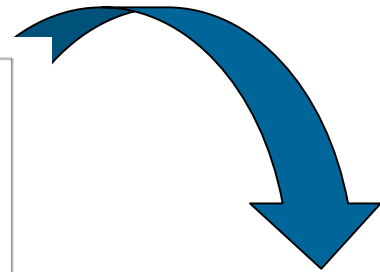
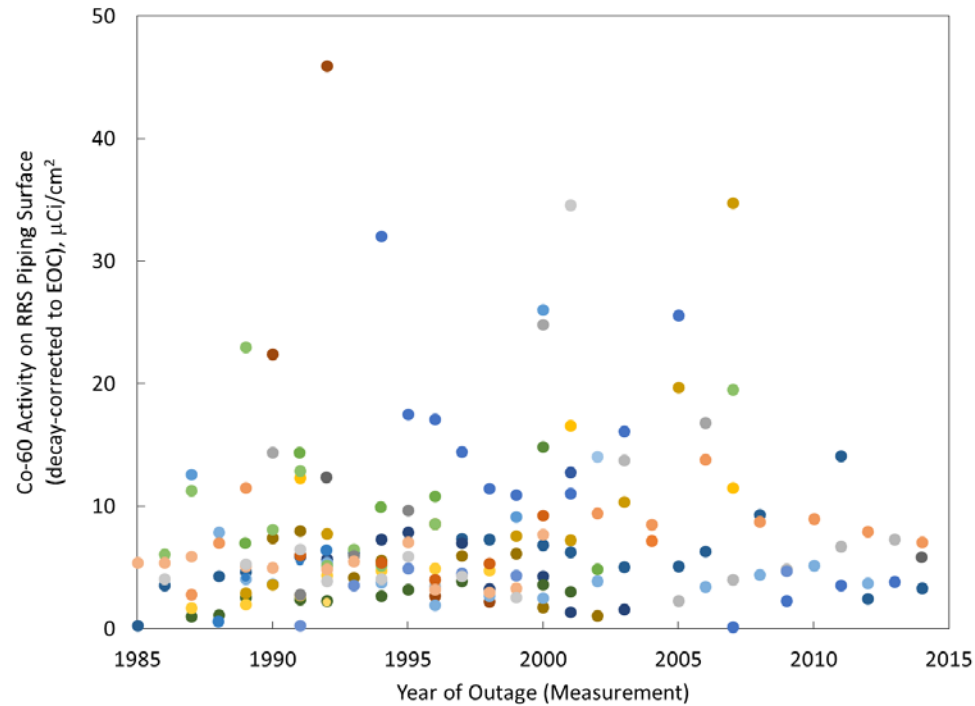
- PWR Shutdown Activity and Corrosion Product Release Analysis
- Micro-Environment Effect on Activity Transport and Radiation Fields
- High-Efficiency Ultrasonic Fuel Cleaning as a Source Term Reduction Tool in Boiling Water Reactors
- Flexible Operations



BRAC Dose Rate History

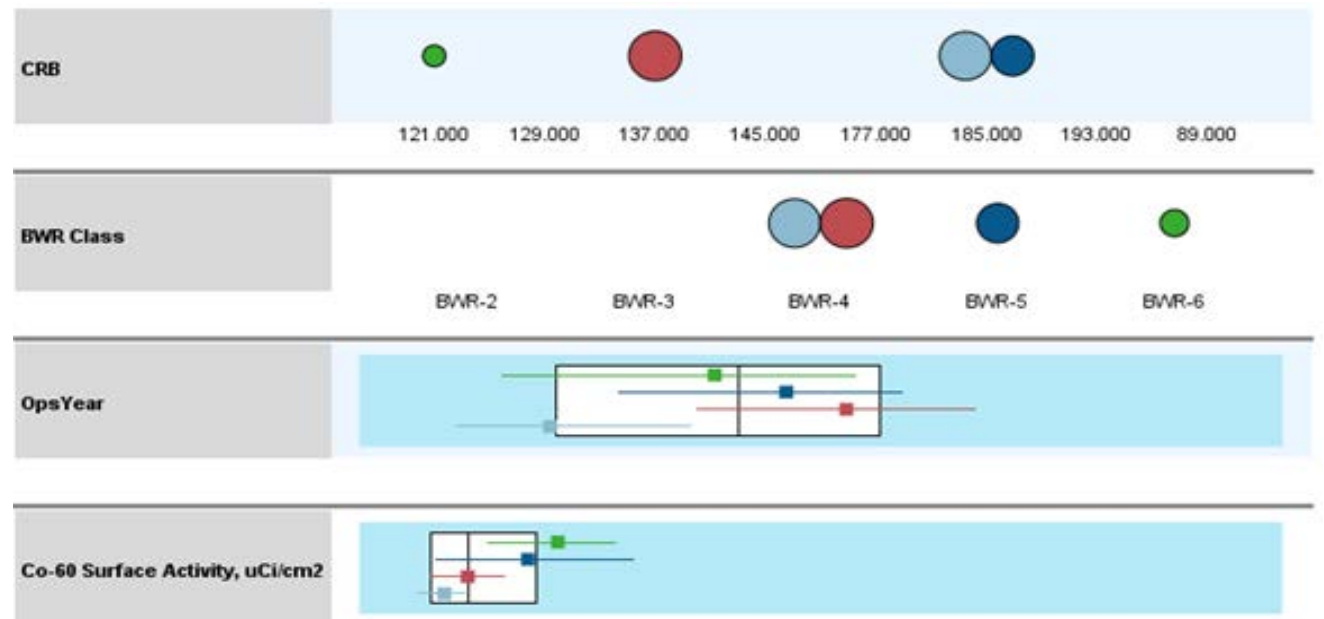
Data Availability Increases Research Efficiency

# Enhanced Data Analysis – BWR Isotopic Radiation Field Data



## Initial Test Cluster Analysis

Size	30.3% (54)	29.2% (52)	24.2% (43)	16.3% (29)
Inputs	CRB 137.000	CRB 185.000	CRB 185.000	CRB 145.000
	BWR Class BWR-4 (100.0%)	BWR Class BWR-4 (100.0%)	BWR Class BWR-5 (79.1%)	BWR Class BWR-6 (55.2%)
	OpsYear 22.46	OpsYear 10.25	OpsYear 17.72	OpsYear 15.62
	Co-60 Surface Activity, uCi/cm2	Co-60 Surface Activity, uCi/cm2	Co-60 Surface Activity, uCi/cm2	Co-60 Surface Activity, uCi/cm2



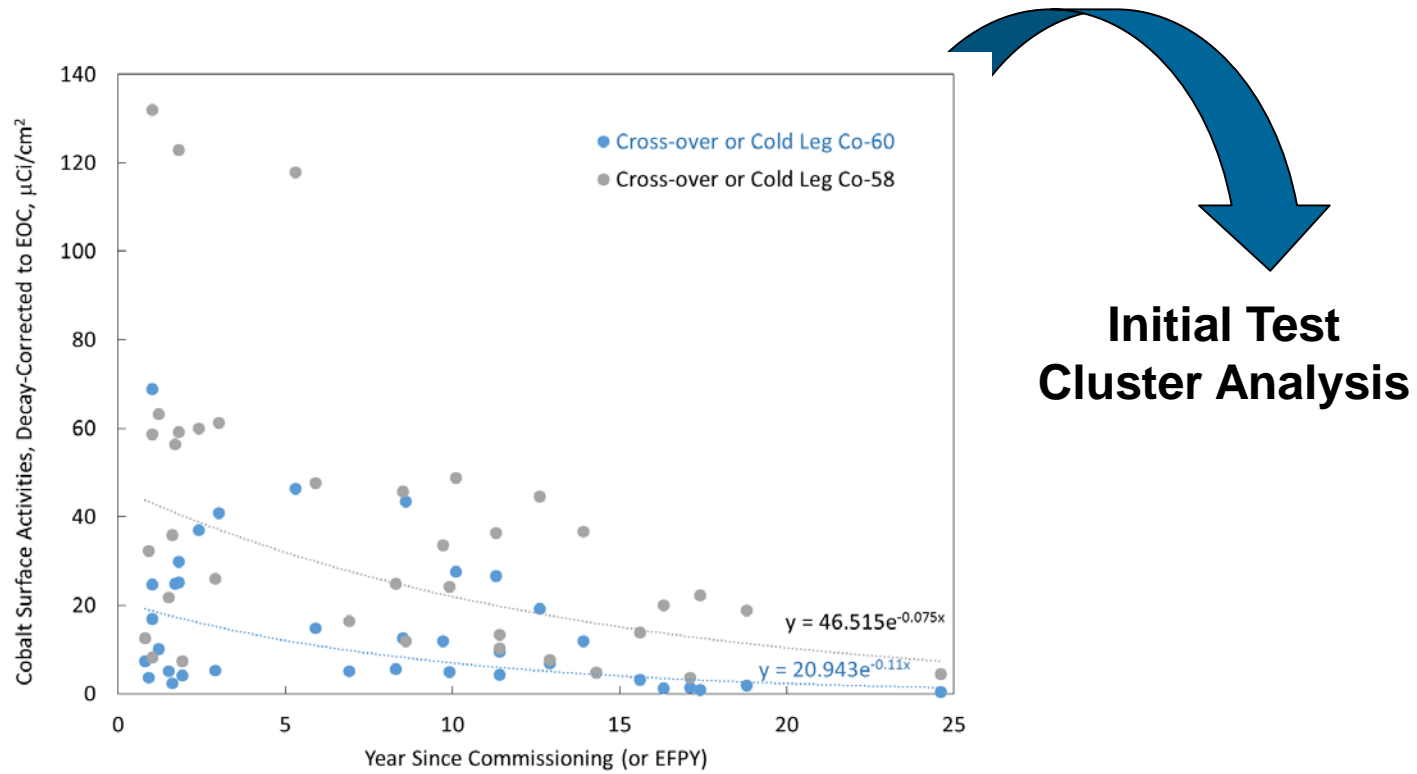
BWR 5 & 6 have above average Co-60 surface activities

- At about similar times in operating life
- No. of CRBs unlikely a contributor (low/high)

→ Additional investigations needed into design and operations differences



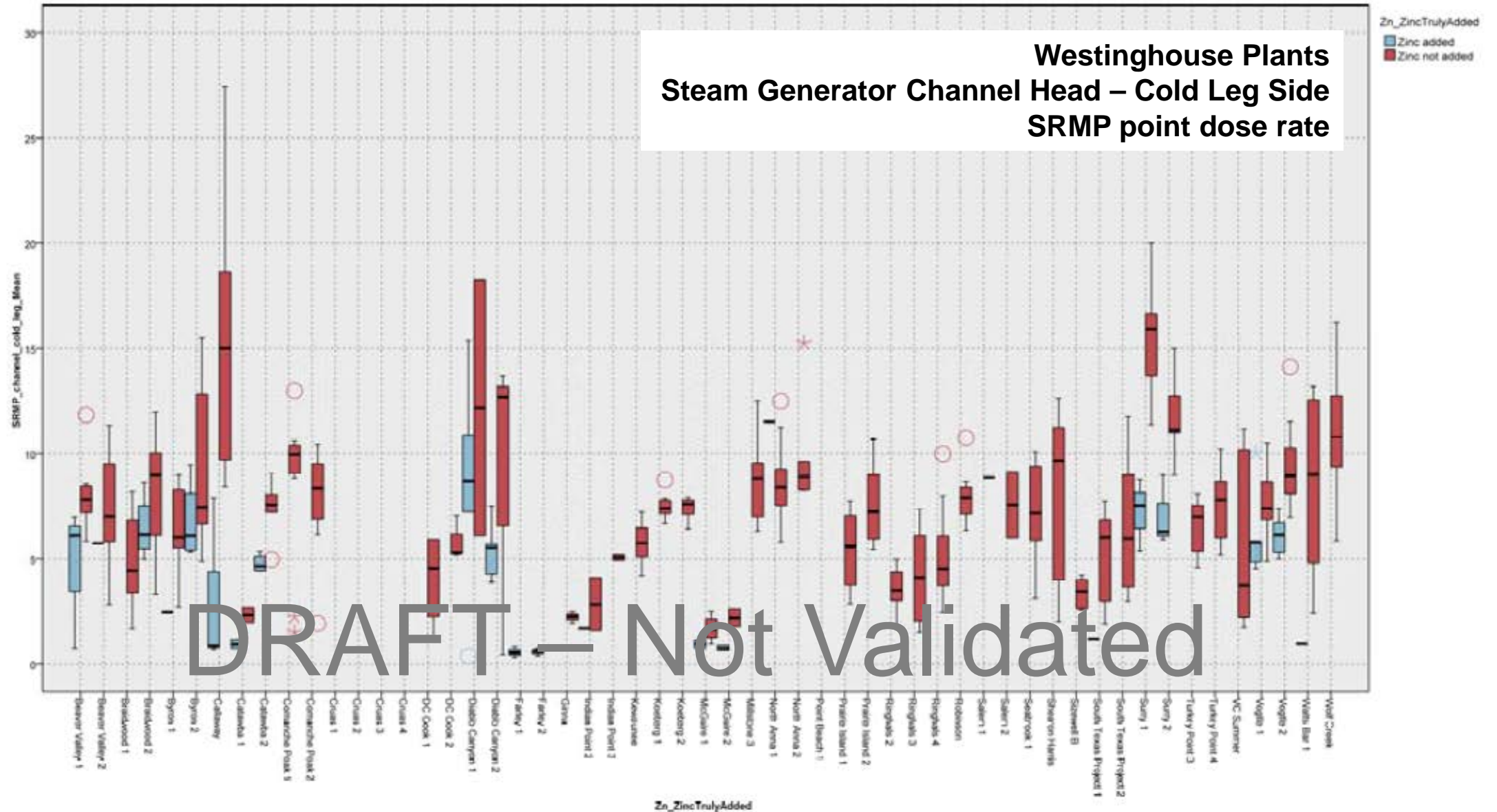
# Enhanced Data Analysis – PWR Isotopic Radiation Field Data



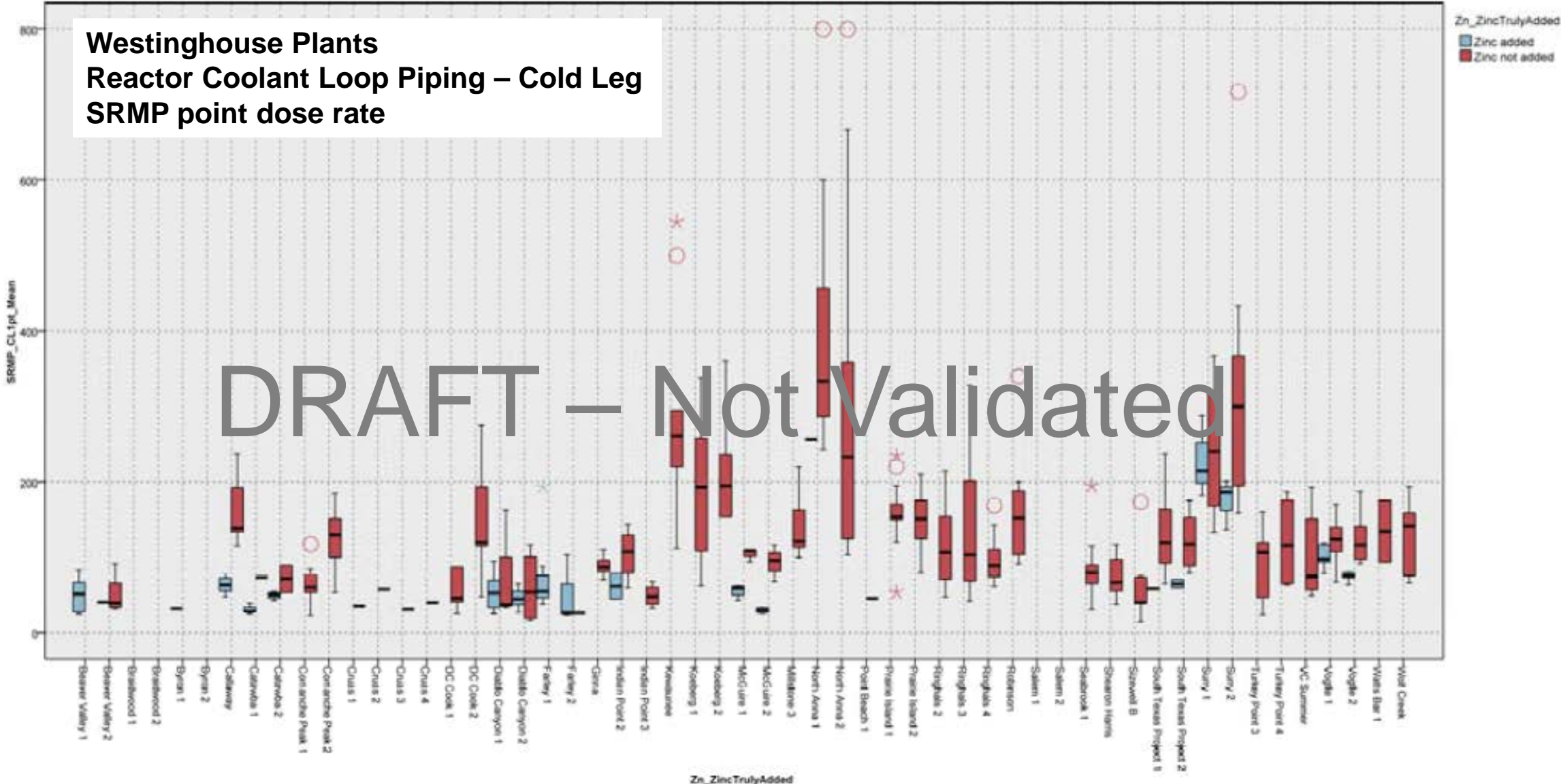
**Initial Test  
Cluster Analysis**

**Work in Progress**

# Enhanced PWR Data Analysis – in Progress – Zinc Benefit



# Enhanced PWR Data Analysis – in Progress – Zinc Benefit



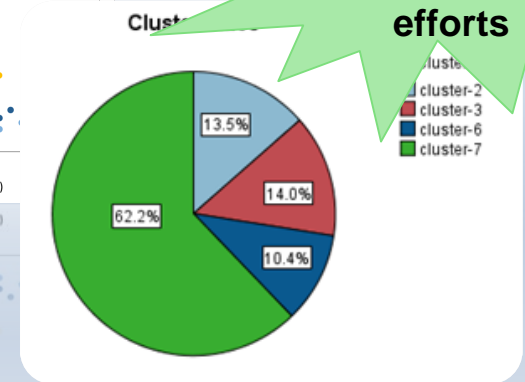
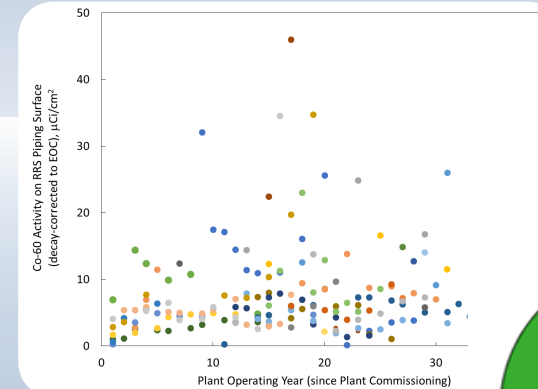
# SMURF's Path Forward

## ■ Short Term Actions

- Merge programs: BRAC + SRMP = SMURF
- Enhance data collection and database infrastructure
- Improve data validation tool

## ■ Long Term Vision

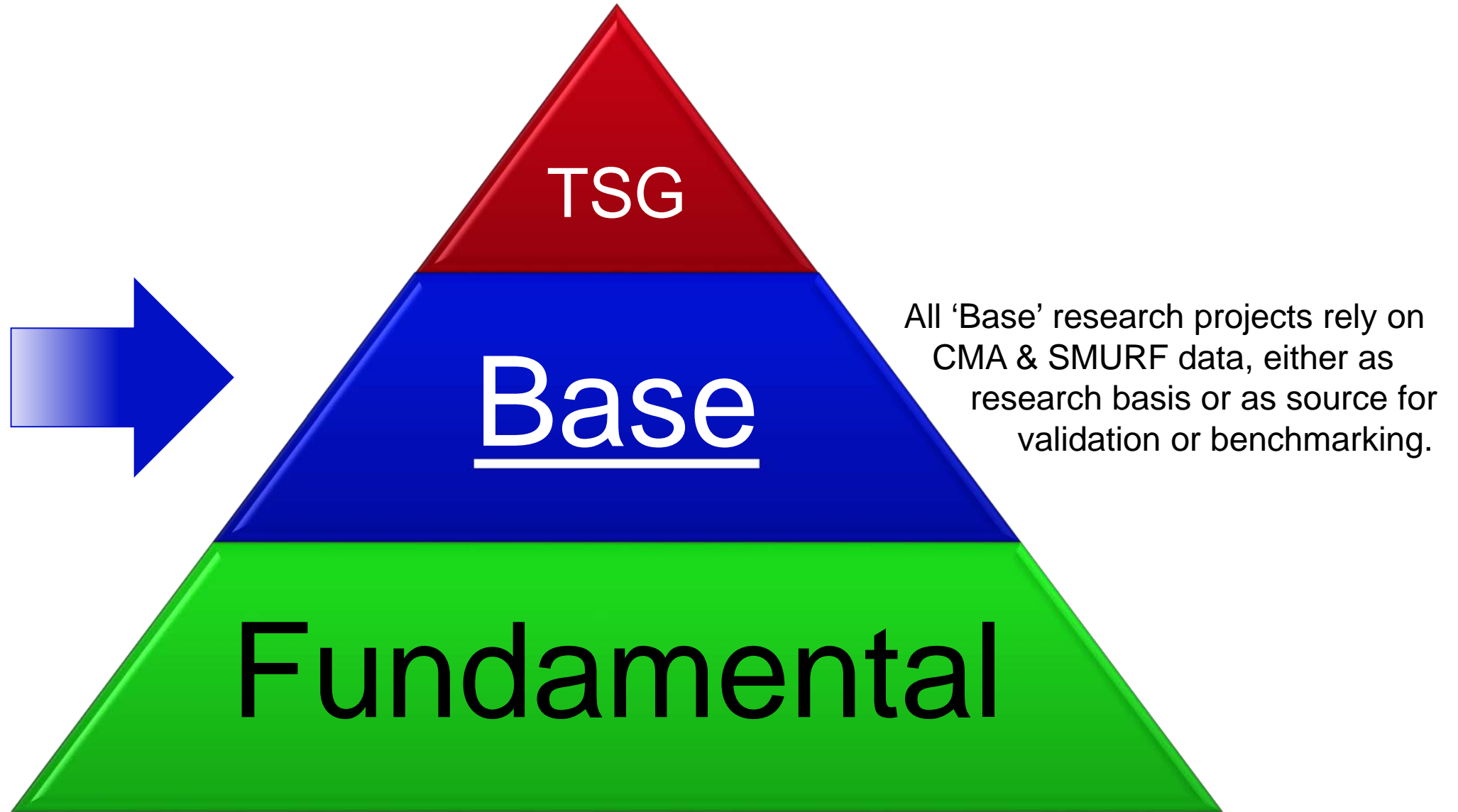
- Make data accessible
- Create a standard user web interface
- Improve data upload
  - Outage data
  - Online radiation field monitoring data



**CMA's are undergoing similar efforts**

Monitoring Data are a Fundamental Asset

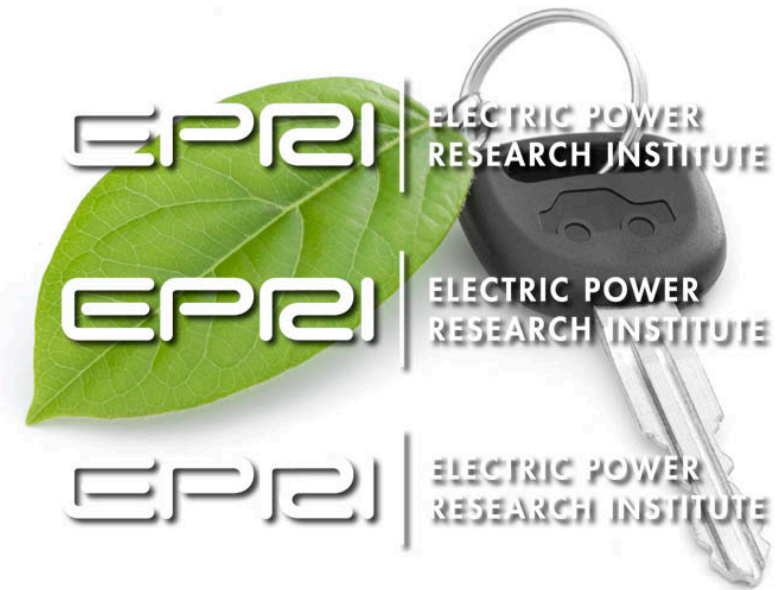
# EPRI's Radiation Field & Source Term Efforts





# Stable Surfaces – Key to Sustainable Low Radiation Fields

- Wetted component surfaces are metal release **source** and activity incorporation **sink**
- Options for surface stabilization
  - In-situ processes – HFT
  - Surface modification during component manufacturing
- 3002005377 summarizes State-of-the-Art



Stopping Metal Release is Most Effective Course of Action



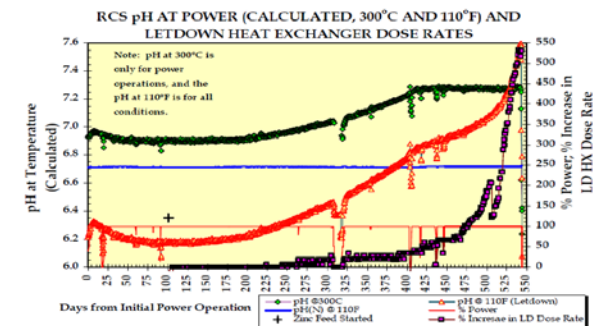
# Effect of Micro-Environments on Activity Transport and Radiation Fields (2015 – 2017)

## Background/Need

- Source term mitigation strategies have shown side effects, sometimes adverse to their intent
  - Zinc – potential impact in low temperature regions
  - Platinum/Hydrogen – crud bursts
- Local (interface/surface) chemistry differs from bulk coolant chemistry
- Multiple, simultaneous changes implemented do not allow to deduce a true cause-response relation

## Project Objectives

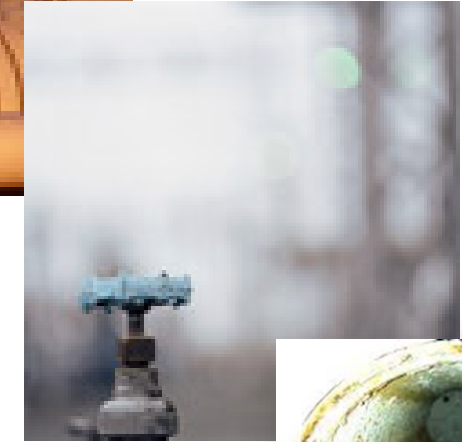
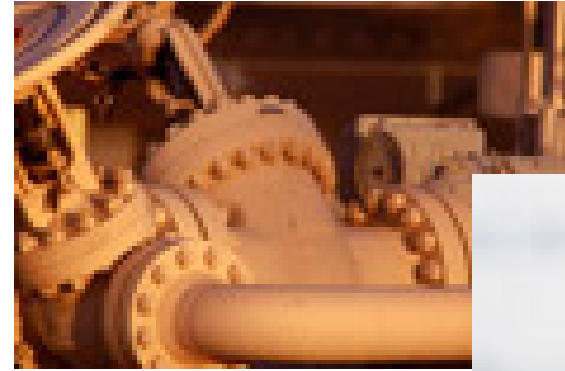
- Investigate impact of global chemistry strategies on radiation field generation under localized environments in primary circuit
- Probe variations of local responses to the same parameter and their potential influences on unanticipated effects



# Phase 1: Characterizing Micro-Environments

## ■ Known Locations:

- Flow **restrictions** such as valves and pipe bends
- **Heat** exchanging surfaces
- Coolant **cleanup** units
- **Stagnant** flow, crevice, and dead-end piping



## ■ Common Observations

- Repeated **hot spot** formation
- Higher dose rates on bottom of **horizontal** piping than on top and side walls
- **Deposit** formation in region of coolant phase change
- Dose rate gradient along **temperature** gradients
- Piping of different materials – dose rates on **carbon steel** piping tends to be higher than on SS
- High dose rates on **control rod** housings and drives



Plant Radiation Fields = Sum of Micro-Environments

# Phase1: Collecting Operational Experiences

## ■ Horizontal piping

- Plant A entered unplanned its outage with a full power scram

(BWRVIP-225, Rev.1):

- 6-inch vertical RWCU piping exhibited expected dose rates (150 – 300 mR/hr; 1.5 – 3 mSv/hr)
- 2.5- and 4-inch bottom head drain piping feeding RWCU piping exhibited significantly above normal radiation fields of 10 R/hr (100 mSv/hr)
- **Apparent cause**: Crud released from core settling out in horizontal piping sections  
concluded based on coolant isotopic data, no isotopic piping data are available
- ***Mitigation***: Extensive flushing operations

## ■ Piping Material

- Plant B experienced high dose rates on RWCU **carbon steel** piping and replaced piping in-kind.

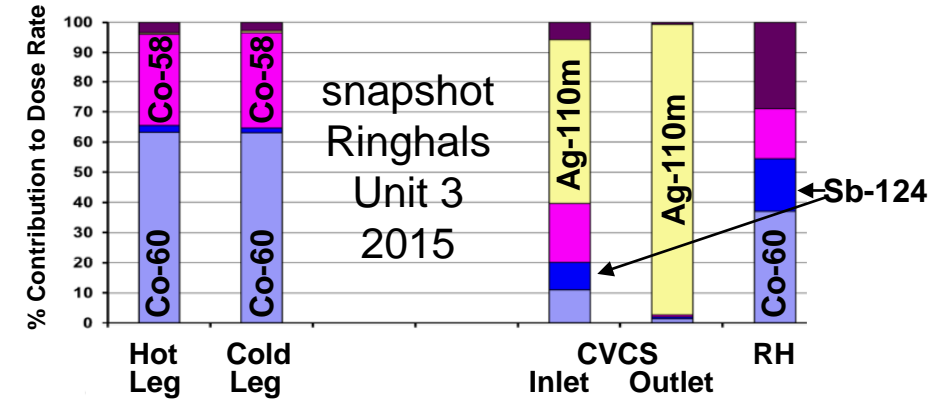
Dose rates after one cycle were again up to avg. 760 mR/hr (7.6 mSv/hr), increasing to 3.2 R/hr (32 mSv/hr) after second cycle and 4.3 R/hr (43 mSv/hr) with max of 7 R/hr (70 mSv/hr) after 3 cycles, at which time another in-kind replacement was performed.



Translate Lessons Learned into Proactive Strategies

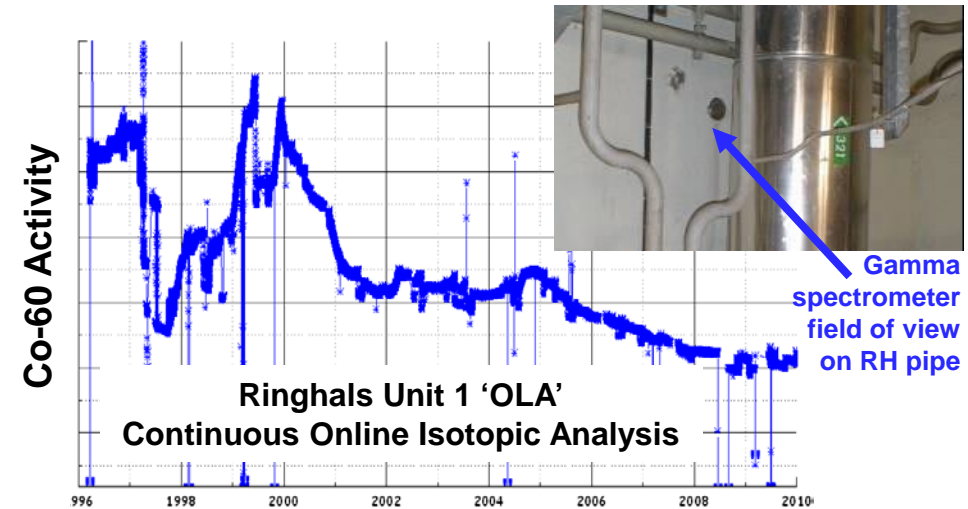
# Phase 1: Translating OE into Hypothesis for Testing

- **To-date** working with limited to 'outage **snapshots**', and lessons learned



- **Going forward**, we need to evaluate available **time-function** data to understand

- The effect of **pH** changes in letdown systems and its influence on Zn, Ag, Co, and other actors
- The effect of **redox**-changing players as caused by
  - Introduction of oxygenated makeup water
  - Trapped air in PWR control rod housings
  - Collapse of unvented, high-hydrogen content pressurizer bubble
- Activated **species** behavior
  - Co-58 solubility differs from Co-60 solubility, several PWRs observed in non-filterable to filterable ratios
  - Ag and Sb behavior



Monitoring Continuously Deciphers Generation

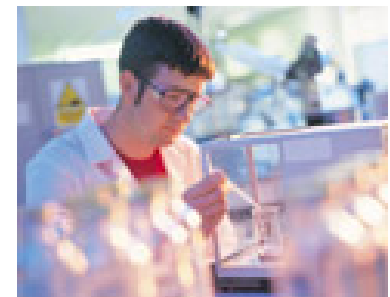
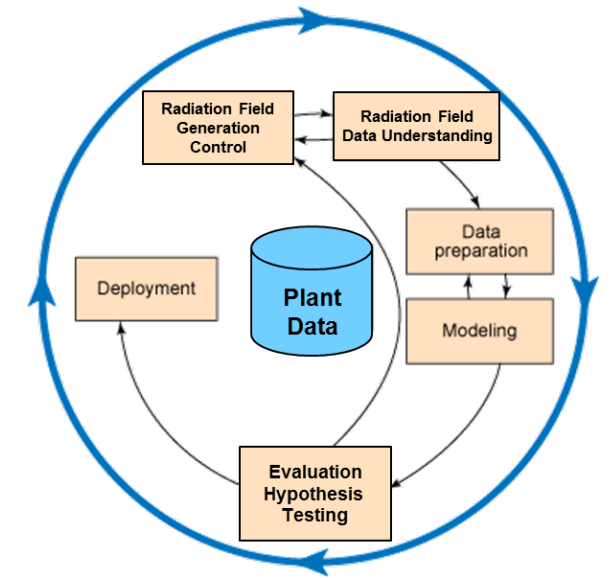
# Phase 1: Building Test Cases

## ■ Sources

- EPRI report library
- INPO OE database
- Chemistry [CMA] and Radiation Field Monitoring [SMURF] Databases
- Plant operating experiences including best possible event characterization including isotopic monitoring

## ■ Assessment Approaches

- Detailed analysis of specific event or observed trending - **ongoing**
- Following specific evolution at plants and collecting data specific to event evolutions – **forthcoming**
- Laboratory simulation to verify developed hypothesis – **forthcoming**



Snapshots are Good – Time Evolutions are more Insightful.



# Effect of Micro-Environments on Activity Transport and Radiation Fields (2015 – 2017)

## Work Scope

Phase 1 – *in progress, summary report 2016*

- Survey and evaluate literature on colloid formation under LWR conditions.
- Survey industry data to identify situations and collate experiences

Phase 2 – *in planning stages*

- Design experimental program to investigate the effect of
  - radiation on local chemistry environments
  - colloid formation and behavior on local chemistry and transport phenomena
- Perform experimental program to validate formulated hypothesis



## Benefits

Expands fundamental knowledge of radiation field generation in multivariate systems in response to implemented chemistry mitigation strategies for asset protection, radiation field and source term reduction



**If you'd be ask**

**What would be your top choices  
of ALARA tools or activities  
that every RP  
at a New Build  
should consider?**



# Top Ten Project – Why, Why Now, & What

## Today - 67 units are under construction globally

- New Builds – Okiluoto, Flamanville, Angra, Barakah, Summer, Vogtle, 24 in China
- Designs – AP1000™, APR1400, AREVA EPR™, US-APWR – what about ABWR, ESBWR

## Objective

- Develop a high-level primer to guide new-build plant personnel in minimizing radiation exposure
  - Based on plant experience, and EPRI research
  - Collate lessons learned
  - Integrate knowledge and technologies available today



Experience, Science, and Technology Centered – Not Cost-Benefit

# Top 10 Activities to a Sustainable ALARA in New Builds

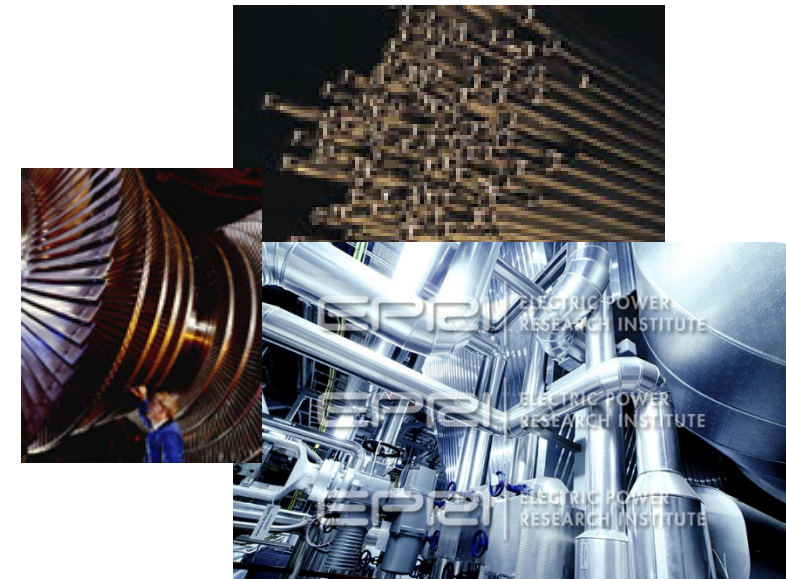
1. Create and foster strong interdisciplinary plant ALARA and Source Term platform to sustain low radiation fields
2. Avoid materials of high cobalt\* content
3. Create corrosion-resistance stable surface
4. Install permanent shielding and work platforms
5. Install infrastructure for and utilize remote monitoring
6. Establish and maintain ALARA planning tools
7. Ensure accessible and functioning sampling, monitoring, & operational stations
8. Automate and implement remote operations as much as possible
9. Optimize coolant chemistry regime (hydrogen, platinum, zinc)
10. Maximize coolant cleanup and component flushing capabilities

Applicable for Operating Fleet, too.

## 2. Avoid Materials of High Cobalt\* Content

- **Need** is for resistance against corrosion and wear
- **Options** are:
  - Special materials
  - Surface treatment (electropolishing, SCrP, passivation during hot functional testing)
- **Be aware** of 'hidden' content, for example,
  - Any nickel bearing metal may contain cobalt unless specified and verified
  - Impurity in alloy 690 steam generator tubing be limited to 0.014% average for the tube bundle with no heat to exceed 0.020%
  - In, or near, the core where neutron flux is high, and for components expected to release significant quantities to reactor coolant stream, cobalt content targets (mean values) lower than 0.05% should be considered.

\* Other dose contributing elements need to be managed, too, such as nickel, silver, & antimony



Unintended Ingress Affects Dose Rates

### 3. Create Corrosion-Resistance Stable Surface

- Use of advanced modern materials, e.g., Alloy 800
- Establish metal surface passivation prior to operations
  - Electropolishing, - plating
  - Stabilized Chromium Process (SCrP)
  - Effective passivation during hot functional testing – include hydrogen and zinc
- Maintain during operations
  - Zinc injection
  - HWC
  - Pt injection in boiling water reactors

Stop Metal Releases to Stop Activation

# 3a. Improved Surface Passivation during HFT

## General Observation

- Advantage: Surface passivation of all-wetted surfaces occurs in-situ
- Drawbacks: Duration needed and multitude of materials involved

## Beneficial Practices

- Sizewell B – two step process
  - (a) passivation – Li + H<sub>2</sub>,
  - (b) HFT<sup>2</sup> – B + Li + H<sub>2</sub> followed by shutdown with H<sub>2</sub>O<sub>2</sub> injection
- Tomari 3 – zinc application
  - 7ppb Zn during HFT (Li + H<sub>2</sub>)

## Lessons Learned

- Traditional HFT preconditioning
  - Resulted in unstable corrosion films that continue to release metals at high rates
  - In lithiated coolant without hydrogen may intensify nickel release during operation
- Japanese testing shows:
  - A stable nickel-enriched corrosion film is formed during initial exposure at high pH (Li without H<sub>2</sub>)
  - This Ni-enriched films dissolves upon exposure to normal PWR operating conditions
- **Hydrogen is crucial for developing stable corrosion file during HFT, Li is not**

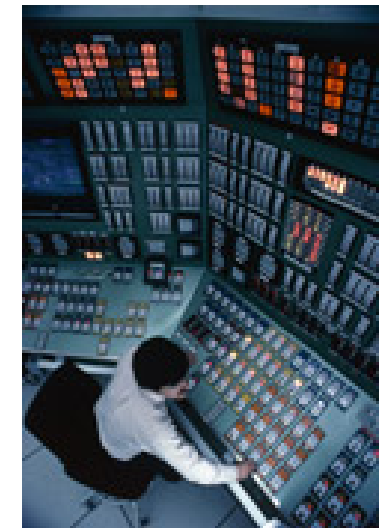
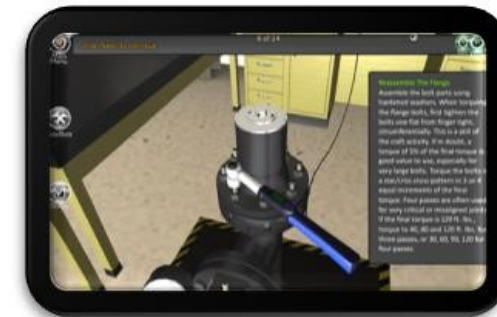


Next ANT Steps: Develop HFT Guidance and HFT Monitoring



# 6. Establish and Maintain ALARA Planning Tools

- Establish ALARA planning tools, such as:
  - Surrogate tour mapping,
  - Laser scanning,
  - Constructing a photo library of high radiation areas prior to operation, and
  - Taking videos of equipment internals
- Develop data warehousing enabling access to data from ALARA planning tools
  - Integrate online and outage radiation field and remote monitoring of work activities
  - Cross link to standardized radiation work permits and task packages
  - Define key descriptors & metrics for success
- Create change capabilities to enable adaptation of emergent technologies
  - Data management and analysis
  - Robotics



Isotopic Radiation Field 3D Real-time Visualization – No Longer a Dream.

# 10. Maximize Coolant Cleanup & Component Flushing Capabilities

- Only tools to remove activated corrosion products from coolant
- Maximize coolant cleanup
  - Select optimal resin and enhance system performance plus availability
  - Optimize coolant flowrate through cleanup
  - Augment during outage with submersible filter/demineralizers
  - Dedicated cleanup system for cavity cleanup in draindown line during refuel activities to effectively remove high-particulate source term
- Install component flushing ports and ensure shortest possible, shielded route to waste management system
- Implement remote online monitoring of performance and remote change out capabilities

Clean Coolant Equals Low Radiation Fields.

# Top EPRI Must Have's on CY/RP Bookshelves

## Chemistry

- 3002002922 - ANT: Preliminary Guidance for Chemistry Control in Advanced Pressurized Water Reactor Designs
- 3002000505 - Pressurized Water Reactor Primary Water Chemistry Guidelines: Revision 7
- 3002002623 - BWRVIP-190 Revision 1: BWR Water Chemistry Guidelines
- 3002001796 - Boiling Water Reactor Zinc Addition Sourcebook
- 3002001942 - BWRVIP-225 Revision 1: BWR Shutdown and Startup Chemistry Experience and Application Sourcebook
- 1025316 - Pressurized Water Reactor Primary Zinc Application Sourcebook Revision 1
- 1021112 - Corrosion Product Transport during Boiling Water Reactor and Pressurized Water Reactor Startups

## Radiation Safety/ALARA

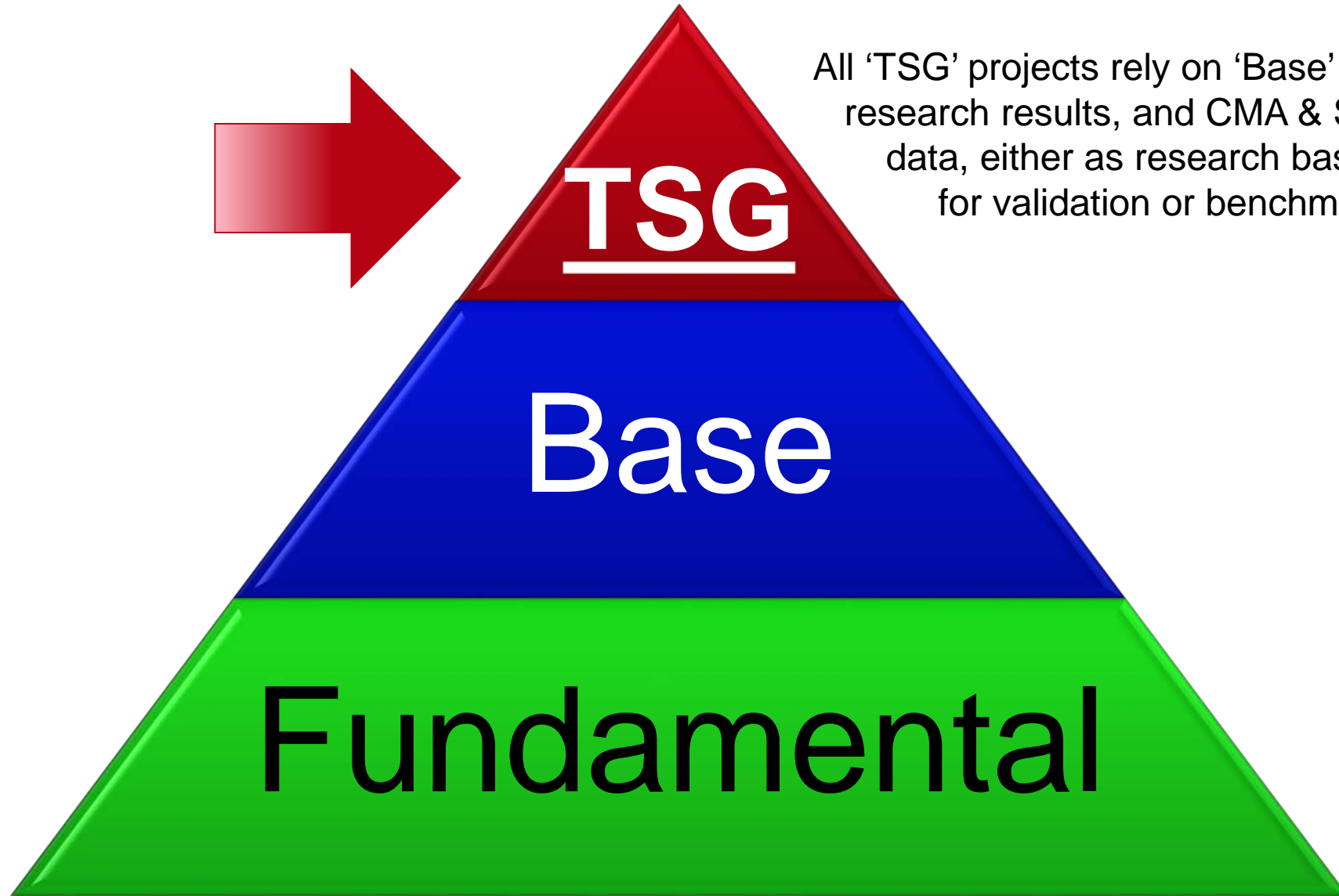
- 3002005480 - Remote Monitoring Technology Guide for Radiation Protection: Field Implementation of Remote Monitoring
- 3002003165 - Guidance for Optimal Performance of Shielding Programs
- 3002000268 - Evaluating Indoor Location Tracking Systems in a Nuclear Facility: Experimentation with Different Techniques in an Industrial Environment
- 3002000032 - 3D Radiation Field Estimation Algorithm v1.0
- 1025309 - Dose Reduction Options for Refueling Tasks
- 1021101 - Evaluation of an Advanced Radiation Shielding Material for Permanent Installation at an Operating Nuclear Reactor
- 1021102 - Scaffold Program Optimization and Dose Reduction Guide

## Source Term

- 1021103 - Cobalt Reduction Sourcebook
- 1003390 - Radiation Field Control Manual
- 3002005377 - LWR Ex-Core Surface Conditioning for Radiation Field Reduction
- 3002005479 - Reactor Cavity Decontamination Sourcebook
- 3002005484 - EPRI Plant Source Term Assessments--2015 Review
- 3002005481 - In-Plant Gamma Spectrometry: Isotopic Data Collection Experiences
- 3002003157 - EPRI BWR Radiation Level Assessment and Control (BRAC) Program: 2014 Revision
- 3002003155 - EPRI Pressurized Water Reactor Standard Radiation Monitoring Program: 2014 Revision
- 1025305 - Impacts of PWR Operational Events on Particulate Transport and Radiation Fields
- 1016766 - High Activity Crud Burst Impacts and Responses

Knowledge Transfer and Retention is Key to Sustainable ALARA

# EPRI's Radiation Field & Source Term Efforts



All 'TSG' projects rely on 'Base' research results, and CMA & SMURF data, either as research basis or as source for validation or benchmarking.

# RMST TSG – Global Industry Peer Group

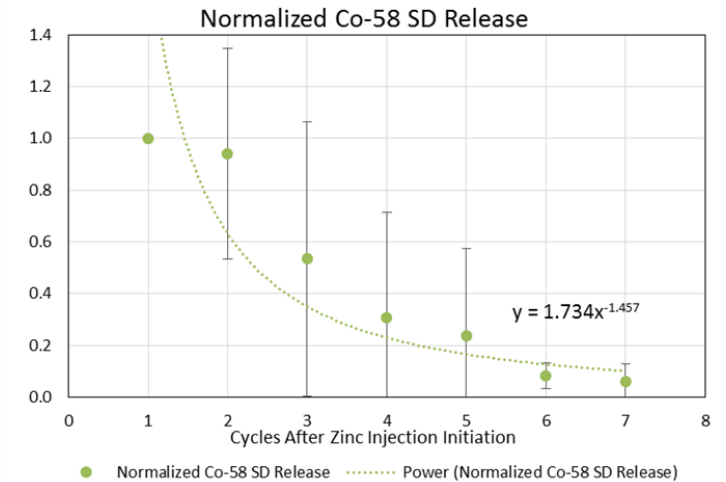
Global experience base of 20 utilities with 74 sites and 166 units (~40% of global fleet) for:

- Benchmarking
  - **Quick surveys to emergent issues**
  - Deeper looks at topics of general interest  
Hot spot practices (3002003158), chemical decontamination (3002000555)
- **Independent objective technical assessments** (3002005484)
  - Topical –  
Source term, alpha, ALARA, remote monitoring, scaffold & shielding
  - Individual –  
Vendor's first-of-a-kind decontamination, fleet-wide practices
- Answering **tactical research** questions
  - PWR shutdown releases (3002005483)
  - BWR ultrasonic fuel cleaning as radiation field reduction strategy (3002005482)
  - Radiation Field modeling – OSCAR
  - Remote Monitoring Technology Implementation Guidance (3002005480)
- Knowledge Transfer
  - Annual Workshops (with associated learning opportunities)  
June - Shielding & Scaffolding; August - Remote Monitoring; September - Radiation Field & Source Term Reduction



# RMST TSG – 2015 Quick Benchmarks

- Zinc effectiveness at high-duty PWRs
  - Similar benefit to radiation fields at SRMP location as in not high-duty plants
  - Six of the seven benchmarked high-duty plants perform UFC each outage
- BWR Shutdown Particulate Release:
  - Follow BWR VIP-225 guidance
  - Implement soft shutdown
  - Ensure cleanup system availability
  - HWC-OLNC chemistry influences chromium chemistry in coolant, which is mostly insoluble
- BWR Chemical Decontamination:
  - Short-term benefits may not measure up
  - Ensure adequate flushing plans and passivation steps are executed to avoid unexpected consequences
  - Ensure loss of platinum is counteracted for adequate asset protection



**Six High Duty, Alloy 690 SGs, UFC, & RCS Zinc of 5-12 ppb started Early in Cycle**

For more information visit the [Radiation Safety Collaboration](#) site



# Review of Industry Source Term Reduction Efforts

- Objective:
  - Identify best practices & lessons learned
  - Identify knowledge gaps and technology needs

- General Observation:

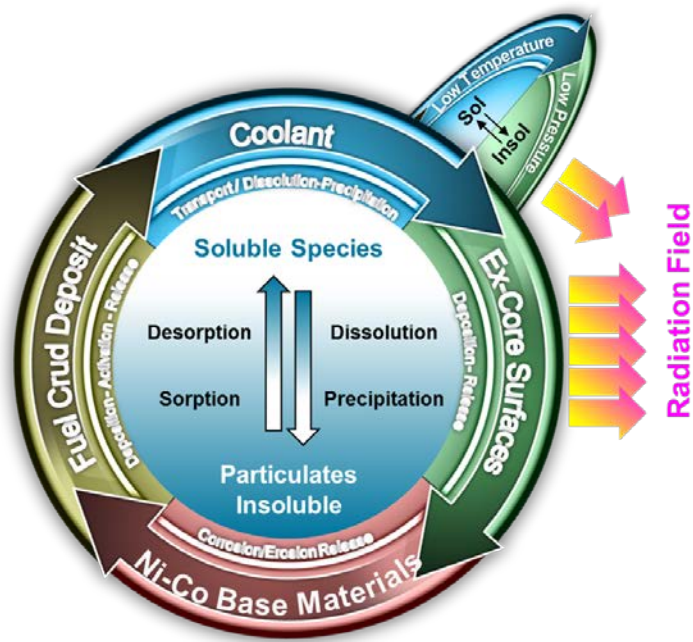
**Do not expect Quick Fixes – Source Term Reduction manifests successes after several cycles**

- Basis:
  - Past EPRI Source Term Assessments  
More than 20 assessments performed globally
    - ~ 2/3 BWR and ~ 1/3 PWR
    - several repeat assessments



TSG report 3002005484 - October 2015

# Source Term Reduction - Ownership and Drivers



**Source Term is controlled and affected by all departments**

**Source Term reduction is most effectively achieved,  
when all department have the same objective:**

**Producing power, cost efficient, while source term conscious**

# Source Term Reduction in Pressurized Water Reactors

- Beneficial source term strategies identified are:
  - Fuel cleaning
  - Zinc chemistry
  - Elevated lithium control programs
  - End-of-cycle chemistry control strategies
  - Crud mitigation
  
- Gaps – future research
  - Develop better understanding and guidance on
    - Optimum time to terminate zinc feed prior to EOC considering Zn ions impact on ex-core surface deposition
    - Changing lithium/pH<sub>T</sub> during the latter portion of a cycle (within Guideline limits) to stabilize fuel deposits (and minimize deposition on ex-core surfaces)

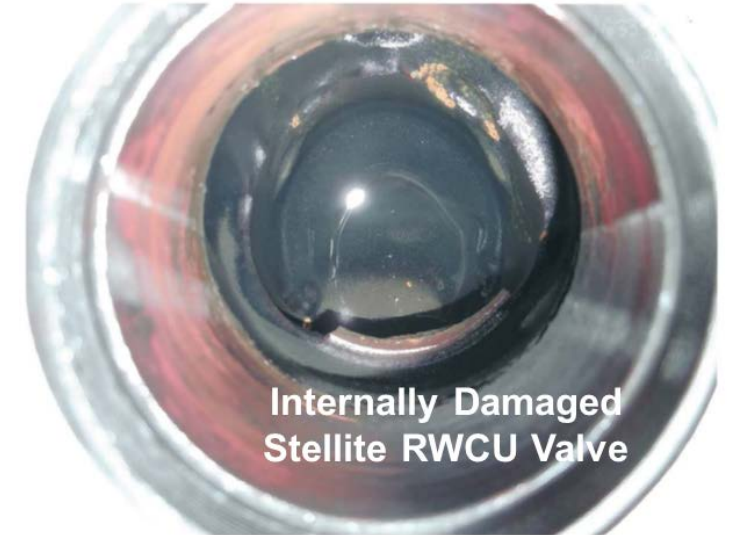
# Source Term Reduction in Boiling Water Reactors

- Common issues found
  - Materials (Stellite™ replacements and material specification/verification)
  - RWCU and RHR materials – carbon steel surfaces generally cause higher radiation fields than stainless steel surfaces
  - Cleanup system performance and availability
- Factors contributing to source term mobility include
  - Fuel failures
  - Change in core design
  - Condenser inleakage
  - Transients affecting hydrogen-oxygen balance in coolant
  - Sequencing of platinum injection
  - Noble metal application close to outage



# Source Term Reduction in Boiling Water Reactors

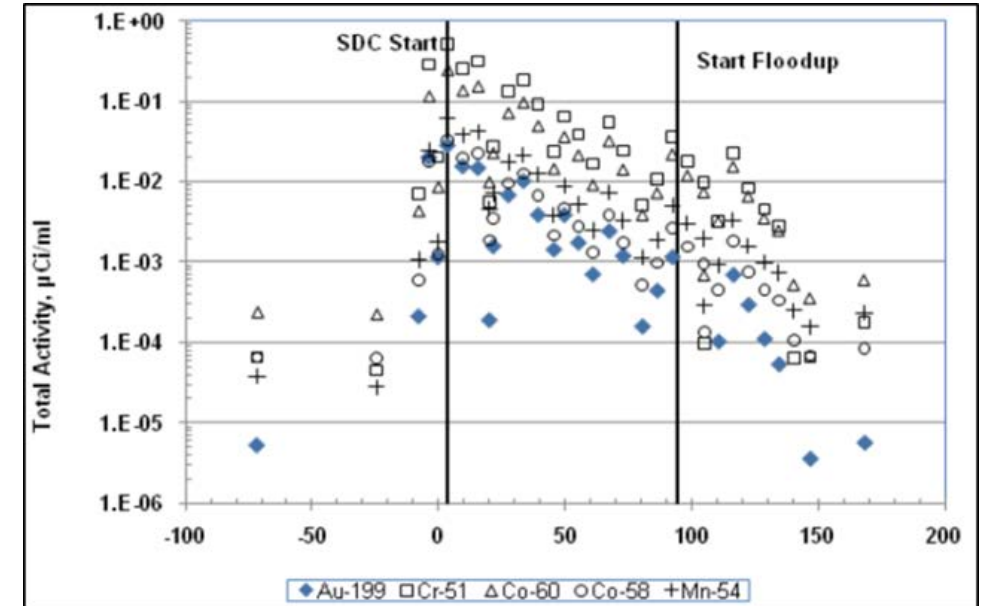
- Beneficial Source Term reduction strategies
  - Reduction of cobalt-containing materials such as Stellite™ (OEM blades, valves...)
  - Excellency in cleanup system performance and availability
  - Optimum chemistry program (HWC, Pt, Zn)
  - Minimize FW iron ingress
  - BWRVIP-225 recommended shutdown practices
- Beneficial outage operational practices
  - Flood up through the condensate treatment system
  - Using submersible filters and demineralizers to supplement cavity cleanup
  - Applying fresh precoats to RWCU F/Ds and fuel pool cooling system F/Ds shortly prior to outage start
  - Maintaining RWCU in service until after cavity floodup is complete, fuel gates are open, and water clarity has been established



# Source Term Reduction in Boiling Water Reactors

## Gaps – future research

- Chemistry
  - Behavior of chromium and Cr-51 under OLNLC, low hydrogen and low iron conditions
  - Impact of OLNLC, low iron, and high zinc chemistry on radiation fields
  - Chemical decontamination – sequencing of noble metal application
  - Behavior of reported Zn-65 and Zn-69m relative to elemental zinc levels needs better understanding
- Materials
  - Impact of removal of admiralty brass condensers on copper source – ECP effect and reduction of natural zinc caused radiation field
  - Impact of in-vessel cobalt sources on cobalt mass balance
  - Cr-51 particulate releases
  - Transition to Inconel® grids will this cause an increased contribution from Co-58
- Operations
  - Impact of shutdown practices on hotspots and associated CRE
  - Cleanup of forward pumped drains
- Fuels
  - Influence of core and/or fuel design on source term and its mobility
  - Control rod sequencing impact of activity transport
- RP
  - Chemical decontamination benefit relative to asset protect and recontamination rates
  - Remote monitoring as part of ALARA program





# Review of Industry Source Term Reduction Efforts

## ■ Do

- Component replacement:
  - Eliminate high cobalt content materials (Stellite™ etc.)
  - Enforce material specifications in regards to cobalt content
  - Enhance surface finishes
- Optimize reactor coolant cleanup efficiency and performance
- Limit core crud buildup and carry-over
- Optimize chemistry program
- Use any additional coolant cleanup system during outage



## ■ Don't

- Replace non-Stellite™ with Stellite™
- Ignore degrading cleanup system performance
- Ignore chemistry and radiation field monitoring
- Expect quick fixes

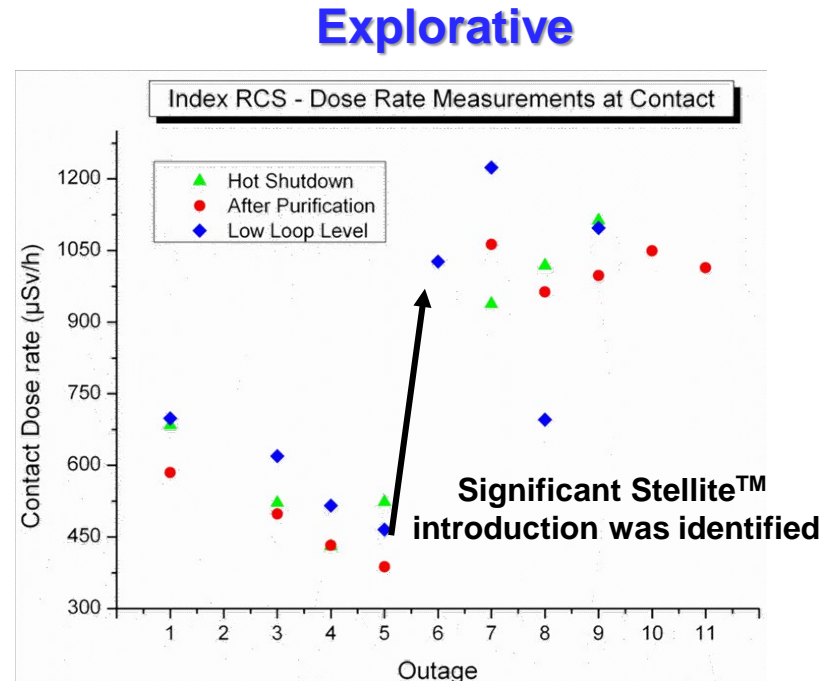
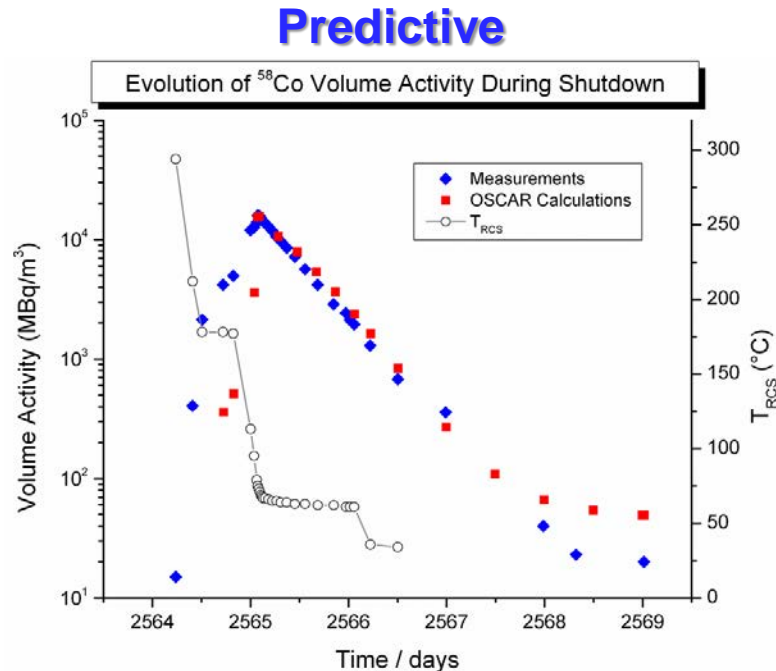
Achieve a Sustainable Low Source Term

# RMST TSG – 2015 Tactical Research

- BWR Ultrasonic Fuel Cleaning (3002005482)
  - Feasible
  - Benefit is expected long term if applied to reload fuel
  - Needs further qualification by fuel reliability/fuel vendors
- PWR Shutdown Release (3002005483)
  - Evaluation of various factors impacting releases and release rates
    - Steam generator design, materials, manufacturing process, and life time
    - Plant design, operating temperature,  $\text{pH}_T$
    - Case studies – UFC and shutdown practices
  - Multivariate system requires long-term, continuing monitoring and analysis
  - This is an ongoing effort – apparent inconclusiveness may be indicative of plant specificity
  - [Status update publication in 2016](#)
- Radiation Field Modeling
  - Review in progress – [publication 2016](#)
  - PWR – **OSCAR** is considered for sensitivity and validation studies to aid industry in implementation of radiation field reduction strategies
- Remote Monitoring Technology Implementation Guide (3002005483)

# OSCAR – a PWR Radiation Field Modeling Tool

- RMST TSG currently working to bring to EPRI members
- Focus on research, sensitivity, and validation studies
- EPRI and Southern are working on validating OSCARs capabilities in 2016 (pending)



Mathieu Corbineau, OSCAR – Modeling Tool for Source Term Management and Dose Reduction: AREVA Use, 2015 EPRI Source Term and Radiation Field Reduction Workshop, 15 July 2015, Charlotte, NC.

# RMST TSG – Tactical Research Topics under Consideration

- PWR zinc guidance
  - EOC termination
  - Zn target concentration
  
- BWR
  - Cr-51, Co-58 contributions & activity transport under ultra-low iron, hydrogen, and platinum
  - Decontamination, when and how to assure asset protection
  
- Coupling radiation field generation modeling with ALARA planning

# RMST TSG Meetings in 2016 & knowledge transfer opportunities

- **Dose Reduction for Scaffolding, Insulation, and Shielding Workshop**
  - June 14-16, 2016 in Charlotte, NC at EPRI Offices
- **Radiation Monitoring Technology Workshop**
  - August 2016 – details TBD
- **Radiation Field and Source Term Reduction Workshop**
  - Sept. 12 - 14, 2016 in Charlotte, NC at EPRI Offices
  - Monday afternoon – Utilities only – Source Term 101
  - Tue/Wed – open workshop
  - In conjunction with PWR Chemistry TSG – Wed pm joint session
- **In-Plant Gamma Isotopic Radiation Field Monitoring – Fundamentals 101**
  - Sept 15, 2016 at EPRI Charlotte offices
  - open to EPRI members - please email interest to [cgregorich@epri.com](mailto:cgregorich@epri.com)

For more information, email [cgregorich@epri.com](mailto:cgregorich@epri.com)



# Together...Shaping the Future of Electricity



# RMST TSG – 2016 Membership

Utility - Membership period		2014-2016	2015-2017	2016-2018
Dominion Resources Inc.	Dominion			x
AXPO	NOK	x		
Comision Federal de Electricidad	CFE	x		
Detroit Edison	DTE Energy	x		
Electricite de France	EDF	x		
FirstEnergy Service Company	FENOC	x		
Korean Hydro Nuclear Power	KHNP	x		
Luminant	Luminant	x		
NA-SA	NA-SA	x		
Nebraska Public Power District	NPPD	x		
Public Service Electric and Gas	PSE&G	x		
Southern Company		x		
Tennessee Valley Authority	TVA	x		
Xcel		x		
Arizona Public Service (Palo Verde)	APS		x	
Energy Northwest			x	
Entergy Services, Inc.	Entergy		x	
Duke Energy	Duke			x
Exelon Corporation	Exelon			x
Omaha Public Power District	OPPD			x

Does RMST TSG Offer Value? – Speak to your NMETT to Join/Renew.

# Getting Access to EPRI

Go to [www.epri.com](http://www.epri.com)

The screenshot shows the EPRI website header with the logo and navigation menu. The main content area features a large banner for SunShot and a section for EPRI Member Login. The login section includes a 'Go To Member Login' button and links for help, registration, and membership information. A blue arrow points to the 'Go To Member Login' button.

**Staff at member utilities  
can create their own  
accounts**