

# **PWR Owners Group Resolution Path for GSI-191**

NRC Meeting, August 22, 2012

# Background and Overview



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Slide 2

# Background

- U.S. PWRs have committed significant resources to improve safety margins related to GSI-191, including the addition of significantly larger sump strainers and removal of problematic sources of debris
- PWROG generic program attempted to evaluate in-vessel effects to bound all plants simultaneously



# Background

- WCAP-16793-NP, Revision 0, utilized WCOBRA/TRAC to evaluate core blockage
  - With over 99% of the core inlet blocked by debris, long term core cooling was still assured
  - ACRS concerns in 2008 with how much debris would block ~99% of the core led to a generic, bounding test program
- WCAP-16793-NP, Rev. 1 and 2, performed generic testing at two facilities to create a bounding fiber limit
  - Single channel test facilities, ~no settling allowed
  - Conservative testing yielded 15 g of fiber/fuel assembly, or 15 g/FA
  - Results are overly constraining to all plants



# Background

- Presentation of WCAP-16793-NP, Revision 2, to ACRS on May 9, 2012, led to several concerns:
  - Questions surrounding p:f ratio, flow rate, temperature, order of debris addition, fiber and particulate size distributions, and water chemistry
- Industry executives chose to institute a “Tiger Team” to develop a comprehensive in-vessel closure plan to create improved debris limits that would benefit all U.S. PWRs and would address previous technical concerns
- Project authorizations currently in process



# Overview

- Tiger Team comprehensive in-vessel closure plan involves three major generic technical programs and one major cafeteria program
  - Independent Third-Party Review of PWROG GSI-191 Test Programs (Generic)
  - Comprehensive Analysis and Test Program for GSI-191 Closure (Generic)
  - Addressing Boric Acid Precipitation to Support GSI-191 Closure and Evaluation Model Development (Generic)
  - Develop Guidance Document for Generic Use of STPNOC Risk-Informed Methodology for Closure of GSI-191 (Cafeteria)



# Overview

- Independent Third-Party Review of PWROG GSI-191 Test Programs (Generic)
  - I3PR involves a knowledgeable but independent third-party reviewing the past PWROG in-vessel testing to provide recommendations for future testing
- Comprehensive Analysis and Test Program for GSI-191 Closure (Generic)
  - In-vessel debris program involves LOCA code calculations, bench testing, and fuel assembly loop debris testing to determine sets of debris limits that bound groups of plants

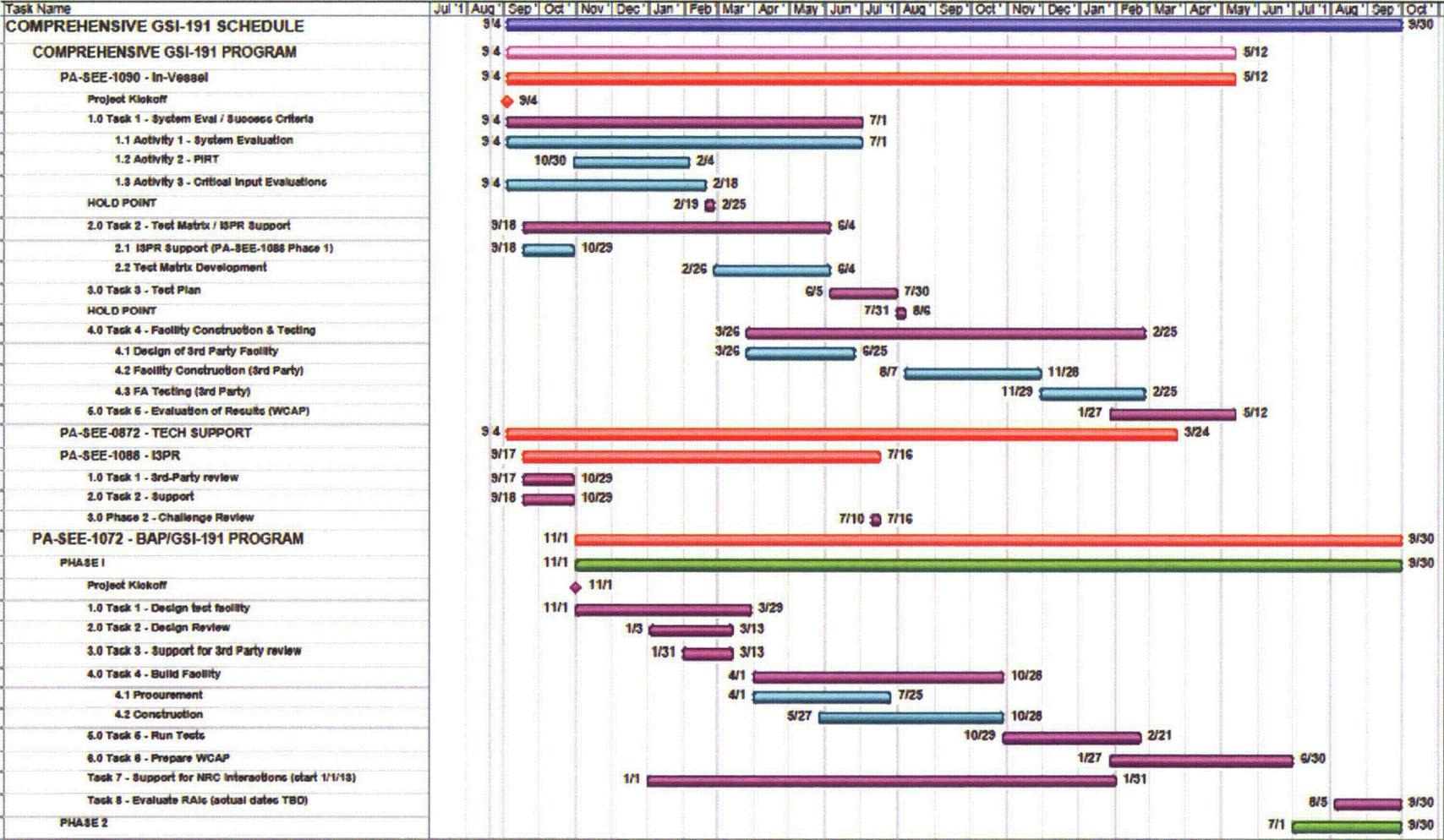


# Overview

- Addressing Boric Acid Precipitation (BAP) to Support GSI-191 Closure and Evaluation Model Development (Generic)
  - GSI-191 BAP program involves multiple assembly test loop with heated rods and detailed lower plenum geometry to demonstrate:
    - that mixing between the lower plenum and core inlet continues to occur in the presence of debris
    - that flow through the baffle region can provide an alternate flow path if the core inlet blocks completely by debris
- Develop Guidance Document for Generic Use of STPNOC Risk-Informed Methodology for Closure of GSI-191 (Cafeteria)
  - RI Guidance program is a cafeteria program to follow and document the STPNOC RI methodology (Option 2 risk informed) for use by other plants



# Comprehensive Schedule



**NOTE:** Schedule discussions will be held as part of the "Industry Questions on GSI-191 SECY" item on the meeting agenda

# PA-SEE-1088

## Independent Third-Party Review (I3PR) of PWROG GSI-191 Test Programs



# PA-SEE-1088

## I3PR of Previous Testing

- Before proceeding forward with two major testing programs (in-vessel debris and GSI-191 BAP), industry executives desired an independent review of the previous test programs by a third-party
  - Third-party needs to be independent of the previous programs
  - Third-party needs to be knowledgeable of GSI-191 concerns and testing
  - Third-party needs to be knowledgeable of BAP programs
  - Alden Labs chosen as independent third-party for this task
- I3PR to review various aspects of previous testing (test facilities, test protocols, test matrices, test results) and provide recommendations on these same items for the in-vessel debris and GSI-191 BAP programs



# PA-SEE-1088

## Challenge Board Review of Path Forward

- After the I3PR recommendations have been reviewed by the Tiger Team and project teams and incorporated into the forward-looking test plans, a Challenge Board will be convened to review the final plans (facility choices, test protocols, test matrices)
- Challenge Board is planned to include independent third-party, Tiger Team, EPRI, and other technical experts
- Tiger Team and project teams will review results of Challenge Board and incorporate into the final plans for both the in-vessel debris and GSI-191 BAP programs



# PA-SEE-1090

## Comprehensive Analysis and Test Program for GSI-191 Closure



# PA-SEE-1090

## Task 1: Work Scope

- Task 1: System Evaluation and Definition of Success Criteria
  - Activity 1: Evaluation; determine effects of blockage on LTCC
    - LOCA code (WCOBRA/TRAC-TF2 and RELAP/MOD2-B&W) calculations assuming core blockage, alternate flow paths and SG overflow – demonstrate actual limits to LTCC – potential that certain breaks/scenarios can be eliminated from testing (core is still cooled)
  - Activity 2: Phenomenon Identification and Ranking Table (PIRT)
    - Determine key input parameters to fuel debris test loop testing
  - Activity 3: Critical Input Evaluations
    - Evaluations and testing (bench top, autoclave, etc.) of prototypical water chemistry, chemical effects (appropriate surrogates, forms, and timing), and strainer bypass debris size distribution



# SYSTEM EVALUATION

## Activity 1 Breakdown

- Activity 1 is broken into the following steps:
  1. Review Previous Analysis Work
  2. Scenario Definition/Selection of Analysis Tool
  3. Code Modification and Validation
  4. Model Generation, Code Execution and Analysis of Results
  5. Final Documentation and Recommendation of Acceptance Criteria



# SYSTEM EVALUATION

## Review of Previous Westinghouse Analytical Work

- Previous Westinghouse Analysis (WCAP-16793-NP Rev. 2)
  - WCOBRA/TRAC Mod7A (Uses TRAC-PD2) Best-Estimate LBLOCA Analysis Tool
  - Focused on blockage at the core inlet and the determination of a “blockage factor” which would no longer sustain core boil-off requirements.
  - Performed for a “mix” of scenarios in an attempt to bound the transient behavior.
    - Ex. Debris bed loading/blockage was assumed based on a HLB scenario whereas the analysis work was performed utilizing a CLB.
- Evaluate and Address ACRS/NRC Comments



# SYSTEM EVALUATION

## Review of Previous AREVA Analytical Work

- Previous AREVA analyses
  - Quasi-steady static-balance calculation
    - System pressure drops are based on steam flow and hydrostatic heads
  - Demonstrates for varying core inlet blockages that the core will be covered by a two-phase mixture following a LOCA
    - long term core cooling assured by two-phase mixture



# SYSTEM EVALUATION

## Scenario Definition

- Define exactly what scenario(s) will be modeled and evaluated
  - This includes specific characteristics important to the system's T/H response (i.e. active components, break location, ECCS performance).
  - As part of this work, a review of all US PWR NSSS types (B&W, CE, Westinghouse) will be completed to identify any alternate flow paths that should be considered in the system models.
  - Post-LOCA steam generator conditions will also be reviewed such that possible U-tube spill-over or HL U-bend spillover will be investigated.



# SYSTEM EVALUATION

## Westinghouse Analysis Tool

- WCOBRA/TRAC-TF2 used for the Analysis of Westinghouse and CE NSSS
  - WCOBRA/TRAC-TF2 created by coupling COBRA-TF with TRAC-PF1
  - Extensive code updates performed and a large assessment matrix for LOCA scenarios was developed.
  - Submittal of Full Spectrum LOCA topical report to USNRC in 2010 (WCAP-16996-NP)
  - Vessel components: Multi-dimensional, two-fluid/three-field formulation
  - Loop components: 1 D, two-fluid/two-field formulation



# SYSTEM EVALUATION

## Westinghouse Code Modification and Validation

- Debris blockage will be simulated by applying a variable loss coefficient (K) at the core inlet.
- Currently, WCOBRA/TRAC-TF2 doesn't have this capability.
- A single application version will be generated that allows increased resistance at the core inlet as a function of time.
- This single application version will need validation to ensure the code is still functioning as expected.
- Documentation required for QA standards will also be generated.



# SYSTEM EVALUATION

## AREVA Analysis Tool

- RELAP/MOD2-B&W used for the Analysis of B&W NSSS alternate flow paths
- B&W NSSS alternate flow paths
  - RELAP5/MOD2-B&W
    - Approved code used for EM licensing analyses of B&W-designed plants
  - S-RELAP5
    - Approved code used for EM licensing analyses of Westinghouse and CE designed plants
  - Vessel components: LP, hot and average channels, baffle region, UP & outlet annulus
  - Loop components: modeled as needed
  - Blockage at core inlet will be applied instantaneously at time of interest (20-30 minutes)
  - Results will be benchmarked to test results from BAP test program



# SYSTEM EVALUATION

## Model Generation

- Models generated for various categories of plants
  - Westinghouse/CE/B&W NSSS
  - ECCS performance and configuration
- Alternate flow paths (i.e., flow into the barrel-baffle or core shroud region, upper head cooling spray nozzles, etc.)
- Steam Generator Condition
  - Heat Source vs. Heat Sink
  - Spill-over into hot legs
- Break Location
  - Hot Leg and Cold Leg Breaks
- Degree of core inlet blockage



# SYSTEM EVALUATION

## Development of Acceptance Criteria

- The analysis results will inform the establishment of acceptance criteria.
- The acceptance criteria will be based on the ability to effectively remove decay heat from the core .
- Fuel debris testing will be performed to meet the acceptance criteria in the rest of the program.



# SYSTEM EVALUATION

## Activity 2 – PIRT

- Activity 2 involves creating a Phenomena Identification and Ranking Table (PIRT) for the future debris testing
  - The PIRT will be created to identify critical inputs and associated phenomena that will impact debris bed formation and pressure drop due to the debris bed
  - It will similarly identify critical inputs and phenomena that will impact boric acid mixing between the lower plenum and the core inlet (both with and without the presence of debris)
  - The PIRT will be used by both testing programs to help develop test matrices and to determine appropriate facilities for both programs
  - The PIRT will be informed by the results of the I3PR



# SYSTEM EVALUATION

## Activity 3 – Critical Input Evaluations

- Activity 3 involves critical input evaluations, analysis, and testing, to supplement the PIRT
  - Prototypical water chemistry
    - Westinghouse testing of facility differences, suggests that water chemistry (DI water, tap water from different locations) impacts fuel assembly debris testing results. Water chemistry is assumed to be a major component of the test result differences between the RTU and CDI facilities
    - Evaluation of the prototypical post-LOCA sump water chemistry will be performed
  - Chemical effects
    - Appropriate surrogates, forms, and timing of their development will be investigated via bench top and autoclave testing to bound individual groups of plants
  - Strainer bypass debris size distribution
    - Bench top tests of different sump screen designs, approach velocities, and debris amounts will be performed to develop prototypical fibrous debris size distributions for use in the fuel assembly debris testing



# PA-SEE-1090

## Task 2: Work Scope

- Task 2: Support for 3rd-Party Review (I3PR) and Development of Test Matrix
  - Activity 1: Support for I3PR
    - As previously discussed an independent third-party review of the past testing will be performed
    - This activity is in parallel with parts of Task 1 and feeds into Task 1 Activity 2 (PIRT)
  - Activity 2: Development of Test Matrix
    - Based on the results of the I3PR and the PIRT development, a matrix of fuel assembly debris tests will be developed to address AREVA and Westinghouse fuel under prototypical conditions for groups of those plants
    - General path forward (matrix, high level facility design, test plan) to be developed in this activity



# DEVELOPMENT OF TEST MATRIX

## Test Considerations

- Two test purposes will be addressed
  - Improve debris limits by changing previous input assumptions to create more realistic tests & bounding groups of plants (rather than all PWRs)
    - Changes to flow rate assumptions, chemical surrogate addition, water chemistry, and temperature are expected
    - These tests will benefit from a more realistic success criteria, developed in Task 1, than the previous  $dP_{\text{debris}} < dP_{\text{available}}$  at a conservative flow rate (44.7 gpm)
  - Address previous NRC and ACRS concerns related to original test program such as;
    - Repeatability
    - Particulate to fiber ratio (p:f ratio)
    - Debris size distribution (fiber and particulate)
    - Flow rate, temperature, water chemistry
    - Bed morphology



# DEVELOPMENT OF TEST MATRIX

## Test Considerations

- Test matrix will include bench tests for certain phenomena, as necessary, to inform larger, more expensive and time-consuming, fuel assembly loop tests
- Certain considerations (full gap sizes, non-uniform debris and flow distribution, full-height assemblies, boiling) will be addressed if necessary, by results of GSI-191 BAP program, since that loop is envisioned to have multiple assemblies, full-height assemblies, and heated rods



# PA-SEE-1090

## Task 3

- Task 3: Development of Test Plan
  - Activity 1: Challenge Board Review
    - As previously discussed, a challenge board will review the path forward and test matrix and provide recommendations
  - Activity 2: Development of Test Plan
    - Based on the results of the challenge board, the path forward (test plan, test matrix, high level facility design) will be finalized/formalized



# PA-SEE-1090

## Task 4 – Construction of Test Facility and Testing

- Includes design phase of facility, which will be informed by the I3PR, PIRT, and Challenge Board Review
- Two primary options currently considered (to be determined by I3PR, PIRT, Challenge Board)
  - Current RTU and CDI test loops, with modifications as necessary
  - Comprehensive 3rd-party test facility
- 20 to 30 tests envisioned (in addition to potential bench tests)
- Will bin and test groups of similar plants – several debris limits envisioned
- Testing will also address previous NRC and ACRS concerns



# PA-SEE-1090 Task 5

## Evaluation of Results and Determination of Debris-Related Limits

- Evaluation of analyses and test results
- Determination of sets of debris limits (fiber, particulate, chemical)
  - Key debris limits still expected to be related to fibrous debris
  - Each set of debris limits will cover different groups of plants
  - All U.S. PWRs will be covered by at least one set of limits
- Preparation of non-proprietary WCAP
- Submittal of WCAP to NRC staff



# PA-SEE-1090

## Schedule

- PA Start Date: 09/04/2012
  - Issue final PIRT report 02/04/2013
  - Issue success criteria report 07/01/2013
  - Issue final test matrix 06/04/2013
  - Complete Test Facility Design 06/25/2013
  - Issue Test Plan 07/30/2013
  - Complete Test Facility Construction 11/28/2013
  - Complete Testing 02/25/2014
  - Issue Final WCAP for submittal 05/12/2014
- PA End Date: 05/31/2014



PA-SEE-1072  
Addressing Boric Acid Precipitation to  
Support GSI-191 Closure and EM  
Development

James Spring, Westinghouse



# AGENDA

- Introduction
- Background
- Purpose
- Previous Testing: Non-Prototypic Aspects
- Work scope
- Preliminary Work
  - Conceptual Design (Key Features)
  - PIRT and Scaling Considerations
- Schedule



# PA-SEE-1072

## Introduction

- Assessment of post-loss-of-coolant accident (post-LOCA) long-term core cooling (LTCC) requires consideration of Generic Safety Issue (GSI) 191 and boric acid precipitation (BAP).
- These two considerations were initially covered by decoupled, separate work efforts within the PWROG.
- Per NRC direction in early 2012, plants wanting to pursue higher fibrous debris loadings than 15g/FA would need to address BAP in context of debris
- This project authorization (PA) couples both work efforts by developing an experimental program that investigates the integral effects of post-LOCA debris on transport, mixing, and precipitation characteristics of borated solution within a reactor vessel.



# PA-SEE-1072

## Background

- PWROG sponsored a program (PA-SEE-0312) to provide analyses and information on the effects of debris and chemical products on core cooling for PWRs when the ECCS is realigned to circulate coolant from the containment sump.
- After working through responses to NRC RAI's on the topical report, WCAP-16793-NP Revision 2 was submitted to NRC for formal review (October 2011). This establishes a generic limit of 15 grams of fiber per fuel assembly (g/FA).
- More recently, NRC identified a concern that in-vessel debris associated with GSI-191 may affect the potential for boric acid precipitation (BAP) due to one or more of the following processes:
  - Reduced mixing/transport of fluids between the core and the lower plenum (should debris accumulate at the core inlet).
  - Reduced lower plenum mixing volume (should debris settle in the lower plenum).



# PA-SEE-1072

## Background (cont.)

- NRC identified that BAP must be addressed with respect to GSI-191 for those plants who plan to take steps to increase their in-vessel fiber limit beyond 15 g/FA.
  - Demonstrate that in-vessel debris does not increase the potential for BAP.
- PA-SEE-1072 specifies the work that would be performed on a generic basis to provide test data that addresses the GSI-191 BAP concerns.
- The BAP Evaluation Model (EM) development program is a continuing project, sponsored by the Analysis Subcommittee for the past several years. The GSI-191 team and BAP EM team have reached a consensus agreement regarding a single facility that will satisfy both program needs.



# PA-SEE-1072

## Purpose

- Evaluate the effect of debris accumulation near the core inlet and/or within the lower internals that may inhibit exchange flow between the core and lower plenum regions or reduce effective vessel mixing volume such that lower debris limits are needed for BAP concerns rather than decay heat removal (DHR) concerns
- Evaluate the effect of suspended debris in the borated solution that may reduce mixing within the reactor vessel such that high concentration regions develop creating the potential for localized precipitation
- Evaluate the effect of in-vessel debris on mixture level swell as it relates to liquid carryover through the reactor vessel vent valves (RVVVs) for B&W-NSSS or liquid carryover to the hot leg for Westinghouse- or CE-NSSS
- Evaluate the effectiveness of alternate flow paths diluting the core region if debris blockages are formed near the core inlet



# PREVIOUS IN-VESSEL TESTING

## Non-Prototypic Aspects

- Debris Accumulation/Suspension in the Lower Head

Previous Testing (WCAP 16793)

- Did not consider a scaled lower head region.
- Included a feature that promoted mixing of debris in the volume just below the core support plate.
- The purpose of this mixing feature was to promote debris transport into the core inlet region.

Proposed Facility

- Utilizes a curved lower head with prototypic internal structures that are scaled such that the flow field is consistent with that expected in the prototypic system.
- Thus, any debris accumulation/suspension that may occur in the lower head region of the test facility is expected to be similar to a full-scale reactor vessel.



# PREVIOUS IN-VESSEL TESTING Non-Prototypic Aspects (Cont.)

- Multi-Dimensional Effects

Previous Facility (WCAP 16793)

- Used only a single fuel assembly.
- The flow was primarily one-dimensional in the vertical direction.

Proposed Facility

- Design is one fuel assembly wide by seven fuel assemblies deep, representing a slice or slab extending from the center to the periphery of the core.
- This design will create a flow field that is more two-dimensional and will result in a non-uniform velocity gradient across the radial direction of the vessel.
- This test facility will demonstrate whether this configuration leads to a non-uniform debris build-up at the core inlet, in which case it is likely that some flow paths remain open to allow flow into the core under higher debris loads than previously tested.



# PREVIOUS IN-VESSEL TESTING Non-Prototypic Aspects (Cont.)

- Buoyancy Driven Convection due to Density Gradients

## Previous Facility (WCAP 16793)

- Did not use borated water.

## Proposed Facility

- Will use borated water.
- As boron-concentration in the core region increases due to boil-off, a density gradient between solution in the core and lower plenum regions develops.
- This generates exchange flow between the regions that may restrict the formation of debris beds or break-up debris beds that have formed prior to the onset of this convection mechanism.



# PREVIOUS IN-VESSEL TESTING Non-Prototypic Aspects (Cont.)

- Effect of Boiling on Debris Bed Formation

Previous Facility (WCAP 16793)

- Used unheated fuel assemblies.

Proposed Facility

- Uses heater rods to simulate decay heat and produce boiling in the core.
- The chaotic action of boiling creates a dynamic system instability caused by the interaction between phases in the two-phase mixture.
- The incorporation of heater rods will allow for the effect of boiling instabilities on debris bed formation to be evaluated.



# PREVIOUS IN-VESSEL TESTING Non-Prototypic Aspects (Cont.)

- Elevated Coolant Temperature

Previous Facility (WCAP 16793)

- Only considered coolant with a high amount of subcooling.

Proposed Facility

- Will be capable of injecting coolant with temperatures up to saturation.

- Fuel Assembly Gap Width

Previous Facility (WCAP 16793)

- The gap around the fuel assembly was half the prototypic value.

Proposed Facility

- Uses a prototypic gap width between assemblies



# PA-SEE-1072

## Work Scope

- Work Scope
  - Design of GSI-191 BAP Test Program, Requirements, and Facility
  - Design Review
  - Support Third-Party Review (I3PR PA)
  - Construct Test Facility
  - Develop Test Procedures and Perform Testing
  - Prepare and Issue Topical Report



# PA-SEE-1072 Schedule

- PA Start Date: 11/01/2012
  - Complete test apparatus / facility design 03/29/2013
  - Complete facility construction 10/28/2013
  - Complete testing 02/21/2014
  - Final WCAP 06/30/2014



# PA in Process

Develop Guidance Document for Generic Use of  
STPNOC Risk-Informed Methodology for Closure of  
GSI-191



# RISK-INFORMED (RI) GUIDANCE PA Cafeteria Program, In Process

- RI Guidance program is a cafeteria program to follow and document the STPNOC RI methodology for use by other plants
- This PA would allow utilities interested in implementing the STPNOC RI methodology to “buy in” to the STPNOC testing and analysis
- The PWROG, through its vendors, would follow the STPNOC program to keep participants informed of progress, direction, and emergent issues



# Backup Slides

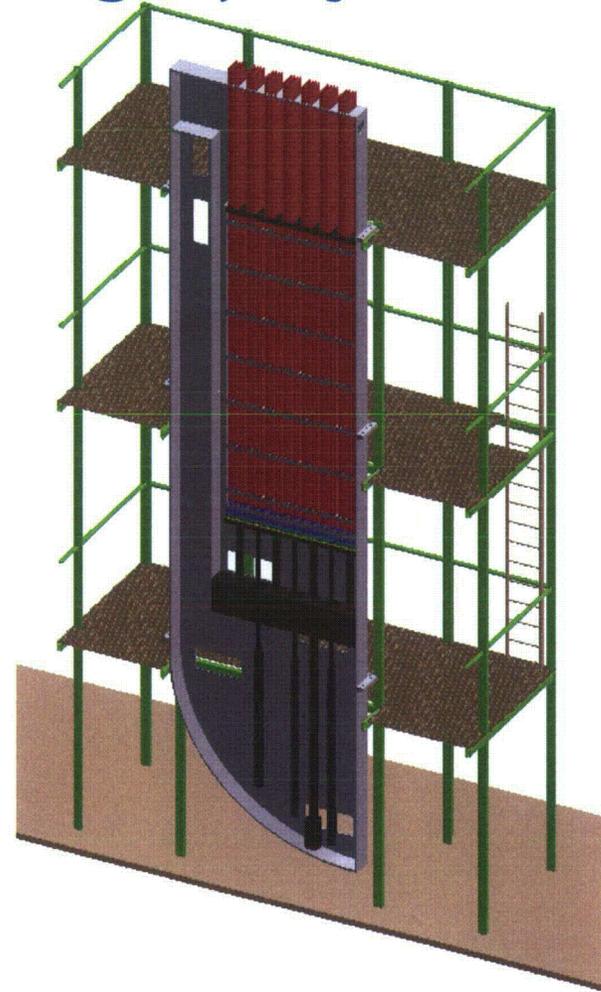


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# Preliminary Work Conceptual Design (Key Features)

- Full-Height, Slab Facility (2-D)
- Flanged Vessel Housing
- View-Windows for Visualization
- Curved Lower Head
- Prototypic Vessel Internals
  - Lower Core Plate
  - Bottom Fuel Nozzle
  - P-grid/First Grid
- Scaled Vessel Internals
  - Lower Support Plate
  - Lower Support Columns
  - Upper Core Plate
- B&W Specific Features



# Preliminary Work

## PIRT Considerations

- PIRT for Unbuffered/Buffered Boric Acid Mixing/Transport and Precipitation Modes in a Reactor Vessel During Post-LOCA Conditions (WCAP-17047-NP)
  - Low Levels of Sump Debris or Chemical Effects – No new important phenomena expected relative to precipitation mode or boron transport/mixing.
  - Moderate to High Levels of Sump Debris or Chemical Effects – PIRT phenomena and rankings will need to be re-evaluated.
    - Core blockage is expected to reduce or restrict convective mixing/transport between the core and lower reactor vessel regions.
    - Sump Debris or chemical precipitates may increase the potential for bulk precipitation of borates.
    - Increased debris volume translates into reduced mixing volume which increases the potential for bulk precipitation.
- PIRT developed under PA-SEE-1090 will address moderate to high debris quantities.



# Preliminary Work Scaling Considerations

- Hierarchical Two-Tiered Scaling (H2TS) Analysis
  - NUREG/CR-5809, Appendix D
  - Provides a scaling approach that is systematic, practical, auditable, and traceable.
  - Compliments the PIRT Process
- Preliminary Scaling Work Funded by the ASC
  - System Level “Top-Down” technique used to identify distortions in the small-scale 3x3 bundle nucleate boiling tests (WCAP-17360-NP).
  - Draft letter describing scaling process was reviewed by AREVA.



# Preliminary Work Scaling Considerations (Cont.)

- Important Processes being Considered as Part of the Scaling Analysis
  - Boiling Heat Transfer/CHF
  - Two-Phase Friction and Loss Coefficients
  - Void Fraction and Mixture Level
  - Two-phase Flow Regimes and Transitions
  - Entrainment/Carryover and De-entrainment
  - Heat and Mass Transport
  - Heat Loss
  - Power Distribution

