BWROG ECCS Suction Strainers Risk-Informed Solutions Committee – NRC Public Meeting

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BWR OWNERS' GROUP

BWR Expertise – Proven Solutions

BWROG Management Introduction

William Kopchick II (PSEG)
BWROG Executive Committee

Topics

- Meeting Objectives
- Purpose / Goals / Background
- Updates Since the June 10, 2015 Public Meeting
  - 2-Day Workshop (August 2015)
  - Project Phase II Addendum: DSE-Components
  - Project Phase III Status
  - Anticipated Project Phase IV Schedule
- Summary

Meeting Objectives

- Receive NRC status and preliminary comments on BWROG-15039: ECCS Suction Strainer Risk-Informed Phase II Report
- Discuss progress and approach associated with project Phase III
- Continue to socialize BWROG's plan for responding to 10 of 12 potential issues stemming from the Grobe Letter
- Project scheduling & closure approach

BWROG ECCS Suction Strainers Risk-Informed Solutions Committee Overview

Larry Naron (Exelon)

Chairman BWROG ECCS Suction Strainers Risk-Informed Solutions Committee

Purpose / Goals / Background

Purpose of Risk Informed Approach

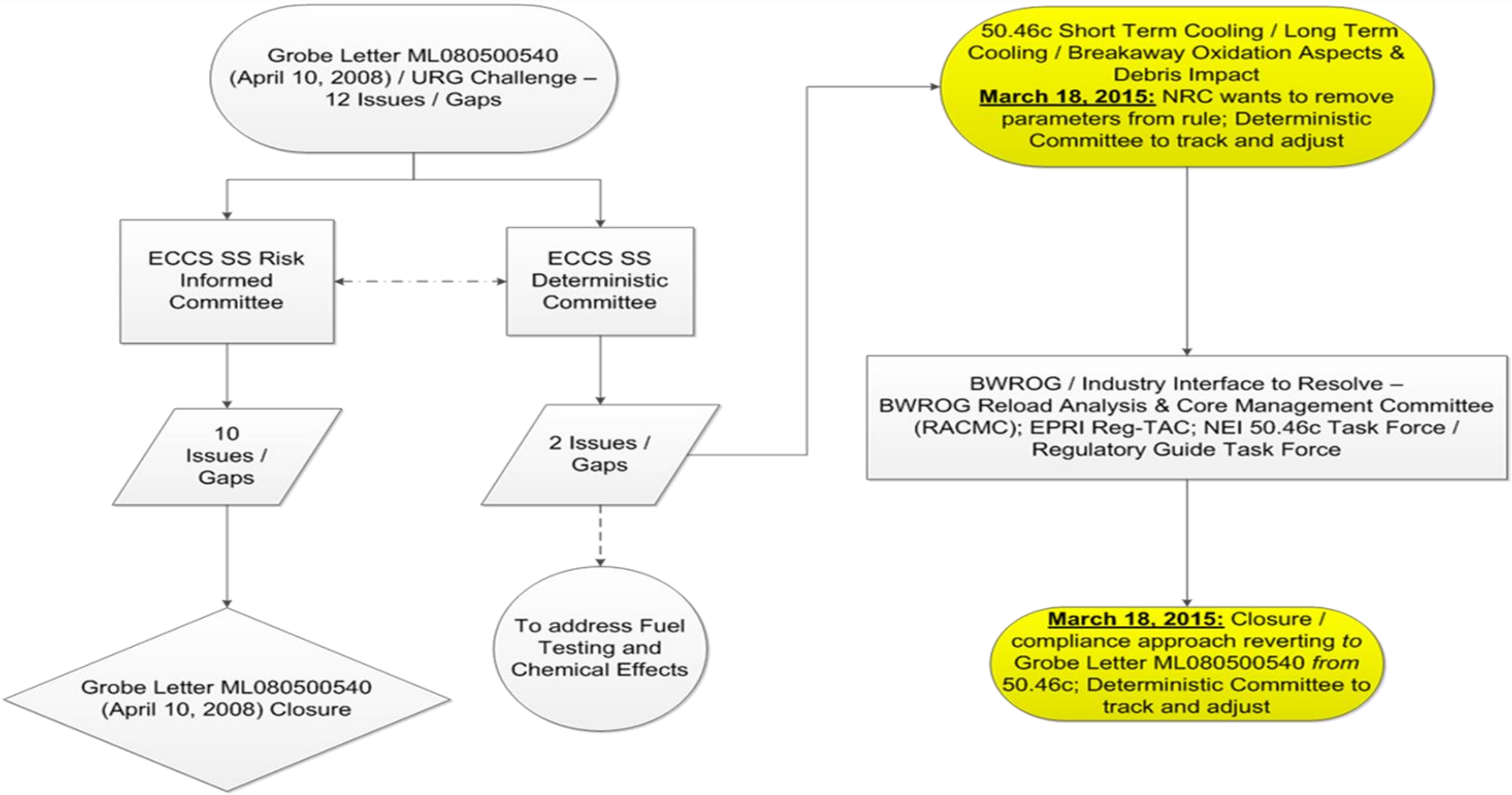
- Establish the risk perspective of an issue within possible range of variability
- Provide a framework for the discussion of issues within a quantitative structure and compare with identified criteria (NRC Acceptance Guidelines)
- Characterize and display variations in results relative to the NRC Acceptance Guidelines

Purpose / Goals / Background (cont.)

Goals

- Develop an analysis consistent with the NRC PRA Policy Statement to reduce unnecessary conservatisms
- Adopt conventional analysis input (e.g., URG, DBA)
- Provide an approach consistent with PWR methods to evaluate potential contributors to BWR ECCS suction strainer blockage
- Provide NRC with a response that characterizes the relative risk of the potential issues
- Enable NRC and Industry to apply their resources toward more safety significant issues

Purpose / Goals / Background (cont.)



Purpose / Goals / Background (cont.)

Project organized into four phases:

Phase I: Proof-of-Principle (completed in 2014). Created analytical model of a pilot plant to enable a risk-informed evaluation of two of the potential issues and provide initial feedback to the BWROG and NRC regarding scope, level of detail, and feasibility of the approach.

Purpose / Goals / Background (cont.)

Background (cont.)

Phase II: Full demonstration of the proposed approach (started in 1Q 2015) for the pilot plant and eight of the twelve NRC potential issues. Phase II exercised the analytical model to evaluate the “scalability” of the methods and model. Phase II report documented in submittal (BWROG-15039).

- Two issues (Downstream fuel impacts, chemical impacts) out of scope for risk-informed analysis
- Two additional issues (Downstream component impacts, coatings assessments) still under investigation; to be addressed during Phase III or IV risk evaluation

Purpose / Goals / Background (cont.)

Phase III Second Plant Selection Considerations

- High quality PRA
- Available CAD model of the Reactor and Containment Systems
- Different containment type than 1st BWR Pilot Plant (Mark II vs. Mark I)
- Different design than 1st BWR Pilot Plant (BWR/5 vs. BWR/4)
- Includes a problematic debris source term component

Purpose / Goals / Background (cont.)

Background (cont.)

- Phase III (began 3Q 2015):
  - Create an analytical model using the same methodology as the Phase II model
  - Exercise the model to evaluate potential issues for the second representative plant
  - Perform sensitivity studies to further represent additional BWRs
  - Determine if a third representative plant should be selected
  - Provide the Phase III submittal by 2Q 2016

Purpose / Goals / Background (cont.)

Background (cont.)

- Phase IV (to begin 2Q 2016):
  - Select and evaluate third representative plant (if required by outcome of Phase III)
  - Perform sensitivity studies to further represent additional BWRs
  - Provide a basis and conclusion of the risk significance of the potential issues relative to the US BWR fleet
  - Document the findings in a BWROG Technical Product

BWROG ECCS Suction Strainers Risk-Informed Solutions Project Update

Larry Lee (ERIN Engineering)
Benjamin Bridges (Alion Science)
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Kent Sutton (iNgrid Consulting)
Rob Choromokos (SIA)

Project Phase III Overview

Tasks for the Phase III Risk-Informed Evaluation

- Estimate strainer failure probabilities using CASA-Grande
- Calculate LOCA Initiating Event Frequencies
- Evaluate LOCA Accident Sequence Logic
- Perform Thermal-Hydraulic Calculations
- Perform Human Reliability Analysis
- Quantify Results
- Document Phase III Evaluations

Project Phase III Overview (cont.)

	Phase II Pilot Plant	Phase III Pilot Plant
Reactor / Containment Type	BWR/4 Mark I (See Figure 1)	BWR/5 Mark II (See Figure 2)
ECCS Summary	• 1 turbine-driven High Pressure Coolant Injection (HPCI) pump (assume minimal credit for pilot project because HPCI suction strainer not upgraded) • 4 Residual Heat Removal (RHR) pumps. 2 RHR pumps per division. • 2 Low Pressure Core Spray pumps • 4 RHR and 2 CS pumps supported by 4 ECCS suction strainers. 1 suction strainer for each division of RHR and CS (typical configuration for many BWR/4 Mark I plants).	• 1 motor-driven High Pressure Core Spray (HPCS) pump. Capable of high volume RPV makeup when the RPV is at high or low pressure. • 3 RHR pumps • 1 Low Pressure Core Spray pump • Each of 5 ECCS pumps supported by a single, separate suction strainer (typical configuration for BWR/5 Mark II plants)

Project Phase III Overview (cont.)

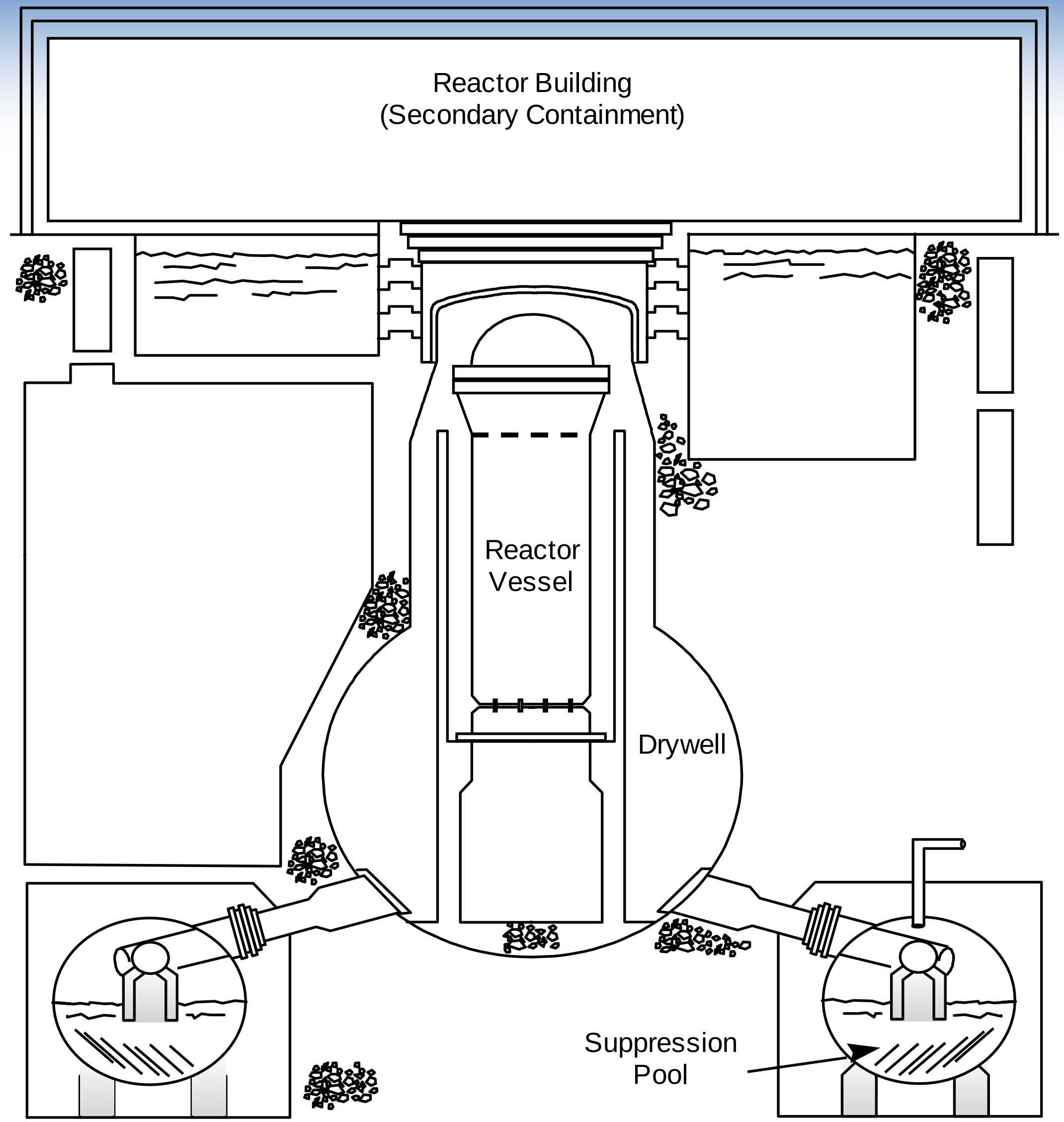


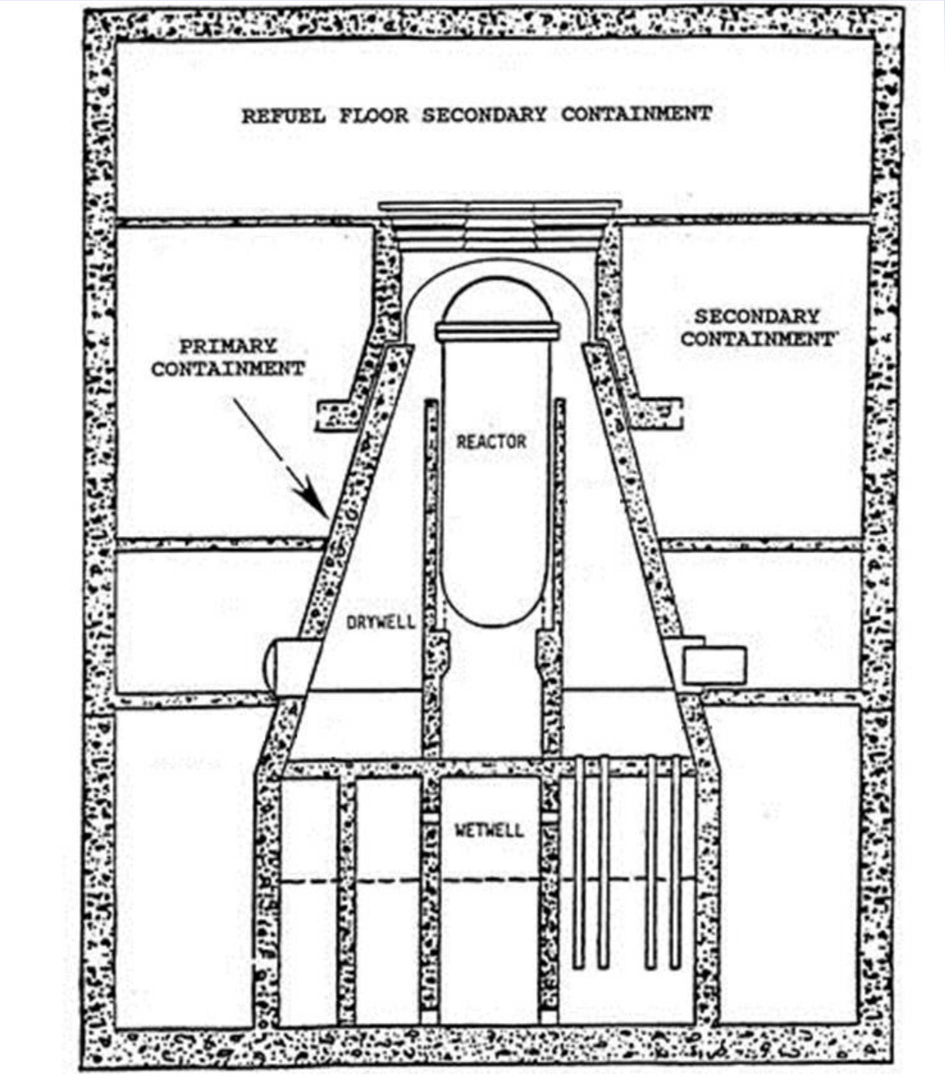
Figure 1

Typical Mark I Containment Simplified Diagram

Project Phase III Overview (cont.)

Figure 2

Typical Mark II Containment Simplified Diagram



Project Phase III Overview (cont.)

- CASA Grande model results used as input to PRA model for ECCS suction strainer common cause failure probabilities and failure timings
  - Used similar assumptions as Phase II project
  - Maintain consistency with the URG and design basis calculations
  - Sensitivities to address Grobe Letter potential issues

Project Phase III Overview (cont.)

- MAAP thermal-hydraulic calculations performed to verify success criteria and identify accident sequence timings (i.e., to support human reliability analysis)
- PRA accident sequence and systems logic based on Phase III Pilot plant specific PRA model. Minor changes required to address enhancements consistent with Phase II Pilot PRA model (i.e., add event tree nodes for ECCS suctions strainer failure)

Project Phase III Overview (cont.)

- Develop sensitivity cases to evaluate quantitative impact of individual ECCS SS potential issues or PRA modeling issues (i.e., credit for operator actions). Perform sensitivity cases to account for multiple issues to evaluate potential synergistic impacts
- Document Phase III evaluation in similar manner as Phase II report

Phase III Baseline

- The goal of the baseline model is to quantify risk of the pilot plant using CASA Grande and the PRA model to analyze the risk associated with pilot plant specific design inputs and industry standard assumptions
- Modifications to these baseline model assumptions are used to quantify changes to risk associated with the potential issues outlined in Grobe Letter
- These modifications will be implemented in a series of sensitivity cases

Sensitivity Overview

- All NRC Grobe Letter potential issues except 1) chemical effects, 2) in-core debris accumulation, 3) downstream effects on components, and 4) coatings assessment will be investigated using parameter variations
- Appropriate parameter variations will be performed for each of the potential issues
  - The most influential plant parameters affecting each issue will be identified
  - The individual risk contribution of each potential issue will be quantified
  - The aggregate risk contribution of selected potential issues will be quantified

NRC ECCS Suction Strainer Issues

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ECCS Suction Strainer Potential Issues of Concern	Explicitly Evaluated in CASA Grande Sensitivity Cases?	ECCS Suction Strainer Potential Issues of Concern	Explicitly Evaluated in CASA Grande Sensitivity Cases?
1. Downstream Effects (Components & Systems)	No	7. Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT)	Yes
2. Downstream Effects (Fuel / In-vessel)	Out of Scope	8. Coatings Zone of Influence (ZOI)	Yes
3. Debris Head Loss Correlations	Yes	9. Debris Transport and Erosion	Yes
4. Chemical Effects	Out of Scope	10. Debris Characteristics	Yes
5. Coatings Assessments	No	11. Near Field Effect / Scaling	No
6. Latent Debris	Yes	12. Spherical Zone of Influence (ZOI)	Yes

ECCS Suction Strainer Potential Issues Sensitivity Analysis

Issues 1, 5, and 11 will not be explicitly addressed through sensitivity cases

- Issue No. 1 : DSE-C is intended to be resolved through appropriate application of WCAP-16406-P
- Issue No. 5: Coatings Assessment is a BWROG programmatic survey response and does not require a RI resolution at this time
- Issue No. 11: Near Field Effects and Scaling is incorporated into the Issue No. 3: Head Loss Correlation sensitivities (similar to Issue No. 10)

Other ECCS suction strainer issues will be addressed through candidate sensitivity cases

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

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Issue 3: Debris Head Loss Correlations

NRC staff has commented that head loss correlations for BWR strainer sizing may not have adequately bounded debris beds with microporous insulation or the thin bed condition

Sensitivity Cases:

- NUREG/CR-6224 head loss correlation will be run as a deviation from the baseline. This correlation treats the effects of microporous insulation and thin bed condition differently than the analysis technique used in the baseline

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 3: Debris Head Loss Correlations (cont.)

Sensitivity Cases (cont.):

- All debris beds that exceed a minimum fiber debris threshold are treated as strainer failures
- This treatment eliminates the uncertainty related to the selected head loss correlation and the modeled debris characteristics (Issue 10)

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 6: Latent Debris

The issue is that accounting for latent debris as only particulate may be non-conservative for low fiber plants

Sensitivity Cases:

- These sensitivity cases will modify the latent debris source term to account for 5%, 10%, and 15% latent fiber by weight, respectively

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 7: ZOI Adjustment for Air Jet Testing

Current closure letter has addressed this issue in combination with Issue 12 for problematic debris sources

Sensitivity Case:

- This sensitivity case will increase the ZOI radius size by 10%, resulting in a 33.1% increase in volume (ignoring shadowing effects) to create additional debris outside the baseline ZOI

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 8: Coatings ZOI

The concern is that the generic baseline value of qualified coatings may be non-conservative when considering plant specific, location dependent ZOI analyses

Sensitivity Case:

- This sensitivity case will use the CASA-CAD geometry and ZOIs to account for qualified coatings debris generation at each break location in containment
- Additionally, the generic value may represent conservatism relative to the forecasted DBA progression

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 9: Debris Transport & Erosion

The staff has suggested the development of transport fractions, including erosion and suppression pool settling, may be potentially non-conservative

Sensitivity Case:

- This sensitivity case will consider additional erosion of Tempmat debris over the first 3 hours of the scenario by modifying the Tempmat transport fractions. Specifically this sensitivity will increase the percentage of erosion from 6.25% in the baseline to 25% over 3 hours
- The baseline model already assumes 100% transport of all Min-K within the break ZOI, so this insulation type is unaffected by this sensitivity case

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Issue 10: Debris Characteristics

Blockage potential of calcium silicate insulation and other problematic materials such as microporous insulation may not have been treated conservatively

Sensitivity Case:

- Since this issue pertains primarily to the head loss (blockage) potential, it is included in Issue 3 Head Loss Correlation sensitivities

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Additional Sensitivity Cases

Sensitivity Case: Transport Time

- This sensitivity case will transport all debris to the suppression pool in the first CASA Grande time step (1 minute) instead of the baseline assumption of constant transport over 10 minutes

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Additional Sensitivity Cases

Sensitivity Case: Cumulative Effects

- This case will examine the cumulative effects of combining the assumptions of the Phase III Pilot’s dominant sensitivity cases

ECCS Suction Strainer Potential Issues Sensitivity Analysis (cont.)

Additional Sensitivity Cases

Sensitivity Case: One Pump Out-of-Service

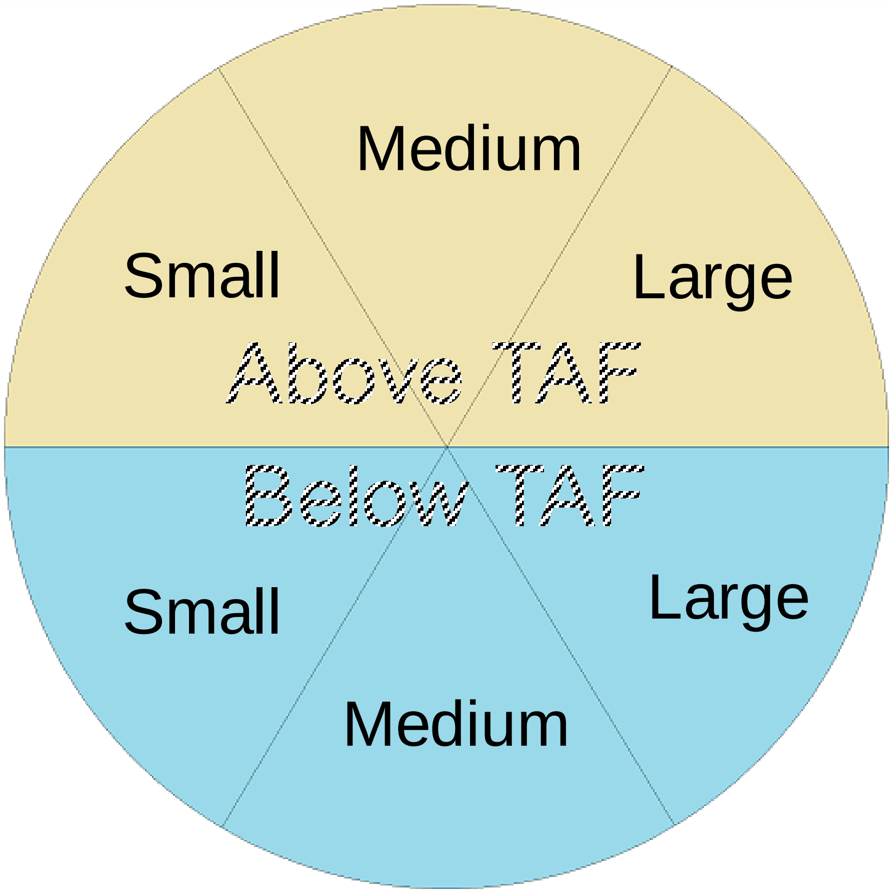
- This case will investigate the effects of modeling a single pump as out-of-service on the ECCS strainer failure probabilities
- This case is integrated into the plant PRA model with the baseline case to estimate core damage frequency

PRA Inputs – CASA Grande Results

- Conditional failure probabilities and failure times from CASA Grande will be used as input to the PRA model
- Conditional failure probabilities will be processed through the PRA to determine ΔCDF

PRA Inputs – CASA Grande Results (cont.)

- CASA Grande provides necessary inputs into PRA for the spectrum of LOCA scenarios
- Six CASA Grande simulations will be run for the baseline and each sensitivity



Calculate LOCA Initiating Event Frequencies

LOCA Initiating Event	Size Diam. (in.)	Location	IE Frequency (based on NUREG-1829)
Small LOCA in RCIC Line (above TAF)	<2"	RCIC	1.5E-06
Other Small LOCA (above TAF)(1)	<2"	Steamline	9.4E-05
Small LOCA below TAF	<2"	Recirc	4.2E-04
Total Small LOCA Frequency			**5.2E-04**
Medium LOCA in RCIC Line (above TAF)	2"-6"	RCIC	6.0E-07
Medium LOCA in CS Line (above TAF)	2"-6"	CS	3.5E-06
Medium LOCA in HPCS Line (above TAF)	2"-6"	HPCS	3.5E-06
Medium LOCA in LPCI Line (above TAF)(1)	2"-6"	LPCI	9.1E-06
Other Medium LOCA (above TAF)	2"-6"	Steamline	1.1E-05
Medium LOCA below TAF	2"-6"	Recirc	9.5E-05
Total Medium LOCA Frequency			**1.2E-04**

Calculate LOCA Initiating Event Frequencies

LOCA Initiating Event	Size Diam. (in.)	Location	IE Frequency (based on NUREG-1829)
Large LOCA in CS Line (Above TAF)	>6”	CS	2.0E-07
Large LOCA in HPCS Line (Above TAF)	>6”	HPCS	2.0E-07
Large LOCA in LPCI Line (Above TAF)(1)	>6”	LPCI	8.6E-07
Other Large LOCA above TAF	>6”	Main Steam	1.6E-06
Large LOCA below TAF	>6”	Recirc	4.5E-06
Total Large LOCA Frequency			**7.3E-06**

(1) For the Phase II study, LOCAs in the LPCI line were categorized as LOCAs below TAF because LPCI injects into the recirculation discharge line for a BWR/4. For the Phase III study, LOCAs in the LPCI line are categorized as LOCAs above TAF because LPCI injects into the RPV shroud for a BWR/5.

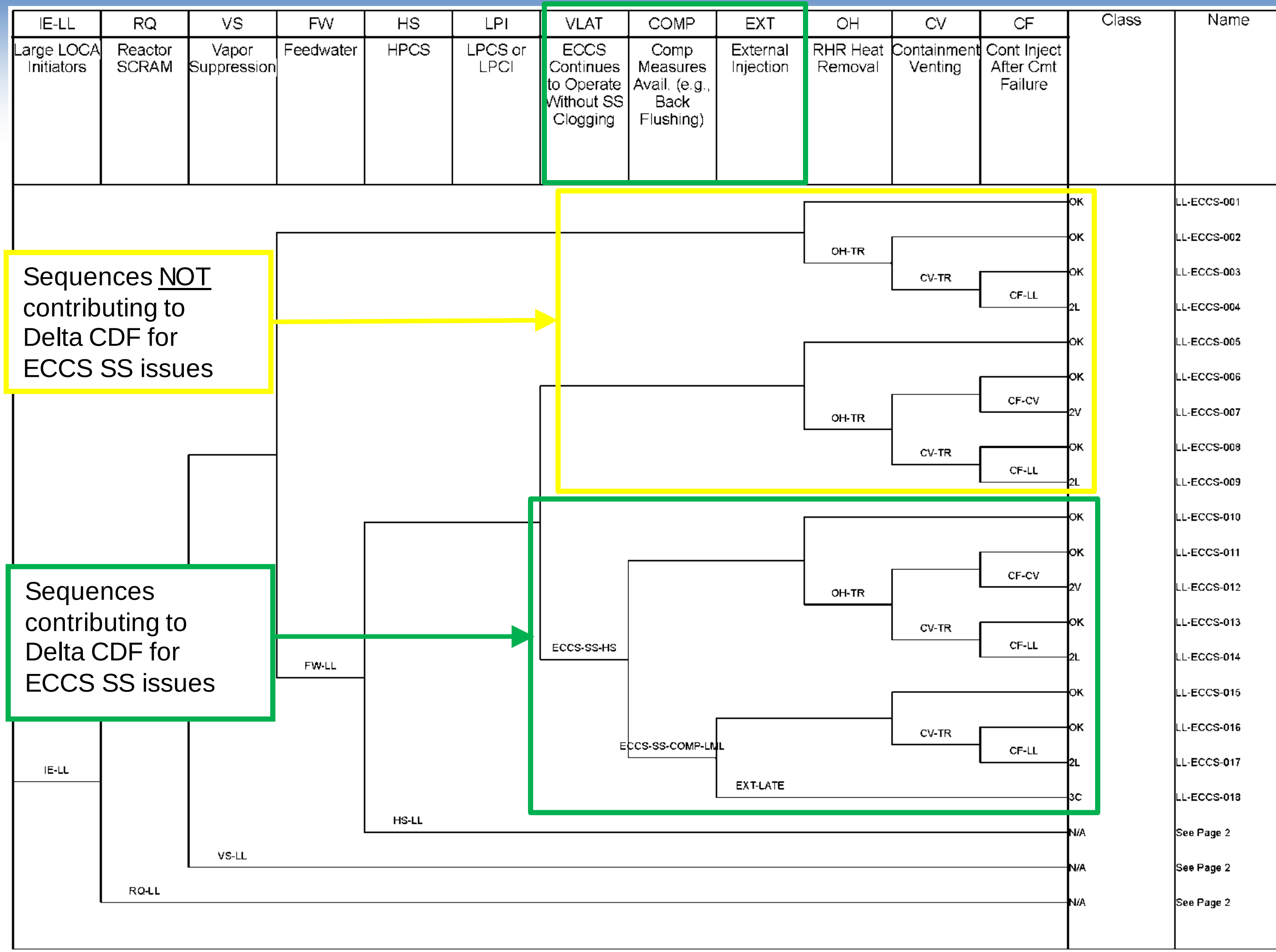
Event Tree Logic Model

The following three (3) event trees are used to support the ECCS suction strainer risk evaluation

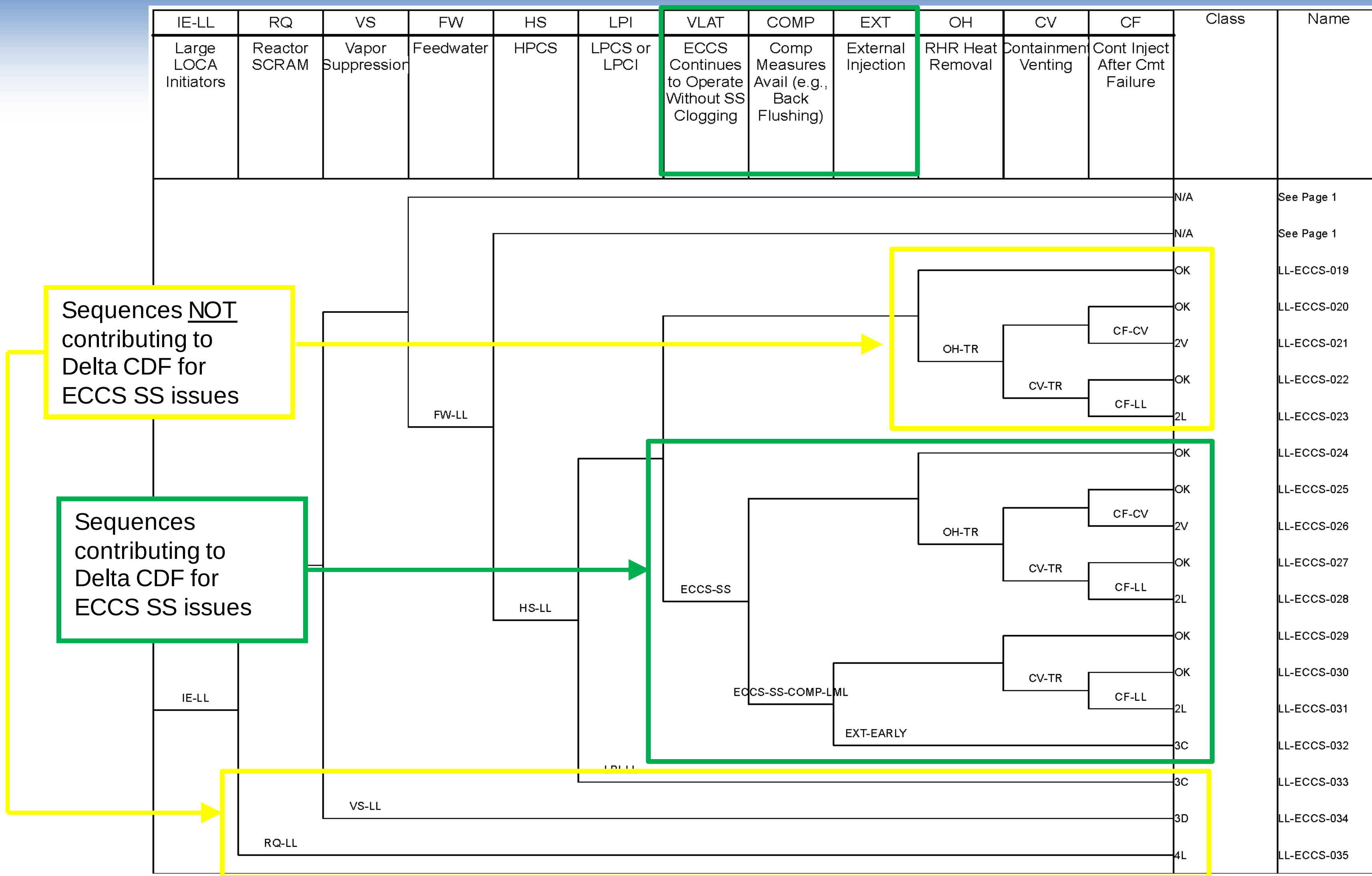
- Large LOCA (above and below TAF)
- Medium LOCA (above and below TAF)
- Small LOCA (above and below TAF)

<u>Note:</u> The PRA model used for the Phase II risk study evaluated above and below TAF LOCAs in separate events trees (i.e., 6 total event trees); PRA modeling preference does not impact the quantitative evaluation

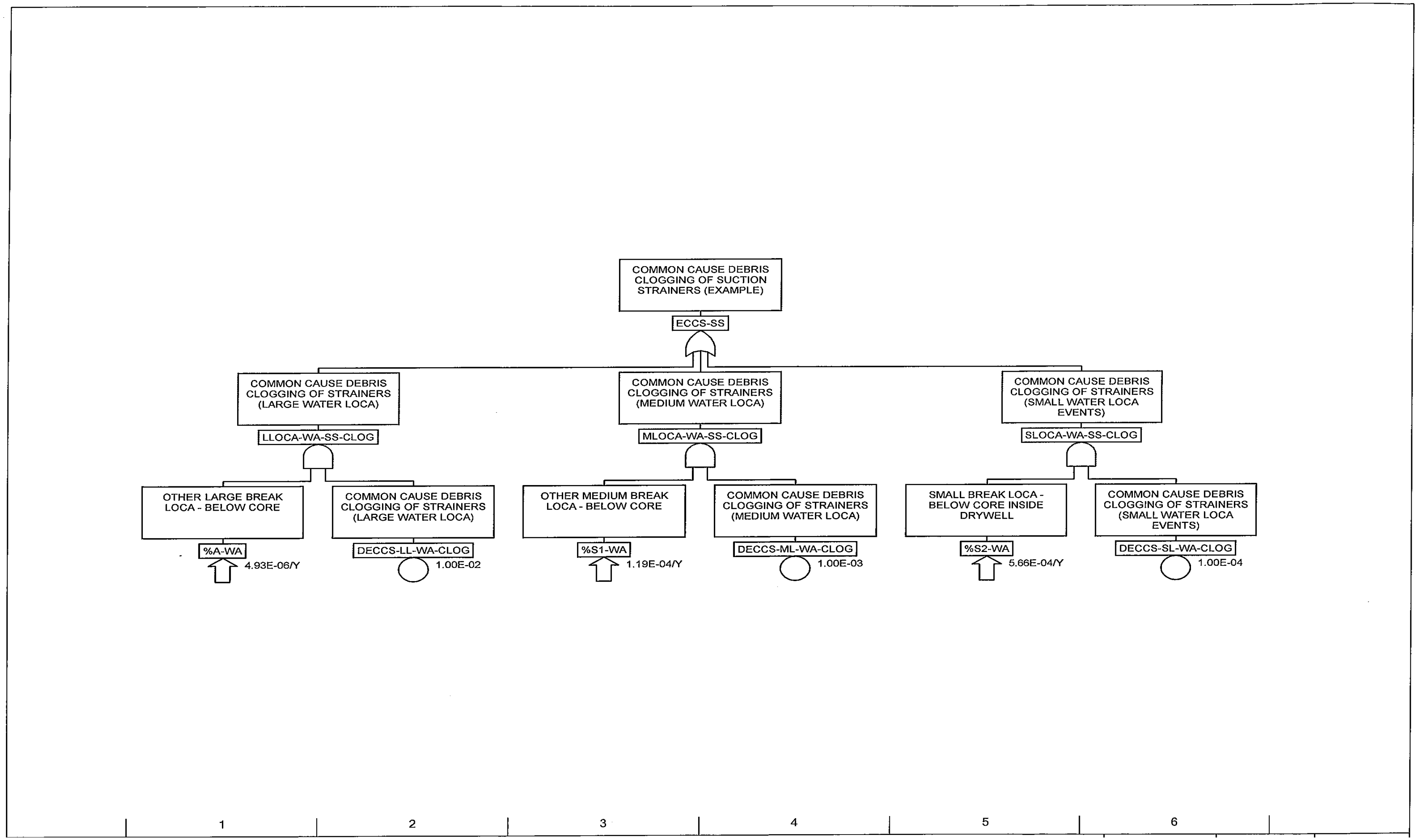
Large LOCA Event Tree (Page 1)



Large LOCA Event Tree (Page 2)



Example Fault Tree Logic to Model Debris Clogging of ECCS Suction



System Fault Tree Logic

- VLAT Node (ECCS Continues to Successfully Operate Without Suction Strainer Clogging) – Added to model ECCS suction strainer failure for the range of LOCA scenarios (size and location)
- COMP Node (Compensatory Measures Successful) – This node considers operator actions to mitigate suction strainer clogging. Potential for limited credit for this node because back flush not proceduralized at Phase III pilot plant

Perform Thermal-Hydraulics Analyses

- MAAP thermal-hydraulic runs will be performed for a variety of LOCA sizes, locations, and scenarios:
  - Verify event tree success criteria and accident timings to support human reliability analysis
- Example Large Water LOCA cases identified the following:
  - With no injection, core damage occurs in approximately 6 minutes
  - With 4 minutes of injection from 1 LPCI pump and long term makeup from CRD at 100 gpm, core damage significantly delayed until approximately 33 minutes
  - Credit for limited high volume makeup may sufficiently delay core damage to support credit for operator mitigation actions
  - Compared to Phase II thermal hydraulic results, higher power core for Phase III plant results in much less delay for core damage

Perform Thermal-Hydraulics Analyses (cont.)

MAAP Scenario	Time to Core Damage Phase II Pilot Plant (BWR/4)	Time to Core Damage Phase III Pilot Plant (BWR/5)
Large water LOCA in recirculation suction line - No RPV injection	6 min.	6 min.
Large water LOCA in recirculation suction line - CRD at 100 gpm and 1 LPCI pump for 4 minutes	63 min.	33 min.(1)
Large water LOCA in recirculation suction line - HPCS pump with suction from CST. CST inventory sufficient for approximately 80 minutes of HPCS makeup to RPV. CRD at 100 gpm	N/A	2.1 hrs.
Large steam LOCA in main steam line - No RPV injection	34 min.	18 min.
Large steam LOCA in main steam line - CRD at 100 gpm and 1 LPCI pump for 4 minutes	No Core Damage	1.6 hrs.(1)
Large steam LOCA in main steam line - HPCS pump with suction from CST. CST inventory sufficient for greater than 36 hours of HPCS makeup to RPV	N/A	No Core Damage

(1) The identified time to core damage would only apply for scenarios where HPCS is probabilistically unavailable (i.e., pump fails to start, system unavailable due to maintenance)

Perform Human Reliability Analyses

Perform human reliability analysis (HRA):

- Review available procedures
- Interview operations personnel (i.e., discuss available cues to support diagnosis, training and operating experience for ECCS suction strainer clogging events, time to implement specific actions)
- Calculate Human Error Probabilities (HEPs)

Operator actions to be investigated:

- Align alternate external RPV makeup (i.e., credit as a sensitivity case to mitigate ECCS suction strainer failure)
- Potential alternate mitigation actions (i.e., manage flow though individual suction strainers)
  - No procedure for ECCS suction strainer back wash at Phase III pilot plant

Quantify Results

- CASA Grande will be used to provide the basis for the ECCS suction strainer clogging failure probabilities and failure timings
- Regulatory Guide 1.174 specifies that a risk-informed approach provides valuable insights and guidance for use in interactions between the NRC and licensees
- The ECCS suction strainer assessment aligns with RG 1.174 guidance

Quantify Results (cont.)

- High volume RPV makeup from motor-driven HPCS is a risk benefit for all LOCA scenarios in delaying or avoiding core damage due to initial pump suction from CST and not suppression pool

CASA Results Input to Phase III PRA

Quantification Description	Failure Probs - LOCAs Above TAF			Failure Probs - LOCAs Below TAF		
	Small	Medium	Large	Small	Medium	Large
Baseline	--	--	--	--	--	--
NUREG/CR-6224 Head Loss	--	--	--	--	--	--
Threshold Bed Failure	--	--	--	--	--	--
10% ZOI Increase	--	--	--	--	--	--
5% of Latent Inventory Fiber	--	--	--	--	--	--
10% of Latent Inventory Fiber	--	--	--	--	--	--
15% of Latent Inventory Fiber	--	--	--	--	--	--
Break Dependent Qualified Coatings	--	--	--	--	--	--
Debris Erosion	--	--	--	--	--	--
Transport Time	--	--	--	--	--	--
Cumulative Effects	--	--	--	--	--	--
One Pump Out-of-Service	--	--	--	--	--	--

Phase III PRA Outputs

Quantification Description	ΔCDF (Per Rx Yr)
Baseline	--
NUREG/CR-6224 Head Loss	--
Threshold Bed Failure	--
10% ZOI Increase	--
5% of Latent Inventory Fiber	--
10% of Latent Inventory Fiber	--
15% of Latent Inventory Fiber	--
Break Dependent Qualified Coatings	--
Debris Erosion	--
Transport Time	--
Cumulative Effects	--
One Pump Out-of-Service	--

BWROG Management Summary

William Kopchick II (PSEG)
BWROG Executive Committee

Summary

- Communicated selection considerations for second representative plant evaluation
- Discussed progress and approach for second representative plant to date
- Continued to socialize BWROG's plan for responding to 10 of 12 potential issues stemming from the Grobe Letter