Draft ECCS Suction Strainer Risk-Informed Analysis Information Excerpts

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1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Nuclear Regulatory Commission's policy statement on probabilistic risk assessment (PRA) [1] encourages greater use of this analysis technique to improve safety decision-making and improve regulatory efficiency.

An area that has required a large resource commitment from BWR utilities and the NRC is the evaluation of adverse conditions that could affect the performance of the ECCS suction strainers in BWR suppression pools. This topic and the associated testing and analysis has been treated since the early 1990s by active BWR and NRC programs.

The NRC EDO has indicated that one method that could be used to close any residual open questions would be the use of a risk-informed perspective.

1.2 PURPOSE

The purpose of this analysis is to bring a risk-informed perspective to the evaluation of ECCS suction strainer performance. The BWROG is using a risk-informed approach as outlined in Regulatory Guide 1.174 [4] to provide additional perspective on the decision-making associated with ECCS suction strainer questions.

The hallmark of the proposed approach is to provide a risk-informed solution that builds on the success of the South Texas Project (STP) approach of combining deterministic modeling of suction strainer performance with the probabilistic risk assessment.

The objective of the approach and its implementation is to result in a successful risk-informed resolution to the residual ECCS suction strainer questions raised by the NRC [5]. A risk-informed analysis is proposed to assess the risk significance of the ECCS suction strainer issues to determine their priority regarding resources to be expended.

1.3 HISTORY

BWR operating experience events have indicated that there is some potential for degraded ECCS suction strainer performance due to blockage of these strainers by debris in the suppression pool.

NRC Bulletin 96-03 identified three potential options to resolve issues with ECCS suction strainer blockage. These options included the following:

1. Installation of a large capacity passive strainer(1)
2. Installation of a self-cleaning strainer
3. Installation of a back flush system

The BWROG has previously evaluated the potential for strainer clogging in order to select one of these options. The results of the evaluation included the installation of large surface area strainers in the suppression pool on the suction of the ECCS pumps. These analyses, testing, and implementation were performed with the knowledge of the NRC. NRC in a letter from J.R. Grobe (NRR) to Richard Anderson (BWROG) on April 10, 2008 [5] indicated the following:

> *The NRC and the nuclear industry conducted research, guidance development, testing, reviews, and hardware and procedure changes from 1992 to 2001 to resolve the issue of debris blockage of BWR strainers. The NRC staff issued NRC Bulletin (NRCB) 95-02, "Unexpected Clogging of a Residual Heat Removal (RHR) Pump Strainer While Operating in Suppression Pool Cooling Mode" and NRCB 96-03, "Potential Plugging of Emergency Core Cooling Suction Strainers by Debris in Boiling-Water Reactors." Both bulletins dealt with ensuring that debris generated during a loss-of-coolant accident (LOCA) would not clog ECCS suction strainers. Such clogging could potentially prevent the ECCS from performing its safety function. Licensee measures to clean the suppression pools and establish foreign material control programs were implemented, each BWR licensee assessed its plant-specific situation and developed a plant-specific approach to resolve the issue, and larger passive strainers were installed in each plant.*
>
> *The BWR Owners Group (BWROG) supported the utilities in addressing NRCBs 95-02 and 96-03 by developing resolution guidance, referred to as the Utility Resolution Guide (URG). The BWROG evaluated potential solutions and conducted tests to obtain needed data to develop the URG. The NRC staff followed the development of the URG and associated testing and reviewed the guidance. The NRC approved the URG with conditions and exceptions in a safety evaluation.*

(1) Strainers installed for Option 1 must be supported by test data that demonstrate their performance characteristics and their ability to handle the worst case scenario for debris deposition on the strainer surface (NRC Bulletin 96-03).

The NRC concluded that all BWR licensees had sufficiently responded to the requested actions of NRCB 95-02 and NRCB 96-03 and considered that generic and plant-specific activities associated with these bulletins were complete.

Therefore, these activities that included significant upgrades to the size of suction strainers involved close communication between the BWROG and the NRC to resolve potential issues.

Prevention and mitigation measures that have been identified and implemented to enhance strainer performance and provide defense-in-depth consist of the following:

- Implementation of strainers with large surface areas sufficient to allow adequate pump flow despite fibrous debris in the suppression pool.
- Use of alternate injection sources from outside containment. This option may be available based on existing plant capabilities. This option will be available as part of FLEX hardware and procedural modifications. The FLEX modifications will support small water LOCA or larger size steam LOCA events (LOCAs above Top of Active Fuel (TAF)) and will also allow a method to flood containment and submerge the core during a LOCA.
- Pool cleaning/desludging to remove corrosion products such as iron oxide sludge that "normally" is present in the pool.
- Back flow (flushing) through strainers (this was a measure put in place by BWRs during the period between the identification of the issue and the resolution through the use of larger strainers.) This compensatory measure was available and used in the 1992 Barsebeck ECCS suction strainer clogging event prior to any other operational experience with this phenomenon.

Following the implementation of the large ECCS suction strainers by BWRs, four plants with the following BWR design / containment configurations were chosen for detailed audits by the NRC staff: a BWR/4 Mark II plant, a BWR/3 Mark I plant, a BWR/4 Mark I plant, and a BWR/6, Mark III plant.

NRC conducted these audits of selected BWRs and published results in LA-UR-01-1595 in March 2001. The results of those audits indicated the following:

- The industry addressed the requirements of NRC Bulletin 96-03 by installing large capacity passive strainers in each plant (NRCB 96-03 Option 1) with sufficient capacity to ensure that debris loadings equivalent to a scenario calculated in accordance with Section C.2.2 of RG 1.82, Revision 2 do not cause a loss of NPSH for the ECCS.
- The audits produced positive response in that all known issues were resolved.

Subsequently, the NRC raised additional questions regarding BWR ECCS suction strainers in light of the PWR evaluation of GSI-191. These questions requested additional detail and testing implying that BWRs had not adequately evaluated similar issues. The questions were transmitted to the BWROG in the form of NRC letter ML080500540 [5].

Subsequently, the NRC EDO in an SRM(1) stated the following:

- The staff should take the time needed to consider all options to a risk-informed, safety conscious resolution to GSI-191.
- While they [the industry] have not fully resolved this issue, the measures taken thus far in response to the sump-clogging issue have contributed greatly to the safety of U.S. nuclear power plants.
- Given the vastly enlarged advanced strainers installed, compensatory measures already taken, and the low probability of challenging pipe breaks, adequate defense-in-depth is currently being maintained.
- The staff should fully explore the policy and technical implications of all available alternatives for risk informing the path forward.

1.4 RISK-INFORMED PERSPECTIVE

1.4.1 NRC PRA Policy Statement

In August 1995, the NRC adopted the following policy statement [1] regarding the expanded use of PRA:

- PRA and associated analyses (e.g., sensitivity studies, uncertainty analyses, and importance measures) should be used in regulatory matters, where practical within the bounds of the state-of-the-art, to reduce unnecessary conservatism associated with current regulatory requirements, regulatory guides, license commitments, and staff practices.
- PRA evaluations in support of regulatory decisions should be as realistic as practicable and appropriate supporting data should be publicly available for review.
- In its approval of the policy statement, the Commission articulated its expectation that implementation of the policy statement will improve the regulatory process in three areas: (1) foremost, through safety decision-making enhanced by the use of PRA insights, (2) through more efficient use of agency resources, and (3) through a reduction in unnecessary burdens on licensees.

(1) NRC Staff Requirements - SECY-10-0113 - Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance, December 23, 2010.

1.4.2 Basis for Analysis Using Risk-Informed Approach

The NRC staff has indicated that it intends to improve consistency in regulatory decisions in areas in which the results of risk analyses are used to help justify regulatory action.

The U.S. Nuclear Regulatory Commission's Policy Statement on probabilistic risk assessment (PRA) [1] encourages greater use of this analysis technique to improve safety decision-making and improve regulatory efficiency. Regulatory Guide 1.174 [4] provides the general guidance for use by licensees in the implementation of risk-informed analyses for regulatory interactions. Even though the risk-informed assessment of ECCS suction strainer questions is not a License Amendment Request (LAR), Regulatory Guide 1.174 specifies that a risk-informed approach provides valuable insights and guidance for use in interactions between the NRC and licensees. As such, the ECCS suction strainer assessment makes use of the RG 1.174 guidance and quantitative acceptance guidelines.

1.4.3 Risk-Informed Objective

In order to ensure that the limited nuclear industry resources are being wisely allocated to the most safety significant issues, it is proposed to examine the safety significance of questions that have been raised regarding the blockage of ECCS suction strainers following an accident, i.e., primarily LOCAs. The proposed approach is to perform probabilistic risk assessment (PRA) quantifications and sensitivities that identify the dominant risk contributors and their risk magnitudes associated with the possibility of increased ECCS suction strainer blockage.

One of the main purposes of this effort is to assess the risk significance of the ECCS suction strainer questions to determine their priority and the appropriate level of resources to be expended commensurate with their risk significance.

1.5 SCOPE

1.5.1 Full Program Scope

The overall scope of the BWROG program (2014-2015) is to close out ten (10) of the twelve (12) questions identified in an NRC letter (ML080500540) [5] to the satisfaction of the utilities and the NRC. This overall technical product will address the following using a combination of deterministic inputs and probabilistic evaluations within a risk-informed framework:

- Downstream Effects (Components & Systems)

- Debris Head-Loss Correlations
- Coatings Assessments
- Latent Debris
- Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT)
- Coatings Zone of Influence (ZOI)
- Debris Transport and Erosion
- Debris Characteristics
- Near Field Effect / Scaling
- Spherical Zone of Influence (ZOI)

Two (2) questions would remain for disposition by deterministic testing:

- Downstream fuel effects
- Chemical effects

Sufficient plants and configurations will be evaluated in the overall program to provide assurance that these questions can be adequately dispositioned using the combination of risk-informed insights and available deterministic information.

1.5.2 2014 Work Scope

The scope of the work for 2014 is a proof-of-principle, single-plant evaluation. This means that a typical BWR is selected for which adequate information is available and two of the twelve NRC questions from Reference [5] are selected for examination using the risk-informed approach.

Section 2 summarizes the questions that have been raised by the NRC [5].

Section 3 provides the problem statement and the methodology/approach to be used including additional descriptions of the work scope. In addition, if the proof-in-principle risk evaluation is determined to be a viable approach, Section 3 identifies potential follow-on tasks in 2015 to expand the scope of the risk-informed evaluation to address ten (10) of the twelve (12) questions identified in an NRC letter (ML080500540) [5].

2.0 NRC IDENTIFIED QUESTIONS RELATED TO ECCS SUCTION STRAINER

The NRC has previously identified twelve (12) questions related to ECCS suction strainer performance. Table 2-1 summarizes these questions related to ECCS suction strainer performance that are documented in Reference [5].

The BWROG is beginning a process for responding to these questions as identified in Figure 2-1 as follows:

- Ten (10) questions could be dispositioned by a risk-informed approach
- Two (2) questions would remain for disposition by deterministic testing:
  - Downstream fuel effects
  - Chemical effects

However, prior to a full implementation of the approach, the BWROG has decided to demonstrate the risk-informed process applied to two of the questions. These two questions are identified below and summarized in Table 2-2:

- Debris head-loss correlations
- Coatings zone of influence (ZOI)

It is noted that two of the twelve questions are being addressed by on-going BWROG sponsored testing and analysis programs. These two questions are:

- Down-stream effects on fuel or core flow
- Chemical effects on the impact on fuel or core flow

Section 3 provides the description of the proposed risk-informed approach that is intended to be applied to examine ten (10) of the twelve (12) questions during 2015 contingent on the success of the proof-of-principle pilot project (refer to Figure 2-1).

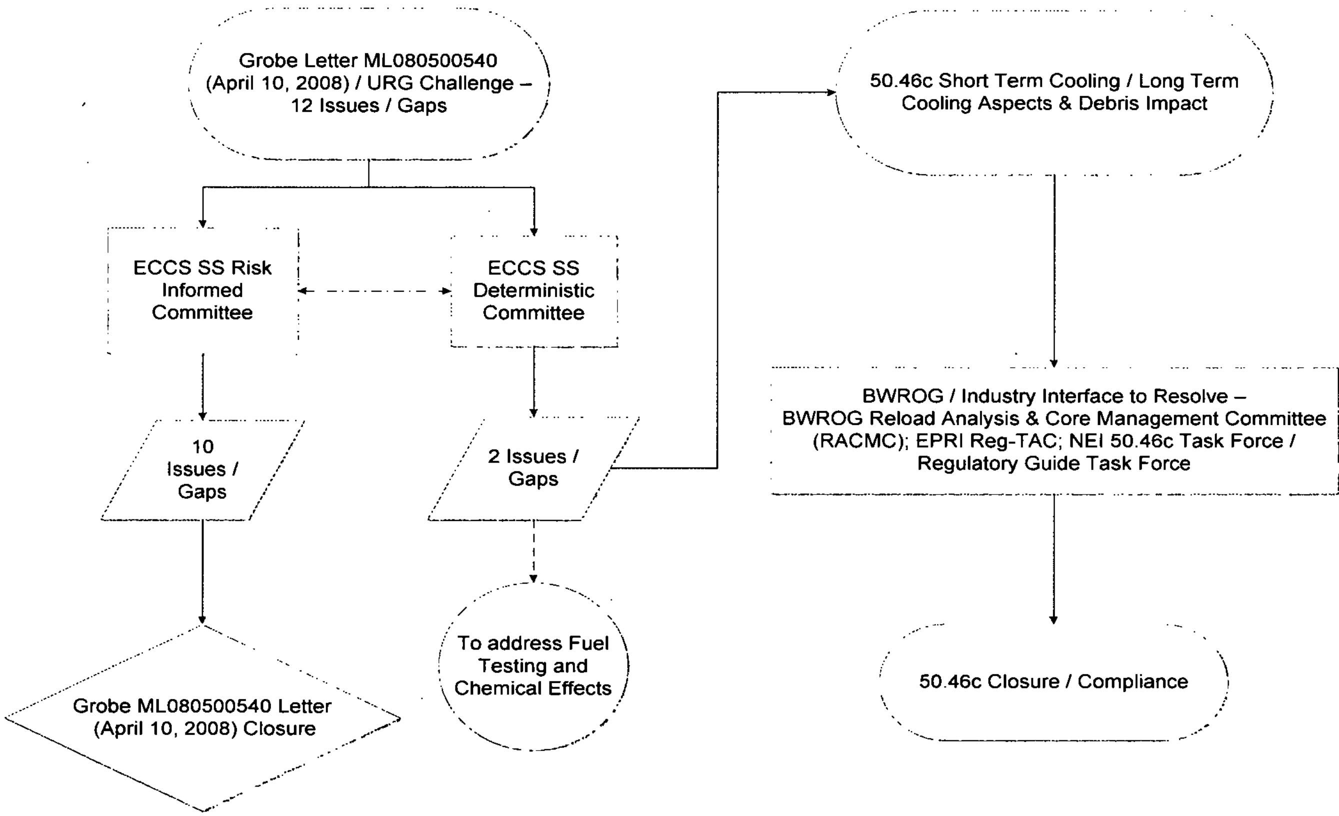


Figure 2-1

PROPOSED APPROACH TO DISPOSITION NRC QUESTIONS FROM REF. [5]

Table 2-1

INITIAL BWROG DISPOSITION OF TWELVE (12) ECCS SUCTION STRAINER ISSUES OF CONCERN

ECCS Suction Strainer Issues of Concern	Initial BWROG Disposition (per September 9, 2014 meeting with NRC)	Initial Disposition for Risk Evaluation
1. Downstream Effects (Components & Systems)	Based on PWROG results, expect to have minimal risk impact. Initial screening analysis to evaluate delta risk utilizing results from WCAP-16406-P method.	Use qualitative information to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.
2. Downstream Effects (Fuel / In-vessel)	Not Applicable / not part of the risk-informed evaluation / expected compliance via 10CFR50.46c.	Out of scope for the risk-informed evaluation. To be dispositioned by deterministic testing.
3. Debris Head-Loss Correlations	Obtain plant-specific data on worse case debris generation for various LOCA scenarios. Consider application of NUREG/CR-6224 to establish proper correlation for debris generation resulting in suction strainer clogging.	Develop probabilities for ECCS suction strainer CCF for different failure modes (e.g., total debris loading and thin bed effects) for a range of LOCAs. Need deterministic input on amount of debris loading for and head-loss correlations. Need to model quantitative impact in PRA.
4. Chemical Effects	Not Applicable / not part of the risk-informed evaluation / expected compliance via 10CFR50.46c.	Out of scope for the risk-informed evaluation. To be dispositioned by deterministic testing.
5. Coatings Assessments	Coatings Assessment issue is administrative in nature related to qualified and unqualified coatings, and will not impact the PRA. A template related to GL 2004-02 (PWR only) associated with Coating Assessments, is expected for receipt by the BWR fleet at a future date to-be-determined (via Generic Letter).	No significant impact on PRA. Use deterministic input to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.
6. Latent Debris	Expected to have minimal risk impact. Issue 6 closure plan details captured in BWROG Chairman's Letter, BWROG-14006 (February 14, 2014) - BWROG Request for Closure of ECCS Suction Strainer Issues: Latent Debris Issue #6; Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT) Issue #7; and Spherical Zone of Influence (ZOI) Issue #12.	No significant impact on PRA. Use deterministic input to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.

Table 2-1

INITIAL BWROG DISPOSITION OF TWELVE (12) ECCS SUCTION STRAINER ISSUES OF CONCERN

ECCS Suction Strainer Issues of Concern	Initial BWROG Disposition (per September 9, 2014 meeting with NRC)	Initial Disposition for Risk Evaluation
7. Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT)	Expected to have minimal risk impact. Issue 7 closure plan details captured in BWROG Chairman's Letter, BWROG-14006 (February 14, 2014) - BWROG Request for Closure of ECCS Suction Strainer Issues: Latent Debris Issue #6; Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT) Issue #7; and Spherical Zone of Influence (ZOI) Issue #12.	No significant impact on PRA. Use deterministic input to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.
8. Coatings Zone of Influence (ZOI)	Expected to have minimal risk impact. Communicated draft results of Coatings Zone of Influence assessment at NRC public meeting on April 30, 2014 (Modeled two Mk I and two Mk II containments (representative). Final submittal of results currently scheduled for NRC delivery on / before March 31, 2015.	No significant impact expected on PRA. Use deterministic input to specify the uncertainty regarding coating loading. This deterministic input is then used to support a quantitative sensitivity evaluation.
9. Debris Transport and Erosion	Homogeneous distribution of debris is expected to be the most limiting case for the risk-informed evaluation. Homogeneous distribution to be employed for the PRA (even for SBLOCA events). Consult / incorporate information as appropriate from NUREG/ CR-6808, NUREG/CR-7172, and NUREG/ CR-6369.	Minor impact on PRA. Assume quantitative impact to be subsumed within the quantitative assumptions for Issue #3.
10. Debris Characteristics	Prototypical characteristics to be employed for the PRA. Consult / incorporate information as appropriate from NUREG/CR-6808 & NUREG/CR-7172.	Minor impact on PRA. Assume quantitative impact to be subsumed within the quantitative assumptions for Issue #3.
11. Near Field Effect / Scaling	No impact to PRA - Near Field Effect / Scaling issue is specific to non-prototypical Head-Loss testing program. Consult / incorporate information as appropriate from NUREG/ CR-6808 & NUREG/CR-7172.	Use qualitative information to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.

Table 2-1

INITIAL BWROG DISPOSITION OF TWELVE (12) ECCS SUCTION STRAINER ISSUES OF CONCERN

ECCS Suction Strainer Issues of Concern	Initial BWROG Disposition (per September 9, 2014 meeting with NRC)	Initial Disposition for Risk Evaluation
12. Spherical Zone of Influence (ZOI)	Expected to have minimal risk impact. Issue 12 closure plan details captured in BWROG Chairman's Letter, BWROG-14006 (February 14, 2014) - BWROG Request for Closure of ECCS Suction Strainer Issues: Latent Debris Issue #6; Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT) Issue #7; and Spherical Zone of Influence (ZOI) Issue #12.	Use qualitative information to resolve issue. Do not need to explicitly model issue as part of Base Case risk evaluation. May use deterministic input in support of a quantitative sensitivity case.

Table 2-2

TWO ISSUES TO BE INCLUDED IN RISK-INFORMED PILOT DEMONSTRATION PROOF-OF-PRINCIPLE

Issue No.	Description	Pilot Project Approach
3	Debris Head-Loss Correlations	Develop probabilities for ECCS suction strainer CCF for different failure modes (e.g., total debris loading and thin bed effects) for a range of LOCAs. **Need distributions on amount of debris loading to evaluate head-loss correlations. Need to model quantitative impact in PRA.**
8	Coatings Zone of Influence (ZOI)	Illustrate the sensitivity of baseline, debris-induced risk to changes in qualified coatings ZOI size.

3.0 RISK-INFORMED ASSESSMENT OF ECCS SUCTION STRAINER ADEQUACY

The proposed approach integrates a detailed model of the phenomenological effects that can influence ECCS suction strainer performance (CASA Grande) with the plant probabilistic risk assessment (PRA) model to evaluate system performance and overall risk impact. The model development for the phenomenology analysis and the probabilistic analysis has the capability to provide a significant level of detail in the evaluation process. The results will be available at a high level to support communication with management, but additional detail will also be available to address detailed staff questions.

3.1 GRADED APPROACH

As noted above, a multi-phase, graded approach is developed to allow the NRC and BWR utilities to assess the merits and progress of the risk-informed approach. This consists of three phases.

The three phases are as follows:

- Phase I: Proof-of-Principle (2014). Initial Probabilistic Risk Assessment framework to structure the risk-informed resolution of the GSI-191 questions and provide initial feedback to the BWROG and NRC regarding scope, level of detail, and feasibility of the approach.

  Hold point at end of Phase I for NRC agreement with viability of the approach.

- Phase II: Full demonstration of the proposed approach (early 2015) for a single plant and ten of the twelve NRC questions. As noted in Section 2 the two questions not included are:

  - Downstream effects (Fuel/In-vessel)
  - Chemical effects

  The Phase II work effort will be an extension of the success achieved in the Phase I (2014) effort that seeks to establish the proof-of-principle for the risk-informed approach to the ECCS suction strainer questions.

  Hold point at end of Phase II for BWROG and NRC agreement that results remain promising for viability of disposition of the NRC questions.

- Phase III: Full demonstration for additional plants (mid 2015) to bound or envelop a large fraction of the US BWR fleet. Phase III includes the extension of the implementation of the framework developed in Phase I and Phase II to two additional "typical" plants and examination of fleet variations in debris and strainer design to allow broader generic conclusions that support applicability to represent the US BWR fleet.

Critical Input Variables in the Plan

The interface with deterministic phenomenology experts is considered vital to the success of the risk-informed approach. The full benefit of work already performed by the BWROG is to be used to assure success of the risk-informed approach. This will provide the NRC confidence that substantial technical bases exist for judgments and probabilistic characterizations.

3.2 SCOPE

The scope of the proposed effort (Over Phases I, II, and III) is limited as follows:

- There are twelve questions based on NRC letter ML080500540; ten of these questions are to be encompassed within a risk-informed approach
- Two questions are the subject of on-going deterministic analysis and testing and are not encompassed by this risk-informed approach:
    - Downstream effects (Fuel/In-vessel core flow)
    - Chemical effects

A multi-phase approach is identified to address the NRC questions regarding the operation of the BWR Mark I, II, and III units and their ECCS suction strainers in a risk-informed manner. The method provides for a graded approach to the resolution of NRC identified questions. This graded approach consists of three phases each with a defined stopping point for NRC and BWROG review and assessment to ensure that the project is on-track to develop the needed products to support the BWROG and the BWR members in their discussions with the NRC.

The 2014 Proof-of-Principle evaluation (Phase I) is limited in the following areas:

- Hazards
- Questions to be addressed
- Number of plants

The following describes the scope limitations associated with the 2014 Phase I risk-informed evaluation associated with each of these areas.

- Hazards

  The generalized hazards to be considered can be taken from the ASME/ANS PRA Standard as follows:

  (a) Internal Events (Part 2)

  (b) Internal Floods (Part 3)

  (c) Internal Fires (Part 4)

(d) Seismic Events (Part 5)

(e) High Winds (Part 7)

(f) External Floods (Part 8)

(g) Other Hazards (Part 9)

The section of the ASME/ANS PRA Standard that addresses each hazard is also identified in the above list.

In addition to these hazard groups for full power operation, it is also postulated that shutdown conditions could offer other unique challenges. Therefore, shutdown operation is also evaluated to assess possible risk contributions associated with ECCS suction strainer blockage.

The hazards of particular concern are those that may introduce phenomena that lead to significant challenges to the effectiveness of ECCS suction strainers during recirculation (e.g., ECCS suction from suppression pool, injection to RPV, and return to suppression pool via LOCA break). These include events that cause the relocation of fibrous insulation or containment coatings (e.g., epoxy) from the drywell or wetwell into the suppression pool and the subsequent blockage of the strainers surface area sufficient to compromise the ECCS pumps. This relocation is postulated to result primarily from energetic sets of steam or water developed during these hazards, i.e., primarily from LOCA events. Other accident challenges are not considered to lead to this phenomenon. For example, scenarios with drywell spray initiation may be excluded because they are judged to not have sufficient energetic means to dislodge significant debris. There is also pre-existing sludge present within the suppression pool that contributes to the total debris loading.

The evaluation of the hazards that are to be addressed in the calculation of the change in risk associated with the perceived phenomena that could lead to ECCS suction strainer blockage includes the following guidelines:

- What plant accident conditions could result in creating debris or causing "fixed" debris to become "free" and available for transport that in turn may lead to additional debris loading on the ECCS suction strainers?
- What initiators or accident sequences could lead to these plant conditions?
- In combination with debris generation and transport, what initiators or accident scenarios also require suction flow through the ECCS suction strainers?

<u>Assumptions</u>

- The sludge debris in the suppression pool could be agitated and suspended in the water due solely to RPV discharge via the SRVs. This homogenous sludge suspension is assumed well within the range of acceptable debris loadings that would not compromise the ECCS suction strainers.
- Fibrous insulation material in the drywell can be dislodged and transported to the suppression pool in sufficient quantities to clog portions of the ECCS strainers.
- Iron oxides present in suppression pool or containment coatings dislodged by the initiating event accentuate plugging probability induced by fibrous material.
- "Chugging" phase of LOCA creates sufficient energy to ensure that sludge (iron oxides) and fibrous material are well mixed in the suppression pool.

First, examining the internal events hazards, the types of accident challenges of interest are identified.

Full Power Internal Events Failure Modes

- There are multiple challenges to safe nuclear plant operation.

  The type of accidents derived from an Internal Events PRA that could lead to core damage include the following:

  - Transient challenges to RPV makeup
    - Loss of RPV makeup at high pressure
    - Loss of RPV makeup at low pressure
    - Loss of RPV makeup due to SBO
    - Transient followed by an SORV
    - IORV
  - Loss of DHR
  - LOCAs
    - RPV rupture
    - Small LOCA
    - Medium LOCA
    - Large LOCA
  - Reactivity Accidents (ATWS)
  - ISLOCA
  - Breaks Outside Containment (BOC)

  Table 3.2-1 displays these postulated challenges and describes their effect on the suction strainer blockage evaluation plus how these challenges are dispositioned for the 2014 plant demonstration proof-of-principle project.

  For the full implementation of the process in 2015 any items that are deferred or not fully implemented in the proof-of-principle evaluation will be re-assessed to justify their treatment.

Fire Hazards

The fire hazards are examined by a review of available BWR fire PRAs. These FPRAs are characterized by fire induced failures that include the following:

- Equipment failures that defeat accident mitigation measures
- Spurious opening of isolation valves that could induce LOCAs outside containment
- Spurious SRV opening. These would lead to reduced RPV pressure and increased suppression pool temperatures but would not lead to the increase in the release of debris into the suppression pool.
- No LOCA events are determined to be generated by the fire initiators that would cause a direct discharge of steam or water from the pressurized RPV to cause disruption of the fixed sources of debris in the drywell.

Based on these observations from BWR fire PRAs, the fire hazards are determined to not contribute to the potential for ECCS suction strainer blockage and are not included in the delta risk metric calculations.

Seismic Hazards

The 2014 proof-of-principle does not address seismic initiated events that can challenge the ECCS suction strainers. It is recognized that some conditional probability of small, medium, and large LOCA may occur as a result of a seismic event. Therefore, the full implementation of the risk-informed process in 2015 will necessitate the evaluation of the seismic hazard as it affects the plant.

Other Hazards (Internal Floods, High Winds, External Floods, Others)

These are dispositioned with similar logic as the Fire Hazards are.

Shutdown

There are multiple reasons that under cold shutdown conditions that ECCS suction strainer blockage is not a significant risk contributor. These include the following:

- The RPV pressure and temperatures are low, precluding damaging LOCA jet stream
- There is no motive force to cause the "fixed" debris to be released and transported to the suppression pool
- The frequency of the need for ECCS makeup is very low
- The decay heat in the RPV is low
- The needed makeup to the RPV is much less than that for a reactor shutdown from power due to an at-power initiating event

Other plant conditions not considered for the 2014 pilot demonstration:

- SRV actuation with a stuck open tailpipe vacuum breaker

  This is a low probability condition and not considered to have any significant debris in its ZOI.
- Recirculation pump seal leakage considered to be extremely low flow rate and not capable of generating a sufficient ZOI to generate any significant debris in its ZOI.
- A stuck open unpiped safety valve

  The reference plant for 2014 does not have any unpiped safety valves. However, other plants may have this as an initiator or result in this condition given an ATWS. These cases will need to be added to the risk profile evaluated for such plants.

• Number of NRC Questions to be Addressed

As suggested by NRC staff, a demonstration or proof-of-principle assessment is desirable that addresses at least two of the ten NRC questions. These would include one that is relatively straightforward and one that involves more complexity. The two questions proposed for assessment in 2014 are the following:

Easier question:

- Desire straightforward question with easily characterized risk impact
- Candidate considered
  - Coatings ZOI (Issue #8) (important factor, definitive guidance, clear approach)

More complex question:

- Head-loss treatment
  - Most challenging and highest potential impact
  - Important feedback to test program
  - Head-loss calculational model sensitivity for uncertainty characterization

Therefore, two of the ten questions are proposed to be evaluated with risk-informed analyses.

- <u>Number of Plants</u>

  A single representative plant will be used for the demonstration.

Table 3.2-1

DISPOSTION OF CHALLENGES TO ECCS SUCTION STRAINER PERFORMANCE

Accident Challenges	Possible Effects on ECCS Suction Strainer Blockage Phenomena	Disposition for Pilot Plant Project 2014
• Transient Challenges to RPV Makeup – Loss of RPV makeup at high pressure	Events following a transient initiator that progresses at high RPV pressure will lead to a periodic actuation of one or more SRVs that will lead to steam discharges to the suppression pool at high pressure. This will cause mixing of any settled debris in the suppression pool. However, the ECCS suction strainers are designed for the latent debris loading present in the suppression pool. This loading is considered very small in comparison with the strainer capability. Therefore, no significant risk effect is associated with these challenges.	These hazards do not need to be quantified in the risk-informed analysis.
– Loss of RPV makeup at low pressure	Events following a transient that involve an RPV depressurization are expected to result in mixing of any settled debris in the suppression pool. However, the ECCS suction strainers are designed for the latent debris loading present in the suppression pool. This loading is considered very small in comparison with the strainer capability. Therefore, no significant risk effect is associated with these challenges.	These hazards do not need to be quantified in the risk-informed analysis.
– Loss of RPV makeup due to SBO	Events following a loss of offsite AC power or SBO are expected to follow one of the above two conditions as far as in-containment conditions are concerned.	These hazards do not need to be quantified in the risk-informed analysis.

Table 3.2-1

DISPOSTION OF CHALLENGES TO ECCS SUCTION STRAINER PERFORMANCE

Accident Challenges	Possible Effects on ECCS Suction Strainer Blockage Phenomena	Disposition for Pilot Plant Project 2014
– Transient followed by an SORV	An IORV or a transient with an SORV are similar to the second item except in the case that an SRV tail pipe vacuum breaker fails open. Under such conditions, the steam would be discharged from the SRV tailpipe vacuum breaker in the drywell. There is some small probability that debris from the drywell could be dislodged, however, it is found that there is no significant debris or coatings in its ZOI.	These hazards do not need to be quantified in the risk-informed analysis.
– IORV	An IORV or a transient with an SORV are similar to the second item except in the case that an SRV tail pipe vacuum breaker fails open. Under such conditions, the steam would be discharged from the SRV tailpipe vacuum breaker in the drywell. There is some small probability that debris from the drywell could be dislodged, however, it is found that there is no significant debris or coatings in its ZOI.	These hazards do not need to be quantified in the risk-informed analysis.
• Loss of DHR	No significant risk effect is associated with these challenges.	These hazards do not need to be quantified in the risk-informed analysis.

Table 3.2-1

DISPOSTION OF CHALLENGES TO ECCS SUCTION STRAINER PERFORMANCE

Accident Challenges	Possible Effects on ECCS Suction Strainer Blockage Phenomena	Disposition for Pilot Plant Project 2014
• LOCAs – Small LOCA – Medium LOCA – Large LOCA	LOCA events will result in the discharge of water, steam, or a mixture from the RPV into the drywell. The flow rates and associated ZOIs are a function of the LOCA size and location (i.e., above or below TAF). The LOCA events may dislodge material from fixed locations in the drywell.	These hazards are explicitly addressed in the 2014 pilot plant analysis.
• Reactivity Accidents (ATWS)	For failure to scram events, more SRVs are anticipated to open and greater mixing and higher temperatures are anticipated in the suppression pool compared to the transient cases discussed with successful scram. Nevertheless, no significant increase in debris is anticipated to be dislodged and sent to the suppression pool. There is one exception and that arises on plants with unpiped safety valves. For such plants these unpiped safety valves are calculated to open based on thermal-hydraulic analyses. Insulation present in the ZOI could be dislodged. These are special cases for certain older plants that will need to be investigated separately in 2015.	These hazards do not need to be quantified in the risk-informed analysis.
• ISLOCA	ISLOCAs and BOCs are postulated accidents which discharge outside of containment. No impact on ECCS suction strainer debris loading is expected.	These hazards do not need to be quantified in the risk-informed analysis.

Table 3.2-1

DISPOSTION OF CHALLENGES TO ECCS SUCTION STRAINER PERFORMANCE

Accident Challenges	Possible Effects on ECCS Suction Strainer Blockage Phenomena	Disposition for Pilot Plant Project 2014
• Breaks Outside Containment	ISLOCAs and BOCs are postulated accidents which discharge outside of containment. No impact on ECCS suction strainer debris loading is expected.	These hazards do not need to be quantified in the risk-informed analysis.

3.3 OVERVIEW

The risk-informed perspective allows an integrated examination of the NRC questions.

Figure 3.3-1 provides a summary of the key elements of the methodology for the risk-informed assessment of ECCS suction strainer failure.

The risk-informed perspective affords the ability to characterize each phenomenological question as well as the integrated set of phenomenological questions within a single framework with a well-recognized acceptance guideline. This provides a valuable measuring stick against which to compare the safety importance of the questions raised by the NRC [5]. The risk-informed perspective provides a safety context for the questions that have been raised.

3.4 RISK-INFORMED METHODOLOGY

For Phases II and III, each of the ten (10) issues identified for investigation using a risk-informed approach is characterized for the specific selected plants to allow the calculation of the probability of ECCS suction strainer failure for the given initiating event.

The risk-informed methodology developed for the proof-of-principle pilot demonstration in 2014 includes the following:

- <u>Accident Initiation</u>

  One of the keys to the development of the risk-informed perspective on ECCS suction strainer issues identified by the NRC is the characterization of possible challenges.

  The challenges to adequate core cooling associated with ECCS suction strainer blockage affecting the CDF risk metric are postulated to result from LOCA initiated accident sequences that could cause debris to be swept from the drywell to the suppression pool to add to pre-existing debris in the suppression pool.

  The frequency of these challenges by system, location, and size are among the key inputs to the risk-informed calculations. The frequency of LOCA initiators and their probability distribution are determined using the NRC sponsored research documented in NUREG-1829.

  Tables 3.4-1 and 3.4-2 summarize the results of NUREG-1829 that are input to the PRA models for the probabilistic evaluation of risk.

  Table 3.4-3 summarizes the characterization of the plant response as a consequence of the initiating events identified in Tables 3.4-1 and 3.4-2.

- Deterministic Inputs to Assessment

  The LOCA phenomenology code calculation uses estimates of debris induced in the containment based on:

  - Plant surveys of the latent debris source in the drywell and torus
  - Direct calculation of the quantity of fibrous debris and coatings that are present within the Zone of Influence for each LOCA initiator over a complete span of the break size and plant systems.

  Figure 3.4-1 shows a typical CAD drawing of a BWR that is used as one of the inputs to the CASA Grande code calculation.

  The accident phenomenology code (CASA Grande) provides a method to calculate the probability distribution of ECCS suction strainer failure given the LOCA initiator and the consequential debris generated as a result of the ZOI. This calculation also includes the assessment of containment flow impact on the time to strainer failure. This time is important in the assessment of defense-in-depth actions. While CASA Grande is inherently designed to propagate uncertainties and predict system response probabilities, maximum use will be made of deterministic assumptions for this application. A good example of a deterministic input is choosing a point value to describe the size of the qualified coating ZOI rather than an uncertainty distribution defined on a range of possible sizes.

  The use of CASA Grande provides a systematic evaluation of phenomena over a spectrum of accidents to define driving factors and provide a risk-weighted perspective relative to the cumulative effects of each of the ten (10) of twelve (12) items in the NRC letter [5] within the scope of the risk evaluation. Relevant pool conditions include time dependent volume, temperature and debris quantity that are most likely to dominate strainer head-loss. The formal risk assessment of head-loss effects at the strainer automatically supports evaluation of boron precipitation effects as well as in-vessel effects. Thus, the extension of the risk-informed methodology CASA Grande, if needed, naturally covers these effects, which can be incorporated into existing conditional core damage probabilities.

  For this study, the standard NUREG/CR-6224 head-loss correlation will be used to quantify pressure drop across the strainers as debris builds up over time. Despite ongoing critiques of this model, it remains the only correlation in widespread regulatory use. The NRC has accepted applications of NUREG/CR-6224 for "evaluation purposes" similar to this screening evaluation, but not for strainer performance qualification in the absence of testing. The STP pilot project applied NUREG/CR-6224 with modifications to account for full bed compaction and for uncertainties in model predictions compared to tests. Sensitivity analyses with the strainer vendor developed pressure drop models may also be performed with CASA Grande.

- Monte Carlo Simulation of ECCS Suction Strainer Failure Probability

  The ECCS suction strainer failure probabilistic evaluation consists of a Monte Carlo simulation to determine the probability of ECCS suction strainer failure (including probability distribution). The Monte Carlo simulation is structured using nonuniform Latin Hypercube Sampling (LHS) for dramatically improved sampling of extreme probability tails like Large-Break LOCA initiating event frequency. A suction strainer failure probability distribution is calculated for each LOCA initiator. Taking the LOCA initiator and the ECCS suction strainer probability as inputs to the PRA model allows the calculation of the risk metrics of interest in the risk-informed assessment.

The other parameter supplied by the comprehensive analysis is the time available before suction strainer failure.

Figure 3.4-2 provides a simple graphic to display the use of the Monte Carlo simulation in the calculation of the ECCS suction strainer failure probability for use in the PRA.

CASA Grande models debris accumulation and head-loss using pump flows associated with the equipment operating state and calculates the probability of ECCS suction strainer failure specific to, or conditioned on, each state. Independent calculations are needed for a small number of dominant plant states to populate the conditional ECCS suction strainer failure probability for each one. The respective products of conditional ECCS failure probability, times probability of the plant state, times annual frequency for LOCA category (small, medium, large), summed over all evaluated states represents the incremental ECCS suction strainer failure associated with debris phenomena.

CASA Grande can calculate the conditional probability of debris-induced ECCS suction strainer failure for a given plant configuration, or "plant state." For example, in the most likely configuration where all equipment functions as designed, all pumps run and the debris challenges a fully operational safety system. Other plant states include various individual pump failures or operational configurations, including loss of an entire train. For the proof-of-principle evaluation in Phase I, only the most likely plant state (full system response) will be examined.

Based on these calculated distributions, the point estimate of the ECCS suction strainer failure probability is determined for each defined LOCA location and size. These failure probabilities are then inserted into the PRA model to calculate the frequency of CDF sequences resulting from the LOCA initiator and the ECCS suction strainer blockage.

- Accident Mitigation

  It is noted that the accident mitigation capability (success criteria) varies with the LOCA initiator because of the timing of possible strainer failure modes and number of alternate mitigating systems available to provide effective mitigation.

  Mitigative actions in response to a LOCA include the following:

  - ECCS operation from the CST (HPCI, HPCS, RCIC) and suppression pool as the primary initial response.
  - Evidence of pump cavitation, or reduced ECCS flow provides indication (symptoms) of possible suction strainer blockage. This alerts the crew to actions to:
    - Backflush the ECCS suction strainers (time dependent action)
    - Control of the ECCS flow through a strainer to reduce the pressure drop
    - Initiation of an alternate injection source (e.g., RHRSW cross-tie, LPCI/CS from CST)

- Success Criteria

  The plant-specific PRA success criteria that have been peer reviewed are used in the analyses for the calculation of successful accident mitigation. These are consistent with generic BWR SAFE calculations by GEH in NEDO 24708A.

- ECCS Suction Strainer Pressure Drop Calculation

The pressure drop calculation used in the analysis is that which is supported by the strainer vendor or adopted from NUREG/CR-6224. This calculation is also the subject of a sensitivity evaluation that examines possible variation in the suction strainer calculation. Specifically, the risk-informed approach allows the suction strainer pressure drop correlation to be modified or replaced to assess how the variability in the pressure drop calculation affects the risk metrics.

- A number of the NRC questions are adequately characterized by BWROG analyses or tests and the NRC has expressed agreement with the response to these questions. These include the following:

  5 - Coatings Assessments

  6 - Latent Debris

  7 - Zone of Influence (ZOI) Adjustment for Air Jet Testing (AJT)

  12 - Spherical Zone of Influence (ZOI)

  It is also expected that the following will be closed in early 2015:

  8 - Coatings Zone of Influence (ZOI)

  9 - Debris Transport and Erosion

  10 - Debris Characteristics

  During Phases II and III, these questions will be folded into the risk-informed analyses either in the base PRA model, the associated sensitivity cases, or as deterministic inputs to the baseline risk calculation.

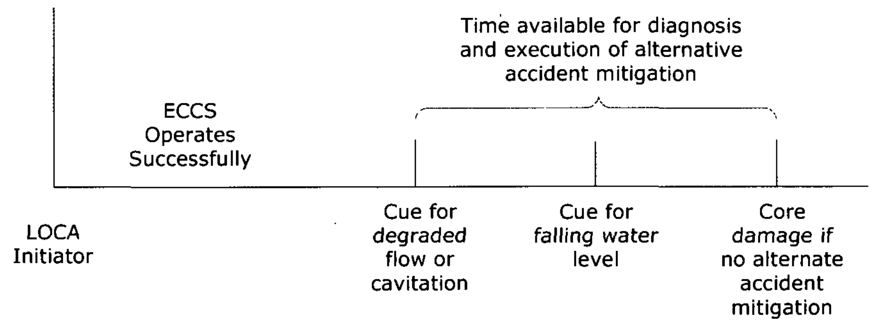
- <u>Available Time for Mitigation</u>

  ECCS suction strainer failure time: The time to ECCS suction strainer failure is important in accident mitigation because this available time results in reduced decay heat that needs to be controlled and extends the time available for the crew to take alternative mitigative actions to ensure adequate core cooling.

- The time to suction strainer failure may be significantly delayed after the LOCA initiator based on a number of a factors such as
  - The amount of debris generation,
  - The water volume of the suppression pool, and
  - The volume of flow through the suction strainers.

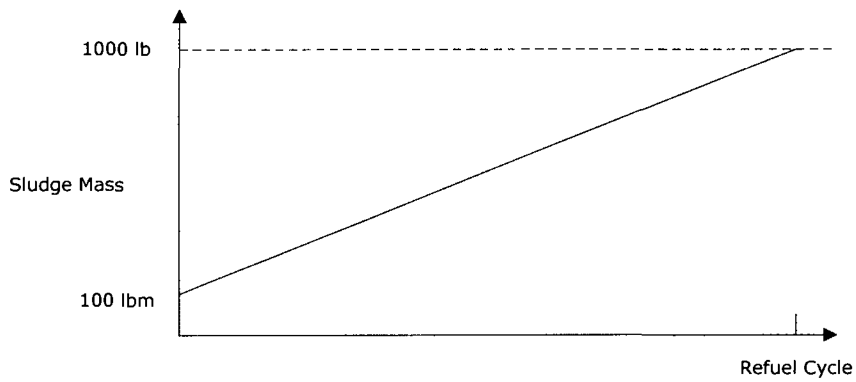
General characterization of the time frames is as follows:

Time Frames Considered for Operator Action



- Buildup of Debris (sludge)

  One of the many conservative assumptions used in the pilot plant evaluation is associated with the assumption of the pre-existing sludge to be assumed present in the suppression pool for the ECCS suction strainer Monte Carlo calculation. This assumption can also be treated as a sensitivity study. The suppression pool is cleaned during each refueling such that during initial restart the sludge volume is quite low and builds up in a linear fashion over the fuel cycle. This time function looks approximately as follows:



  A realistic point assessment of the sludge mass would be approximately 500 lbm, which is consistent with both the pilot plant debris generation report and a mid-cycle estimate of the sludge volume based on the figure above. Alternatively, the worst case assumption of the end of cycle mass volume could be used as part of a sensitivity study.

- Location Dependent Debris

  There may be selected locations within the containment where a choice has been made to use particularly problematic materials such as Min-K and Ca Silicate. However, a review of these applications indicates that these materials are preferentially used near containment penetrations. As it turns out, these locations are also those that are specially designed (sometimes referred to as "super pipe"). This pipe is designed to be constructed and restrained such that the probability of a break is considered incredible. This means that the problematic material is not credibly within a ZOI. Sensitivity evaluations will investigate the impact of these unique configurations.

- Plant Selection

  Table 3.4-4 summarizes the possible criteria for plant selection.

  Some preliminary observations used in formulating a plant for the proof-of-principle include the following:

  - Mark I – No motor driven injection from outside containment except
    - Condensate/Hotwell
    - Selected plants with SW cross-tie for RPV makeup
    - Selected plants with FPS or FLEX cross-tie for RPV makeup
    - CRD injection for above core LOCAs
  - BWR/5-Mark II – Smaller contributor from ECCS suction strainer blockage because HPCS can initially inject from CST for >30 min. (~70 min.) depending on the size of the LOCA
  - Mark III – Same as Mark II except larger strainer surface area

  The selected 2014 Phase I example plant is as follows:

  - BWR/4 Mark I
    - PRA sufficient to support risk-informed application
    - PRA model is readily available
    - PRA quality is commensurate with its use in risk-informed application (Capability Category II on all critical Supporting Requirements (SRs) as assessed by Peer Review)
    - Level of detail available to address suction strainer effects and defense-in-depth
  - CAD Model is available with sufficient capability for proof-of-principle (See Figure 3.4-1)
    - Proof-of-principle pilot will use a selection of several hundred typical weld locations facilitated by the CAD drawing. Failure probabilities specific to small, medium, and large LOCA will be compiled as needed by the PRA.
    - Insulation is assigned based on detailed description from the pilot plant

  The treatment of selected individual plants is incorporated into Phase II and Phase III. The culmination of the risk-informed analysis is a determination by the NRC that all or most BWRs have no open questions related to the NRC letter [5] except possibly those related to in-vessel downstream effects or chemical effects.

Table 3.4-1

SUMMARY OF LOCA FREQUENCIES FROM NUREG-1829 AND THE PRINCIPAL CONTRIBUTORS (%)

Category	LOCA Size (gpm)	Effective Break Size (in.)	LOCA Mean[1] Frequency (Per Cal. Yr)	RF[6]	Contributors (%)[2]												
					RCIC	SRV	Head Spray	Drain	Inst.	SLC	CRD	RWCU	RHR	HPCS/ LPCS	Main Steam	FW	Recirc
1	>100	½	6.5E-4	8.3	0.28%	1.9%	1.0%	27.8%	18.5%	0.9%	9.3%	9.3%	7.4%	7.4%	0.6%	1.9%	13.9%
2[3]	>1,500	1.87	1.3E-4	12.6	0.28%	1.9%	1.0%	27.8%	18.5%	0.9%	9.3%	9.3%	7.4%	7.4%	0.6%	1.9%	13.9%
3	>5,000	3.25	2.9E-5	13.5	1.3%	3.8%	4.1%	--	--	2.6%	--	17.9%	12.8%	5.1%	1.3%	17.9%	33.1%
4[4]	>25,000	7	7.3E-6	18.4	1.3%	3.8%	4.1%	--	--	2.6%	--	17.9%	12.8%	5.1%	1.3%	17.9%	33.1%
5	>100,000	18	1.5E-6	27.7	--	--	--	--	--	--	--	32.0%	21.4%	--	2.1%	8.9%	35.6%
6	>500,000	41	6.3E-9[5]	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Notes to Table 3.4-1:

(1) From NUREG 1829 Table 7.7 at 25 year life.

(2) Based on distributors from Appendix L of NUREG-1829 and converted to mean values before determining the percent contribution.

(3) Contributor distribution based on Category 1 distribution as reasonably representative.

(4) Contributor distribution based on Category 3 distribution as reasonably representative.

(5) Based upon RPV failure/rupture.

(6) Range factor assuming log normal distribution.

Table 3.4-2

SUMMARY OF LOCA FREQUENCIES FROM NUREG-1829 AND THE PRINCIPAL CONTRIBUTORS (PER RX YR)

Category	LOCA Size (gpm)	Effective Break Size (in.)	LOCA Mean[1] Frequency (Per Cal. Yr)	RF[6]	Contributors (Per Rx Yr)[2]												
					RCIC	SRV	Head Spray	Drain	Inst.	SLC	CRD	RWCU	RHR	HPCS/ LPCS	Main Steam	FW	Recirc
1	>100	½	6.5E-4	8.3	1.82E-06	1.24E-05	6.50E-06	1.81E-04	1.20E-04	5.85E-06	6.05E-05	6.05E-05	4.81E-05	4.81E-05	3.90E-06	1.24E-05	9.04E-05
2[3]	>1,500	1.87	1.3E-4	12.6	3.64E-07	2.47E-06	1.30E-06	3.61E-05	2.41E-05	1.17E-06	1.21E-05	1.21E-05	9.62E-06	9.62E-06	7.80E-07	2.47E-06	1.81E-05
3	>5,000	3.25	2.9E-5	13.5	3.77E-07	1.10E-06	1.19E-06	--	--	7.54E-07	--	5.19E-06	3.71E-06	1.48E-06	3.77E-07	5.19E-06	9.60E-06
4[4]	>25,000	7	7.3E-6	18.4	9.49E-08	2.77E-07	2.99E-07	--	--	1.90E-07	--	1.31E-06	9.34E-07	3.72E-07	9.49E-08	1.31E-06	2.42E-06
5	>100,000	18	1.5E-6	27.7	--	--	--	--	--	--	--	4.80E-07	3.21E-07	--	3.15E-08	1.34E-07	5.34E-07
6	>500,000	41	6.3E-9[5]	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Notes to Table 3.4-2:

(1) From NUREG 1829 Table 7.7 at 25 year life.

(2) Based on distributors from Appendix L of NUREG-1829 and converted to mean values before determining the percent contribution.

(3) Contributor distribution based on Category 1 distribution as reasonably representative.

(4) Contributor distribution based on Category 3 distribution as reasonably representative.

(5) Based upon RPV failure/rupture.

(6) Range factor assuming log normal distribution.

Table 3.4-3

CONSEQUENCES OF LOCA INITIATING EVENT REGARDING DEBRIS GENERATION AND ITS EFFECTS

• Definition of Zone of Influence (ZOI) as a function of LOCA size
• Calculation of insulation within the ZOI (plant specific)
• Calculation of insulation debris released in ZOI (NEDO-32786)
• Calculation of insulation debris transferred to suppression pool (NUREG/CR-6369)
• Calculation of debris transit time
• Calculation of insulation debris adheres to suction strainer: – Sludge – Chemical impacts – Film thickness exceeds "allowable" value and causes pump cavitation/failure
• Additional compensatory measures

Table 3.4-4

SELECTION CRITERIA FOR PHASE II and PHASE III PLANTS
(Follow-on to the Phase I Proof-of-Principle Plant)

Selection Variable	Criteria	
Containment Type	Mark I – most plants Mark II – most restricted NPSH Mark I – smallest strainers Mark I – most debris	
PRA Model Readily Available	BWR Plant #1 (Mark I) BWR Plant #2 (Mark I) BWR Plant #3 (Mark I) BWR Plant #4 (Mark I) BWR Plant #5 (Mark I) BWR Plant #6 (Mark I)	BWR Plant #7 (Mark I) BWR Plant #8 (Mark II) BWR Plant #9 (Mark II) BWR Plant #10 (Mark II) BWR Plant #11 (Mark III)
CAD Model Available (Pipe, steel, concrete)	BWR Plant #1 (Mark I) BWR Plant #8 (Mark II) BWR Plant #12 (Mark I) BWR Plant #13 (Mark II)	
General Assistance Available	Most Plants	
Debris Generated	General Description	
Strainer Design Vendor[1]	GEH PCI ABB Enercon	

Notes to Table 3.4-4:

[1] Plant Selection

The compilation of strainer types may be one consideration in the evaluation of the BWR population. This compilation can be summarized as follows for U.S. BWRs:

	Number of BWR Units		
Strainer Vendor	**Mark I BWR/2, 3, 4**	**Mark II BWR/4-5**	**Mark III BWR/6**
GEH	9	3	1
PCI	12	3	-
ABB	2	2	-
Enercon	--	-	3
Total	**23**	**8**	**4**

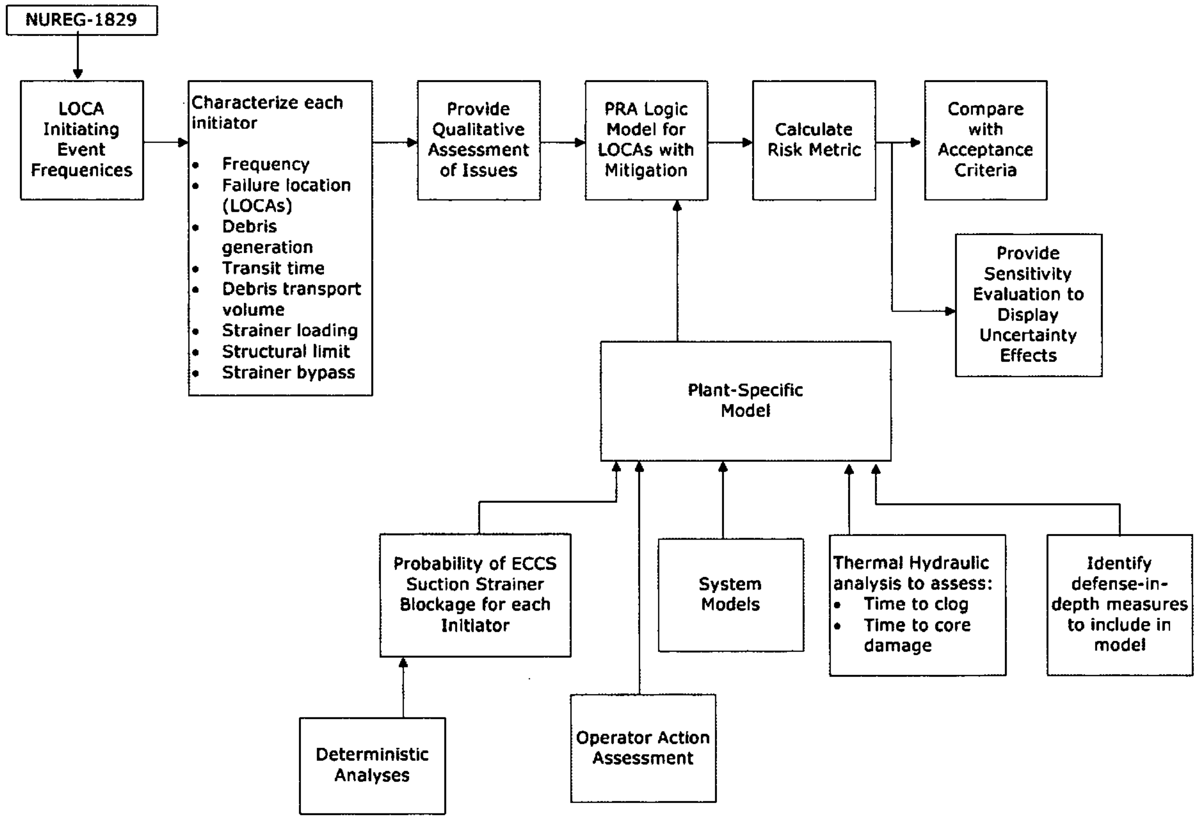
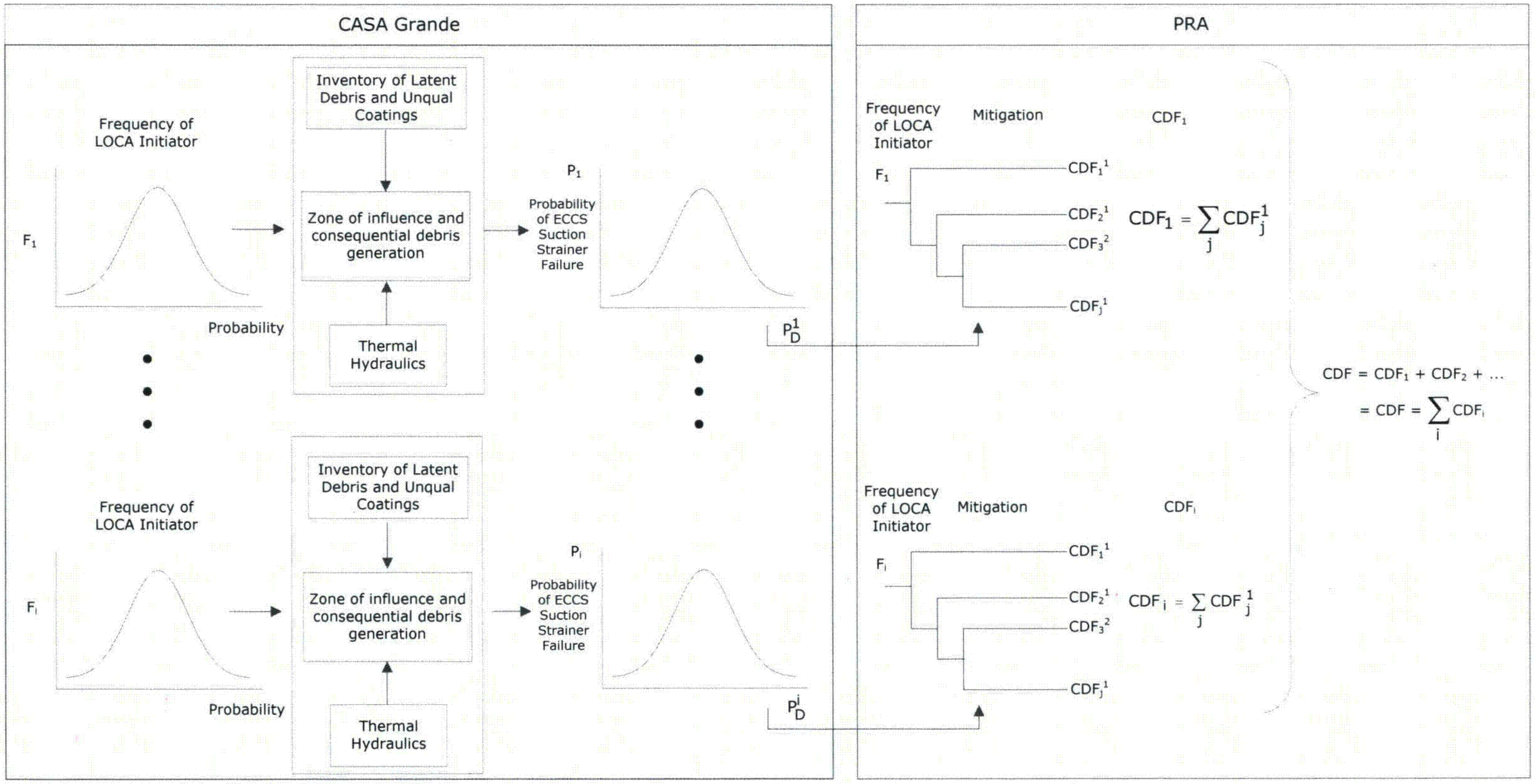


Figure 3.3-1

METHODOLOGY ELEMENTS FOR RISK-INFORMED ASSESSMENT OF ECCS SUCTION STRAINER FAILURE

Figure 3.4-1

CAD MODEL FOR TYPICAL BWR/4 MARK I CONTAINMENT



Legend
F_i = Frequency Distribution Function of the ith LOCA
P_i = Probability Distribution Function of the ECCS Suction Strainer given the ith LOCA
P_D^i = Mean Failure Probability of the ECCS Suction Strainer given the ith LOCA
CDF_i = CDF for the ith LOCA

Figure 3.4-2

FLOW INFORMATION RELATED TO ECCS SUCTION STRAINER FAILURE AND USE IN PRA

4.0 RISK-INFORMED ELEMENTS

4.1 SUMMARY OF KEY ELEMENTS

As part of the risk-informed process, there are a number of elements to the process that are desirable. These elements are clearly defined in Regulatory Guide 1.174 [4] and are summarized in Table 4-1.

The U.S. Nuclear Regulatory Commission's Policy Statement on probabilistic risk assessment (PRA) [1] encourages greater use of this analysis technique to improve safety decision-making and improve regulatory efficiency. Regulatory Guide 1.174 [4] provides the general guidance for use by licensees in the implementation of risk-informed analyses for regulatory interactions. Even though the risk-informed assessment of ECCS suction strainer questions is not a License Amendment Request (LAR), Regulatory Guide 1.174 specifies that a risk-informed approach provides valuable insights and guidance for use in interactions between the NRC and licensees. As such, the ECCS suction strainer assessment makes use of the RG 1.174 guidance and quantitative acceptance guidelines. Table 4-1 provides a summary of the key elements specified in RG 1.174 and how these elements are addressed in the ECCS suction strainer risk-informed assessment.

4.2 DEFENSE-IN-DEPTH

Table 4-2 summarizes the BWR defense-in-depth measures that are implemented or under consideration to provide additional compensatory measures assuming that ECCS suction strainers were blocked.

4.3 RISK METRICS

The NRC has established the guidance for risk-informed submittals to the NRC in Regulatory Guide 1.174. As part of this guidance discussed in Section 4.1 is the establishment of a set of quantitatively based acceptance guidelines that provide measures to characterize the level of risk attributed to actions or submittals. Figures 4-1 and 4-2 provide these acceptance guidelines for the two risk metrics:

- ΔCDF (change in core damage frequency)
- ΔLERF (change in large early release frequency)

Critical in the assessment of the change in risk metrics (ΔCDF, ΔLERF) is the baseline case to be used as the reference point[(1)] for any changes in the calculated risk metrics.

The two conditions to be evaluated to assess the risk metrics of ΔCDF and ΔLERF are as follows:

- A plant assuming that the design basis requirements on debris and ECCS suction strainers is 100% effective in preventing ECCS suction strainer blockage will represent the base or reference condition for comparison purposes.

  The case to be compared with the reference is a case with the calculated ECCS suction strainer blockage for the cases involving postulated phenomena associated with the NRC questions will be calculated by CASA Grande using plant specific inputs such as:

  - Debris inventory (e.g., sludge, unqualified coatings, insulation and ZOIs)
  - Transport of debris
  - Time for blockage
- A plant that is subject to phenomena related to debris in the containment that while meeting the design requirements nevertheless could (under some low frequency conditions) lead to ECCS suction strainer blockage.

The above then will form the two cases to calculate the change in risk.

A second set of sensitivity cases will be exercised to also calculate the change in risk compared to the reference case. This 2nd case may have many possible subcases. These subcases could include:

- Single phenomena: coatings released that increase the debris loading on the strainers
- Multiple phenomena added together

In addition to these cases, there are additional sensitivity evaluations that will be performed (e.g., changes to operator action compensatory measures). These sensitivity calculations will also produce change in risk metrics. These measures will reflect variations in the ΔCDF/ΔLERF about the baseline values discussed in the first bullet above.

(1) While most BWRs already have a probabilistic assessment of suction strainer blockage in their PRAs. The bases for these probabilities are generally based on judgment and reliance on the design basis to provide adequate protection. In order to avoid providing a potentially non-conservative calculated risk change, i.e., ΔCDF, the base reference case is assumed to be a plant that has 100% probability that the design requirements prevent ECCS suction strainer blockage. This yields the maximum calculated risk change.

Application of the Acceptance Guidelines

It is recognized that RG 1.174 provides acceptance guidelines and that there is some flexibility in the determination of what quantitative estimates are "acceptable".

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
Element 1 – Define the Objective	The objective of the risk-informed assessment involves the disposition of the NRC questions regarding individual aspects of ECCS suction strainer analysis that could affect the strainer failure probability. A change in the plant or its licensing basis is not requested. Rather, the risk perspective is included to address the possibility that uncertain postulated phenomena associated with LOCAs could result in degrading the plant response to licensing basis conditions. The purpose is to show that these phenomena are of such low risk significance that they do not represent a substantial contributor to the risk profile.
– Meets current regulations	As part of this definition, the BWROG submits that the ECCS suction strainers meet current NRC regulations. The disposition of the subject NRC questions also meets the current regulations. This disposition meets the objectives of the NRC's PRA Policy Statement because it results in: • Sufficient Safety Margin • Reduction in unnecessary burden on utility resources to further investigate already very small risk contributors • Better allocation of scarce resources to other higher priority safety issues

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
Element 2 - Perform Engineering Analysis	A combination of deterministic and probabilistic analyses is performed to establish the technical bases for dispositioning the postulated phenomena. This includes an assessment of: • Defense-in-depth • Safety margins • Small increases in risk Extensive deterministic evaluations have been performed to support the ECCS suction strainer designs. These are documented in the BWROG URG and individual site implementation of the URG. CASA Grande methodology is implemented to develop the ECCS suction strainer failure probability.
- Consistent with Defense-in-Depth Principles	The ECCS suction strainer assessment recognizes the need for a defense-in-depth philosophy. Incorporation of defense-in-depth concepts is a key part of the assessment and disposition of the questions.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
– Sufficient Safety Margin	Safety margins are maintained. The safety margin associated with the ECCS suction strainer meets the design basis as documented in the URG. Safety analysis acceptance criteria in the LB (e.g., FSAR, supporting analyses) are met. There is the appropriate balance maintained among prevention of core damage, prevention of containment failure, and consequence mitigation. The risk of each remains very small. There is no over reliance on programmatic or compensatory measures to assure safety. • System redundancy, independence, and diversity are preserved commensurate with the expected frequency, consequences of challenges to the system, and uncertainties (e.g., no risk outliers). • Defenses against potential common-cause failures are preserved, and the potential for the introduction of new common-cause failure mechanisms is assessed. • Independence of barriers is not degraded. No barriers are degraded. • Defenses against human errors are preserved. No reduction in human performance occurs --See Table 4-2. • The intent of the plant's design criteria is maintained <u>PRA</u> The PRA is used to integrate the deterministic results, the CASA Grande calculations, and the probabilistic assessment of accident sequences to determine the appropriate risk metrics to reflect the available safety margin.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
– Sufficient Safety Margin (cont'd)	The risk-acceptance guidelines are based on the principles and expectations for risk-informed regulation discussed in RG 1.174 and are structured as shown in Figures 4-1 and 4-2. Regions are established in the two planes generated by a measure of the baseline risk metric (CDF or LERF) along the x-axis, and the change in those metrics (ΔCDF or ΔLERF) along the y-axis (Figures 4-1 and 4-2). Acceptance guidelines are established for each region as discussed below. These guidelines are intended for comparison with a full-scope (including internal and external hazards, at-power, low power, and shutdown) assessment of the change in risk metric. However, it is recognized that many PRAs are not full scope and PRA information of less than full scope may be acceptable. <u>Uncertainties</u> An extensive uncertainty analysis is also incorporated. The characterization of the uncertainties associated with the evaluation is provided to ensure that the decision makers have an appreciation of the potential variation in the assessed risk. The PRA assessment addresses the increases in risk metrics and appropriately identifies how these risk metrics compare with NRC established acceptance guidelines related to risk increases. <u>Scope</u> The scope of the PRA analysis considers all hazards. However, it is found that the impact on the CDF risk metric is limited to LOCA initiators. The PRA models that have risk significant LOCA initiators are the following: • Internal events • Seismic initiators

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
- Sufficient Safety Margin (cont'd)	It is noted that most BWRs have undergone a full PRA Peer Review for the internal events PRA and that these internal events PRAs generally meet Capability Category II. Therefore, most BWR PRAs are fully capable of supporting this risk application. However, few BWRs currently have a seismic PRA that fully meets the seismic portion of the ASME/ANS PRA Standard. Consistent with the Commission's policy, the seismic contribution remains a small contributor to the assessed risk metric and therefore, does not affect the decision being made. As such, the seismic PRA is formulated using appropriate engineering methods but ones that do not fully comply with the ASME/ANS PRA Standard. <u>Technical Adequacy</u> The technical adequacy of a PRA analysis used to support an application is measured in terms of its appropriateness with respect to scope, level of detail, technical adequacy, and plant representation. The scope, level of detail, and technical adequacy of the PRA are to be commensurate with the application for which it is intended and the role the PRA results play in the integrated decision process. <u>Level of Detail</u> A direct treatment of the cause and effect of the ECCS suction strainer failure on the risk metrics is explicitly modeled. The level of detail corresponding to Capability Category II of the ASME/ANS PRA Standard is adequate for this application; and, the PRA meets Capability Category II for all essential Supporting requirements.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
– Sufficient Safety Margin (cont'd)	PRA Technical Adequacy (PRA Pedigree) The PRA used for the 2014 Proof-of-Principle evaluation is vetted to ensure that the technical adequacy and quality is commensurate with the risk-informed decision process. The Full Power Internal Events (FPIE) PRA that is used in the analysis has a pedigree consistent with the ASME/ANS PRA Standard as evaluated by a self-assessment and confirmed by a PRA Peer Review. The PRA is judged by the PRA Peer Review team to have the appropriate scope, level of detail, technical adequacy, and as-built, as-operated fidelity to be able to be used to support Licensing Amendment Requests (LARs). Regulatory Guide 1.200 [3] and the ASME/ANS PRA Standard are used in conjunction with a PRA Peer Review to assure that the PRA pedigree is adequate to support risk-informed decision-making. The PRA results used to support an application are derived from a PRA model that represents the as-built and as-operated plant to the extent needed to support the application. The PRA realistically reflects the risk associated with the plant.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
Sufficient Safety Margin (cont'd)	<u>Comparison of Probabilistic Risk Assessment Results with the Acceptance Guidelines</u> RG 1.174 states: *In the context of integrated decision-making, the acceptance guidelines should not be interpreted as being overly prescriptive. They are intended to provide an indication, in numerical terms, of what is considered acceptable. As such, the numerical values associated with defining the regions in Figures 4-1 and 4-2 of this regulatory guide are approximate values that provide an indication of the changes that are generally acceptable.* *Therefore, this comparison of the PRA results with the acceptance guidelines is based on an understanding of the contributors to the PRA results and on the robustness of the assessment of those contributors and the impacts of the uncertainties, both those that are explicitly accounted for in the results and those that are not. This is a somewhat subjective process, and the reasoning behind the decisions is well documented.* The following uncertainties are addressed: • Parametric uncertainties • Modeling uncertainties • Completeness uncertainties <u>Integrated Decision-Making</u> In making a regulatory decision, risk insights are integrated with considerations of defense-in-depth and safety margins. The degree to which the risk insights play a role, and therefore the need for detailed staff review, is application dependent.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
Element 3 – Define the Monitoring Program	Performance Monitoring BWRs have multiple programs that address aspects of the ECCS suction strainer design adequacy. These include the following: • Assurance that pipe integrity is maintained and therefore LOCA frequencies remain low. This includes the pipe weld inspection requirements of the primary system piping • Qualified coating program to ensure that coatings applied to the containment interior are qualified and will not be significantly affected by accident conditions to become debris loading. • Coating inspections to monitor the aging of coatings. • Insulation inventory to track the insulation debris in the containment to monitor any increases in their debris source. • Foreign Materials Exclusion Program: Program to ensure that miscellaneous debris is not present in the drywell or suppression pool by maintaining inventory control of material that enters and leaves the containment • Pool Cleanliness: Cleaning of the suppression pool is carried out at refuel outages to remove debris from the suppression pool accumulated during the previous cycle of operation. This maintains a standard of cleanliness that supports the ECCS strainer performance. This performance monitoring provides feedback on the continued adequacy of the in-containment conditions to assure plant safety response given postulated LOCA.
Element 4 – Transmit to NRC	Adequate documentation is developed to support a thorough review of the analysis for the purpose of determining the level of safety significance.

Table 4-1

SUMMARY OF ECCS SUCTION STRAINER RISK-INFORMED ASSESSMENT ELEMENTS

Elements and Principles of Regulatory Guide 1.174	Treatment of the Aspect in the ECCS Suction Strainer Risk-Informed Assessment
Element 5 – Quality Assurance	The quality of the analysis and supporting documentation is to be sufficient to support the risk determination and its proper understanding by decision-makers. This includes the following: • Use personnel qualified for the analysis. • Use procedures that ensure control of documentation, including revisions, and provide for independent review, verification, or checking of calculations and information used in the analyses. (An independent peer review is used as an important element in this process.) • Provide documentation and maintain records
Element 6 - Documentation	Each of the elements specified in RG 1.174 is documented for the proof-of-principle plant and for each plant to be evaluated in 2015. This documentation will be maintained as a BWROG document. Key assumptions and uncertainties are identified.

Table 4-2

DEFENSE-IN-DEPTH STRATEGIES OR FEATURES

Defense-in-Depth Strategy/Feature	Advantage
Reduce Flow through Strainer Control flow through strainer to the minimum needed to maintain adequate core cooling (EOP changes likely required for large recirculation break).	Reduction in flow to strainer increases the potential for debris to settle to bottom of containment away from the strainer. Reduces head-loss which minimizes structural challenge to the strainer.
Alternate the use of Strainers Transfer between strainers. Maintain one division of ECCS/DHR equipment in standby to avoid clogging of its strainer. Use the other division as a sacrificial strainer until debris collection makes it untenable.	Preserves a division of equipment for longer term operation. Conflict if suppression pool cooling is required. No viable cues to initiate this action.
Strainer Backwash BWRs have developed procedures that can be used to backwash the strainers to remove debris and allow restart of the ECCS/DHR equipment after the back flush.	This would allow long term operation from the suppression pool.
CST Alignment and Refill Some BWRs have either or both LPCI and CS capable of being aligned to the CST. This local manual alignment could be used to provide clean RPV makeup for core cooling. This would generally require refilling the CST to allow long term operation. (Most applicable for above core LOCAs.)	It may also require a suppression pool water management procedure/pathway to prevent overfilling.
Alternate Injection Sources Use other injection sources: • Condensate (from Hotwell/CST) • CRD (from CST) • HPCS (from CST) • SW cross-tie • B.5.b • FLEX	These sources do not result in dependence on the ECCS strainers or cause contamination from the suppression pool to enter the reactor. However, they may be of finite volume or have other potential foreign material that would complicate core cooling. Some of the methods allow rapid alignment on the order of 10-20 min.

Table 4-2

DEFENSE-IN-DEPTH STRATEGIES OR FEATURES

<table>
<tr><th>Defense-in-Depth Strategy/Feature</th><th>Advantage</th></tr>
<tr><td><u>Flooding the RPV to Above the Steam Separator Return or use of In-Shroud Water Discharge</u>

GEH has performed a study regarding clogging of the fuel channel inlets and determined that the ideal response includes either or both:
Flooding the RPV to above the steam separator return. This allows the core to remain submerged. GEH indicates that such a shutdown and submerged core remains cooled despite inlet blockage.
Injection to inside the shroud with core spray or in-shroud LPCI systems.</td><td>Most applicable to above core LOCAs.</td></tr>
<tr><td><u>Containment Venting</u>
If the LOCA debris compromises the suction strainers to RHR, then an alternative containment heat removal method is required.</td><td>Containment venting using an engineered hard pipe path is not compromised by ECCS suction strainer clogging, it is a diverse redundant method of heat removal.</td></tr>
</table>

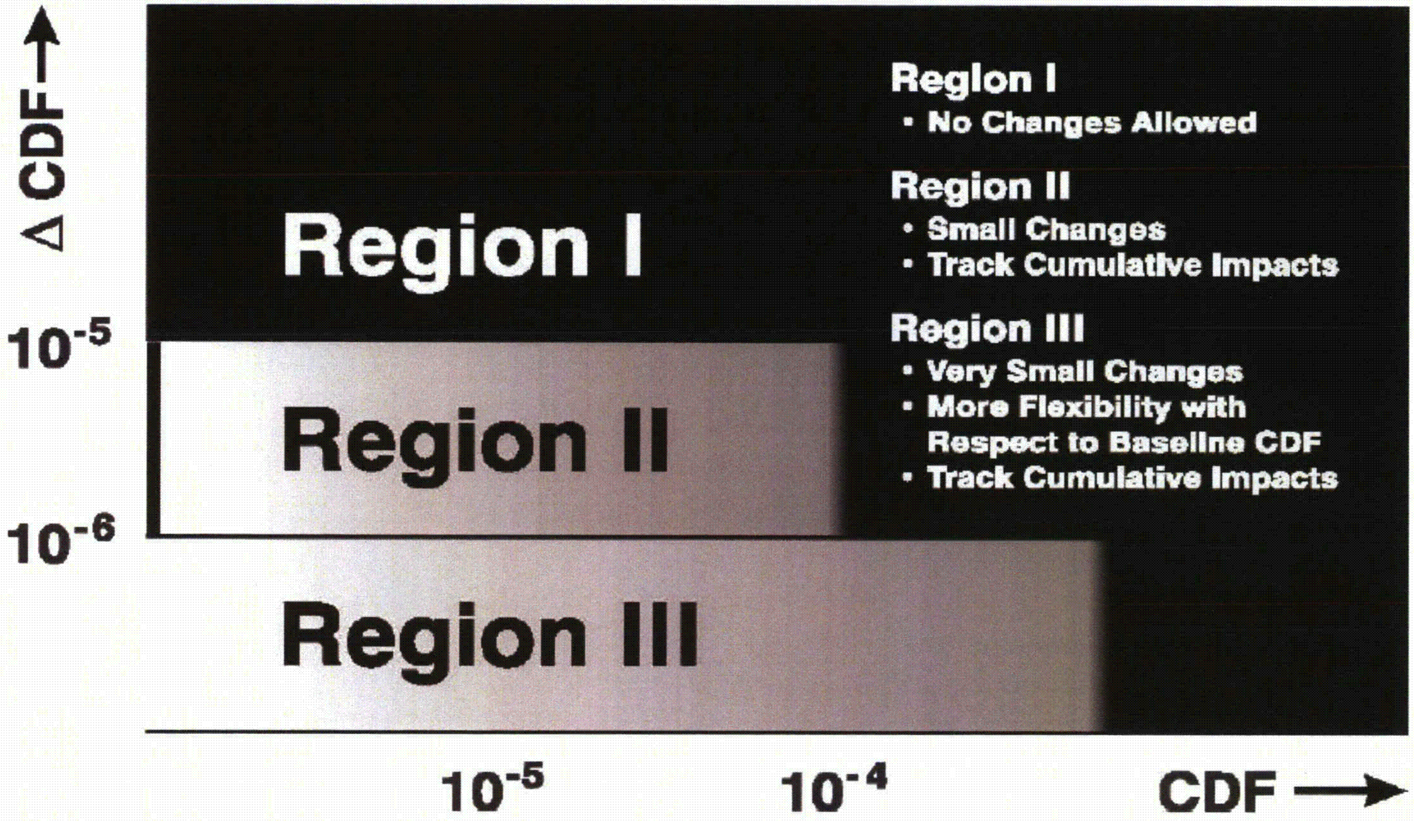


Figure 4-1

ACCEPTANCE GUIDELINES* FOR CORE DAMAGE FREQUENCY

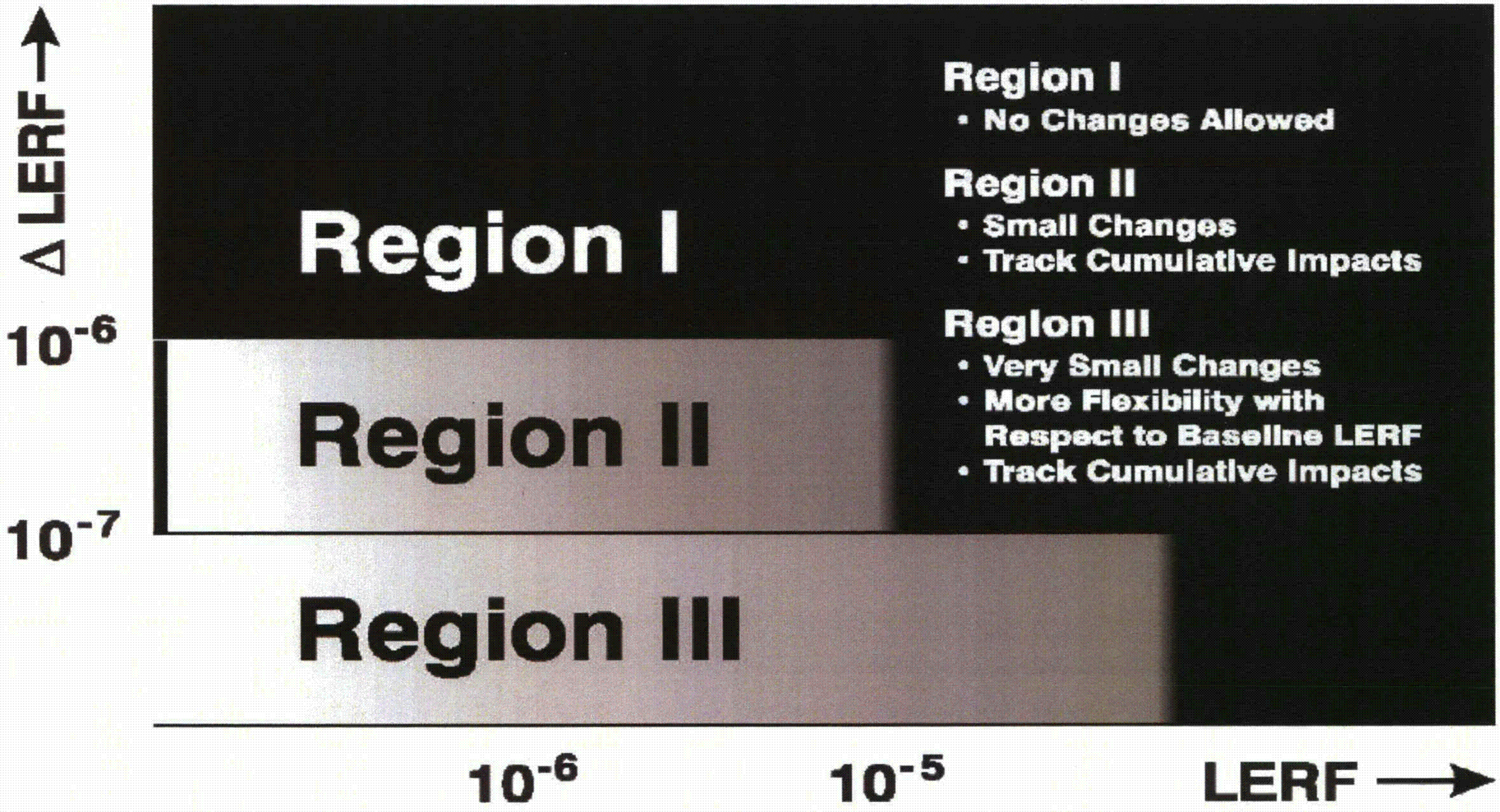


Figure 4-2

ACCEPTANCE GUIDELINES* FOR LARGE EARLY RELEASE FREQUENCY

5.0 ECCS SUCTION STRAINER FAILURE PROBABILITY

5.1 INPUTS

5.1.1 CAD Drawing

For the 2014 pilot plant, the existing CAD model plus the available insulation information provides a good reference model. The insulation inventory provided thickness and type on every system, so there is good representative accuracy regarding the insulation inventory and its location. A small amount of insulation was also added to the RCPs, but no other equipment insulation was identified.

For the 2014 proof-of-principle calculation, 289 weld points were added to existing pipes in the CAD model at locations typical for plant construction. The welds represent the most likely origin for breaks. Breaks of all sizes, up to and including a double-ended guillotine break (DEGB), are postulated at every weld. CASA Grande traces each break as an independent accident scenario and tabulates debris-induced failure probabilities based on the break size category (small, medium, large) and the elevation of the break above or below TAF.

5.1.2 Debris Sources

Available deterministic analyses were consulted to select values for latent debris, miscellaneous debris, suppression pool sludge, and unqualified coatings. For each independent break scenario, CASA Grande calculates the amount of damaged insulation and damaged qualified coatings inside of the ZOI. Material-specific ZOI sizes are applied to each insulation type to calculate total debris volumes available for transport to the suppression pool. Separate debris transport factors are applied to damaged insulation volumes that reside above or below the lowest drywell grating.

After appropriate drywell transport factors have been applied, all debris is introduced to the pool immediately with no transport delay. Pump flow histories are used to partition debris accumulation across respective strainers, and time-dependent head-loss is predicted for each strainer throughout the transient and compared to the mechanical buckling limit. Individual NPSHmargin is also monitored for each operating pump to identify onset of cavitation.

5.1.3 Containment Flows Through Strainers

Currently, the BWROG EPGs and implementation at the reference plant emphasize the desire/direction to maximize suppression pool cooling when torus water level is above the EPG threshold (~95°F).

Given this direction, there can be significant flow through the RHR suction strainers to support operation in the suppression pool cooling (SPC) mode. For the reference plant, this is approximately 9600 gpm total (1 RHR pump per heat exchanger loop).

Therefore, the highest probability flow states will include at least 9600 gpm of RHR flow. Six separate flow histories (with corresponding strainer assignments) were constructed to emulate operator actions for small, medium, and large breaks that occur above or below TAF. Separate failure probabilities are tabulated for each of the six accident response conditions.

5.1.4 Suction Strainer Integrity

The suggested performance thresholds used to develop a probabilistic evaluation include the following:

Performance Measures	Performance Thresholds[(1)]
Strainer	$\Delta P \geq NPSH_{margin}$
Strainer	$\Delta P \geq NPSH_{buckling}$

5.2 METHODOLOGY

CASA Grande is an important computational engine for merging conventional deterministic assumptions with statistical methods used in PRA to quantify incremental changes in risk. CASA Grande provides an integrated risk-management tool capable of folding in LOCA event frequencies as a function of size and location, propagating uncertainties in key input parameters using state-of-the-art statistical techniques, quantifying sensitivities to key parameters, and diagnosing principal systemic risk contributors (like break location, or transition break size) with quantitative risk ranking.

CASA Grande automates manual hand calculations of debris generation, transport and head-loss so that many thousands of accident scenarios can be traced efficiently from start to finish. Each scenario has a unique point of origin on the reactor piping system and each scenario causes a time-dependent head-loss response on the strainer. Data from a CAD model that includes coated steel, concrete, pipes and insulation provide the basis for automated calculation of debris formed within the ZOI of each break. CASA Grande identifies "end states" as "ECCS suction strainer blockage" for those scenarios that exceed engineering performance goals like NPSH margin and strainer structural limits. In general, the NRC questions [5] represent challenges to engineered safety limits that can be tracked during each postulated accident scenario to see which issues pose the greatest challenge to ECCS performance.

For this study, the standard NUREG/CR-6224 head-loss correlation is used to quantify pressure drop across the strainers as debris builds up over time. This correlation is the only predictive head-loss correlation in widespread regulatory use. The NRC has accepted applications of the NUREG/CR-6224 correlation for "evaluation purposes" similar to this screening evaluation, but not for strainer performance qualification in the absence of testing. The South Texas Project (STP) pilot project applied the NUREG/CR-6224 correlation with modifications to account for full bed compaction and for uncertainties in model predictions compared to tests. While the correlation may eventually be replaced with alternate models, it should provide a sufficient foundation for comparative risk assessment and a basis for sensitivity evaluations.

CASA Grande automatically samples and assigns an initiating event frequency for each analyzed break scenario based on the size of the break that is selected. Although a LOCA of any size is rare, small breaks are thousands of times more likely to occur than very large breaks. The relative frequency "weight" is applied to the outcome of each scenario (success or failure) to calculate the probability that the ECCS system will fail given the challenges posed by LOCA-generated debris. Because the entire spectrum of break sizes is evaluated for each calculation, CASA Grande reports the probability of ECCS failure for each LOCA category Small, Medium, and Large as defined in the PRA. CASA Grande is also equipped to propagate uncertainties present in engineering inputs when it is desirable to do so. In this study, maximum use will be made of deterministic assumptions where possible, and the primary "risk" factor will be introduced by sampling the initiating event frequency for each postulated break.

5.3 CASA GRANDE QUALITY

The prototype version of CASA Grande was developed at Los Alamos National Laboratory (LANL) to support the South Texas Project (STP) GSI-191 Pilot Project. Alion Science & Technology holds an exclusive commercialization license with LANL to further develop and apply the software for commercial nuclear safety applications. The commercialization agreement stipulates that all improvements to the software must be made available for non-commercial government use through the LANL technology transfer office. CASA Grande is developed and distributed as Alion Proprietary Software.

Because CASA Grande was first developed at a federal laboratory, the NRC has perpetual access to the program through the government use agreement just described. Both the source code and the current executable program have been supplied to the NRC for review, and an extensive validation of physical trends and statistical propagation techniques was performed by South West Research Institute (SwRI). The SwRI continues to review and extract code-level information from CASA Grande that has served as a basis for numerous requests for additional information (RAI) as part of the STP Pilot Project. Likewise, information extracted from CASA Grande has been used to disposition the majority of RAIs. Remaining issues relate to physical assumptions and approximations. There have been no criticisms or questions regarding the statistical methods employed in the software.

The NRC has stated that they cannot provide a blanket endorsement of CASA Grande unless Alion submits a topical report and requests formal review. However, they do anticipate that CASA Grande analyses will be "accepted" for GSI-191 applications after all outstanding issues have been addressed. Comments from the PRA branch have been used to refine assumptions and tighten the correlation between the PRA and CASA Grande intermediate calculations.

The statistical and numerical methods developed and implemented in CASA Grande are commonplace in many engineering disciplines, including risk assessment for geologic nuclear waste repositories. Alion Science & Technology is presently finishing a full Software Quality Assurance (SQA) validation of CASA Grande to certify the code for Appendix B safety-related applications. As a computational engine, CASA Grande provides unmatched flexibility and efficiency to trace plant-specific accident scenarios in a statistically rigorous framework. The software was designed from the bottom up to complement an existing plant

PRA by aggregating the effects of accident phenomenology on plant performance to quantify ECCS system failure probabilities for direct use in the PRA.

STP and a consortium of PWR owners have invested in an extensive SQA program that will be completed in December 2014. When the work is finalized, CASA Grande will satisfy all requirements for Appendix-B safety-related applications. Key elements of the SQA program include:

1. Software Requirements Specification (SRS)
2. Software Design Description (SDD)
3. Software Verification and Validation Plan (SVV)
4. Theory Manual
5. Users Guide
6. Issue Tracking Report system (ITR)
7. Configuration Management Program (CMP)

All elements of the SQA program are available for NRC review or audit All elements of the SQA except the Software Design Description, which is treated as Alion Proprietary information, are available for distribution to individual license holders. Of particular interest are the Software Verification and Validation Plan (SVV), the Issue Tracking Report (ITR) system, and the Configuration Management Program (CMP):

- Software Verification and Validation includes 100% verification (accurate implementation) of all equations presented in the Theory Manual, detailed comparison of CASA Grande debris generation to CAD calculations, extensive automated memory mapping tests between code modules, and confirmation/disposition of all software requirements in the SRS.
- Issue Tracking Reports are entered into a software development tool. A "triage" system is employed to rank the severity of a new issue from "green" – recommendation for a new feature or a new feature description, through "red" – potentially large impact to physical or statistical predictions. A communication chain and timeline for disposition is assigned commensurate with potential severity level. A software tool is used to archive objective evidence that documents successful disposition of each issue.
- Configuration management is achieved using the software development system called SubVersioN (SVN). SVN tracks every change made to the source code so that any intermediate version can be recreated. While many programmers can check out the most current subroutines to diagnose problems and draft new features, the master version is controlled by a single administrator. No changes are adopted to the master code without SQA review.

5.4 SENSITIVITY STUDIES

A "sensitivity study" refers to the quantification of change in risk caused by a change in an input parameter. Numerous sensitivities can be explored by repeating baseline risk calculations with small perturbations to various input variables that are identified as driving total risk. Dominant variables are likely to include head-loss correlation parameters, coating ZOI size, flow rates, and strainer attributes. Both individual (sequential) and aggregate (combined) sensitivities will be reported.

5.5 APPLICATION TO BWR FLEET

The goal of fleet-wide disposition requires a generic, categorical evaluation of vulnerability to each issue [5]. This will be accomplished by performing a screening study that addresses the following objective:

> Quantify the risk of debris-induced ECCS failure leading to core damage for a matrix of plant conditions that exist across the BWR fleet. The methodology will use risk-informed analyses to support fleet-wide disposition of remaining NRC issues to the maximum degree possible.

The screening approach planned for this work is similar in concept to the parametric evaluation developed for the NRC to assess pressurized water reactor recirculation sump performance (Ref. GSI-191 Technical Assessment: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance (NUREG/CR-6762, Volume 1)). The PWR parametric evaluation was based on an industry survey of risk-dominant plant features including:

- insulation type and quantity,
- strainer surface area,
- maximum water velocity,
- failed coatings inventory, and
- NPSH margin.

A simple engineering model of debris transport and head loss was evaluated for every plant to identify head-loss conditions that exceeded available margin. For this study, CASA Grande will be used to evaluate the variation in risk caused by variations in dominant plant features including insulation type, strainer area, and resident particulates.

Fleet-wide screening is based on associations of individual plants into groups, or subpopulations. An obvious group is containment type, and a pilot plant will be selected to represent each containment type. Since the EOPs for plants of a given type are very similar, CASA Grande will implement pump assignments following a generic EOP for each containment type. A CAD model for each containment type is also needed. CAD models for Mark I and Mark II containments are already available for use with minor improvements. As an option, a Mark III containment model can be built with comparable detail to support this evaluation if desired. (Further discussion includes the Mark III option for generality). Features that distinguish individual plants within a containment type include insulation types, unqualified coatings and sludge inventory, and strainer area. A set of 3 composite plant descriptions will be defined for each containment type to reflect plant variations within the population. These descriptions can either be based on actual plants, or on artificial combinations of bounding conditions like maximum particulate load paired with minimum strainer surface area, etc. Some liberties will be taken in the screening study by mapping alternate plant-specific insulation inventory onto the reference plant piping systems. Surrogate insulation definitions can be applied very conveniently in a CAD model and then exported to CASA Grande for risk quantification.

The 3 x 3 matrix shown in Figure 5.5-1 represents the screening that can be used to compare individual plant conditions to quantified risk for the discrete cases; colors represent notional levels of equivalent ΔCDF corresponding to risk regions defined in RG 1.174.

	Mark I	Mark II	Mark III
Case 1	G	R	R
Case 2	R	B	B
Case 3	R	B	R

Figure 5.5-1 Notional grouping of equivalent ΔCDF (common color) for a matrix of BWR containment type and three cases of plant-specific attributes

The evaluation matrix presented in Figure 5.5-1 can be used to eliminate individual plants from concern by comparing plant-specific attributes to the test cases quantified.

5.6 UNCERTAINTY

Areas of uncertainty associated with the calculation of ECCS suction strainer head-loss include the following:

- Amount of debris in the containment
  - Sludge
  - Coatings
  - Fiber insulation within ZOI
- The potential for thin bed effects. This would include the possibility that small and medium LOCAs could cause lower release of fiber debris but this condition could lead to a thin fiber bed that would prevent adequate strainer flow rates (pressure drop too high).

6.0 PRA LOGIC MODEL DEVELOPMENT

6.1 OVERVIEW

The PRA model used to support the ECCS suction strainer risk evaluation is based on the Proof-of-Principle plant PRA model. This reference plant PRA event tree and fault tree models have been enhanced to explicitly incorporate logic to address the pertinent ECCS suction strainer issues along with specific defense-in-depth measures to compensate for postulated suction strainer blockage phenomena.

6.2 EVENT TREE LOGIC MODEL

The following event trees are used to support the ECCS suction strainer risk evaluation:

- Large Water LOCA (below TAF)
- Large Steam LOCA (above TAF)
- Medium Water LOCA (below TAF)
- Medium Steam LOCA (above TAF)
- Small Water LOCA (below TAF)
- Small Steam LOCA (above TAF)

Within these event trees, system specific effects as a result of initiators within a given system are explicitly accounted for.

Figure 6.2-1 shows the event tree for the Large Water LOCA (LOCA below TAF) initiating event. Figure 6.2-1 is based on the Large Water LOCA event tree from the Proof-of-Principle plant PRA model with the following enhancements:

- 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). This node is considered given successful early RPV makeup from Core Spray or LPCI. Success at the VLAT node supports that ECCS continues to operate without suction strainer clogging. Failure at the VLAT node leads to consideration in the next node of compensatory measures to mitigate suction strainer clogging (i.e., COMP node).
- COMP Node (Compensatory Measures Successful) – This node considers operator actions to mitigate suction strainer clogging. This node evaluates operator action to diagnose suction strainer clogging issues and implement appropriate mitigation actions (e.g., back flush of suction strainers). Success at the COMP node results in continued ECCS suction from the suppression pool. Failure at the COMP node results in unavailability of suction from the

suppression pool. Based on the results of the deterministic evaluations (i.e., from CASA Grande), this node may credit the delayed time until ECCS suction strainer failure.

- V1 Node (External Injection Successful) – This node existed in the base PRA model. However, based on the deterministic evaluations, the HEPs for alternate injection may credit the delayed time until ECCS suction strainer failure.
- W Node (Suppression Pool Cooling) – This node may credit Shutdown Cooling (SDC) as an alternate method of decay heat removal if Suppression Pool Cooling (SPC) is unavailable (e.g., due to ECCS suction strainer clogging). However, alignment of SDC may be precluded during LOCA events if the SDC suction valves are isolated due to a high drywell pressure or low RPV water level signal.

The LOCA event tree logic models have been revised in an appropriate manner to account for the above enhancements.

6.3 FUNCTIONAL FAULT TREES

Functional fault trees are developed to support the event tree logic enhancements identified in Section 6.2. Figure 6.3-1 provides an example fault tree for the down branch of the VLAT node (ECCS Continues to Successfully Operate Without Suction Strainer Clogging). Figure 6.3-1 shows example basic events for common cause ECCS suction strainer failure for a variety of LOCA initiating events. The data used to support the functional fault trees is discussed in Section 6.4.

Functional fault trees for the other event tree nodal changes are straightforward and are not reproduced here.

6.4 DATA

The majority of the data used to support the ECCS suction strainer risk evaluation is based on the Proof-of-Principle plant PRA model. Additional data are obtained from the following sources:

- Initiating event frequencies for various LOCA sizes (e.g., Small, Medium, and Large) and locations (e.g., above and below TAF) are calculated based on plant specific piping information from the Proof-of-Principle plant as well the LOCA frequency data from NUREG-1829, which is the NRC preferred data source.
- The phenomenology code (CASA Grande) provides a method to calculate the probability distribution of ECCS suction strainer failure given the range of LOCA initiators (size and locations) and the consequential debris generated as a result of the resulting Zone of Influence (ZOI). This calculation also includes the

assessment of containment flow impact on the time to strainer failure. This time is important in the assessment of defense-in-depth actions.

- Human Reliability Analysis – A Human Reliability Analysis (HRA) of operator actions is performed to support the ECCS strainer clogging risk evaluation. Refer to Section 6.5 for additional information.

6.5 OPERATOR ACTIONS

Operator actions that are incorporated into the base evaluation include the following:

- Operator Fails to Diagnose ECCS Suction Strainer Blockage – This operator action evaluates the procedural guidance available to the operating crew to properly diagnose ECCS suction strainer blockage (e.g., loss of NPSH) in order to implement compensatory measures in sufficient time.
- Operator Fails to Implement Strainer Back Flush Procedure - BWRs have developed procedures that can be used to backwash the strainers to remove debris and allow restart of the ECCS/DHR equipment after the back flush.
- Operator Fails to Manage ECCS Flow to Mitigate Suction Strainer Blockage – This operator action involves controlling the flow through the strainer to the minimum needed to maintain adequate core cooling (EOP changes likely required for large recirculation break). Another method to manage ECCS flow would be to alternate pump operation in order to limit the flow and associated debris collection on the associated strainer. (This also would require additional guidance.)
- Operator Fails to Align Alternate Injection – This operator action involves alignment of alternate injection sources. These sources do not result in dependence on the ECCS strainers or cause contamination from the suppression pool to enter the reactor. However, they may be of finite volume (e.g., core spray with suction from CST or condensate from the hotwell); or they may have other potential foreign material that would complicate core cooling (e.g., SW cross-tie with suction from raw water source). Some of the methods allow rapid alignment on the order of 5-20 min.
- Insufficient Cooling From Shutdown Cooling – The alignment of SDC provides an alternate decay heat removal method from SPC that is not dependent on the ECCS strainers because Shutdown Cooling takes suction from the RPV. However, this alignment may be precluded during LOCA events if the SDC suction valves are isolated due to a high drywell pressure or low RPV water level signal.

Other operator actions that are not explicitly credited in the base ECCS suction strainer risk evaluation (e.g., alignment of FLEX equipment, refill of CST) are evaluated separately as part of sensitivity studies.

6.6 SENSITIVITY STUDIES WITH EXISTING LOGIC MODELS

Sensitivity studies to evaluate the risk impacts of various modeling issues include the following:

- LOCA initiating event frequencies
- Aspects of debris head-loss correlation to calculate common cause ECCS suction strainer clogging probabilities (e.g., debris generation, transit time, debris transport volume, strainer loading)
- HEPs for compensatory measures (e.g., operator actions for identification of head-loss, back flushing, managed control of ECCS flow)
- Quantitative evaluation of Coatings Zone of Influence (ZOI)
- Operator action for alternate external injection (e.g., SW cross-tie, FLEX equipment)
- Credit for additional time until ECCS suction strainer clogging
- Alignment of the CST as a backup water source and refill of the CST
- Credit for alternate decay heat removal methods (e.g., Shutdown Cooling)

The above sensitivity studies help to characterize the uncertainties associated with the ECCS suction strainer risk evaluation. The characterization of the uncertainties associated with the evaluation is provided to ensure that the decision makers have an appreciation of the potential variation in the assessed risk

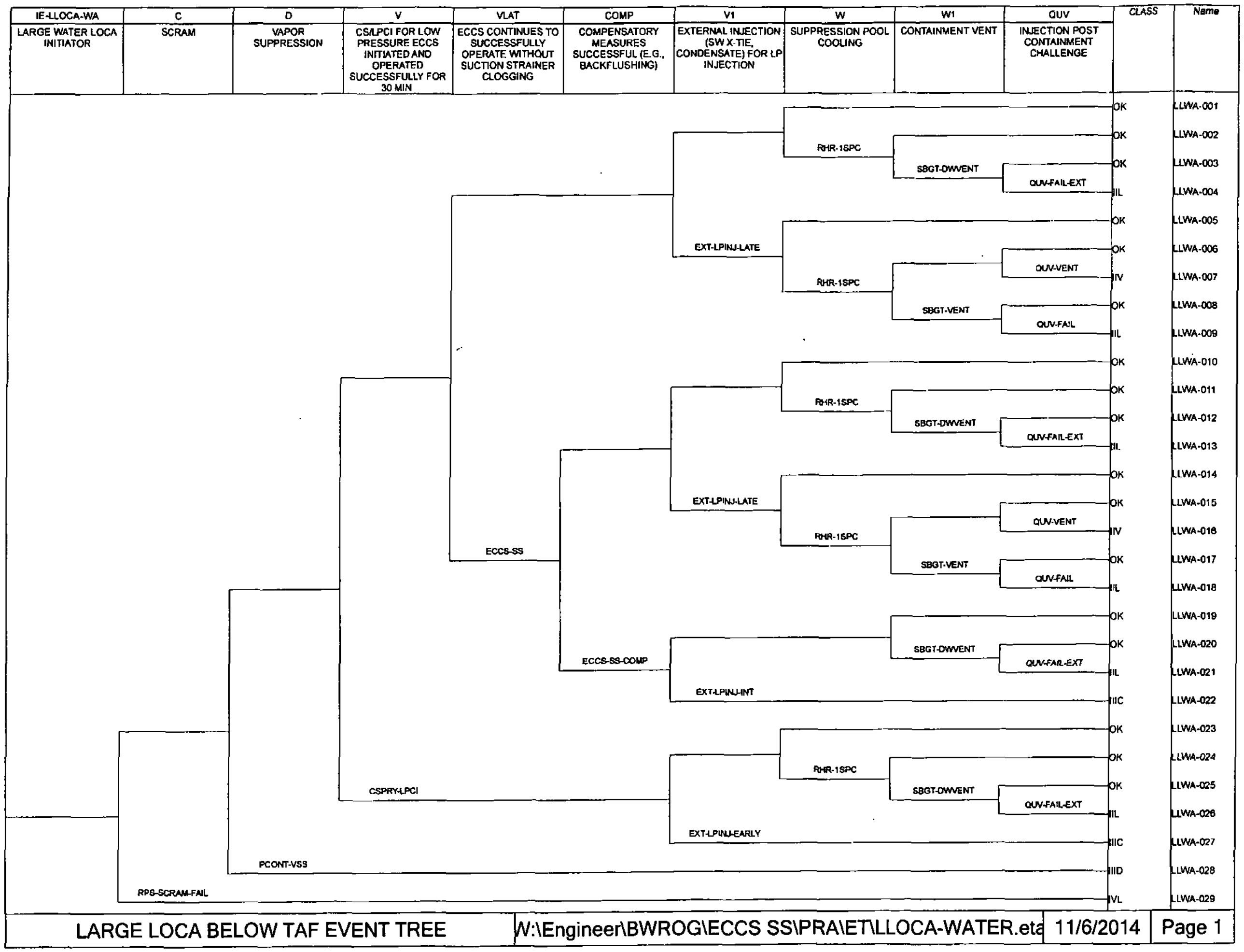


Figure 6.2-1

EXAMPLE LARGE WATER LOCA EVENT TREE

****DRAFT PRELIMINARY****

AWAITING CASA GRANDE CALCULATIONS

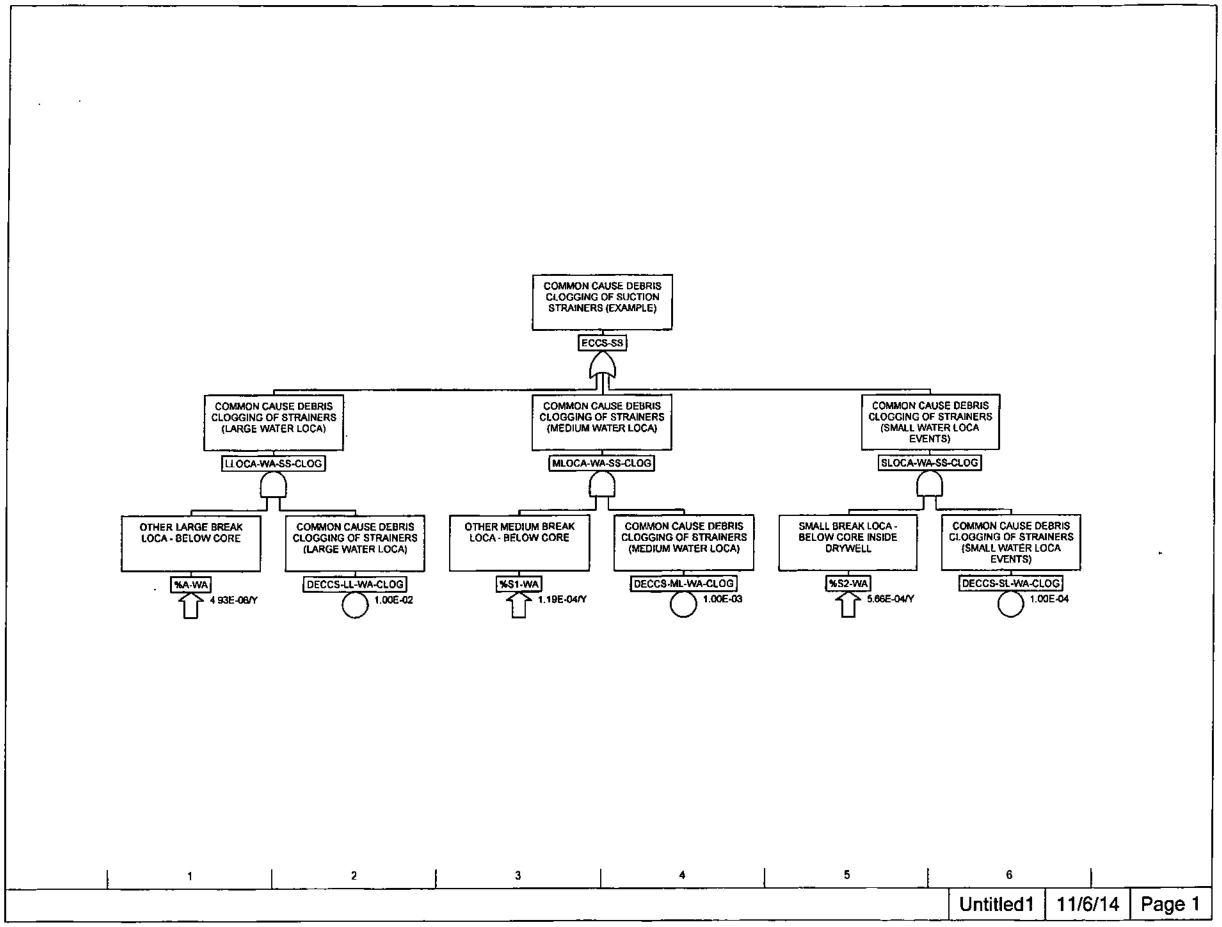


Figure 6.3-1

EXAMPLE FAULT TREE LOGIC TO MODEL DEBRIS CLOGGING OF ECCS SUCTION STRAINERS

7.0 RESULTS AND CONCLUSIONS

7.1 BASE MODEL RESULTS

[TO BE COMPLETED]

7.2 SENSITIVITY RESULTS

[TO BE COMPLETED]

8.0 REFERENCES

[1] 60 FR 42622, "Use of Probabilistic Risk Assessment Methods in Nuclear Activities: Final Policy Statement," *Federal Register,* Volume 60, Number 158, p. 42622, Washington, DC, August 16, 1995.

[2] Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," U.S. Nuclear Regulatory Commission, Washington, DC.

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[4] Regulatory Guide 1.174, An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis, U.S. Nuclear Regulatory Commission, May 2011, Revision 2.

[5] Letter from J.R. Grobe [USNRC] to Richard Anderson (BWROG Executive Chairman), Potential Issues Related to Emergency Core Cooling Systems (ECCS) Strainer Performance at Boiling Water Reactors, dated April 10, 2008.

[6] ASME, "Standard for Level 2/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications", ASME/ANS RA-Sa-2009.

[7] NRC Staff Requirements - SECY-10-0113 - Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance, December 23, 2010.